In Search of Meaningful Measures of Hearing Protector Effectiveness

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ABSTRACT

The appropriateness of the present Environmental Protection Agency (EPA) Hearing Protector Labeling Regulations has been seriously debated for several years. In response to concerns expressed by professional, industrial, governmental, and military sources, the National Hearing Conservation Association (NHCA) established a multi-organizational *Task Force on Hearing Protector Effectiveness* in the summer of 1993, to address labeling-related issues. The recommendations of the Task Force were published in the May 1995 issue of *Spectrum [12(2), p. 1 and 6-13],* and were followed later that summer by a letter to the EPA petitioning them to review and revise the labeling regulations per the Task Force's findings. This lecture will describe the background of this project as well as the recommendations of the Task Force. The research and ongoing efforts of a related endeavor by Accredited Standards Working Group S12/WG11 *Field Effectiveness and Physical Characteristics of Hearing Protectors* will also be discussed. WG11 is developing a laboratory-based test method and related draft standard, intended to yield useful estimates of the field performance of hearing protectors. The combination of an improved test method, and revised and expanded labeling information, is designed to enhance the ability of both hearing conservation professionals and the typical consumer, to better recommend and select hearing protection devices. The authors of the paper are the Chair of WG11, and the Chair of the NHCA Task Force, respectively.

OVERVIEW

Prior to 1979, attenuation data for hearing protection devices (HPDs) were commonly available from manufacturers, but only in the form of octave-band attenuation and standard deviation values at test frequencies from 125 Hz to 8000 Hz. Although methods of utilizing those data were described in the literature and at least one standard specified a scheme of classification based on attenuation data (CSA, 1974), U. S. hearing conservationists almost exclusively utilized the octave-band method of computation (also called the "long" method) - which is to say that in many instances HPD attenuation values were simply ignored because of the difficulty of acquiring octave-band work place noise measurements with the instrumentation of that era, combined with the difficulty in the pre-calculator and pre-PC age of performing multiple computations requiring either a nomogram or antilogarithms.

The advent of the Noise Reduction Rating (EPA, 1979) and the accuracy and simplicity that it seemed to provide, substantially changed the picture. Much attention was then focussed on HPD attenuation values. In many instances, either purchasing specifications or hearing conservation program (HCP) policies were based upon use of the NRR. As a result, manufacturers highlighted the NRR to a greater extent in their literature, and a battle of numbers arose as more attention was directed at this ostensibly critical parameter. In many

cases, purchasing decisions came to be predicated upon differences in NRRs of as little as 1 dB.

Use of the NRR became even more entrenched in 1981/83 when OSHA included it as the preferred method for assessing HPD adequacy for compliance with the Hearing Conservation Amendment (OSHA, 1983). One result has been that in many instances additional key parameters of performance such as comfort, compatibility, communication needs and hearing ability are neglected or overlooked in favor of choosing the HPD with the highest possible NRR. This can lead to wearer dissatisfaction and consequent misuse or even non-use, resulting in inadequate protection, or none at all. At the other extreme, correct use of products with too much noise reduction can create communication and safety problems, especially for workers with preexisting hearing losses.

Beyond the melange of problems already discussed, a further issue concerns the capability of answering a natural and seemingly straightforward question: How much noise reduction can hearing protectors provide? Regrettably, this has not been an easy question to answer. In fact, the accurate estimation of the attenuation that wearers of HPDs receive under conditions of actual use (also called "real-world attenuation), has been a topic of substantial research and much debate (Berger, 1993a; Berger, Franks, and Lindgren, 1996). Although the technicalities of the measurement problem are well understood and standardized, the methods of modeling the behavioral aspects of real-world users in a laboratory setting are only now being fully explored (J. Royster, et al., 1996).

With this in mind, it shouldn't be surprising that the NRR is generally acknowledged to provide little useful guidance in the selection and specification of hearing protection devices. In fact, it can be said with little exaggeration that perhaps the <u>only</u> value in the NRR, is that it indicates the product with which it is associated has been designed for and tested for noise reduction. Firm reliance upon the NRR can be very misleading.

