Hearing Conservation in Construction –Listening to New Perspectives on an Old Problem

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Introduction

Occupational noise induced hearing loss (NIHL) has been a major concern since the beginning of the industrial revolution. Several hundred years later, noise and hearing loss are still major concerns for the construction work force, management and safety professionals. Depending on the trade, one study of more than 1300 noise measurements indicated approximately 70% of the construction workers had a full shift time weighed average (TWA) exposure at or above the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) of 85 dBA. About 10% of those workers had full shift average exposures above the current US Occupational Safety and Health Administration (OSHA) construction Permissible Exposure Limit (PEL) of 90 dBA. [Neitzel, et al. 2011a] Noise levels of typical construction equipment can range from approximately 88 dBA for circular saws, to 96 dBA for chipping guns, to 102 dBA for jackhammers. [ANSI 2013] In calculations made by the Center for Construction Research and Training (CPWR) using data from the 2010 National Health Interview Survey, 21% of construction workers self reported some type of hearing problem. [CPRW 2013] In addition, exposure to noise has been associated with increased pulse rate, high blood pressure, muscle tension, sleeplessness and fatigue. [Basner, et al. 2014]

While hearing loss continues to be a problem for the construction industry, a significant amount of research has been published which gives possible insight as to why the problem persists, shortcomings in past efforts to control noise and more importantly new ideas to help reduce this problem. This paper will look at five main areas of construction hearing conservation:

- Exposure Assessment – What are the options to determine worker exposure?
- Occupational Exposure Limits – What are the current regulatory and good practice limits for noise and how do they affect the evaluation of a worker’s exposure?
- Use of Hearing Protection Devices (HPD) – While engineering controls are the preferred method to prevent occupational exposure, in construction HPD is typically the control method implemented. Accepting this for now, how can selection and wearing practices be improved to maximize use and more importantly actual effectiveness?
- Training – What techniques and insights can be utilized to improve training to make it more impactful to the worker and encourage hearing healthy attitudes and behaviors in the workforce?
- Engineering Controls – How can engineering controls be used more in construction?

Exposure Assessment
Exposure assessment has always been a challenge in construction. In general industry, tools and tasks performed are typically constant from day to day, producing relatively consistent levels of noise exposure. This consistency allows the safety professional to more efficiently determine noise exposure for multiple workers by assigning them to similar exposure groups (SEG) and monitoring a representative number of that group. Construction, however, is the opposite. Tools used and duration of use, specific tasks performed, individual worker technique and worksite environment – both physical environment (e.g. indoors, outdoors, open area, enclosed area) and operational environment (i.e. what other activities are occurring in the vicinity) are some of the variables that can affect an individual worker’s noise exposure from day to day. Workers are often exposed to noise not of their own making simply due to proximity to other activity. Even within a specific trade, workers may still perform a variety of tasks or activities leading to very different noise exposures during a shift. [Neitzel et. al. 2009, 2011] Consequently, with traditional noise dosimeter exposure assessment several problems can arise:

- Number of samples required to make a statistically precise estimation of a worker’s exposure can grow to the point of impracticality. [Virji, et al. 2009]
- Difficulty in predicting future exposure due to the variability noted above.
- Utility of dosimeter results to workers and management in a constantly changing environment.
- Time weighted average results may mask peak exposure levels, making identification of significant noise sources or exposure to impact/impulse noise difficult.

Two possible alternatives to traditional noise dosimetry are discussed here.

**Task-Based Exposure Assessment Model (T-BEAM)**

In this method, individual tasks are identified, duration of each task noted and sound levels related to the task determined. Then modeling of any combination of tasks and durations can be done using the formula:

\[
\% \text{ Dose} = \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots \right) \times 100
\]

\(\% \text{ Dose} \) – percentage of daily maximum allowable dose (e.g. 85 dBA 8-hour TWA = 100%)

\(C_n\) = duration (in hours) worker spends at a specific sound level

\(T_n\) = allowable duration (in hours) for the specified noise level (e.g. NIOSH Table 1-1) (NIOSH 1998)

A very simple example would be repairing asphalt pavement:

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration of Task (hrs)</th>
<th>Noise Level of Task* (dBA)</th>
<th>Allowable Exposure Duration per NIOSH (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement breaking</td>
<td>2</td>
<td>102</td>
<td>0.16</td>
</tr>
<tr>
<td>Drive truck</td>
<td>2</td>
<td>78</td>
<td>25</td>
</tr>
<tr>
<td>Paver operation</td>
<td>4</td>
<td>86</td>
<td>6.5</td>
</tr>
</tbody>
</table>

*From Appendix 2 Probable Noise Levels of Common Construction Tools [ANSI/ASSE 2013]

\(\% \text{ Dose} = \left( \frac{2}{0.16} + \frac{2}{25} + \frac{4}{6.5} \right) \)

\(\% \text{ Dose} = \left( 12.5 + 0.08 + 0.6 \right) \times 100 = 1319\% \) of allowable dose or an equivalent 8 hour TWA of 96.2 dBA.
If a different day/job required different time on task, the calculation can be modeled and exposure estimated.

