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AMERICAN NATIONAL STANDARD

**Methods of Estimating Effective A-Weighted Sound  
Pressure Levels When Hearing Protectors are Worn**

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ANSI/ASA S12.68-2007

Accredited Standards Committee S12, Noise

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Standards Secretariat  
Acoustical Society of America  
35 Pinelawn Road, Suite 114 E  
Melville, NY 11747-3177

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**Methods of Estimating Effective A-Weighted Sound Pressure Levels When Hearing Protectors are Worn**

**Secretariat:**

**Acoustical Society of America**

**Approved August 20, 2007**

**American National Standards Institute, Inc. (ANSI)**

**Abstract**

This standard specifies three methods, in ascending order of complexity of use and potential accuracy, for the estimation of the sound pressure levels that are effective when a hearing protector is worn. The application of the procedures in turn requires an estimate of the real-ear attenuation of the device for groups of users and an estimate of the noise levels to which the users are exposed. The simplest method is the Noise Level Reduction Statistic for use with A-weighting ( $NRS_A$ ) that can be directly subtracted from an A-weighted sound level or sound exposure estimate. A more accurate procedure is the Noise Level Reduction Statistic, Graphical ( $NRS_G$ ) that requires measurements of both the A- and C-weighted sound levels or exposures, and the application of a set of graphical data. Potentially the most accurate approach is the octave-band method utilizing the octave-band real-ear attenuation and noise measurement data. Each of the simplified ratings, the  $NRS_A$  and  $NRS_G$ , is to be computed at both the 80<sup>th</sup> and 20<sup>th</sup> percentiles to reflect the range of performance to be expected based on the variation in the attenuation data.

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Acoustical Society of America  
ASA Secretariat  
35 Pinelawn Road, Suite 114E  
Melville, New York 11747-3177  
Telephone: 1 (631) 390-0215  
Fax: 1 (631) 390-0217  
E-mail: [asastds@aip.org](mailto:asastds@aip.org)

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## Foreword

*[This Foreword is for information only, and is not a part of the American National Standard ANSI/ASA S12.68-2007 American National Standard Methods of Estimating Effective A-Weighted Sound Pressure Levels When Hearing Protectors are Worn].*

This standard comprises a part of a group of definitions, standards, and specifications for use in noise. It was developed and approved by Accredited Standards Committee S12 Noise, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S12 is as follows:

*Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation, and control, including biological safety, tolerance, and comfort, and physical acoustics as related to environmental and occupational noise.*

This is a new American National Standard that pertains solely to the computation of number ratings for hearing protectors; acquisition of the data themselves is described in other ANSI standards. Though number ratings have been heretofore specified by regulation in the U.S., this is the first American National Standard method that specifies how to compute such numbers. This standard compares to ISO 4869-2, *Acoustics – Hearing Protectors – Part 2: Estimation of Effective A-Weighted Sound Pressure Levels When Hearing Protectors are Worn*. Like that standard it includes three different rating methods of increasing accuracy, but unlike that document it includes a number that is suitable for direct application to A-weighted sound pressure level measurements ( $NRS_A$ ), whereas the ISO document's simplest approach still requires the measurement of C-weighted sound pressure level measurements. Both standards include a multi-number rating that requires use of both A- and C-weighted sound pressure level measurements—in the ANSI document an  $NRS_G$  and in the ISO document an HML. The  $NRS_G$  is similar in application to the HML as specified in ISO 4869-2:1994; however, the two methods differ in how they are calculated. The  $NRS_G$  more accurately achieves the targeted protection rate while providing a simplified graphical presentation for ease of use. Both standards include as their most accurate descriptor an octave-band computational method identical in all aspects except that the ANSI document excludes 63 Hz from the computations since such attenuation data are not normally available and even when they are, they usually have negligible impact on the overall A-weighted noise reduction.

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<b>U.S. Naval Surface Warfare Center - Carderock</b> .....	M. Craun
.....	VACANT (Alt.)

Individual Experts of Accredited Standards Committee S12, Noise, were:

P.K. Baade	W.J. Galloway	J. Pope
L.L. Beranek	R.D. Hellweg	P.D. Schomer
E.H. Berger	R.K. Hillquist	J.P. Seiler
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B.M. Brooks	D. Lubman	W.R. Thornton
A.J. Campanella	W.J. Murphy	L.A. Wilber
K.M. Eldred	M.A. Nobile	G.E. Winzer
L.S. Finegold	R.J. Peppin	G.S.K. Wong

Working Group S12/WG 11, Hearing Protector Attenuation and Performance, which assisted Accredited Standards Committee S12, Noise, in the development of this standard, had the following membership.

	E.H. Berger, Chair	
W. Ahroon	D. Gauger	B. Mozo
A. Behar	L.D. Hager	W.J. Murphy
J.G. Casali	T.K. Madison	D. Ohlin
C. Dixon-Ernst	R. McKinley	B. Witt
	K. Michael	

Suggestions for improvements of this standard will be welcomed. They should be sent to Accredited Standards Committee S12, Noise in care of the Standards Secretariat of the Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747-3177. Telephone: 631-390-0215; FAX: 631-390-0217; E-mail: [asastds@aip.org](mailto:asastds@aip.org)

## Introduction

Though there exists today, and has for many years, an American National Standard for the measurement of real-ear attenuation at threshold (ANSI S12.6), there has never been a U. S. national standard for the estimation of effective A-weighted sound pressure levels when hearing protection devices (HPDs) are worn. This standard addresses that need by specifying procedures for estimation, values suitable for labeling of HPDs, and guidelines on the accuracy that can be expected.

Many issues are involved in estimating the protection that users achieve while wearing HPDs. These include obtaining valid estimates of the hearing protector's attenuation as influenced by user training and motivation, the proportion of exposure time during which users actually wear the devices, and accurate measurements of the noise exposure in question. Perhaps of greatest concern is the issue of individual variability in the fit and performance users achieve. Even with precise computational schemes such as an octave-band analysis of the noise, the issue of variability remains critical. Once predictions are made, one can estimate the percentage of users in various noises that achieve the targeted protection values, called the protection performance, and use this metric to evaluate the accuracy of various rating systems. For example, if the goal is to protect 84% of the population to a "safe" exposure level, it is desirable to know how closely the protection performance approaches the desired value.

Numerous rating systems have been proposed in the past 30 years. Those materials were used as the basis for an extensive research project that was reviewed and approved by ANSI Accredited Standards Committee S12/WG11 (Gauger and Berger, 2004). That project expanded upon the prior published literature by introducing new concepts and new data. Methods of varying complexity were examined, from an octave-band approach to ones involving ratings used with C-weighted sound levels or exposures, from those that work with A-weighted measurements to those that are simple class or grading schemes. It became apparent that the straightforwardness of what are called A – A' ratings is appealing. Such ratings predict, by simple subtraction from the A-weighted ambient noise levels, the effective A-weighted levels ( $L'_A$ ) when an HPD is worn. A – A' ratings, which by their very nature are easier to use and less prone to computational errors, are of sufficient precision for most applications considering the many sources of variability inherent in predicting protection.

An important collateral issue to the development of a rating procedure is the underlying attenuation data from which the rating is to be computed. Gauger and Berger examined various techniques, especially Methods A and B as specified in the ANSI S12.6 standard. Subsequent to publication of their report an interlaboratory study was completed (Murphy et al., 2006) and the results demonstrated differences in the repeatability and reproducibility of the two methods. Since both methods have merits and applications as discussed in ANSI S12.6 and the selection of one for labeling purposes is primarily a matter of public policy, the decision was made to incorporate both methods as options in this standard.

Various sets of representative noise data have been published since the 1950s to provide a picture of the occupational noise scene. They originated from around the globe and included industrial, military, and specialized environments. Most of the prior hearing protection analytical studies have based their work on the "NIOSH 100" (Kroes et al., 1975). Gauger and Berger assessed a variety of additional data sets to make sure that the 60-year old data from which the NIOSH 100 were selected were indeed still representative. They were, and thus those values are utilized for the most simplified of the proposed ratings. For the more complex graphical approach, data were included from specialized Air Force and aviation spectra in order to assure the suitability of the recommendations for a broader range of noises.

The basis for the research in support of this standard is the pioneering work of Dick Waugh (1976, 1984). Building upon his analytical methods allowed examination of the ratings that best met the goals of simplicity, consistency, and accuracy. What emerged were two ratings, the Noise Level Reduction Statistic for use with A-weighting ( $NRS_A$ ), and the somewhat more complex and more accurate Noise Level Reduction Statistic, Graphical ( $NRS_G$ ). Finally as the "gold standard" for comparison purposes and for cases in which the maximum accuracy is warranted, a classical octave-band noise-reduction computational scheme is described as a third method.

A substantial divergence in this standard from prior publications and other standards (CSA Z94.2; ISO 4869-2; SA/SNZ 1270) is the recommendation that the simplified ratings be presented as pairs of numbers in order to provide additional information about the precision of the ratings, and to supply better user guidance for labeling purposes. This pair of values describes the range of performance at the 80<sup>th</sup> and 20<sup>th</sup> percentile level; the specific meaning depends upon whether Method-A or Method-B data are utilized, as defined below:

- Method A,  $NRS_{A80}$  (80<sup>th</sup> percentile value) - the protection that is possible for *most individually trained* users to achieve or exceed.
- Method B,  $NRS_{B80}$  (80<sup>th</sup> percentile value) - the protection that is possible for *most users* to achieve or exceed.
- Method A or Method B,  $NRS_{A20}$  (20<sup>th</sup> percentile value) - the protection that is possible for *a few motivated proficient users* to achieve or exceed.

The 20<sup>th</sup> percentile number has the same meaning regardless of the procedure, Method-A or Method-B, since the results of the Murphy et al. (2006) study demonstrated that the high-performing users achieved approximately the same protection regardless of the test procedure. This was not the case for the low-performing subjects.

The rationale for the two-number approach is:

- It indicates that a range of performance is to be anticipated.
- It represents, via the range between the high and low numbers, products that offer more or less inter-subject variability.
- It diverts the attention of the buyer from a single value and the associated tendency to focus on the seeming "accuracy" of that value.
- It supports the rating of the product with a conservative number that may appear low to some observers, while still indicating a much higher level of protection that is potentially attainable when a hearing protector is fit in an exemplary manner.
- It draws attention, via the higher number, to the possibility of overprotection.
- It may also encourage more careful fitting of hearing protection, especially among consumers who are buying products for their own use, by explicitly demonstrating what exacting application of the product can achieve.