THE DANGER OF HIGH LABELED NRRs

The average NRR on devices sold in North America today is greater than 23 dB. This number clearly overstates the protection afforded to most occupationally noise-exposed workers. Such NRRs are dangerous because they mislead both buyers and users of HPDs. Taking an NRR of 22 at face value, one is led to presume that his or her work force will be protected for time-weighted average exposures to over 100 dBA. Since this easily accounts for most noisy industries, it suggests that almost all workers in almost all environments will be protected if only they are simply given hearing protection.

We have come to learn that such expectations are far from the truth. Fostering such beliefs leads to hearing conservation programs in which inadequate attention is paid to the aspects of a program that can make it work - training, motivation, supervision, and enforcement. The program managers may be lulled into a false sense of security.

POTENTIAL SOLUTIONS

A multifaceted approach was required to deal with the problems outlined above. Not only are data with better inherent predictive capabilities required, but there is also a strong need for an improved scheme of labeling HPDs, including better guidance in selection and dispensing. Accordingly, two separate initiatives were developed to address the problems,

and are described in this paper: 1) the efforts of the Acoustical Society of America's Accredited Standards Committee on Noise, S12, Working Group 11 (S12/WG11), chaired by Elliott Berger, and 2) the deliberations of the National Hearing Conservation Association's inter-society Task Force on Hearing Protector Effectiveness, chaired by Larry Royster.

WG11 AND ITS EFFORTS TO DEVISE A BETTER LABORATORY TEST METHOD

S12/WG11, entitled *Field Effectiveness and Physical Characteristics of Hearing Protectors* was established in 1987 to "explore the problems inherent in using optimum-laboratory real-ear attenuation data to estimate achievable and/or typical workplace protection, and to propose a plan of action to identify or develop laboratory and/or field procedure(s) that yield useful estimates of field performance." Subsequent to an evaluation of the literature, WG11 decided to focus on developing an improved laboratory test standard that would generate data to provide a useful indication of the field performance of HPDs. A draft protocol was devised which was tested by both pilot and full-scale interlaboratory studies (Berger, 1993b). Subsequently, a draft standard was prepared which is currently out for vote by the S12 Committee on Noise, and the first of a series of articles explaining the research will be appearing shortly (J. Royster, et al., 1996).

WG11's draft standard, S12.6-199X is a revision to the existing ANSI standard for real-ear attenuation measurements on hearing protectors, S12.6-1984. Whereas the 1984 standard provides only a single method of experimenter-supervised fit which "is intended to yield optimum performance values which may not usually be obtained under field conditions," the draft revision also provides an alternative subject-fit procedure "intended to provide an approximation of the upper bound to the attenuation that can be expected for groups of occupational users." The reason for offering two methods is that the experimenter-supervised-fit values are useful in the design of HPDs and can provide a theoretical understanding of their performance limitations. Subject-fit values correspond more closely to real-world performance. Therefore it is the preferred method for labeling purposes as discussed in the next section.

The subject-fit method as described in the draft standard differs in a number of respects from prior ANSI and international standards. Two key differences comprise experimenter involvement and prior listener experience with HPDs. Experimenter involvement is explicitly defined, to the extent that much of the information given to the subjects consists of verbatim quotes to be read from the draft document. Furthermore the fitting procedure entails telling the subject that the purpose of the test "is to estimate the noise reduction that you would be likely to attain while wearing this hearing protector in a noisy environment," and then asking him or her to read the manufacturer's written instructions and to fit and adjust the hearing protector to the best of his or her ability. The experimenter is not allowed to assist in that process.