T-BEAM has several advantages over traditional full shift (FS) dosimetry monitoring:

- Exposure levels can be estimated for a range of task combinations and differing amounts of time on task.
- Individual exposures can be assessed by accounting for within and between worker variability in work activities.
- Better identification of tasks with high exposure potential allowing more efficient targeting of noise reduction efforts. This allows construction safety professionals to focus not necessarily on the highest decibel level source, but the task with the combination of sound level and time on task that produces the greatest percentage of the worker’s noise dose. For example, 3 hours at 90 dBA produces more exposure (120% of allowable dose) than 1 hour at 94 dBA (100%) using NIOSH exposure criteria.
- Increased sampling efficiency by focusing measurement activity on component tasks with the greatest exposure level or variability. [Seixas, et al. 2003][Neitzel, et al. 2011]

While helpful, T-BEAM assessments must be done carefully to yield useful information. Real world exposures can be far more complicated than the simple example in Table 1. Factors that can influence the agreement between a task-based estimated exposure and full shift assessments include:

- Sample time duration, intra-task variability (pressure applied to the tool, orientation of the worker to the tool, individual work methods) and mobility may all cause significant intra-task exposure variation. Similarly, trades that work in close physical proximity to other trades are more likely to be exposed to a variety of noise sources. For example, an electrician may not create much noise in their own job, but if working next to a demolition crew, could receive significant secondary or carryover exposure. More isolated trades would have less variability in noise sources. This must be assessed to help determine appropriate sample duration and actual exposure levels. Highly mobile or variable tasks would require longer duration sampling periods than less variable/mobile tasks. [Seixas, et. al. 2003] [Virji, et al. 2009] [Neitzel, et al. 2011]
- Determination of time on task. While a dedicated observer may be the most accurate, this can be very labor intensive and limit the number of workers to be evaluated. One alternative is worker reported time on task. Several studies have noted good agreement between worker reported time on task and independent observer reported time. Worker data collection appears to work best when the worker has fewer, less specifically defined tasks, verses numerous, rigidly defined tasks. [Virji, et al.2009]
- The definition of the task itself. [Seixas, et al. 2003] [Virji, et al. 2009]

This last point may be the most important and difficult factor to assess. Deciding the specificity of the task can be complicated and is critical to the accuracy of the results. If task definitions are too simplistic significant measurement errors in the exposure estimate may occur. Seixas gives the following example for constructing wall forms. [Seixas, et al. 2003] One could designate ‘making wall forms’ the task. However, is this specific enough? Perhaps that task should be multiple tasks – that could be broken down even further:

- Sawing wood
  - Fixed saw or portable
  - Hand saw or power
- Hamming
  - Hand hammer
  - Nail gun

- Erecting and various materials handling
  - Type material
  - Type equipment used to move materials

- Location
  - Indoors
  - Outdoors

Each variation can significantly affect the exposure assessment results. The authors note that more specific task definition produces better results; however, detailed task classification can quickly become infeasible. Seixas noted that specificity of task definition and accuracy in assessment of time spent on task was equally important as measurement of actual exposure levels in applying T-BEAM to exposure evaluations. Neitzel echoed that view stating that repeated measurements of noise levels need to be taken for each task and inaccuracy in time on task data can be a significant source of error. [Neitzel, et al. 2011] The safety professional has to strike a balance of specificity of task, practicality of recognizing/differentiating between tasks and the determination of time on task.

In a field study comparing the two methods, Virji [Virji, et.al, 2009] concluded that task-based assessments can be used to obtain exposure assessments that agreed well with FS dosimetry measurements. Agreement increases with reduced worker exposure variability, complexity and mobility. Conversely, a field study by Seixas showed only a low to moderate agreement between T-BEAM and FS sampling. [Seixas, et al. 2003] Both studies noted that task definition, inter-individual variability and context of work were all sources of potential error in individual exposure assessments. Agreement between TB and FS results improved with increasing specificity of task definitions. Seixas concluded that T-BEAM may hold more promise for targeting high noise sources for exposure reduction than overall exposure assessment.