The Gauger and Berger report summarizes the rationale for the choices made in this standard and provides comprehensive recommendations on how to implement them. It included presentation of the data in a primary label [much like the existing primary label required by the U.S. Environmental Protection Agency (1979)] that incorporated a pair of  $NRS_A$  values and new explanatory wording along with supporting information.

## American National Standard

# Methods of Estimating Effective A-Weighted Sound Pressure Levels When Hearing Protectors are Worn

## 1 Scope and Applications

### 1.1 Scope

This standard specifies a choice of three methods for use with hearing protector attenuation data to estimate the effective A-weighted sound pressure levels when a hearing protector is worn. The three methods, the Noise Level Reduction Statistic for use with A-weighting ( $NRS_A$ ), the Noise Level Reduction Statistic, Graphical ( $NRS_G$ ), and the octave-band method are presented in order of increasing complexity of use and potential accuracy. Furthermore, the standard specifies in the case of the  $NRS_A$  and the  $NRS_G$  that values will be presented for both the 80<sup>th</sup> and 20<sup>th</sup> percentiles, indicated as  $NRS_{A80}$  and  $NRS_{A20}$ , and as  $NRS_{G80}$  and  $NRS_{G20}$ , to reflect the range of attenuation that can be anticipated.

The  $NRS_A$  specifies an attenuation value, the Noise Level Reduction Statistic for use with A-weighting, determined from the octave-band attenuation data of a hearing protector in an ensemble of 100 representative noises, which may be directly subtracted from an A-weighted noise assessment to estimate  $L'_A$ , the effective A-weighted sound pressure level when the hearing protector is worn.

The  $NRS_G$  specifies an estimated noise level reduction value deduced from a graph (or, alternatively, an arithmetic interpolation done by a spreadsheet) that relates the protection in a given A-weighted exposure to the difference between the C- and A-weighted sound pressure levels of the noise. It requires two noise measures (A- and C-weighted), instead of the single measure (A-weighted) necessary for use with the  $NRS_A$ . The  $NRS_G$  is determined by applying the octave-band attenuation data for a hearing protector to an ensemble of 67 noises that span a broader range of spectral types than used for the  $NRS_A$  computation.

The octave-band method specifies a procedure for directly applying the octave-band attenuation data of a hearing protector to a set of octave-band measurements of the noise. The computation includes a correction that is a multiple of the standard deviation in order to adjust the prediction for the desired protection performance.

### 1.2 Applications

The methods of this standard are applicable to estimating either the sound pressure level or the equivalent continuous or time-weighted average sound pressure levels that are effective when hearing protectors are worn.<sup>1</sup> Although primarily intended for steady noise exposures, the methods are also

<sup>1</sup> The estimated value represents the "effective" sound level when the hearing protector is worn, i.e., the A-weighted sound level at the head center with the listener absent (commonly estimated by the on-the-shoulder measurement with a dosimeter), minus the attenuation of the HPD. This is not the same as the sound level in the ear canal. The ear canal sound level differs from that in the sound field by the transfer function of the open ear. It cannot simply be estimated by subtracting the HPD's attenuation from the A-weighted level. However, it is the "effective" values that are required to assess noise hazard, as it is those values that are normally compared to the classical damage-risk curves and permissible exposure limits.

applicable to noises containing impulsive components. These methods may not be suitable for use with peak sound pressure levels exceeding 140 dB.

The methods are suitable for setting minimum acceptable sound attenuation requirements for given noise environments, as guidance in selecting or comparing hearing protectors. Because of the simplicity of the application of  $NRS_A$  and  $NRS_G$ , they are also recommended for use as ratings for labeling purposes.

For passive HPDs the calculation methods are to be applied to real-ear attenuation at threshold data derived from ANSI S12.6, using either Method A or B. For active devices, real-ear insertion loss data obtained using other measurement methods besides real-ear attenuation at threshold may be used with certain limitations as described in Clause 4.

The methods are primarily intended for estimations of the performance for groups of users as opposed to precise predictions for a given individual. However, if actual hearing protector attenuation and noise exposure information for a given individual are available as might be developed using a field test method, then the computations specified in this standard, especially the octave-band procedure, can be applied with some confidence to individual cases.

Due to the large spread of the sound attenuation provided by hearing protectors when worn by individual persons, all three methods are nearly equivalent in their accuracy in typical industrial noise environments. Even the simplest of the methods, the  $NRS_A$ , will provide a reasonably accurate estimate to aid in the selection and specification of hearing protectors for such applications. In special situations such as extreme noise exposures over 100 dBA or with noises that have substantial low-frequency energy as indicated by a  $L_C - L_A$  value that exceeds 5 dB, it is recommended to use the alternate methods that require more than just the A-weighted level to describe the noise environment. Of these, the  $NRS_G$  is preferable to the octave-band method in most cases since it is simpler to apply while being only marginally less accurate, and the required input noise data are easier to obtain (C- and A-weighted levels versus octave-band levels).

The accuracy of the estimations is critically dependent upon the degree to which the real-ear attenuation and noise exposure data correspond to the values experienced by the population or the users in question. With respect to the attenuation values, the protection performances are valid only when:

- the hearing protectors are worn correctly and in the same manner as worn during the test,
- the anatomical characteristics of the subjects involved in the laboratory test are a reasonable match for the population of actual wearers, and
- the hearing protectors are properly maintained.

Thus, the principal sources of potential error in the use of the methods in this standard is first and foremost the hearing protector attenuation data as influenced by the selection of test method (ANSI S12.6, Method A or B), test subjects and their experience and instruction, and additionally the noise measurement data with which they are combined.

In general, differences of 3 dB or less in the determination of the effective sound pressure levels for comparable HPDs are not significant for the purposes of distinguishing between products. For specific guidance on given sets of data, please refer to Annex D for the calculation of confidence intervals.

## 2 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI S1.4, *American National Standard Specification for Sound Level Meters*.

ANSI S3.20, *American National Standard Bioacoustical Terminology*.

ANSI S12.6, *American National Standard Methods for Measuring the Real-Ear Attenuation of Hearing Protectors*.

ANSI S12.42, *American National Standard Microphone-in-Real-Ear and Acoustic Test Fixture Methods for the Measurement of Insertion Loss of Circumaural Hearing Protection Devices*.

## 3 Terms and definitions

For the purposes of this standard, the terms and definitions given in ANSI S3.20, ANSI S12.6, and the following apply:

**3.1 active hearing protection device.** A hearing protector that contains electronic components, including transducers, to affect the transmission of sound into the ear canal.

**3.2 assumed protection value ( $APV_{fx}$ ).** The protection in a given octave band,  $f$ , computed as the mean attenuation less the standard deviation multiplied by a constant. The constant is determined using the table in Clause 5 that relates its value to the desired protection rate,  $x$ .

**3.3 effective A-weighted sound pressure level ( $L'_A$ ).** The sound pressure level, A-weighted and referred to an equivalent diffuse field condition, that is estimated to be experienced by users when the hearing protector is worn, calculated by any of the three methods of this standard.

**3.4 estimated noise level reduction (ENR).** The value in decibels derived using the Noise Level Reduction Statistic, Graphical procedure that is subtracted from the A-weighted sound pressure level to estimate the effective A-weighted sound pressure level when the hearing protector is worn.

**3.5 hearing protection device (HPD).** A personal protective device, also referred to as a hearing protector, worn to reduce the harmful auditory and/or annoying subjective effects of sound.

**3.6 Noise Level Reduction Statistic for use with A-weighting ( $NRS_{Ax}$ ).** A single-number rating in decibels, for a specified protection performance,  $x$ , that may be subtracted from the A-weighted sound pressure level to estimate the effective A-weighted sound pressure level when the hearing protector is worn.

**3.7 Noise Level Reduction Statistic, Graphical ( $NRS_{Gx}$ ).** A method that uses a graphical technique for estimating the noise level reduction for a specified protection performance,  $x$ , based on the difference between the C- and A-weighted sound pressure levels for the environment in which the hearing protector is used.

**3.8 passive hearing protection device.** A hearing protector that lacks electronic components, and therefore relies solely on its structural elements to block or otherwise control the transmission of sound into the ear canal.

**3.9 pink noise.** Noise for which the spectrum density varies as the inverse of frequency.

**3.10 protection performance (x).** The percentage of situations in which the desired degree of protection is achieved or exceeded, where a situation is defined as a unique combination of protector, wearer and noise spectrum. The rate is designated by adding a subscript to the statistic according to the selected method, as in  $NRS_{A80}$ .

**3.11 spectral balance (B).** The difference in decibels between the C-weighted and A-weighted levels of a spectrum ( $L_C - L_A$ ), indicating the proportion of energy at low frequencies in the spectrum.

## 4 Measurement of Sound Attenuation of Hearing Protectors

For passive hearing protection devices the sound attenuation data utilized for the computations in this standard shall be the real-ear attenuation at threshold values derived from ANSI S12.6, Method A or Method B<sup>2</sup>.

For active hearing protection devices the real-ear insertion loss data obtained using other measurement methods than real-ear attenuation at threshold may be used, but only if the test protocol is comparable in subject selection and instruction to Methods A or B of ANSI S12.6, and the measurement method yields data statistically equivalent to one of those methods when applied to passive devices.<sup>3</sup>

## 5 Noise Level Reduction Statistic for Use with A-Weighting ( $NRS_A$ )

### 5.1 Introduction

The  $NRS_A$  for a hearing protector is comprised of a single pair of values describing lower and upper bounds on the reduction of A-weighted noise level the HPD provides. The pair of  $NRS_A$  values corresponds to two protection performances; specifically, 80% for the lower bound and 20% for the upper bound.

### 5.2 Calculation

Calculation begins by computing the A-weighted noise level reduction  $\Delta L_{A,pn}$  using Equation (1), for each subject  $p$  for which attenuation data are available in each noise  $n$  of the NIOSH 100 database of industrial noise spectra (Kroes et al., 1975; see Annex A). This results in a  $p$ -by- $n$  table of values (e.g., 2000 values in the case of a 20-subject set of attenuation data).

<sup>2</sup> If an employer or other organization using a particular HPD utilizes a fit-test system to directly check performance in the field, it would be appropriate to either allow use of the values measured with such a system for the individuals on whom these measurements are made, or to provide a means of interpolation between the 80<sup>th</sup>/20<sup>th</sup> percentile values to derive a rating more representative for their population.