Listener experience is controlled such that subjects are naive with respect to the use of hearing protection (within certain defined bounds) but are audiometrically practiced and experienced. The specification of prior subject experience using HPDs is required in order to control interlaboratory variability, and because with a subject-fit protocol the prior level of experience can substantially affect results (Berger, 1992). Additional discussion and justification can be found in the draft standard itself (S12.6-199X).

Examples of subject-fit results, compared to representative real-world performance and existing manufacturers' labeled values for a foam earplug and an earmuff are shown in Figures 1 and 2. A key point to observe, and one that may surprise some readers, is that even with the requirement for naive HPD wearers and no experimenter assistance in fitting the devices, the subject-fit data still provide an upper-bound estimate of field performance. By comparison, the labeled values, especially for earplugs, substantially overestimate achievable field performance. In fact, in the authors' experience, there has never been a field study conducted in which currently labeled values of HPD attenuation have been achieved for groups of users under real-world conditions. Similar results have been previously reported in the literature (Berger, 1988).

Fig. 1 - Three measures of the attenuation of the E-A-R® Classic foam plug. "Real-world" is avg. of 15 studies with 575 subjects; "Subject Fit" is avg. of 4 labs testing the WG11 subject-fit protocol; "Labeled" is mfgs.' published data.

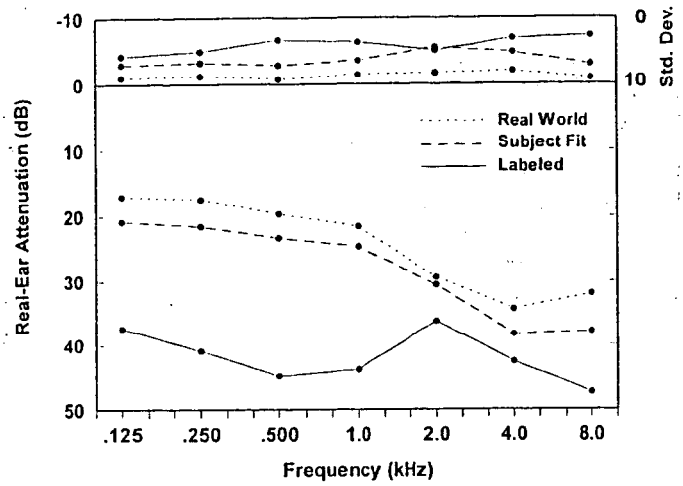
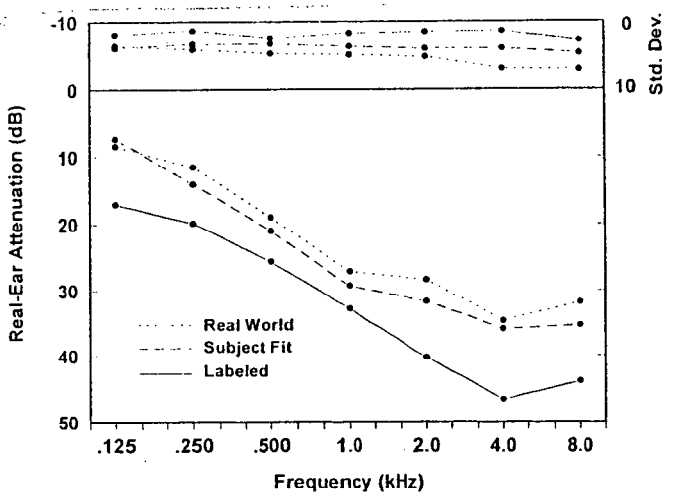


Fig. 2 - Three measures of the attenuation of the Bilsom UF-1 earmuff. "Real-world" is avg. of 3 studies with 51 subjects; "Subject Fit" is avg. of 4 labs testing the WG11 subject-fit protocol; "Labeled" is mfgs.' published data.



THE NHCA TASK FORCE AND THE EPA LABELING REQUIREMENTS

With the possibility of having more representative data in hand, the remaining part of the problem was how to communicate that information to the public, especially in light of the existing EPA hearing protector labeling regulation which calls for laboratory-based experimenter-fit test results per EPA's interpretation of ANSI S3.19-1974.

