

## INTRODUCTION

Would it be nice if you could determine how effective a hearing protector was under workplace conditions. In Appendix IV:C of the OSHA Field Manual, *Methods for Estimating HPD Attenuation*, U.S. OSHA states, “The actual effectiveness of any individual hearing protector cannot be determined under workplace conditions” (U.S. Department of Labor). This has never been completely true. It has been difficult, but not impossible, to determine the actual effectiveness of any individual hearing protector for any individual user because of two issues. First, there has been no available commercial product for testing hearing protector effectiveness for the individual user until just recently – for less than 10 years compared to an OSHA regulation on noise and hearing conservation that dates back almost 45 years in its most skeletal form.

Second, there have been no accessible commercial methods for determining the effectiveness of any individual hearing protector for any individual until recently. In fact, now there are three:

- There are methods involving simulations of the real-ear attenuation at threshold (REAT) using large-cupped earphones to place over the ears to test earplugs. (Michael and Associates FitCheck, Workplace INTEGRA, Inc. INTEGRAfit, NIOSH Well-Fit and FitCheck Solo)
- There are methods involving having a person balance the loudness of a signal presented to an open ear to that of a signal presented to an ear occluded with an earplug. (Howard Leight VeriPRO)
- There are methods that employ the use of a sub-miniature or probe microphone placed in a surrogate protector to predict what attenuation a user would receive when wearing the actual hearing protector in a similar manner. (3M EARfit)

Regardless of method, the concept has been labeled as Field Attenuation Estimation Systems (FAES). A standard for release as ANSI S12.71 is in development and refers to these methods as Field Attenuation Estimating Systems (FAES) (ANSI S12.71, 20XX). Rather than develop a preferred method, ANSI S12.71 will focus on how to manage the uncertainty of the measurements taken with such systems so they can be compared.

The end goal of FAES has been to obtain a Personal Attenuation Rating (PAR) that may be compared to the labeled Noise Reduction Rating (NRR) provided by the manufacturer of the hearing protector. Or, in not enough cases, the PAR is used to see if the hearing protector user is getting enough attenuation to allow the prevention of hearing loss due to exposure to the noises for which the hearing protectors are being worn.

What is hoped that the reader will obtain from this white paper is a sense of whether the uses of these types of assessment of PARs are consistent from method to method. And, more important, what should be done these procedures and their data to optimize the effectiveness of the hearing loss prevention program.

## MYTHS OF HEARING LOSS PREVENTION Programs

When a Hearing Loss Prevention Program (Program) is administered effectively, it can be one of the most burdensome of all the occupational safety and health programs that a company may have. It can also be one of the most rewarding. There is an underlying premise to any occupational safety and health program: workers will leave the job at the end of the day as healthy as when they arrived, if not healthier. For too long, various illnesses and injuries have been accepted as being part of the trade or occupation.

It has only been in last 100 years that occupational illnesses and injuries have been studied and plans taken to ameliorate them. Alice Hamilton, considered as the founder of occupational safety and health in the United States began studying the work-related illnesses of workers at the beginning of the last century, publishing her first paper in 1908 (Hamilton, 1943)

It wasn't until the end of World War II that the Veteran's Department began to deal with noise-induced hearing loss from weapons fire. While the U.S. Walsh-Healy Occupational Safety and Health Act determined that in the U.S. the permissible exposure level for eight hours was to be 90 dBA (with a 5-dB exchange rate to allow for the time the ear *recovered* from noise exposure while away from work), the U.S. Army didn't conduct its first large survey of the hearing of enlisted military from enlistment/inscription to retirement until 1971. The U.S. Army's regulation for hearing conservation was issued in 1974 (U.S. DoD, DoA, 1998). It took from 1969 until 1983 for U.S. OSHA to have a final rule that described "an effective hearing conservation program."