<sup>3</sup> At present, no standard exists describing how to obtain such data for active devices. A suggested approach is to use the microphone in real-ear method of ANSI S12.42 to determine the active contribution to the device's insertion loss (electronics on versus off) and the real-ear attenuation method of ANSI S12.6 to determine the passive attenuation (electronics off). If the same subject pool and device-fitting instructions are used for the microphone and for the real-ear attenuation at threshold tests, consistent with ANSI S12.6 Method A or B, then the active and passive contributions for each subject may be obtained by averaging across trials (i.e., device fittings). The total device attenuation for each subject is then determined by summing, at each test frequency, the two average values in decibels. The resulting set of total attenuation data may be applied as attenuation  $R_{p(k)}$  in Equations (1), by inference in (8), and in (11).

$$\Delta L_{Apn} = L_{An} - L'_{Apn} = 10 \lg \sum_{k=1}^7 10^{0.1(L_{nf(k)} + A_{f(k)})} - 10 \lg \sum_{k=1}^7 10^{0.1(L_{nf(k)} + A_{f(k)} - R_{pf(k)})} \quad (1)$$

where

- $f(k)$ ..... represents the octave-band center frequencies from 125 Hz ( $k=1$ ) to 8 kHz ( $k=7$ );
- $n$ ..... is the noise spectrum index ranging from 1 to  $N = 100$  ( $N$  is the number of noises);
- $L_{nf(k)}$ ..... is the sound pressure level in decibels for the octave centered on  $f(k)$  for the  $n^{\text{th}}$  noise in the NIOSH 100 spectra;
- $A_{f(k)}$ ..... is the frequency weighting A in decibels for the octave centered on  $f(k)$  in accordance with ANSI S1.4;
- $p$ ..... is the subject index ranging from 1 to  $P$ , where  $P$  is the number of subjects;
- $R_{pf(k)}$ ..... is the attenuation in decibels measured for the hearing protector on the  $p^{\text{th}}$  subject at octave-band center frequency  $f(k)$ , averaged across trials.

Next, one computes the normal statistics  $m$ ,  $s_{\text{subject}}$ , and  $s_{\text{spectrum}}$  of  $\Delta L_{Apn}$  as shown in Equations (2) through (5). The two standard deviations  $s_{\text{subject}}$  and  $s_{\text{spectrum}}$  describe the uncertainty in noise level reduction  $\Delta L_{Apn}$  resulting from variation in fit between subjects and between noise spectra, respectively. The intermediate values  $m_p$  and  $m_n$  given by Equation (2) are, respectively, the mean noise level reduction for the  $p^{\text{th}}$  subject (averaging across noises) and the  $n^{\text{th}}$  noise (averaging across subjects).

$$m_p = \frac{1}{N} \sum_{n=1}^N \Delta L_{Apn} \quad m_n = \frac{1}{P} \sum_{p=1}^P \Delta L_{Apn} \quad (2)$$

$$m = \frac{1}{PN} \sum_{n=1}^N \sum_{p=1}^P \Delta L_{Apn} \quad (3)$$

$$s_{\text{subject}} = \sqrt{\frac{1}{P-1} \sum_{p=1}^P (m_p - m)^2} \quad (4)$$

$$s_{\text{spectrum}} = \sqrt{\frac{1}{N-1} \sum_{n=1}^N (m_n - m)^2} \quad (5)$$

To calculate  $\text{NRS}_{Ax}$ , the Noise Level Reduction Statistic for use with A-weighting at protection performance  $x$ , one treats the two standard deviation estimates computed in Equations (4) and (5) as independent, and for a desired value of  $x$ , selects the appropriate value for  $\alpha$  from Table 1, which is based upon the standard normal distribution. For illustrative purposes, numerous values are presented in Table 1. However, for reporting the  $\text{NRS}_A$ , this standard specifies that the values of  $x = 80\%$  and  $20\%$  are to be used.

$$\text{NRS}_{Ax} = m - \alpha_x \sqrt{s_{\text{subject}}^2 + s_{\text{spectrum}}^2} \quad (6)$$

Table 1 – Values of  $\alpha$  for various protection performance values  $x$ 

Lower Value		Upper Value	
Protection performance $x$ (%)	Value of $\alpha$	Protection performance $x$ (%)	Value of $\alpha$
75	0.6745	25	-0.6745
<b>80</b>	<b>0.8416</b>	<b>20</b>	<b>-0.8416</b>
84.1	1.0000	15.9	-1.0000
85	1.0364	15	-1.0364
90	1.2816	10	-1.2816
95	1.6449	5	-1.6449
97.7	2.0000	2.3	-2.0000

NOTE Specified values shown boldface

When reported by a testing laboratory the pair of  $NRS_A$  values shall be rounded to the nearest tenth decibel; intermediate values shall be computed to the full precision available to minimize accumulated errors due to rounding. When used for product labeling or in application (estimation of the effective A-weighted level  $L'_{Ax}$ ) the  $NRS_A$  shall be rounded to the nearest whole decibel. When presented graphically, the axis shall extend from 0 to 50 dB with a 5-dB grid. Annex B describes a Microsoft Excel workbook supplied as part of this standard that computes the ratings in this standard; see cell range C4:L5 in Figure B.2 for an example of a suggested  $NRS_A$  bar graph. Hearing protector attenuation reports supplied by a testing laboratory that compute the  $NRS_A$  shall also include values for the standard deviations  $s_{\text{subject}}$  and  $s_{\text{spectrum}}$  as well as a histogram of the values of  $m_p$  (with bin edges at multiples of 3 dB) to illustrate the distribution of the hearing protector's attenuation. Annex D describes the calculation of a confidence interval on the  $NRS_{A80}$  that may be used for comparing two tests on the same product for statistically significant difference.

### 5.3 Application

The effective A-weighted sound pressure level  $L'_{Ax}$  for protection performance  $x$  percent is computed from the  $NRS_A$  using the following equation:

$$L'_{Ax} = L_A - NRS_{Ax} \quad (7)$$

where  $L_A$  is the A-weighted sound pressure level or the exposure appropriate for use in assessing hearing damage risk.

EXAMPLE For the earmuff used in the Excel workbook shown in Annex B (computed using Method-B data):

$$NRS_{A80} = 19 \text{ dB} \quad \text{and} \quad NRS_{A20} = 27 \text{ dB}$$

For a workplace noise sound pressure level  $L_A$  of 95 dBA then the bounds on the effective A-weighted sound pressure level are:

$$L'_{A80} = 95 - 19 = 76 \text{ dBA} \text{ — the effective A-weighted level most users will not exceed.}$$

$$L'_{A20} = 95 - 27 = 68 \text{ dBA} \text{ — effective A-weighted level a few motivated proficient users will not exceed.}$$

The  $NRS_G$  should be used instead of the  $NRS_A$  for noises that have a rumbling, thunderous, or heavy sound to them, for sounds that are from air-moving equipment, for passengers in moving vehicles, for sound levels exceeding 100 dBA, or if the measured difference between C- and A-weighted sound levels exceeds 5 dB.<sup>4</sup> At that  $L_C - L_A$  difference the  $NRS_A$  overestimates performance by 3 dB on average.

## 6 Noise Level Reduction Statistic, Graphical ( $NRS_G$ )

### 6.1 Introduction

The uncertainty represented by the difference between the upper and lower  $NRS_A$  values results from both variation in the attenuation as measured on different subjects ( $s_{\text{subject}}$ ), and variation in attenuation across frequency as that interacts with the range of assumed noise spectra ( $s_{\text{spectrum}}$ ). The  $NRS_G$  reduces the uncertainty in estimating the A-weighted noise level reduction by requiring additional data about the noise environment; specifically, the C-weighted level ( $L_C$ ) in addition to the A-weighted level ( $L_A$ ).<sup>5</sup>

### 6.2 Calculation

The  $NRS_G$  for a hearing protector is defined by a table of four pairs of values describing lower and upper bounds on the reduction of A-weighted noise level the HPD provides. Each pair of  $NRS_G$  values corresponds to computations for two different levels of protection performance,  $x$ , and a single spectral balance parameter  $B = L_C - L_A$ , that describes the proportion of low-frequency energy present in a noise. The four standard values of  $B$  associated with each pair of protection values  ${}_B NRS_{Gx}$  are -1, 2, 6 and 13.

For each standard value of  $B$  one computes the pair of protection bounds  ${}_B NRS_{Gx}$  by first calculating the A-weighted noise level reduction  $\Delta L_{A,pr}$  using Equation (1) for each subject  $p$  in each noise  $n$  of the subsets of the noises corresponding to each of the four values of  $B$ , as tabulated in Annex A.<sup>6</sup> For each noise, a mean and standard deviation of the resulting  $P$  values of  $\Delta L_{A,pr}$  is then computed, and normal statistics are used, as shown in Equation (8), to compute a protection value,  $\beta_{nx}$ , equal to the mean less a constant  $\alpha_x$  times the standard deviation. The constant  $\alpha_x$  is determined from the specified protection performance,  $x$ , in accordance with Table 1. Finally, the resulting  $\beta_{nx}$  values are averaged across the subset of  $N$  noises for each standard value of  $B$  for a given  $x$  to obtain the protection bounds  ${}_B NRS_{Gx}$ . Figure 1 illustrates the calculation by showing the  $\beta_n$  and resultant  $NRS_G$  values for a typical HPD.

<sup>4</sup> An  $L_C - L_A$  value of 5 dB is only exceeded by 18% of the NIOSH 100 noises that are representative of industrial noise exposures. However 50% of the of the 50 Air Force spectra (Johnson and Nixon, 1974) exceed an  $L_C - L_A$  of 5 dB.

<sup>5</sup> The  $NRS_G$  is similar to the HML (high-medium-low) method as specified in ISO 4869-2:1994. Both utilize the parameter  $L_C - L_A$  to estimate the noise level reduction performance of a hearing protector in a given spectrum and yield similar answers. The two methods differ in how they are calculated, and in that the  $NRS_G$  more accurately achieves the targeted protection rate while providing a simplified graphical presentation for ease of use. The  $NRS_G$  as defined in this standard is mathematically simpler with negligible loss of accuracy compared to the original in Gauger and Berger (2004).