Early in 1993 the Industrial Safety Equipment Association (ISEA) organized a meeting of interested parties including the ISEA membership and others. A lively discussion and debate ensued, out of which grew the concept of NHCA establishing a multi-organizational task force to prepare recommendations to both the professional community and concerned government agencies, especially the EPA. The recommendations were to address guidelines for labeling HPDs, the provision of suitable educational materials, and guidelines for HPD selection and use. Larry Royster volunteered to chair this effort for the NHCA and was able to formulate a consensus position as summarized below and described in greater detail by Royster (1995).

An attempt was made to involve all of the principal governmental and non-governmental organizations and committees concerned with noise and hearing conservation. Nineteen groups agreed to participate as summarized in Table I. Some of the organizations participated informally, not intending to or by nature of the organization not being able to, obtain approval of the Task Force's final recommendations from their governing bodies.

The recommendations of the Task Force were finalized in April, 1995, and accepted with only two negative votes. Since that time, in addition to the NHCA, four of the other associations have formally endorsed the recommendations (AAOHN, AIHA, ASHA, and CAOHC), and sent letters to EPA petitioning the agency to change the HPD labeling regulations accordingly. Additionally, two organizations not directly involved with the Task Force [American Academy of Audiology (AAA) and American Society of Safety Engineers (ASSE)] have endorsed the recommendations and written the EPA.

Table I - The NHCA Task Force on Hearing Protector Effectiveness

Organization	Type	Representative
AAOHN - American Assoc. of Occup. Health Nurses	Association	Barbara Panhorst
AAO-HNS - American Acad. of Otolaryngol.- Head and Neck Surg.	Association	Robert Dobie
ACOEM - American College of Occup. and Env. Medicine	Association	Tom Markham
AIHA - American Industrial Hygiene. Assoc.	Association	Dennis Driscoll
ASA - Acoustical Society of America	Association	Jim Patterson
ASHA - American Assoc. of Speech-Language Pathology and Audiol.	Association	Rena Glaser
CAOHC - Council for Accreditation in Occup. Hearing Cons.	Association	Rena Glaser
ISEA - Industrial Safety Equipment Assoc.	Association	Jeff Birkner
NHCA - National Hearing Conservation Assoc.	Association	Larry Royster
NSC - National Safety Council	Association	Jill Niland
EPA - Environmental Protection Agency	Government	Ken Feith
MAA - Military Audiology Assoc.	Government	Doug Ohlin
MSHA - Mine Safety and Health Administration	Government	Leonard Marraccini
NIOSH - Natl. Institute for Occup. Safety and Health	Government	John Franks
OSHA - Occup. Safety and Health Administration	Government	Deborah Gabry
WG10 - Hearing Protector Attenuation	ANSI/ASA	Charles Nixon
WG11 - Field Effectiveness of Hearing Protectors	ANSI/ASA	Elliott Berger
WG12 - Evaluation of Hearing Conservation Programs	ANSI/ASA	Julia Royster
WG35 - Eval. of Comm. Ability in Noise for Individ. w/Hearing Prot.	ANSI/ASA	Ed Toothman

A key recommendation emerging from the Task Force discussions was that no single HPD characteristic, such as attenuation (as represented by the present NRR), or any other feature, should be the sole arbiter influencing selection of an HPD. As such, the labeling information

should guide a user to consider all relevant factors, although within the limitations of a regulation and a label-format, it was not possible to actually provide all the guidance needed. Furthermore many of those present noted that the available data indicate that greater than 90% of the noise-exposed population needs only 10 dB of actual delivered real-world attenuation. In many instances the exact amount of laboratory-measured attenuation is not critical or at the very least, much less important than the educational, motivational, supervisory, and enforcement aspects of the HCP in which the wearers are involved.