OSHA, in 29 CFR 1910.134, requires that spirometry be performed for all workers using respirators at least every three years by persons who take a Centers for Disease Control and Prevention course on spirometry. OSHA provides no mandated follow-up to remove persons who breathing has become impaired due to work-related inhalants. Thus, persons can have their developing chronic obstructive pulmonary disease well documented, including medical evaluations. Similarly, OSHA, in 29 CFR 1910.95, requires that all persons who must use hearing protection must receive annual audiometry. Their results are compared to a baseline audiogram and corrections for aging may be used. If they show a Standard Threshold Shift after they've already developed material hearing impairment, the outcome is reported in accordance with 29 CFR 1904.10 as hearing loss if no reason other than workplace noise can be found. Intervention steps are limited to re-evaluating the workers' use of hearing protection and retraining. Thus, their progressive noise-induced hearing loss can be well documented since is there not a provision for removing the workers from the noise. This has been called *audiometric voyeurism* by persons frustrated with magnitude of noise-induced hearing losses that continue to present themselves.

In an effort to assure that the hearing protection provided to the noise-exposed worker is adequate, and in recognition that the Noise Reduction Rating (NRR) listed on every hearing protector sold in the U.S. (40 CFR 211, Subpart B) is generally over predictive of the protector's ability to reduce noise for the average worker, OSHA requires a 50% derating of the NRR (Occupational Safety and Health Administration, 1998). OSHA acknowledges that NIOSH has a derating scheme that was dependent upon

protector type and also used a different formula for accounting that the NRR is intended to be used with C-weighted noise levels, while employee exposure levels are A-weighted. NIOSH, in its criteria document, applied the derating schemes (25% for earmuffs, 50% for slow-recovery form earplugs, 70% for preformed earplugs) and the 7-dB C-A correction factor in an algebraically correct manner (NIOSH, 1998). NIOSH also suggested that if testing of the earplugs were conducted using a subject-fit, rather than an experimenter-fit, method, no derating should be necessary (recent research has shown the C-A correction is closer to 3 dB than 7db).

NIOSH's 1998 suggestion may be all the more true if a singular event were to occur: The EPA would release its revision of 29 CFR 211 should it call for hearing protectors to be tested in accordance with ANSI S12.6 – Method B (American National Standards Institute, 2006) and use of a two-number rating system as described by ANSI S12.68 (American National Standards Institute, 2012). This position was taken by the National Hearing Conservation Association, the American Speech-Language-Hearing Association, the Acoustical Society of America, the American Industrial Hygiene Association, as well as a few expert scientists (U.S. Environmental Protection Agency, 2004). However, the EPA changed to recommend ANSI S12.6-Method A in its proposed final rule, but has yet to release it (U.S. Environmental Protection Agency, 2009)

The mythic elements are:

1. That the Program effectiveness can be created by the application of hearing protection to all noise-exposed workers and that the effectiveness of the Program can be demonstrated by the lack of Standard Threshold Shift.
2. That all that is needed to boost Program effectiveness is that the introduction of FAES, which will round out the program and add to audiometry's effectiveness.

## Myth Busting

### Hearing Protection versus Noise Control

When the noise levels are reduced to what can be considered hazardous, such as below 82 dBA, one important thing happens: there is no need for a Program if facility-wide or, if limited to certain area, workers from that area no longer need to be in the Program. Being absent from a program does not mean that the workers are immune to concerns about noise-induced hearing loss, it just means that if noise-induced hearing loss were to develop, it would be due to non-work-related issues.

**BUSTED!** It means that the worker has not been in a continuing training program about the hearing hazard that noise poses and so may have developed a noise- or music-induced hearing loss because of ignorance. Further, it means that the hearing loss will not be noticed until it begins to interfere with the workers day-to-day living, including success at work at times and in places where communication is important and/or warning signals need to be identified and responded to appropriately. However, the one sure benefit of noise control is that it may be confidently and universally applied. If the noise level

results in an exposure that is less than 82 dBA  $L_{eq,8}$ , then the confidence that any hearing loss incurred is not work related may be high.

### Audiometric Surveillance

If the noise exposure levels are sufficiently high to require the use of hearing protectors, greater than 85 dBA  $L_{eq,8}$ , then hearing protectors must be supplied and, in the United States and some Canadian provinces, audiometry is required according to a schedule. Most Program administrators seem to believe that the provision of hearing protectors and performing audiometry will prevent noise-induced hearing loss.