<sup>6</sup> Twenty noises each are used ( $N = 20$ ) to compute the protection bounds for  $B = -1$  and 2, nineteen noises for  $B = 6$ , and eight for  $B = 13$ . The average values of  $B$  computed using the noises within each set are within 0.1 dB of the corresponding integers assigned to the standard values of  $B$  used to designate those sets.

$$\Delta L_{An} = \frac{1}{P} \sum_{p=1}^P \Delta L_{Apn} \left( \begin{array}{l} \text{The mean noise reduction across subjects for noise } n \\ \text{where } \Delta L_{Apn} \text{ is computed using Equation (1).} \\ n \text{ is the noise index from the first column of the table in Annex A.} \end{array} \right)$$

$$\beta_{nx} = \Delta L_{An} - \alpha_x \sqrt{\frac{1}{P-1} \sum_{p=1}^P (\Delta L_{Apn} - \Delta L_{An})^2} \quad (8)$$

$${}_B \text{NRS}_{Gx} = \frac{1}{n_{\max} - n_{\min} + 1} \sum_{n=n_{\min}}^{n_{\max}} \beta_{nx} \quad \text{where } n_{\min} : n_{\max} = \begin{cases} 1 : 20 & \text{for } B = -1 \\ 56 : 75 & \text{for } B = 2 \\ 100 : 118 & \text{for } B = 6 \\ 123 : 130 & \text{for } B = 13 \end{cases}$$

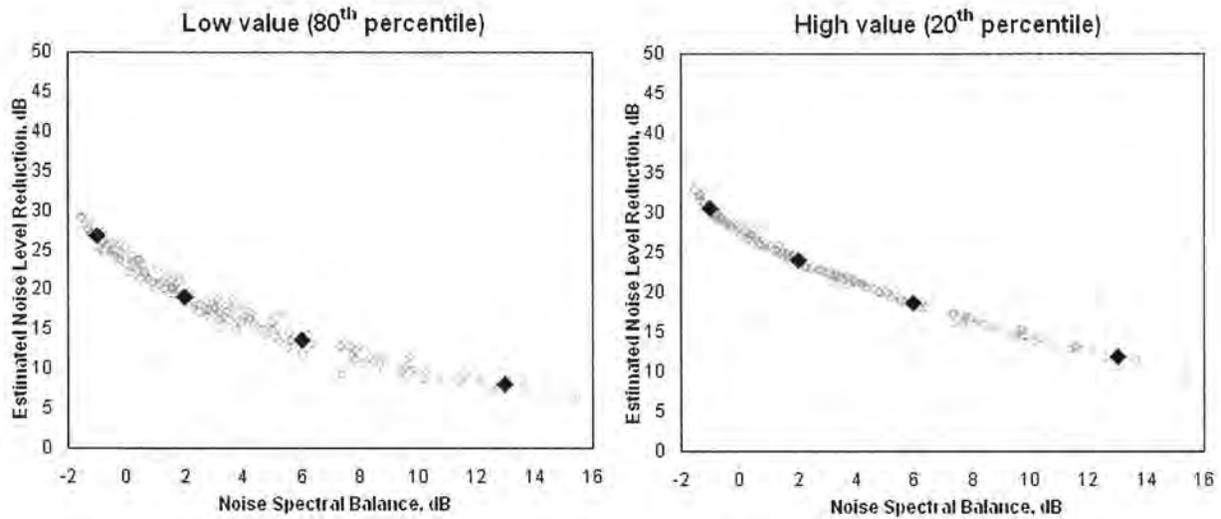


Figure 1 – Computation of the  $\text{NRS}_G$

NOTE Open gray circles are the  $\beta_{nx}$  values and solid black diamonds are the averages defining the end-points of the  $\text{NRS}_G$  line segments. Data are for a typical earmuff. The gray circles are for all 170 noises (NIOSH 100 plus 70 aviation noises) described in Annex A.

When presented graphically, the spectral balance axis shall be shown with a 2-dB grid spanning the range from -2 to 16 dB and the estimated noise level reduction axis shall be shown with a 5-dB grid spanning the range from 0 to 50 dB. The four pairs of  ${}_B \text{NRS}_{Gx}$  values are plotted at their corresponding  $B$  values and straight lines are used to join them and extrapolate to the extremes of the  $B$  axis as shown in Figure 2. When presented in tabular form, the four  ${}_B \text{NRS}_{Gx}$  values for protection performance  $x$  shall be rounded to the nearest tenth decibel to reduce accumulation of rounding error when calculating the estimated noise level reduction,  $\text{ENR}_x$ , using interpolation as described in the next section. When computing  ${}_B \text{NRS}_{Gx}$ , intermediate calculations shall be made to full available precision.

Annex B describes a Microsoft Excel workbook supplied as part of this standard that computes the  $\text{NRS}_G$ , including screen images. Sample hearing protector data are included as well as the resulting  $\text{NRS}_G$  graph and table of defining values.

### 6.3 Application

The estimated noise level reduction ( $ENR_x$ ) for an HPD is determined using the noise spectral balance, either graphically from a plot of the  ${}_B NRS_{Gx}$  values or calculated directly from a table of the values. The graphical approach is simpler and, given the precision with which the average spectral balance of the noise is usually known, estimates the noise level reduction with negligible loss of accuracy. To use the graph, one locates the point on the horizontal axis corresponding to the spectral balance of the noise in which the HPD is to be used, finds the corresponding points on the high and low  $NRS_G$  lines on the graph (representing two values of protection performance  $x$ ), and then reads the corresponding ENR values from the graph's vertical axis. The noise spectral balance should be determined from broadband measurements, such as from an integrating sound level meter that can simultaneously measure the A- and C-weighted levels. If the spectral balance is computed from noise spectra, it is preferable to use all bands for which data are available rather than limiting the calculation to the 125 Hz to 8 kHz octaves.

To calculate the ENR from a table of  $NRS_G$  values, one linearly interpolates the values using the following equation:

$$ENR_x = {}_S NRS_{Gx} + (B - S) \frac{L NRS_{Gx} - S NRS_{Gx}}{L - S} \quad (9)$$

where  $S$  and  $L$  are the spectral balance values in the table that bracket the actual noise spectral balance;  $S$  is the smaller (more high-frequency weighted) value and  $L$  is the larger (more low-frequency weighted) value.<sup>7</sup> If the measured spectral balance exceeds 16 dB, a value of  $B = 16$  shall be used with either the  $NRS_G$  graph or Equation (9) to determine the estimated noise level reduction.

Once the  $ENR_x$  values are determined, the effective A-weighted sound pressure  $L'_{Ax}$  for protection performance  $x$  percent is computed using the following equation:

$$L'_{Ax} = L_A - ENR_x \quad (10)$$

where  $L_A$  is the A-weighted sound pressure level or the exposure appropriate for use in assessing hearing damage risk.

**EXAMPLE** Figure 2 shows the  $NRS_G$  graph and table for the earmuff data used in Figure 1 and in the Excel workbook in Annex B. Arrows are shown on the graph for a noise with  $B = 5$  dB; the corresponding interpolation of the table to determine the ENR values is also shown.

For a workplace noise sound pressure level  $L_A$  of 95 dBA the corresponding bounds on the effective A-weighted sound pressure level are:

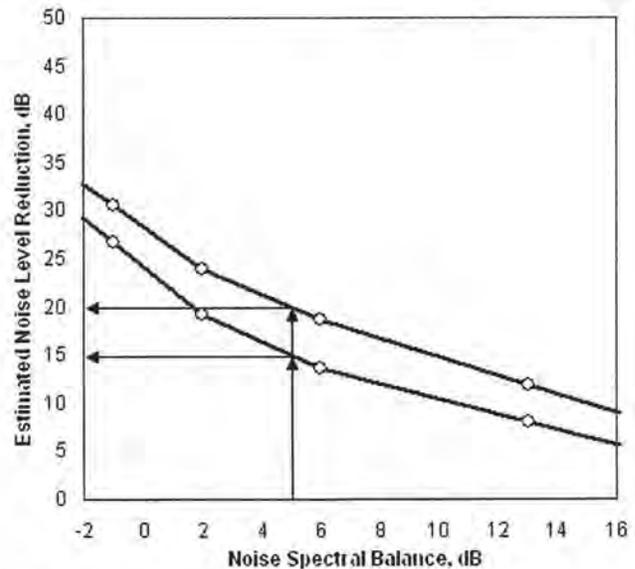
$$L'_{A80} = 95 - 15 = 80 \text{ dBA} \text{ — the effective A-weighted level most users will not exceed.}$$

$$L'_{A20} = 95 - 20 = 75 \text{ dBA} \text{ — effective A-weighted level a few motivated proficient users will not exceed.}$$

<sup>7</sup> If the noise spectral balance is outside of the range  $-1$  to  $13$ , then use the two nearest values from the  $NRS_G$  table and extrapolate using Equation (9).

<i>B</i>	-1	2	6	13
<i>x</i> =20%	30.6	24.0	18.7	11.9
<i>x</i> =80%	26.8	19.2	13.7	8.1

$$\text{ENR}_{20\%} = 24.0 + (5 - 2) \frac{18.7 - 24.0}{6 - 2} = 20.0 \text{ dB}$$

$$\text{ENR}_{80\%} = 19.2 + (5 - 2) \frac{13.7 - 19.2}{6 - 2} = 15.1 \text{ dB}$$
Figure 2 – Example of using the  $\text{NRS}_G$  graph and table

## 7 Octave-Band Method

### 7.1 Introduction

This method requires octave-band sound pressure levels of the noise and assumed protection values,  $\text{APV}_{fx}$ . Since the method is noise specific, it shall be made for each noise situation.

### 7.2 Calculation

The calculation begins with the selection of the desired protection performance,  $x$ , and the associated constant  $\alpha_x$  as found in Table 1. Next, one computes the mean and standard deviation of the measured attenuation for each octave band in the range 125 Hz to 8 kHz as shown in Equation (11). From these statistics, one determines the assumed protection values,  $\text{APV}_{fx}$  of the hearing protector for each octave band using Equation (12):

$$m_f = \frac{1}{P} \sum_{p=1}^P R_{pf} \quad s_f = \sqrt{\frac{1}{P-1} \sum_{p=1}^P (R_{pf} - m_f)^2} \quad (11)$$

$$\text{APV}_{fx} = m_f - \alpha_x s_f \quad (12)$$

where  $f$  and  $R_{pf}$  are as defined for Equation (1).