Early in the deliberations of the Task Force it was agreed that the hearing protector attenuation data used in computing the existing NRRs were too high; they provided a very poor indicator of potential field performance. This was much the same conclusion reached by S12/WG11. Whatever method of communicating attenuation data was selected, the data themselves would have to be taken from laboratory tests yielding results more representative of field performance. Thus, the Task Force decided that its recommendations would hinge on the completion and adoption of the WG11's draft standard described in the previous section, such that labeled values would be based upon subject-fit testing.

General Overview of the Recommendations

The recommendations of the Task Force consist of proposals for a new Primary Label (like the box with the NRR that currently appears on all hearing protector packaging), a new Secondary Label (like the accompanying octave-band data and instructions that must by law, currently be made available to customers), and two administrative issues regarding how and when the test data are to be obtained. The proposed Primary and Secondary Labels appear as Fig. 3 and as Table II respectively.

Primary Label

Although the Task Force had clearly decided it would recommend the use of subject-fit data, one of the most contentious issues it addressed was how those data should be presented. Should an NRR-type computation be retained, or should the potentially more accurate and more complex HML be utilized (ISO 4869-2:1994), or should there be no number at all on the Primary Label? Should only the octave-band data be provided? And what type of range in values should be specified - the average, or the mean plus and minus either one or two standard deviations?

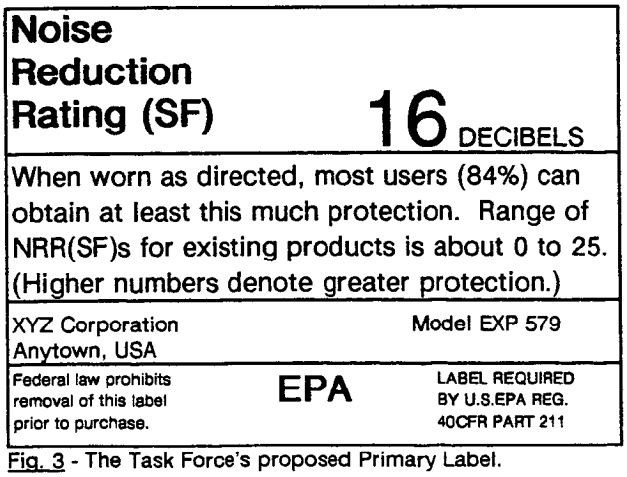


Fig. 3 - The Task Force's proposed Primary Label.

The decision was to use an NRR-like number, called the Noise Reduction Rating (Subject Fit), designated NRR(SF). The intention was to make it clear that the new rating was indeed different than the old rating. Although the three-number HML (high/medium/low) method was considered, it was felt that the additional complexity it presented to the user, combined with the limited ability of laboratory test data to represent any given individual or group of individuals, offset the small theoretical increases in accuracy that it could provide. A recent

study by Thomas and Casali (1995) supports the wisdom of that decision since it indicates that with or without training, both experienced and inexperienced users make more errors in computing protected noise exposures when using an HML procedure than when using the NRR.

Also considered was simply reporting the octave-band data. In the recommendation, those values (along with the HML) are reported on the Secondary Label for those who wish to use them, but it was decided that the vast majority of users, especially those in the consumer sector, would be unable to use a more complex approach. Furthermore, the value of such a procedure was difficult to justify in consideration of the variability of octave-band spectra and the related inherent problems of acquiring sufficient samples for a precise estimate of employee exposures.

Other changes in the Primary Label include the additional of explicit indication that the level of protection will vary among individuals, with most users (84%) potentially expected to achieve the labeled values, and the fact that the range of NRR(SF)s is anticipated to be about 0 - 25, vs. the range of 0 - 30 dB stated on the existing EPA label.