While T-BEAM may have shortcomings for assessing FS exposure, it can still provide significant value to a hearing conservation program. As noted, it can be effective in identifying noise exposure sources which may not be immediately obvious, but may be significant due to the combination of noise level plus exposure duration. This can lead to more efficient/effective exposure reduction actions. Kerr [Kerr, et al. 2002] felt task-based sampling may be more valuable and impactful in training programs. Relating exposure to activity makes the risk more real to the exposed worker. Discussing a worker’s exposure in terms of specific tasks, sound levels and duration will likely be more impactful than merely relaying the 8 hour average or full shift dose. Virji notes that while T-BEAM may have limitations, it still may be more practical and cost effective than large scale FS sampling. [Virji, et al. 2009]

**Ceiling Level Exposure Limit**

Another suggested option to traditional noise dosimetry for determination of the need for engineering controls or HPD use is to eliminate the need to determine a full shift TWA by making the exposure limit a ceiling limit. A ceiling limit, unlike a TWA exposure limit, cannot be exceeded at any time during the work cycle. Because of the difficulty in establishing a worker’s TWA, the ANSI/ASSE A10.46-2013 Hearing Loss Prevention in Construction and Demolition Workers standard recommends a ceiling limit of 85 dBA. [ANSI 2013] Any
exposure above 85 dBA (even instantaneously) would be considered an overexposure and require controls be implemented. This provides several advantages:

- Simplified rules for when HPD must be worn. With a ceiling exposure level, HPD should be worn whenever high noise exposures occur regardless of task exposure duration or full shift exposure. NIOSH notes that it is prudent to wear HPD during all high noise exposures regardless of the 8-hour TWA [NIOSH 1998]
- Less complicated exposure assessment since there is no need to determine the 8 hour TWA.
- A basic, relatively inexpensive sound level meter can be used to make noise level determinations.

In the end, the safety professional must determine how to best assess worker exposure for their particular situation. Task-based assessment is an option, likely better suited for workers with moderately complex task lists and exposure level variability. As the number of tasks, complexity and variability simplify, traditional dosimetry is likely more practical. As tasks increase in number, complexity and variability, accurate task based assessment may become unfeasibly labor intensive and difficult. At some point, implementing a ceiling level exposure limit may be the most practical assessment strategy.

Perhaps however, as Neitzel suggests, one specific methodology simply may not be sufficient in construction. Instead, a combination of data information from multiple sources may be required and combined to determine if a worker is exposed to excessive noise levels and action should be taken. This could include using job titles/trade, both task based and traditional dosimetry along with subjective information such as worker interviews regarding noise exposure intensity, frequency of occurrence and duration to better identify at risk workers for NIHL. [Neitzel, et al. 2009, 2011b]

**Occupational Exposure Limit**

Exposure assessment is a critical part of a construction hearing conservation program. Equally important is the criteria used to evaluate that exposure and determine what actions need to be taken. Currently US OSHA has an 8-hour time weighted average (TWA) Permissible Exposure Limit of 90 dBA for the construction industry (29CFR1926.52). When determining the 8-hour TWA, a 90 dBA measurement threshold is applied, meaning that only noise 90 dBA and above is integrated into the calculation. [OSHA][OSHA 1999] All noise below the threshold (less than 90 dBA) is ignored. For a theoretical 8 hour work day at a continuous 89 dBA, the final dosimeter reading would be 0% of the allowable daily noise dose. For noise above 90 dBA, US OSHA uses a 5 dB exchange rate to account for the increased energy level of the noise as the decibel level increases. For every 5 dBA increase over 90 dBA, the allowable exposure duration is reduced by 50%. The worker can be exposed to 90 dBA for up to 8 hours. If the TWA exposure increases to 95, the allowable exposure would be halved to less than 4 hours. If the exposure level increases to 100 dBA, the allowable exposure duration is halved again to 2 hours.

However, NIOSH and the American Conference of Governmental Industrial Hygienists (ACGIH®), recommend a different occupational exposure limit and different monitoring parameters when assessing worker exposure. Both groups recommend an 85 dBA exposure limit using an 80 dBA threshold level and 3-dB exchange rate. Depending on the sound levels encountered, variability during the work shift, and occurrence of impulse noise, this can lead to significantly different findings compared to US OSHA criteria. [Neitzel, et al. 2009 ] Under the NIOSH criteria, 8 hours of exposure at 85 dBA would yield 100% dose exposure. As noted
above, the US OSHA construction criteria would indicate a 0% dose exposure. As another example, a construction worker exposed to 85 dBA for 7.5 hours and 95 dBA for 0.5 hours would have a dose of 161% and 8 hour TWA of approximately 87 dBA under the NIOSH criteria. Under the OSHA criteria, the dose would be 12.5% and an 8 hour TWA of 75 dBA. Table 2 gives a comparison of % dose and allowable exposure durations for several noise levels using the US OSHA construction, US OSHA general industry, and NIOSH exposure criteria.