When presented in tabular form the  $m_f$ ,  $s_f$ , and  $\text{APV}_{fx}$  values shall be shown rounded to 0.1 decibel precision to reduce accumulation of rounding error when calculating the effective A-weighted level  $L'_{Ax}$ .

NOTE If third-octave noise and attenuation data are available, Equations (11) and (12) can be extended in a straightforward manner; the APV is computed at each third-octave frequency and  $L'_{Ax}$  is computed summing across all third-octave bands. If octave-band attenuation data must be applied to third-octave noise data, then octave-band noise spectra must be computed first by energy summing the set of three third-octave noise bands corresponding to each octave; e.g., the 500 Hz octave-band level is:

$$L_{500 \text{ Hz octave}} = 10 \lg \left( 10^{0.1L_{400 \text{ Hz th.oct.}}} + 10^{0.1L_{500 \text{ Hz th.oct.}}} + 10^{0.1L_{630 \text{ Hz th.oct.}}} \right)$$

### 7.3 Application

The A-weighted sound pressure level effective when the hearing protector is worn,  $L'_{Ax}$ , is calculated using the following equation:

$$L_{Ax} = 10 \lg \sum_{k=1}^7 10^{0.1(L_{f(k)} + A_{f(k)} - APV_{f(k)x})} \quad (13)$$

where  $f(k)$  and  $A_{f(k)}$  are as defined for Equation (1) and  $L_{f(k)}$  is the sound pressure level of the noise in the octave band.

The resulting  $L'_{Ax}$  value shall be rounded to the nearest integer, and all intermediate calculations computed to full available precision. An example of the calculation for a protection performance of 80% is shown in Table 2 for a NIOSH noise from Annex A, with a spectral balance of 5 dB. The calculation of the APV values is illustrated in Annex C.

**Table 2 – Calculation of  $L'_{A80}$  using the octave band method in a representative noise with greater than average low-frequency content ( $B = 5.0$  dB)**

Octave-band center frequency, $f$ , Hz	125	250	500	1000	2000	4000	8000
Measured octave-band sound pressure level of the noise, $L_f$ (NIOSH noise 43 from Annex A)	98	93	89	92	88	83	75
Frequency weighting A (from ANSI S1.4)	-16.1	-8.6	-3.2	0	1.2	-1.0	-1.1
A-weighted octave-band sound pressure level of the noise, $L_f + A_{f(k)}$	81.9	84.4	85.8	92.0	89.2	82.0	73.9
APV <sub>80</sub> from Table C.1	6.2	7.8	19.0	26.5	27.4	32.3	31.1
$L_f + A_{f(k)} - APV_{80}$	75.7	76.6	66.8	65.5	61.8	49.7	42.8
NOTE All values in decibels.							

$L'_{A80}$  is calculated by substituting the values from the last row of Table 2 into Equation (13) as follows:

$$L'_{A80} = 10 \lg \left( 10^{0.1(75.7)} + 10^{0.1(76.6)} + 10^{0.1(66.8)} + 10^{0.1(65.5)} + 10^{0.1(61.8)} + 10^{0.1(49.7)} + 10^{0.1(42.8)} \right) \quad (14)$$

After rounding the answer is 79.7 dB. This yields an A-weighted noise level reduction in this particular noise with an A-weighted sound pressure level of 95.4 dB, of 15.7 dB, which rounds to 16 dB. By comparison, for the protector selected (same as used in Clauses 5 and 6), the value of  $NRS_A$  is computed to be 19 dB and in this noise,  $NRS_G$  is computed to be 15.1 dB.

EXAMPLE For the hearing protector example in Clauses 5, 6, and 7, compute the  $L'_{A80}$  values in a noise with  $L_A = 95$  dBA and  $B = 5$

$$L'_{A80} \text{ using } NRS_A \text{ method} = 76 \text{ dB (see Clause 5.2)}$$

$$L'_{A80} \text{ using } NRS_G \text{ method} = 80 \text{ dB (see Clause 6.2)}$$

$$L'_{A80} \text{ using octave-band method} = 80 \text{ dB (see Table 2 and Equation 14)}^8$$

---

<sup>8</sup> For an earplug with its less steeply sloping attenuation spectrum than is the case for the typical earmuff in this example, the divergences between the three methods are smaller. Furthermore, for noise with less-extremely sloping spectrum, closer to the median spectral balance  $B$  of 1.8 dB, the agreement would be closer between the three methods for both earmuffs and earplugs. These differences must be viewed in the larger perspective of the inaccuracies due to errors in estimating the attenuation achieved by the actual users and in estimating their true noise exposures.

## Annex A

(normative)

### Noise Spectra Used in Calculating the $NRS_A$ and $NRS_G$

Table A.1 shows the 130 noise spectra required to compute the  $NRS_A$  and  $NRS_G$ . This is a subset of the 170 noises that result from pooling the NIOSH 100 representative industrial noise spectra (Kroes et al., 1975) with the fifty Air Force spectra (Johnson and Nixon, 1974) and twenty spectra from civil aviation (Gauger and Berger, 2004); the source of each noise is shown in the third column. The table is sorted by increasing value of spectral balance  $B$  ( $L_C - L_A$ ). Only the NIOSH 100 are used in computing the  $NRS_A$ . The noise subsets used in the computation of the  $NRS_G$  are indicated by the corresponding average  $B$  value in the second column. The remainder of the 170 noises may be found in the reference data table in the spreadsheet described in Annex B that accompanies this standard.

NOTE All spectra used in the calculation of the  $NRS_A$  and  $NRS_G$  shall be rounded to integer values as shown. The A-weighted levels ( $L_A$ ) in the table were computed from the 125 to 8-kHz spectra, and are for reference only. Actual computation of  $NRS_A$  and  $NRS_G$  shall be accomplished using  $L_A$  computed with full precision as opposed to using the rounded values shown in the table.

**Table A.1 – Spectra used to compute  $NRS_A$  and  $NRS_G$ , with the particular spectrum (NIOSH#43) used in example calculations in Clauses 5.2, 6.2, and 7.2 shown in bold**

Noise Index	$NRS_G$ $B$	Source & Index	Octave Band Center Frequency (Hz)							125 – 8000 Hz	
			125	250	500	1k	2k	4k	8k	$L_A$	$B$
1		NIOSH#99	81	85	93	90	101	103	104	108.0	-1.5
2		NIOSH#95	94	96	97	104	108	111	113	116.3	-1.5
3		NIOSH#93	78	78	85	96	100	97	100	105.0	-1.3
4		NIOSH#80	85	86	89	91	96	97	101	103.6	-1.3
5		NIOSH#73	81	81	90	98	103	102	98	107.6	-1.3
6		AF#3	101	102	104	104	104	110	117	117.7	-1.3
7		NIOSH#72	90	95	96	97	106	104	106	110.9	-1.2
8		NIOSH#87	79	79	77	86	95	89	83	97.6	-1.2
9		NIOSH#55	82	82	84	93	95	93	92	100.0	-1.0
10	<b><math>B = -1</math></b>	AF#4	83	91	91	88	90	94	101	101.9	-0.9
11		NIOSH#84	91	89	95	100	101	101	100	107.1	-0.8
12		NIOSH#90	78	79	75	74	79	84	88	89.8	-0.8
13		NIOSH#7	82	80	84	87	92	90	85	96.3	-0.8
14		NIOSH#75	84	83	90	109	109	100	96	113.0	-0.8
15		NIOSH#61	85	85	85	92	94	93	92	99.5	-0.8
16		NIOSH#70	81	86	84	88	95	90	82	98.0	-0.8
17		NIOSH#96	81	90	91	99	99	96	98	104.6	-0.8
18		AF#8	89	81	88	94	96	93	95	101.2	-0.7
19		NIOSH#9	85	85	88	90	92	94	89	98.6	-0.6
20		NIOSH#38	79	79	81	84	83	84	89	91.8	-0.6

Noise Index	NRS <sub>G</sub> B	Source & Index	Octave Band Center Frequency (Hz)							125 – 8000 Hz	
			125	250	500	1k	2k	4k	8k	L <sub>A</sub>	B
21		NIOSH#86	74	79	82	83	79	87	84	90.9	-0.5
22		NIOSH#15	82	83	82	84	89	88	86	94.0	-0.5
23		NIOSH#89	80	80	85	93	92	87	82	97.0	-0.4
24		NIOSH#47	78	78	80	83	83	83	86	90.3	-0.4
25		NIOSH#20	85	87	88	87	92	93	84	97.5	-0.4
26		NIOSH#2	72	75	79	90	85	77	74	91.9	-0.2
27		NIOSH#11	76	81	83	86	86	85	80	91.8	-0.2
28		NIOSH#6	78	80	81	88	85	85	78	92.0	-0.2
29		NIOSH#8	84	87	90	90	92	91	85	97.4	0.0
30		NIOSH#79	86	90	92	95	92	90	95	99.9	0.1
31		NIOSH#24	81	96	91	99	98	95	85	103.4	0.1
32		NIOSH#16	85	81	75	81	85	85	86	91.1	0.2
33		NIOSH#30	80	82	83	93	83	83	80	94.3	0.2
34		NIOSH#14	84	85	84	84	86	88	84	92.9	0.3
35		NIOSH#13	85	84	83	87	87	86	85	93.1	0.4
36	Not used for NRS <sub>G</sub>	NIOSH#71	101	102	103	104	104	104	103	110.7	0.4
37		NIOSH#77	90	87	91	96	91	92	84	99.3	0.4
38		NIOSH#88	88	87	87	98	88	84	83	99.0	0.5
39		NIOSH#92	72	75	93	90	87	88	88	95.9	0.5
40		NIOSH#98	115	116	112	113	114	115	120	122.7	0.5
41		NIOSH#18	90	88	91	96	88	89	92	98.9	0.6
42		NIOSH#29	90	88	91	96	88	89	92	98.9	0.6
43		NIOSH#91	120	119	118	120	119	120	122	127.0	0.6
44		NIOSH#74	91	89	87	94	91	90	88	98.0	0.7
45		NIOSH#58	87	86	85	87	85	88	88	93.8	0.7
46		NIOSH#52	83	85	86	86	87	85	79	92.4	0.7
47		NIOSH#69	81	85	83	85	84	83	81	90.6	1.0
48		NIOSH#17	83	73	73	75	75	81	82	85.7	1.1
49		NIOSH#33	91	89	92	92	92	88	80	97.4	1.2
50		NIOSH#42	91	89	92	92	92	88	80	97.4	1.2
51		NIOSH#54	86	84	84	90	84	79	77	92.1	1.3
52		NIOSH#3	90	82	94	96	86	70	77	97.6	1.4
53		NIOSH#94	86	88	87	90	88	80	77	93.7	1.4
54		NIOSH#44	95	91	95	96	94	90	78	100.2	1.5
55		NIOSH#100	101	101	98	99	98	94	103	106.0	1.5