Additional Details of the NRR(SF) Computation

The NRR(SF) is computationally very similar to the existing NRR with the following exceptions:

a) The NRR is computed with a subtractive 2-standard-deviation (SD) correction, whereas the NRR(SF) is computed with a subtractive 1-SD correction. For subject-fit data of the type called for by WG11, 1 SD amounts to about 3 - 12 dB. Use of a 1-SD instead of the 2-SD correction in existing NRRs, offsets to some extent the change from best-fit (NRR) to subject-fit [NRR(SF)] data.

b) Although the actual computations involved in the NRR(SF) and the NRR are nearly the same, the NRR(SF) is based on the SNR procedure in ISO 4869-2:1994, whereas the NRR is based on prior NIOSH work (1975). Even if the same set of octave-band attenuation values are used as the input data for both single-number calculations, and the same number of SDs are subtracted (for example a 1-SD correction in both instances), small differences between the methods cause the computed NRR(SF)/SNR-type value to exceed the computed NRR by 3.5 dB.

c) Besides the requirement in the NRR(SF) to use subject-fit data, another modification in the NRR(SF) as compared to both the EPA's NRR and ISO's SNR procedure, is that the NRR(SF) is intended to be subtracted from A-weighted values. By comparison, both the NRR and the SNR are designed to be subtracted from C-weighted values. Although use of single-number ratings with A-weighted values gives rise to a loss in accuracy, the Task Force determined that the increased ease of and likelihood of correct application by more users, was the governing consideration.

   To permit use with A-weighted decibels, with no loss in safety, the NRR(SF) must include a constant -5 dB adjustment, i.e. NRR(SF)s are 5 dB less than SNRs computed from the same set of data. The Task Force's 5-dB correction (Royster and Stephenson, 1976; Miller, 1995) is less stringent than the 7-dB value used by NIOSH for adjusting the NRR for use with A-weighted decibels, and which was adapted by OSHA for the Hearing Conservation Amendment. A note is added to the computational example in

the Secondary Label, indicating that the 5-dB can (and should) be eliminated when the NRR(SF) is ("correctly") subtracted from C-weighted values.

In summary, differences between the new NRR(SF) and the old NRR will vary product by product, depending upon the relationship of the old EPA experimenter-fit test data to the new proposed subject-fit data. The divergence will also be affected by the change from a 2-SD to a 1-SD correction, and the constant offset of 3.5 - 5.0 = -1.5 dB as discussed in paragraphs b) and c) above. The new NRR(SF) will be less than the NRR, generally by approximately 5 - 20 dB, with the differences being less for earmuffs than for earplugs.

Secondary Label

The Secondary Label must accompany the device in a manner that insures its availability to the prospective user. For earplugs sold in bulk boxes the information should appear on plug dispensers. The Secondary Label is presented in Table II.

Table II - Secondary Label

Instructions for use (specific to each product)

[NOTE: This section may contain unlimited text and pictures at the discretion of the manufacturer.]

Selecting hearing protectors

The most critical consideration in selecting and dispensing a hearing protector is the ability of the wearer to achieve a comfortable noise-blocking seal which can be consistently maintained during all noise exposures.

Additional important issues include:

- Hearing protector's noise reduction
- Wearer's daily equivalent noise exposure
- Variations in noise level
- User preference
- Communication needs
- Hearing ability
- Compatibility with other safety equipment
- Wearer's physical limitations
- Climate and other working conditions
- Replacement, care and use requirements

Laboratory attenuation values re ANSI S12.6-199x (subject fit),[1] along with corresponding HML[2] values and the NRR(SF)

Test Frequency (Hz)	125	250	500	1000	2000	4000	8000	H	M	L	NRR (SF)
Mean Attenuation (dB)	17.9	19.0	21.0	24.7	29.9	35.6	34.6	25	18	14	16
Standard Deviation (dB)	7.3	6.3	7.3	6.4	5.3	5.0	5.4				

[1] These are representative data for a foam earplug. For 2- and 3-position devices such as earmuffs or semi-insert HPDs, data would also have to be provided for the alternative positions, so the above table could contain up to four additional rows.

[2] See section on Additional Information to find out about the HML.