Table 2 – Comparison of Allowable Exposure Durations for Different Noise Levels

<table>
<thead>
<tr>
<th>Exposure Level (dBA)</th>
<th>Allowable Duration (hours) US OSHA Construction</th>
<th>Allowable Duration (hours) US OSHA General Industry</th>
<th>Allowable Duration (hours) NIOSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>--</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>8</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>92</td>
<td>6</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>95</td>
<td>4</td>
<td>4</td>
<td>0.75</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>105</td>
<td>1</td>
<td>1</td>
<td>4 minutes</td>
</tr>
<tr>
<td>110</td>
<td>0.5</td>
<td>.5</td>
<td>1.5 minutes</td>
</tr>
</tbody>
</table>

Several studies have compared the difference between dosimetry results using the US OSHA and NIOSH criteria in actual worksites. It should be noted that these studies used the US OSHA general industry hearing conservation program (HCP) criteria (29 CFR1910.95), which requires a threshold of 80 dBA instead of the construction industry 90 dBA threshold. The 80 dBA threshold results would likely be higher than 90 dBA dose results; how much higher would depend on sound levels encountered and their variability, especially if they range between the two threshold values of 80 dBA (29CFR1910.95) and 90 dBA (29CFR1926.52).

The results showed that the NIOSH monitoring criteria indicated exposure levels typically 4 and 6 dB higher than when OSHA criteria was used. [Petrick 1996][Neitzel, et al. 1999][Sriwattanatamma, et al. 2000][Seixas, et al. 2005] Neitzel’s and Seixas’s studies specifically looked at the construction industry. The other two studies looked at general industry work populations, but with variable exposure levels and durations which is typical of construction. Using the NIOSH recommended exposure limit (REL) and monitoring criteria would significantly increase the number of workers considered overexposed to noise and would initiate more widespread implementation of engineering controls or use of HPD.

As noted above, two differences between the US OSHA and NIOSH criteria are the exposure limit and the exchange rate. The 85 dBA REL is a 50% reduction in the US OSHA PEL (assuming a 5 dB exchange rate). The NIOSH criteria document states that the estimated excess risk for NIHL over a 40 year working lifetime at an exposure level of 90 dBA is approximately 25%. [NIOSH 1998] Therefore, even exposure controlled at, or just below the current US OSHA PEL, still leaves a significant population at risk for NIHL. NIOSH estimates there is still an excess risk of 8% even at the REL of 85 dBA. NIOSH, ACGIH, and the US Department of Defense all recommend an exposure limit of 85 dBA as an 8-hour TWA. In 2009 the National Hearing Conservation Association (NHCA) petitioned US OSHA to revise their PEL and exchange rate to 85 dBA and 3 dB respectively, stating “Unfortunately, OSHA’s hearing conservation regulation is not consistent with current scientific knowledge, is not uniformly
applied across all industries, and has not proven effective in preventing NIHL”. [NHCA 2009] NHCA also specifically recommended that these changes include the construction industry.

The exchange rate used can also significantly impact the final noise exposure assessment. The 3 dB exchange rate recommended by NIOSH is based on the Equal Energy Hypothesis (EEH). EEH states that “…equal amounts of sound energy will produce equal amounts of hearing impairment, regardless of how the sound energy is distributed in time.” [NIOSH 1998] The 3 dB exchange represents an actual doubling (or halving) of the sound energy. The doubling or halving of the exposure duration as the sound energy decreases or increases keeps the total amount of energy the ear is exposed to equal. Conversely, the US OSHA 5 dB exchange rate is not based on doubling of the energy, but rather, the idea that damage to the ear during exposure to high noise levels can be repaired during intermittent low noise levels that typically occur during the work period. Equal amounts of energy will not produce equal amounts of damage depending on how the energy is spread over time. Hearing loss will not be as great if the noise energy comes in clumps, as it would be if the noise exposure was continuous. This leads to lower estimates of damage from high noise periods that would be produced assuming the EEH. While animal studies have shown some recovery of the ear may occur during quiet periods, it is thought that in an industrial setting, even the quiet time may not be quite enough to permit recovery, and the occurrence of the quiet times are not evenly spaced throughout the day. [NIOSH 1998]

While there may still be some question regarding which is more appropriate for use in the occupational setting, NIOSH has stated that “the 3-dB exchange rate is the method most firmly supported by scientific evidence for assessing hearing impairment as a function of noise level and duration.” [NIOSH 1998] The 3 dB exchange is currently used or recommended by US Department of Defense, most Canadian providences, Australia, United Kingdom, Germany, ACGIH® and the International Organization for Standardization (ISO), amongst others. The reader may want to refer to two of the references for a more complete history and discussion of the 3 and 5 dB exchange question. [NIOSH 1998] [Suter 2006]