Noise Index	NRS <sub>G</sub> B	Source & Index	Octave Band Center Frequency (Hz)							125 – 8000 Hz	
			125	250	500	1k	2k	4k	8k	L <sub>A</sub>	B
56		NIOSH#10	86	84	80	84	84	84	75	90.1	1.5
57		NIOSH#78	102	98	97	98	97	96	102	105.3	1.6
58		NIOSH#85	87	88	86	92	83	81	81	93.8	1.6
59		NIOSH#40	83	84	86	88	82	76	74	90.6	1.7
60		NIOSH#41	82	86	85	89	82	72	70	90.9	1.7
61		NIOSH#51	82	86	85	89	82	72	70	90.9	1.7
62		NIOSH#39	84	86	83	87	84	79	76	90.5	1.7
63		AF#21	98	97	98	99	96	94	89	103.2	1.8
64		NIOSH#19	87	81	88	87	84	82	74	91.4	1.9
65	<b>B = 2</b>	NIOSH#82	90	83	87	93	79	72	77	93.9	1.9
66		NIOSH#25	86	95	96	95	92	86	78	99.1	1.9
67		AF#19	98	97	96	98	95	92	92	102.2	2.1
68		NIOSH#36	81	94	95	94	88	86	78	97.6	2.1
69		AF#23	102	101	107	104	100	95	95	108.5	2.2
70		AF#6	81	86	83	84	82	76	75	88.4	2.3
71		NIOSH#22	87	89	92	86	86	86	72	93.6	2.3
72		NIOSH#48	85	87	84	86	82	82	71	90.1	2.4
73		NIOSH#67	87	87	84	83	83	83	83	90.3	2.5
74		AF#5	72	73	75	70	69	69	66	77.1	2.5
75		NIOSH#27	86	92	92	84	78	90	74	94.1	2.6
76		NIOSH#21	86	96	95	95	84	84	74	97.7	2.8
77		NIOSH#97	99	95	92	95	92	93	91	100.1	2.8
78		NIOSH#4	91	87	87	88	86	80	77	92.2	3.0
79		NIOSH#1	91	90	89	90	84	80	84	93.4	3.1
80		NIOSH#35	89	87	86	86	83	82	78	90.8	3.1
81	Not	NIOSH#31	94	88	85	91	87	82	83	94.1	3.1
82	used	NIOSH#60	93	101	101	99	90	78	66	102.3	3.2
83	for	NIOSH#23	89	96	88	84	89	89	85	95.3	3.2
84	NRS <sub>G</sub>	NIOSH#64	88	91	92	85	83	83	84	93.0	3.3
85		NIOSH#83	90	88	87	88	81	81	74	91.2	3.5
86		NIOSH#5	86	91	91	88	80	76	73	92.1	3.6
87		NIOSH#59	92	90	89	88	87	78	72	92.9	3.6
88		NIOSH#26	85	91	86	84	83	81	73	90.3	3.8
89		NIOSH#66	91	94	94	91	82	76	65	94.9	3.9
90		NIOSH#50	92	83	83	83	87	73	64	90.2	4.0

Noise Index	NRS <sub>G</sub> B	Source & Index	Octave Band Center Frequency (Hz)							125 – 8000 Hz	
			125	250	500	1k	2k	4k	8k	L <sub>A</sub>	B
91		NIOSH#37	87	90	91	86	79	75	60	91.1	4.0
92		NIOSH#68	93	91	92	91	78	72	75	93.7	4.1
93	Not used for NRS <sub>G</sub>	NIOSH#34	94	91	89	90	84	82	78	93.4	4.3
94		NIOSH#81	90	87	87	84	82	78	77	89.6	4.3
95		NIOSH#57	92	86	82	82	81	86	70	90.0	4.3
96		NIOSH#62	92	86	82	82	81	86	70	90.0	4.3
97		NIOSH#65	90	89	87	83	82	82	74	90.0	4.4
98		NIOSH#76	100	98	97	94	91	90	86	99.7	4.4
99		NIOSH#28	91	93	88	89	78	74	77	91.9	4.8
100		AF#38	105	103	103	98	95	91	85	104.0	5.0
<b>101</b>		<b>NIOSH#43</b>	<b>98</b>	<b>93</b>	<b>89</b>	<b>92</b>	<b>88</b>	<b>83</b>	<b>75</b>	<b>95.4</b>	<b>5.0</b>
102		NIOSH#49	98	93	89	92	88	83	75	95.4	5.0
103		CA#2	99	97	98	92	87	83	77	98.1	5.2
104		AF#16	92	94	93	85	81	80	76	93.0	5.2
105		AF#35	100	102	98	94	92	87	80	100.3	5.3
106		AF#27	92	78	81	82	81	81	73	87.8	5.4
107		AF#46	112	118	114	106	105	101	96	114.9	5.5
108	<b>B = 6</b>	NIOSH#46	93	90	85	88	77	75	72	90.4	5.6
109		AF#41	98	98	93	90	88	84	85	96.4	5.7
110		AF#47	108	115	112	99	95	92	90	111.3	6.1
111		AF#45	110	111	111	95	92	89	84	109.4	6.1
112		CA#14	74	75	70	68	59	52	48	72.4	6.2
113		NIOSH#45	99	94	94	90	84	82	75	95.2	6.3
114		CA#1	99	97	92	90	86	85	80	95.6	6.4
115		AF#14	94	90	89	79	77	77	73	89.1	7.4
116		AF#34	108	103	102	96	92	87	82	102.7	7.4
117		NIOSH#12	84	103	93	85	75	70	66	96.1	7.4
118		CA#6	98	92	90	86	82	79	75	92.0	7.7
119	Not used for NRS <sub>G</sub>	NIOSH#32	97	98	85	87	81	80	82	93.1	7.7
120		NIOSH#56	97	90	89	84	78	77	74	90.2	8.2
121		NIOSH#63	101	98	92	85	85	83	76	94.7	8.5
122		NIOSH#53	110	109	101	89	82	79	80	103.1	9.6

Noise Index	NRS <sub>G</sub> <i>B</i>	Source & Index	Octave Band Center Frequency (Hz)							125 – 8000 Hz	
			125	250	500	1k	2k	4k	8k	L <sub>A</sub>	<i>B</i>
123	<b>B = 13</b>	AF#17	109	101	94	89	86	82	79	98.1	11.5
124		CA#5	102	94	88	81	77	74	69	91.0	11.6
125		CA#17	97	90	82	73	68	59	56	85.6	12.1
126		CA#20	90	84	69	62	58	53	57	78.2	12.7
127		CA#19	98	89	79	76	64	58	55	85.4	13.0
128		CA#7	106	93	87	79	84	75	71	92.9	13.2
129		AF#39	108	92	89	84	82	78	74	94.3	13.7
130		CA#9	116	97	90	84	78	74	68	100.5	15.3

## Annex B

(informative)

### Spreadsheet Illustrating Calculation and Use of the $NRS_A$ and $NRS_G$

An Excel workbook (HPDratings\_S12.68\_NRSA-G-OB.xls) has been created to calculate the ratings defined in this standard. The Excel workbook provided with this American National Standard is entirely informative and provided for the convenience of the user. Use of the provided software is not required for conformance with the Standard. The workbook is not warranted to be appropriate for any particular purpose. No warranties or guarantees are provided.

Below is a brief description of the structure and use of the spreadsheet. First, the "input & calcs" sheet shown in Figure B.1 is described.

1. All input cells on the spreadsheet are shaded light blue; these are the only cells into which data should be entered or that should be modified.
2. A description of the device tested and any other pertinent information about the test (laboratory, date, test index number, etc.) should be entered into cell C5. This information is mirrored on the "ratings" page of the spreadsheet.
3. The spreadsheet is structured presuming use of attenuation data for up to twenty subjects with two trials per subject. This is typed or pasted into cells D9:J48 – any unneeded input cells (e.g., if data for an earmuff with only ten subjects is being entered) should be left blank. Instructions are provided at cell L32 describing how to modify the spreadsheet to accept data for more than twenty subjects (e.g., if pooling data from multiple tests).
4. Either "A" or "B" should be typed into cell I6 to indicate which ANSI S12.6 method was used to measure the REAT data. The protection rates  $x$  defining the upper and lower values of the ratings are specified in cells I2:J2.
5. The subject-mean attenuation values (average across trials) are computed in cells M9:S29. To the right of these cells, beginning with column Y, the individual subject-mean noise level reductions for each of the noises used to define the  $NRS_A$  and  $NRS_G$ , one column per spectrum, are calculated using Excel array formulas. Array formulas eliminate the need to have cells containing intermediate results in performing calculations such as are used by the octave-band method; see Excel's documentation for more information on array formulas.
6. The lists of subjects in columns L and W automatically update to reflect the number of subjects for whom data was input. All the formulas in columns M:EW reference the corresponding cell in column L so that results are only calculated for the actual number of subjects. This allows the spreadsheet to easily be expanded to use data for more than 20 subjects.
7. Cell ranges T9:29 and X30:EW30 give the individual noise level reduction after averaging across the NIOSH 100 noises and across subjects, respectively. The standard deviation over each of these ranges is computed (in cells AX4:AX5) to determine  $s_{\text{subject}}$  and  $s_{\text{spectrum}}$ ; these two values characterizing the variation in observed attenuation are plotted in the chart at the top of columns R:T. A histogram of the subject averaged-across-spectra attenuation values is computed in cells X2:AS5 and plotted at the top of columns L:Q, along with a normal statistics fit to the data. This plot gives a visual indication of how normally distributed the attenuation data is.
8. The spectra used in columns X:EW are sorted by increasing spectral balance  $B_n$ ; an "N" in row 7 indicates if the spectrum is one of the NIOSH 100. Upper and lower noise level reduction bounds  $\beta_{nx}$ , in each spectrum are computed, based on the specified protection rates  $x$ , in cells X33:EW34 where they are also grouped into the four ranges corresponding to the four standard values of  $B$  defining the  $NRS_G$ . These are averaged on the "ratings" spreadsheet to compute the values in the  $NRS_G$  table.