How to use the Noise Reduction Rating (Subject Fit), [NRR(SF)]

The NRR(SF) may be subtracted from an A-weighted sound level or a time-weighted average noise exposure as follows:

1. The noise level is 92 dBA.
2. The NRR(SF) is 16 dB.
3. Most users (84%) should be protected to a level of 76 dBA.

Tip: A better estimate of the protected level can be obtained by adding 5 dB to the NRR(SF) and subtracting it from a noise measurement made using C- instead of A-weighting.

Applicability of noise-reduction estimates
FAILURE TO FIT THIS HEARING PROTECTOR ACCORDING TO INSTRUCTIONS WILL REDUCE ITS EFFECTIVENESS. When used as directed this hearing protector is expected to provide between 16 and 30 dB of noise reduction for about 66% users. Of those remaining, 17% will be likely to obtain less than 16 dB of protection, and the other 17% will be likely to obtain more than 30 dB.

Differences between hearing protector ratings of less than 3 dB are not important.

Estimating noise reduction for individual users
The labeled values of noise reduction are based on laboratory tests. It is not possible to use these data to reliably predict levels of protection achieved by a given individual in a particular environment. To ensure protection, those wearing hearing protectors for occupational exposures must be enrolled in a hearing conservation program. Non-occupational users should have hearing evaluations by an audiologist, qualified physician, or other qualified professional, on a regular basis.

Impulse noise
Although hearing protectors are useful for protection from impulsive noise, the noise reduction measurements are based on tests in continuous noise and may not be an accurate indicator of the device's performance for impulsive sounds such as gunfire.

Additional information
For additional information call NIOSH at 800-35-NIOSH to obtain document 9X-XXX,[3] or contact the EPA at ...

[3] The referenced document will be a cartoon pamphlet explaining all features of the Secondary Label. The NHCA Task Force will prepare such a document for consideration by all interested parties.

The recommendations to use the subject-fit procedure of the WG11 draft standard, means that as stipulated in the standard, subjects use the manufacturer's provided written instructions in fitting the HPD for test purposes. In other words, the manufacturer must develop adequate instructions, otherwise its products will end up with lower tested NRR(SF)s. The hope is that this will lead to better and more user-friendly instructions.

A very important section of the Secondary Label is the section on selection. As stated, "the most critical consideration in selecting and dispensing a hearing protector is the ability of the wearer to achieve a *comfortable* noise-blocking seal which can be consistently maintained ...." That and the 10 other factors listed in this section are intended to guide the hearing conservationist or the end user to consider more than simply noise reduction. A cartoon-like pamphlet to describe and amplify the selection topics will be developed by the Task Force at a later date should the current labeling recommendations be implemented. It would be available from an agency such as NIOSH. Additional discussion of the information on the Secondary Label can be found in Royster (1995).

Administrative Considerations
The final two aspects of the Task Force recommendations pertain to administrative issues. To achieve greater consistency and reliability among test data, it was recommended that all attenuation testing be conducted in laboratories accredited by the Department of Commerce's National Voluntary Laboratory Accreditation Program (NVLAP). Furthermore, mandatory product retesting should occur within a specified and limited time frame. The Task Force suggested that a value in the range of 5 to 10 years be selected. This recommendation was included because of the concern that HPD manufacturing processes and composition can change over time, and this should either be controlled for or accounted for in the testing/labeling process.

CONCLUDING REMARKS

Change does not come easily. Although the problems described in this article have been acknowledged and discussed since the early 1980s, it has been in excess of a 10-year process to raise awareness and concern sufficiently to permit the development of alternative suggestions to improve the situation. The efforts of WG11 and the NHCA Task Force have now presented the hearing conservation community with the potential to advance the effectiveness and utility of hearing protection devices by providing users and specifiers with clearer and more reliable labeling information. You can promote the process by reviewing the literature cited herein, considering these concepts, and lobbying for their adoption.

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