Which exposure assessment criteria and exposure limit to use in evaluating noise levels is a critical decision that the safety professional must assist management in making. As noted above, numerous organizations in the United States and globally have adopted the 85 dBA exposure limit and 3dB exchange rate. If an 85 dBA exposure limit is adopted, then for the construction industry, the threshold level where noise begins to be integrated obviously has to be reduced from the current US OSHA 90 dBA. Using the US OSHA PEL and assessment criteria is proper for compliance with current US OSHA regulations, but could mask exposures that may have the potential to still cause NIHL cases. The safety professional, along with management must decide the goal of the hearing conservation program.

Use of Hearing Protection Devices (HPD)

While engineering controls is the preferred method of reducing noise exposure, and per US OSHA required to be used to the extent feasible, HPD is the most commonly used control on construction sites. Unfortunately, actual use – and more importantly effective use, of HPD are typically poor. The transient nature of the workforce, the abstract, gradual and painless nature of NIHL, the lack of an immediate cause/effect loop, and the annoyance and potential discomfort caused in some cases by wearing HPD has led to low usage rates of HPD in the construction industry.
Effective use depends on both duration of use and actual attenuation achieved. Several studies have reported that construction workers, on average, use HPD about 20 to 40% of the time that measured noise levels exceeded 85 dBA. [Neitzel, et al. 2005][Edelson, et al. 2009] In addition, the noise attenuation most workers receive in the real world is significantly less than the manufacturer’s published Noise Reduction Rating (NRR) for the HPD used. Individual results, however, are dependent on proper selection and use of HPD and highly variable with many wearers getting attenuation approaching the NRR and others getting much less. [Neitzel, et al. 2005][Edelson et al. 2009] Variable attenuation combined with actual usage time, hinders accurate predictions of total noise protection achieved over the course of a work day. Using the formula $R = 10 \times \log\left\{\frac{100}{100 - P \left(1 - \frac{10 - N}{10}\right)}\right\}$, the realized attenuation (R) of an HPD with a nominal NRR (N) of 30 worn for 90% of a full 8 hour shift (P) in percent would be less than 10 dB. [Arezes, et al. 2002] In a field study, actual user attained attenuation levels combined with wear time produced realized net HPD protection levels of less than 3 dB. [Neitzel, et al. 2005]

Many causes of low HPD use have been suggested:

- Lack of comfort – Several studies have recommended that comfort be given greater emphasis rather than the traditional focus on the NRR. A study by Byrne indicated that comfort and actual attenuation achieved in naïve HPD wearers was inversely related. [Byrne, et al. 2011] More comfort with subsequently greater worker acceptance (i.e. wear time), but less attenuation, may still give more overall protection versus high attenuation but less wear time. [Neitzel, et al. 2008][Arezes, et al. 2002]
- Lack of availability on the job site – convenience is critical. If HPD are not readily available, workers are likely not to leave their job location to find them.
- Lack of training on proper use of HPD. Training and the importance to workers of feeling they can properly select and don HPD is a critical factor in their decision to wear HPD. This is further discussed in the Training section of this paper.
- Over attenuation – As noted, HPD is frequently selected solely on the basis of high NRR. However, around 90% of TWA occupational noise exposures are 95 dBA or less. [Franks 1988] An HPD that delivers 10 dB of actual attenuation will cover the majority of exposures and reduce noise exposure below 85 dBA. The ANSI/ASSE A10.46 standard suggests attenuation below 70 dBA be considered overprotection which may needlessly interfere with speech communication or warning signals and should be avoided. European Union Guidelines (Stand No. EN 458:2004) suggest an optimal “protected level” of 75-80 dBA, with an acceptable range of 70 - 85 dBA.
- Personal selection – in many cases, only one type of HPD is provided. Any single product may over protect workers or be uncomfortable for some people to wear. Ear canal size and shape varies significantly from person to person. A protector that fits well for one person with good attenuation may be uncomfortable and perform poorly for the next person.
- Safety climate and worker’s perception of safety’s priority in the workplace.