Next, the "ratings" sheet shown in Figure B.2 and the "conf" sheet (not shown) are described.

1. The  $NRS_A$  values are computed in cells C2 and H2 using array formulas to implement Equations (3) and (6). A range of cells on the input sheet named "niosh" (cells X7:EW7) are tested to see if the noise spectrum is one of the NIOSH 100; only these spectra are used to compute the  $NRS_A$  values.
2. The octave band normal statistics and APV corresponding to  $x = 80\%$  (or the value specified in input sheet cell I2) are calculated in cells Q5:W8 and plotted in a corresponding figure in those columns.
3. The noise level reduction bounds  $\beta_{nx}$  calculated on the input sheet are averaged in cells E28:H29 to compute the end points of each line segment in the  $NRS_G$  graph. The  $NRS_G$  graph appears above the table.
4. Starting at row 30 the spreadsheet is set up to provide an example of the application of the rating values. Noise parameters (A- and C-weighted levels) may be entered in cells E32:E33. Cells N32:P34 illustrate the use of  $NRS_A$  and cells X32:Z36 illustrate the use of  $NRS_G$ .
5. On the "conf" sheet cells U2 and W2 contain the results of the confidence interval calculation on the  $NRS_{A80}$  as described in Annex D. Cells B4:U2051 give the subject indices for the Bootstrap sampling of the attenuation data with each row representing a sample, and cells W4:AP2051 give the corresponding  $A - A'$  values averaged across the NIOSH noises. The  $\eta\{z\}$  values for each sample are given in column V and the expanded uncertainty (half the width of the confidence interval) is calculated from column V in cell W1.

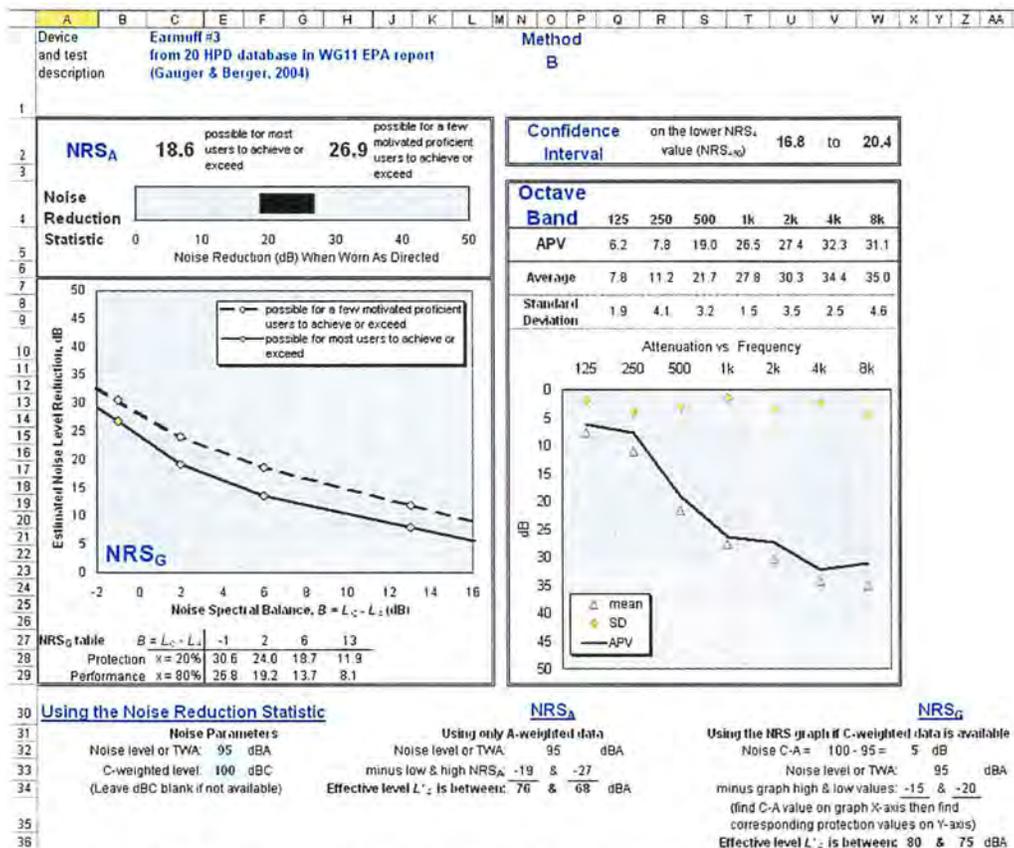


Figure B.2 – "Ratings" output sheet of Excel rating computation workbook

## Annex C

(informative)

### Example of the Calculation of the Assumed Protection Values and the Use of the Octave-Band Method

In this example, the  $APV_{f80}$  values for a hearing protector are calculated, i.e., this is based upon a protection performance of 80% and a corresponding constant of  $\alpha = 0.84$  from Table 1. These  $APV_{f80}$  values are used in the octave-band computation in Clause 7.2.

**Table C.1 – Calculation of assumed protection values for a protection performance of 80%**

Octave-band center frequency, $f$ , Hz	125	250	500	1000	2000	4000	8000
$m_f$	7.8	11.2	21.7	27.8	30.3	34.4	35
$s_f$	1.9	4.1	3.2	1.5	3.5	2.5	4.6
$\alpha_{sf}$ ( $\alpha = 0.84$ )	1.6	3.4	2.7	1.3	2.9	2.1	3.9
$APV_{f80} = m_f - \alpha_{sf}$	6.2	7.8	19.0	26.5	27.4	32.3	31.1

NOTE All values in decibels

## Annex D

(informative)

### Calculation of the Confidence Interval for the $NRS_{A80}$

A current direction in the international standards community is to report not just the results of measurements but the uncertainty as well, generally presented as a confidence interval. For a hearing protector rating that may be used for labeling products as part of a regulatory mandate, such a confidence interval is particularly useful. It can serve as a gauge to determine if rating values resulting from two different tests on the same product are statistically significantly different.

Computing the uncertainty of a hearing protector rating is challenging for several reasons. The rating value depends on both the mean and standard deviation of the attenuation data. In addition, the variation between subjects is strongly correlated at frequencies of 1 kHz and lower, and the data appears bimodal in some cases (Murphy et al., 2002, 2004). These factors make developing an analytical formula for the uncertainty challenging at best and prone to error because of the need to assume a specific form for the distribution, typically the normal distribution.

For these reasons this Annex specifies use of a computational statistics method for determining the uncertainty. Specifically, the Bootstrap method (Efron and Tibshirani, 1993; Martinez and Martinez, 2002) is used because it does not assume any particular form for the underlying distribution of the data as, for example, the Monte Carlo method does. Instead, the empirical data are simply assumed to represent the true shape of the larger population. The data are sampled randomly to create sets that omit some subjects while containing multiple instances of others. For example, given a 5-subject data set  $R = \{R_1, R_2, R_3, R_4, R_5\}$ , let  $R\{q\}$  be the  $q^{\text{th}}$  random sample taken from  $R$ .  $R\{1\}$  might be  $\{R_1, R_4, R_3, R_4, R_5\}$ , subject 2 replaced by subject 4, and  $R\{2\}$  might be  $\{R_3, R_2, R_3, R_5, R_5\}$ , subject 1 replaced by subject 3 and subject 4 replaced by subject 5. In the sampling process each subject's data has an equal probability of being selected. Many such sample sets are created and the statistic for which a confidence interval is to be determined (e.g. the hearing protector rating) is then calculated for each set. The uncertainty is then estimated from the variation in the resulting values and the confidence interval calculated by adding and subtracting the uncertainty from the rating value.

The procedure outlined below details how to calculate the 95% confidence interval (two-tailed  $\alpha = 0.05$ ) for the lower  $NRS_A$  bound,  $NRS_{A80}$ . One could also apply the Bootstrap method to compute confidence intervals for any rating in this standard ( $NRS_{Ax}$  at any value of  $x$ , the  $NRS_G$  or an octave-band  $APV^{D1}$ ). However, since the  $NRS_{A80}$  is the proper rating to use in assessing the adequacy of the protection provided by an HPD in industrial noise of a given level but unknown spectrum, it is most appropriate to compare confidence intervals on the  $NRS_{A80}$  computed from different attenuation tests on the same product to determine if the tests are significantly different.

Begin by defining the following functions and variables.

$U_{95}$  .....the expanded uncertainty of the  $NRS_{A80}$ , e.g., half the width of the confidence interval.

$R$  .....the attenuation data set provided, averaged across trials, for  $P$  subjects.

$p$  .....the index over the subjects in  $R$  ranging from 1 to  $P$ , the number of subjects.  
 $R_p$  is the attenuation data for the  $p^{\text{th}}$  subject; the frequency index is implicit.

<sup>D1</sup> To apply the Bootstrap to the octave-band method the random sampling should be done on subjects rather than independently at each frequency in the attenuation data.

- $\min(a,b)$  .....a function that returns the lesser of the two values  $a$  and  $b$ .
- $\text{rand}(a,b)$  .....a function that returns a two-dimensional array of uniformly distributed independent random numbers that each span the range  $[0:1]$ , indexed by row  $a$  and column  $b$ .
- $\text{ceil}(a)$  .....a function that rounds a whole number  $a$  to the next greater integer value.
- $t(\alpha,d)$  .....the value of the inverse  $t$ -distribution, at two-tailed probability  $\alpha$  and with  $d$  degrees of freedom.
- $z$  .....the Bootstrap sample index ranging from 1 to  $Z$ , the number of samples. Typically  $Z \geq 2048$ ; see more information below on convergence of the Bootstrap.
- $q$  .....the index over the subjects in a given Bootstrap sample, ranging from 1 to  $Q$ , where  $Q = \min(P, 20)$ ; e.g., for attenuation data  $R$  with more than 20 subjects each Bootstrap sample will be comprised of 20 subjects.
- $P_{qz}$  .....the subject index in the original data  $R$  (i.e., the value of  $p$ ) for the  $q^{\text{th}}$  subject in the  $z^{\text{th}}$  Bootstrap sample.
- $R\{z\}$  .....the attenuation data for the  $z^{\text{th}}$  Bootstrap sample.
- $m(R\{z\})$  .....the mean  $A - A'$  ( $\Delta L_A$ ) value across all combinations of attenuation data and NIOSH noises computed for the  $z^{\text{th}}$  Bootstrap sample using Equation (3), Clause 5.
- $s_{\text{subject}}(R\{z\})$  ..the standard deviation across subjects for the  $z^{\text{th}}$  Bootstrap sample computed using Equation (4), Clause 5.
- $s_{\text{spectrum}}(R)$  ....the standard deviation across noise spectra for the provided attenuation data  $R$ , computed using Equation (5), Clause 5, and used in Equation (6) to calculate the  $\text{NRS}_{A80}$ .
- $\text{NRS}_{A80}$  ..... =  $m(R) - 0.8416\sqrt{s_{\text{subject}}(R)^2 + s_{\text{spectrum}}(R)^2}$  (Equation 6, Clause 5).
- $\eta\{z\}$  .....the  $\text{NRS}_A$  value computed for the  $z^{\text{th}}$  Bootstrap sample.