**BUSTED!** Because no two individuals will receive the same amount of noise reduction from a given hearing protector, even when fitted *properly*, the risk of noise-induced hearing loss is different for each. Consider the case of workers whose  $L_{eq,8}$  values are 92 dBA. They will need 10 dB or more of noise reduction of their hearing protection. Some workers will fit the hearing protector so that they don't achieve occlusion of the ear canal and may even get an increase in the noise levels rather than a reduction. Others will deeply insert the hearing protector and achieve 20 dB more noise reduction than they need and isolate themselves in the process, potentially becoming safety hazards of their own.

Audiometry is an after-the-fact surveillance system. Thus, the Program administrator can react only after the noise-induced hearing loss has established itself, even though it may be initially marginally material. If OSHA guidelines for recording Standard Threshold Shift (called Hearing Loss by the regulations) are followed, then the workers already has a mild-to-moderate noise-induced hearing loss before reporting it is necessary. If the Standard Threshold Shift requirement in 29 CFR 1910.95 is followed,, looking for a 10-dB Standard Threshold Shift regardless of hearing levels, then there is a chance that material hearing impairment can be avoided. Nonetheless, hearing must be lost for the triggers in the audiometric component of the Program to be initiated.

### Field Attenuation Estimation Systems (also called Fit Testing Systems)

FAES provide the potential to substantially reduce the prevalence of noise-induced hearing loss. As described above, it is impossible given the label on almost any hearing protector to predict what the individual worker will realize. However, with FAES it is possible to measure what the worker has realized. Further, it is possible to check what the worker is getting at various times to assess the consistency of the outcome. Last, it is possible to assure that the worker is realizing sufficient noise reduction program the hearing protector to not be at risk of occupational noise-induced hearing loss and also to not be isolated due to over protection.

The key word here is *possible*. It is also possible to use FAES and measure a level of noise reduction that the worker does not typically achieve. It is possible to not have sufficient corollary information available to actually use the FAES data, other than to record them. It is also possible to adopt a FAES system that

will provide data dissimilar from another in use in the same Program. Consider these in reverse order: FAES to FAES incompatibility, using FAES in a vacuum, and atypical FAES measurements.

## FAES to FAES incompatibility

This concept does not mean that one commercial FAES system is better or worse than others. What it means is that the methods outlined at the top of this white paper will produce different values. What is important is that within the data produced by the use of any one of the systems there is consistency; test-retest consistency. The units that are used to measure real-ear attenuation at threshold (REAT) should all produce the same PAR with allowances for earphone placement, calibration variances, and test-retest variance of the person being tested. What will also affect the PAR value is the number of frequencies tested.

If a hearing protector were tested and retested for the same person, it would be possible to measure that person's noise reduction for each frequency band tested each time. The data could be used to calculate the mean and variance values and then applied to the distribution of the data for each frequency band. Using this concept, Murphy and Stephenson (Murphy, 2013), determined what the  $NRS_A$  for a hearing protector (the  $NRS_A$  being the A-weighted Noise Reduction Statistic from ANSI S12.68) and applied it to a specific noise spectrum, NIOSH 100 Noise #33. The results are shown in Table 1 below.

<b>Freq</b>	<b>125</b>	<b>250</b>	<b>500</b>	<b>1000</b>	<b>2000</b>	<b>4000</b>	<b>8000</b>	<b>Total</b>
NIOSH 100 Noise #33	91	89	92	92	92	88	80	
A weight	-16.1	-8.2	-3.2	0.0	1.2	1.0	-1.1	
Noise +Awt	74.9	80.4	88.8	92.0	93.2	89.0	78.9	97.4
Attenuation	11.0	13.0	12.0	17.5	27.5	33.0	22.0	
NAwt –Atten	63.9	67.4	76.8	74.5	65.7	56.0	56.9	79.5
Awt Atten								17.9

Figure 1. Example of calculation table for sample earplug and selected noise spectrum.

In this case, the  $NRS_{A50}$  is the mean value is rounded up to 18 dB. It is obtained by calculating the log sum for the A-weighted octave-band noise levels (Noise+Awt), subtracting the mean attenuation for the earplug for the person being tested and calculating that log sum (NAwt-Atten), and then determining the difference between the two log sums – (Noise+Awt)-(NAwt-Atten) = Awt Atten.