One recent development that can assist in addressing some of these areas is fit testing of hearing protection. Several manufacturers now provide methods to fit test ear plugs. There are two basic types of fit-testing methodology:

- Subjective – results are based on the subject’s response to a test signal.
- Objective – results are based on physical measurement of sound levels to calculate ear plug attenuation.
All field attenuation estimation systems yield a metric termed Personal Attenuation Rating (PAR). [Hager 2011] There is currently no standardized method for PAR calculation, and therefore inherent differences between test methods and conditions can yield different PARs. Still, fit-testing can be a significant improvement in estimating the worker’s expected protection from a specific HPD. Hager goes on to point out multiple benefits from fit-testing that address many of the causes listed above:

- HPD can be selected on a basis of both comfort and adequate protection, instead of protection alone. As noted above, comfort is a critical factor in determining usage of HPD. Fit-testing can identify the most comfortable HPD for the user that still provides adequate protection.
- Avoiding over protection. Fit testing can help identify the HPD that provides the lowest, but still sufficient noise attenuation, which may result in less interference with communication and warning signals.
- Training and motivation of the wearer. Fit testing can demonstrate to the wearer that they can successfully use the HPD and achieve an acceptable fit (self-efficacy). Particularly for roll down types of ear plugs, this can also help the wearer understand the difference between proper and improper roll down and correct depth of insertion.
- Training of the trainer – fit-testing can help the trainer/HPD dispensing person learn how to recognize good/poor fit and the effect on attenuation.
- Inventory control – identifying that additional makes or models may need to be added to the inventory to provide an adequate selection (or conversely, while still providing a variety of selection, perhaps not as many HPD need be stocked as originally thought).
- Use in follow-up to standard threshold shifts to show the HPD used is appropriate for the individual’s noise environment.
- Prioritize re-training for wearers who may need additional assistance in obtaining and maintaining adequate attenuation.
- Documentation for audits or help in determining hearing loss etiology.

While construction is currently exempt from 29CFR1910.95(c) Hearing Conservation, safety professionals should be aware that at this time US OSHA has not accepted PAR as a method to comply with Appendix B of 29 CFR1910.95. Contractors may want to consider that any PAR based HPD selection also complies with Appendix B.

Two other areas that the safety professional should consider to address potential barriers to HPD use include:

- Compatibility with other safety equipment. Safety glass temple bars, welding helmets, face shields and head protection may all interfere with HPD. Wells reported that ear muff attenuation when worn with safety glasses may be reduced approximately 2 to 11 dB depending on temple bar design and ear muff cushion style (foam or liquid filled). [Wells 2013] Discussions with PPE suppliers may help identify PPE that is designed to work together or at least is more compatible with each other.
- New styles and features:
  - Stemmed foam ear plugs that can be used more easily with gloved hands and do not require the wearer to roll down or touch the part that inserts into the ear with their possibly dirty hands. By avoiding roll down, this can simplify insertion as inadequate roll down is a common mistake.
  - Plugs with a “cool” factor (e.g. flames printed on the exterior of the plug, or a plug in the shape of a wood screw).
  - Plugs with lanyards or other keeper devices that allow for easy retention and reinsertion in areas where plugs may be frequently inserted and removed.
Safety professionals need to take a closer look at HPD selection, particularly ear plugs. There is a much greater variety of HPD on the market now than in the past. Multiple models with multiple features should be considered when selecting HPD, not just picking the first one in the catalog or the one with the highest NRR. Comfort should be a greater consideration than simply getting the highest NRR in order to maximize actual wear time. Fit-testing, as noted, can help address many of the problems with HPD. As the cool factor has been added to safety glasses, it is now showing up in HPD. Safety directors should take advantage of that when possible to help promote use.

**Hearing Conservation Training**

Because of the unpredictability and intermittent exposure to noise, it is important that construction workers be able to recognize hazardous exposures and know how to protect themselves. [Tabeau, et al. 2008] Effective training is important, particularly for those just entering the trade. It is not uncommon for a 25 year old construction carpenter who does not use hearing protection to have the hearing acuity of a 50 year old non-occupationally noise exposed person. [Stephenson 2001] This group particularly has a critical need for effective HCP training to reduce exposure and increase use of HPD before hearing damage can start to occur.

Unfortunately, effective training in HCP and use of HPD is often non-existent in construction. [Neitzel, et al. 2008] Stephenson [Stephenson, et al. 2011] notes that most HCP training focuses just on presentation of knowledge:

- Effects of noise
- Advantages/disadvantage of certain HPD
- Care of HPD

While important, the training must also address motivational aspects of the worker to get a desired behavior change (i.e. wearing HPD). It is important to develop a framework that delivers the information in a way that acknowledges the workers’ needs and concerns. One such framework that has been investigated is the Health Promotion Model (HPM). [Pender, et al. 1990] The key idea in HPM is that a person’s decision to take action is determined by the expected outcome of that decision and the person’s evaluation of those outcomes. [Ronis, et al. 2006] Lusk used the HPM to identify five cognitive/perceptual factors that appear to influence HPD use. [Lusk, et al.1997] These include:

- Self-efficacy: confidence in one’s ability to perform a task – in this case to properly wear HPD. Even if the benefits outweigh the barriers, the person may not take action unless they believe they can successfully carry that action out.
- Barriers: expected negative aspects of the behavior (e.g. wearing HPD).
- Benefits: expected positive effects of the behavior (e.g. wearing HPD).
- Control of health: the extent of a person’s perception of his/her ability to maintain personal health.
- Value of use: the perceived importance of the outcome of using HPD.