The expanded uncertainty,  $U_{95}$ , is calculated by first creating a  $Q$ -by- $Z$  array of uniformly distributed independent random integers that span the range  $[1:P]$  (Equation D.1). These random integers are then used to create  $Z$  new samples of attenuation data from the original data  $R$  (Equation D.2). An  $\text{NRS}_A$  value  $\eta\{z\}$  is then found for each sample by calculating  $m$  and  $s_{\text{subject}}$  for each sample  $R\{z\}$  and using the  $s_{\text{spectrum}}$  value calculated from the original data  $R$  (Equation D.3).<sup>D2</sup> Finally, the standard

<sup>D2</sup>  $s_{\text{spectrum}}$  is fixed at the value computed from the original full attenuation data rather than recalculating it for each Bootstrap sample because it is a substantial reduction in the amount of computation required; it is necessary to make the confidence interval calculation in the accompanying Excel workbook tractable. In principle it is reasonable because the Bootstrap sampling evaluates the impact solely due to varying the pool of subjects, not the noise spectra. In addition, for most HPDs,  $s_{\text{spectrum}}$  is less than  $s_{\text{subject}}$  so the root sum square value is dominated by the latter. In practice, the effect of this simplification is minor: a comparison of the  $U_{95}$  value computed as described to the value determined using  $s_{\text{spectrum}}$  recalculated for each Bootstrap sample over the many data sets in Murphy et al. (2006) shows a typical underestimation of  $U_{95}$  of 0.05 dB with a worst-case underestimation of 0.17 dB.

deviation over these values is computed and then multiplied by both the square root of the ratio of the Bootstrap sample size to the number of subjects<sup>D3</sup> and by the appropriate value of  $t$  to get the expanded uncertainty  $U_{95}$ .  $U_{95}$  is added and subtracted from the  $NRS_{A80}$  to estimate the confidence interval, the bounds within which the rating can be expected to lie with 95% confidence on future tests (Equation D.4).<sup>D4</sup>

$$R_{qz} = \text{ceil}(\text{Prand}(q, z)) \quad (\text{D.1})$$

$$R\{z\} = \{R_{P_{1z}}, R_{P_{2z}}, \dots, R_{P_{Qz}}, \dots, R_{P_{Qz}}\} \quad \text{where } Q = \min(P, 20) \quad (\text{D.2})$$

$$\eta\{z\} = m(R\{z\}) - 0.8416 \sqrt{s_{\text{subject}}(R\{z\})^2 + s_{\text{spectrum}}(R)^2} \quad (\text{D.3})$$

$$U_{95} = \sqrt{\frac{1}{Z-1} \sum_{z=1}^Z \left( \eta\{z\} - \frac{1}{Z} \sum_{z=1}^Z \eta\{z\} \right)^2} \sqrt{\frac{Q}{P}} t(0.05, P-1) \quad \text{where } t \text{ is given in Table D1} \quad (\text{D.4})$$

With 95% confidence future tests will yield ratings in the range  $NRS_{A80} \pm U_{95}$ .

**Table D.1 – Values of  $t$  for 95% two-tailed confidence and various numbers of subjects  $P$**

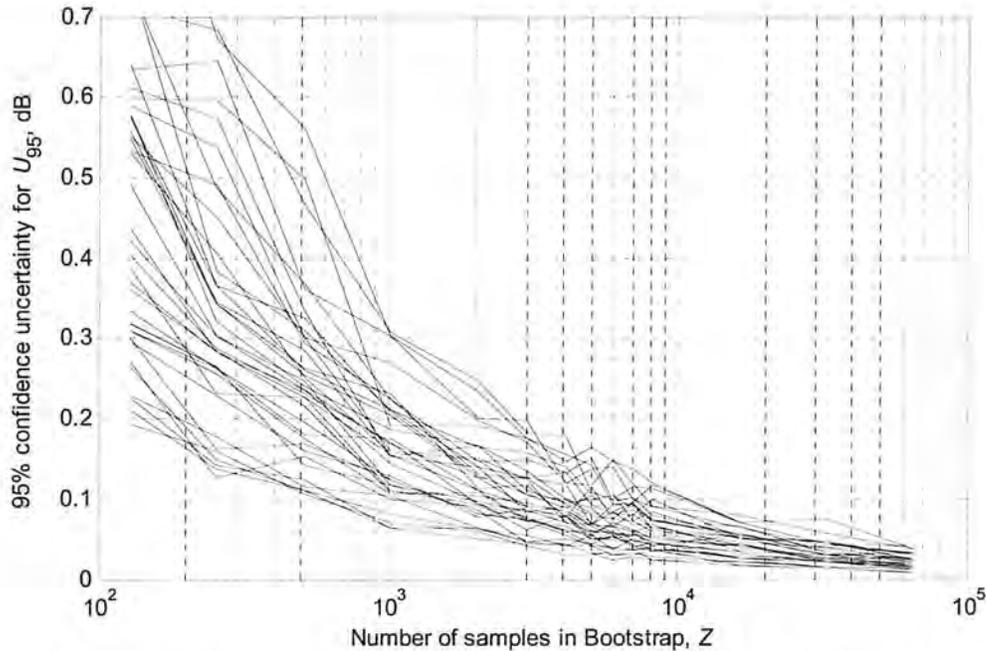
$d=P-1$	$t(.05, d)$	$d=P-1$	$t(.05, d)$	$d=P-1$	$t(.05, d)$
10	2.2281	14	2.1448	18	2.1009
11	2.2010	15	2.1314	19	2.0930
12	2.1788	16	2.1199	20	2.0860
13	2.1604	17	2.1098		

Because of the use of a random number generator in the Bootstrap method, the value of  $U_{95}$  that results varies slightly with each repetition of the calculation; a large value  $Z$  is required to ensure repeatable values for  $U_{95}$ . The accompanying Excel spreadsheet, described in Annex B, implements this calculation of the  $NRS_{A80}$  confidence interval with  $Z = 2048$ . Figure D.1 shows how the Bootstrap

<sup>D3</sup> This term, the square root of  $Q/P$ , is needed to adjust for the limiting of the Bootstrap sample size to a maximum of 20. For data  $R$  with 20 or fewer subjects this term equals one. The limiting of  $Q$  to a maximum value of 20 limits the size of the calculation for large attenuation data sets, making the calculation possible in tools like Excel.

<sup>D4</sup> The distribution of percentile estimates for samples of a normal population is slightly asymmetric, which this calculation does not capture. To reflect this asymmetry the confidence interval could be calculated from the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles on the set of  $Z$  values  $\eta\{z\}$ . Comparing this to the calculation in Equation (D.4) shows that the standard-deviation calculation prescribed yields an overly broad confidence interval, with a lower bound that is typically 0.5 dB lower than the percentile calculation and an upper bound that is 0.2 dB higher. However, the percentile calculation is less reproducible, requiring many more Bootstrap samples to converge. For this reason the standard deviation calculation shown was chosen.

$U_{95}$  calculation converges for increasing values of  $Z$ . At this value for  $Z$  successive recalculations of the confidence interval should result in values that vary by  $\pm 0.1$  dB typically and  $\pm 0.25$  dB worst-case.



NOTE Each line represents the 95% confidence uncertainty over 30 repetitions of the Bootstrap calculation of  $U_{95}$  for each of the 72 sets of attenuation data in Murphy et al. (2006).

**Figure D.1 – Convergence of the estimate of the expanded uncertainty  $U_{95}$  with increasing  $Z$**

To provide an indication of representative confidence interval widths, computations were made using the data from Murphy et al. (2006) for earplugs and earmuffs. The values appear in Table D.2. The values shown are the averages across the two HPDs of each type and the six laboratories in that study; for single tests the confidence interval widths range from 30% to 170% of the values shown. Note that the experimental design of this study used the same naïve (Method B) subjects for first the Method B followed by (after training on fitting the HPD) the Method A measurements. As such, the Method A protocol departs from ANSI S12.6. With experienced subjects one would expect the Method A confidence interval widths to decrease.

**Table D.2 – Typical widths of the confidence interval ( $2 \times U_{95}$ )**

	Method A	Method B
Plugs	7 dB	9 dB
Muffs	5 dB	6 dB

Given two attenuation tests on independent subject panels with their associated confidence intervals  $NRS_{A80} \pm U_{95}$ , the ratings cannot be deemed statistically significantly different if the confidence

intervals overlap. Only if the confidence intervals *do not* overlap can the ratings be considered different and should a decision be made about the priority of one test result over the other. If there is reason to believe the product has changed or that one of the tests was problematic in some way, then the data and rating from one test should be rejected and superseded by the rating from the other. If there is no reason to reject one of the tests, the best estimate of the device performance is to pool the data from the two tests; for example, computing the  $NRS_A$  and  $NRS_G$  using  $P = 40$  subjects for an earplug or  $P = 20$  subjects for an earmuff. The pooled value represents the best estimate of the performance of the product given the varying conditions and subjects under which it has been tested.

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2117 Robert Drive  
Champaign, IL 61821  
Tel: +1 217 359 6602  
Fax: +1 217 359 3303  
Email:  
[schomer@SchomerAndAssociates.com](mailto:schomer@SchomerAndAssociates.com)

### **S.B. Blaeser, Standards Manager**

Standards Secretariat  
Acoustical Society of America  
35 Pinelawn Rd., Suite 114E  
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Fax: +1 631 390 0217  
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