The  $NRS_{A20}$  is the value for the 20<sup>th</sup> percentile; the value expected of those who are well trained in the use of the hearing protector and calculates to 21 dB. The  $NRS_{A80}$  for the 80<sup>th</sup> percentile calculates to 16 dB and reflects what most informed wearers should experience. Those  $NRS_A$  values should express the range that would be acceptable for PARs determined with the various measurement systems, provided that they were measuring with more than just one frequency and using a real-ear attenuation at threshold technique.

In Figure 2 are displayed the PARs for six FAES units. Notice that they range from 12 to 19 dB. The VeriPRO, as noted above, uses a loudness balance procedure while the INTEGRAfit uses one frequency, 500 Hz, to determine the PAR. This example is specific to the noise spectrum shown in Figure 1, which is weighted in the lower frequencies, but the C-A difference is 1.1 dB because of the equal octave band levels in the frequencies that receive equal emphasis (500, 1000, and 2000 Hz) from both A- and C-weightings. With a different noise spectrum and with a different attenuation pattern, the results would vary. Nonetheless, setting the VeriPRO and INTEGRAfit systems aside, the PARs of the other systems are within the range of this example.

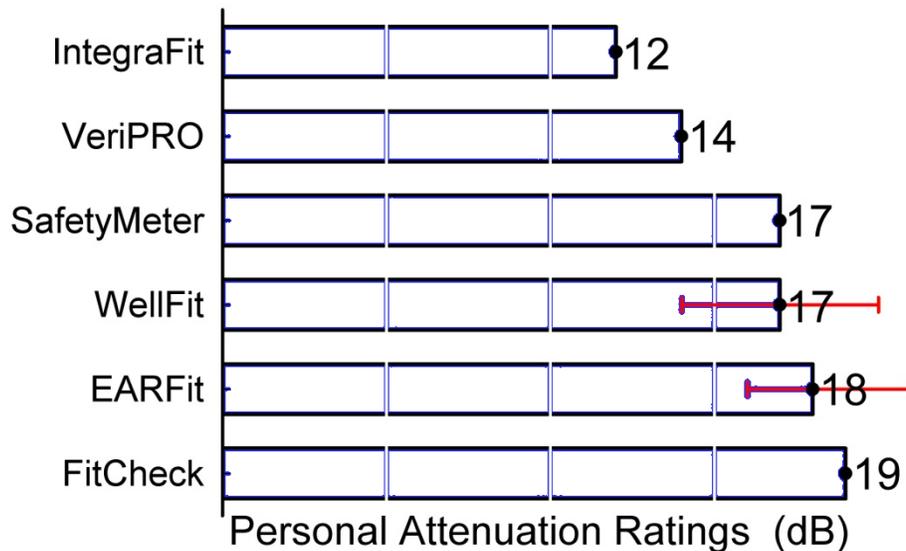


Figure 2. Example PARs for FAES of the different manufacturers for the same earplug for the same person.

#### Using FAES in a Vacuum

It does absolutely no good to have an NRR,  $NRR(SF_{84})$ , H-M-L, or PAR for a hearing protector if the noise exposure level of the wearer is not known. That may seem like a strong statement, but one of the observations from many Programs is that people using hearing protection continue to lose hearing. There are two likely reasons for this. First, the worker may be wearing the hearing protector in such a manner that it either doesn't provide adequate noise reduction or may actually increase the noise levels in their ears. A foam earplug that has not been rolled down prior to insertion and that has been shoved into the ear canal actually be more hazardous to hearing than no earplug at all. An earplug that is just barely occluding the ear canal can provide so little noise reduction as to be useless, and even worse than useless in that it can still interfere with hazard awareness and communication with other workers.

If the worker is given an earplug capable of providing much more noise reduction than needed, such as 33 dB for use in a 92 dBA  $L_{ex,8}$  environment, over protection and its associated isolation may occur. There is no manner by which such an earplug could be used *correctly* and not over protect. Nonetheless, some workers will feel the need to insert an earplug to get as much noise reduction as possible, thus isolating themselves. In many plants, the noise exposure levels have not been measured, and the disposable earplugs with the highest NRR are provided – for many workers disposable becomes one-

time use, so they are always getting a new pair whenever they come off break or back from lunch. In some of those plants the noise exposure level is typically 90 dBA  $L_{ex,8}$ , and so hearing protectors that provide around 10 dB of noise reduction are most appropriate, but can't be found. And, when FAES is employed in the information vacuum, the wearers may be encouraged to fit the earplugs so that they approach the higher noise reduction rating.