Studies indicate that the worker’s use of HPD in response to the risk of NIHL is strongly influenced by self efficacy – their perceived ability to correctly select and use HPD. [Stephenson, et al. 2011] Fit-testing during training is one method that can be used to visually demonstrate to workers that they have selected an HPD that offers sufficient protection, that they can wear it properly and actually receive that desired level of protection. While PARs may vary depending
on the fit test method, precision may be less important than the value of self-efficacy and motivation of the worker. [Schultz 2011]

Training should devote a significant amount of time to hands-on training activities and demonstrations to help develop a high level of skill mastery. Training should be done one on one or in small groups to allow interaction between the worker and the trainer. In addition, the trainer should be familiar enough with the work site so they can relate actual on-site exposures during training. [Stephenson, et al. 2011]


- Use of HPD can be perceived to be time consuming.
- Wearing HPD can be uncomfortable.
- Wearing HPD can make it harder to hear speech or warning signals.
- Using ear plugs is too complicated.
- Worker underestimation of the danger of their particular noise exposure.

Barriers should be identified and addressed in ways specific to the audience. For example, carpenters may think table saw noise is insignificant as it occurs only intermittently during the day. Training may include a discussion of task based noise monitoring of saw sound levels and durations on that particular job site compared to recommended exposure duration limits. Fit-testing, as noted above, may help the safety professional address other barriers such as comfort or speech interference.

Other training techniques include:
1. Delivery format. Murphy [Murphy, et al. 2011] compared video, manufacturer’s printed instructions and one-on-one training to determine the effects of training on attenuation achieved when HPD is donned. Subjects with no experience using HPD received one of the training methods and then donned the HPD. The subjects were then tested to determine achieved noise reduction using ANSI/ASA S12.68.2007 methodology. The video and printed materials showed similar performance in noise reduction achieved after donning. However, the individually trained subjects showed an average of 5-8 dB increase in achieved attenuation verses the other two training method subjects. Similarly, Joseph [Joseph, et al. 2007] compared small group training to one-on-one training and to manufacturer’s written instructions. They found a similar increase in achieved attenuation over written instructions for both small group and one-on-one training. There was no significant difference in achieved attenuation between the small group and one-on-one. For construction contractors, Joseph concluded that small group training would be sufficient with one-on-one training required when a worker demonstrates a significant threshold shift. Both studies indicate that method of training can be the difference between achieving adequate and marginal protection.
2. Gain framing (emphasizing the gain to be realized by doing the desired action) the behavior instead of loss framing. Gain framing would communicate that wearing hearing protection prevents hearing loss, maintains health and allows the worker continue to enjoy the sounds of your family and friends like you are now. Contrast that with loss framing – by not wearing hearing protection you are likely to lose your hearing. Stephenson felt that gain framed messages tend to better promote prevention behavior. [Stephenson, et al. 2011]
3. Make the training industry specific. Use construction examples and graphics. Keep any text to a simple reading and comprehension level. [Neitzel, et al. 2008b]
4. Emphasis of management support for the use of engineering controls and HPD, the need for effective hearing conservation training and the importance of preventing NIHL. [Edelson, et al. 2009] Company leaders must be highly visible wearing HPD and encouraging workers to do the same. [Ronis, et al. 2006]

5. Use of noise indicators. Noise indicators are small devices the worker wears on their clothing. It typically flashes red when noise levels exceed a pre-set level such as 85 dBA. This notifies the wearer that they are in a high noise area. One study, using noise indicators along with base line training and reinforcement tool box talks showed a marked increase in use of HPD compared to training alone. The noise indicator gave them real time information on noise levels and was a reminder to wear HPD. [Seixas, et al.  2011] Noise indicators may also be a useful in instituting a ceiling level exposure limit discussed earlier in this paper.

Engineering Controls

As noted above, while use of HPD is the most common form of controlling noise exposure on construction sites, engineering controls are still the preferred method, and the one US OSHA requires employers to use when feasible. A description of specific engineering controls is beyond the scope of this paper; however, construction safety professionals should investigate all opportunities to utilize engineering controls not only to protect workers, but also to simplify their hearing conservation program by eliminating or reducing potential noise sources. There are multiple sources available that can help construction safety professionals learn more about utilizing these controls in their operations some examples include:

- NIOSH Controls for Noise Exposure website [http://www.cdc.gov/niosh/topics/noisecontrol/]

Some general examples of potential engineering controls include:

- Reduction of vibration from surfaces – e.g. sandbags on re-bar when cutting, securely clamping work piece as close to the work area as possible when grinding.
- Remote operated equipment – e.g. rig mounted hydraulic pavement breakers. This can also potentially reduce other health hazards such as ergonomic and silica exposures.
- Use of electrically powered equipment instead of diesel powered and hydraulic powered instead of pneumatic.
- Distance – moving workers away from noisy equipment (or vice versa). A 105 dBA noise source at a distance of 5 feet would be 102 dBA, at 20 feet would be 90 dBA and at 40 feet would be 84 dBA depending on other surrounding noise sources. Using a rotary grinder and sound level meter to demonstrate the noise reduction effect of maintaining or increasing distance from noise sources or erecting a simple barrier between the worker and noise source may be useful during worker training. [Neitzel, et al. 2008]
- Restricted or controlled access zones around high noise areas to limit the number of persons potentially exposed.
- Worker rotation to spread the noise energy out over several workers.
- Shutting down equipment when not in use.
Buy Quiet
Buy quiet is the concept of including noise emission specifications when purchasing or renting equipment. Manufacturer designed and built-in noise suppression is usually more effective and less expensive than trying to retrofit controls onto existing equipment. Quieter equipment may reduce the need for (or at least reliance) on HPD to sufficiently protect the worker. Reducing noise during the design phase or purchasing phase of the machinery’s life cycle helps prevent NIHL for all the workers who may ultimately use that machinery. Quieter equipment can also help contractors respond to municipal or state ambient noise regulations during outdoor projects. NIOSH (http://www.cdc.gov/niosh/topics/buyquiet/) and NASA (http://buyquietroadmap.com/?doing_wp_cron=1409255549.8635869026184082031250) have websites with information and suggestions for implementing a buy quiet program. NIOSH is in the process of developing a Power Tools Data Base which provides noise data to tool buyer and users. A much more extensive data base is available through the European Commission (http://ec.europa.eu/enterprise/sectors/mechanical/noise-outdoor-equipment/database/index_en.htm)

Audiometric Testing
A full discussion of audiometric testing is outside the scope of this paper. However, audiometric testing can be a critical component of a hearing conservation program and is required in the US OSHA General Industry standard. Construction poses several challenges to audiometric testing that are not present in general industry (e.g. transient workforce with multiple employers, remote work sites). The 2002 US OSHA notice in the Federal Register (Federal Register 67:50610-50618) lists multiple questions that need to be addressed to have a cost-effective, functional audiometric testing program for construction. The reader is encouraged to review the notice, consider US OSHA’s questions and determine the feasibility of implementing an audiometric testing program for their specific work force.

Conclusion
Noise exposure and hearing loss in construction is not a new topic. Multiple papers and presentations have documented the issue sufficiently. It is, however, time to hear and listen to some new thoughts on how to address it. Considering new and better ways to determine worker exposure and how to evaluate those exposures is the first step. T-BEAM, ceiling limits, revised occupational exposure limits are some of the ways to do that. Next we need to hear the training programs from the worker’s side of the classroom. Being aware of what motivates workers and the most effective ways of communicating knowledge needs to be incorporating into our hearing conservation training. Finally, selection of controls, maybe investing a little more up front to buy a quieter worksite and making a more informed, worker customized selection of HPD need to be considered.

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Bibliography


**Appendix A – Definitions**

Unless otherwise noted, definitions are from the NIOSH Criteria for a Recommended Standard Occupational Noise Exposure Revised Criteria 1998.
Exchange rate - “An increment of decibels that requires the halving of exposure time, or a decrement of decibels that requires the doubling of exposure time. For example, a 3-dB exchange rate requires that noise exposure time be halved for each 30 dB increase in noise level; likewise, a 5 dB-exchange rate requires that exposure time be halved for each 5-dB increase.” [NIOSH 1998]

Noise Induced Hearing Loss (NIHL) – Percentage (of the population) with material impairment of hearing in an occupational-noise-exposed population after subtracting the percentage who would normally incur such impairment from other causes in a population not exposed to occupational noise.

Threshold Level – noise level where integrating noise measuring equipment begins to accumulate noise exposure information.

Appendix B – Noise Measurement Criteria

<table>
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<th>US OSHA – General Industry – Hearing Conservation</th>
<th>US OSHA – Construction Industry</th>
<th>American Conference of Governmental Industrial Hygienists</th>
<th>National Institute for Occupational Safety and Health</th>
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