Peter Rabinovich has noted from studying a large corporation that the inclusion of FAES did little to improve the outcomes (Rabinovich, 2013). There are various reasons for this, the most intriguing being that workers who have been over protected for years may be resistant to wearing a new earplug that gives them adequate protection because they have become accommodated to the isolation provided by overprotection.

Before the appropriate earplug can be selected, it is necessary to know the noise environment in which it will be worn. In the absence of that information, incorporating FAES into the Program will result in little change in overall program outcome. The use of FAES becomes just another procedure because, among other things, it operates in a vacuum.

#### Atypical FAES Measurements

In an ideal setting, the factors that create a worker's Program environment include accurate assessment of the noise exposure level, accurate assessment of the amount of hearing protection the worker is receiving from the hearing protector, and accurate assessment of the worker's hearing via audiometry. Two of those factors can occur at the same time: assessment of the protection and of the hearing. Thus, the FAES is inserted into the annual audiometry as the Program training should be included as well.

While, at least in the U.S., workers are permitted and even encouraged to participate in the measurement of workplace noise, they can little effect on the outcome. So long as the measurements taken reflect typical work-day experiences and there is no intentional corrupting of the data, such as retreating to a break area for the duration that a dosimeter is worn, the values should be representative enough to allow determination of exposure levels.

When Park and Casali (1991) conducted a study of the noise reduction of a group of workers, workers retrieved from their workplaces without prior knowledge of when they were to be tested and were not permitted to readjust the fit of their HPDs. In this manner, Park and Casali were able to obtain a *candid* assessment of the attenuation due to the hearing protector as normally worn.

If FAES is included into the annual audiometry/training event, then the workers may have time or opportunity to adjust the fit of their hearing protectors. In many cases, they may arrive at the testing site, remove their hearing protection for audiometry and the determination of their unoccluded hearing thresholds for the FAES test signals, and then refit their hearing protectors for the occluded portion of the test procedure. The FAES result, then, may reflect a higher PAR than if the workers were to be retrieved from the worksite, not allowed to refit or adjust the hearing protectors, and had the occluded portion of the test procedure administered first. However, this is a logistical problem that may be impossible in many facilities.

## Effects of Training on Protector Performance or PARS

Casali and Park (1991), Murphy, et al. (2011), Tufts, et al. (2013) studied the effects of training on the performance of hearing protectors. For Casali and Park the focus was on the effects of training on protector performance and they found that with training attenuation improved more for slow-recovery foam earplugs than for semi-inserts (often called ear canal caps) or earmuffs. For Murphy, et al. the focus was on the style of training – written, video, or one-on-one (individual) - and they found written training and training by presentation of a video tape to yield a substantively smaller change in hearing protector performance than with individual training. While the protector performance improved from first to second session (whether first was written or video), the improvement following individual training was statistically greater than either written or video training.

For Tufts, et al the focus was on the consistency of the fit over time and the effect of training for different types of hearing protectors – flanged pre-moulded or custom moulded. The measurement where taken using the FitCheck system. For the first two measurement sessions the study subjects were untrained (naïve to wearing earplugs). The subsequent two sessions followed individual training. The study found that, across repeated fittings, training improved the consistency of protector performance for both earplug types. Further, the custom-moulded earplug provided more consistent attenuation than the non-custom earplug.

### Summary

What is to be gained from the insertion of FAES into a hearing loss prevention program? The answer will vary depending upon the Program more than on the manufacture and model of the FAES. If the FAES is used in a vacuum where there is little or no information about the noise exposure levels and goal of the application of FAES is to merely note the workers' PARS, then there will be no benefit. If, the purpose of using the FAES to training the workers to achieve the maximum attenuation possible from an earplug chosen with no concern for noise exposure levels, then there will be little benefit. If the FAES is incorporated into the annual audiometry/training session, training is individual rather than by brochure or video tape, and the hearing protectors provided are selected based on the workers' noise exposure levels, then FAES may be used as a documentation of the effectiveness of both the hearing protection and training portions of the Program. Audiometry, used as a surveillance tool, should only confirm the Program's success.