
The Noise Manual
Fifth Edition

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Foreword

The American Industrial Hygiene Association's fifth edition of *The Noise Manual* represents the most current information available on the subject of noise and hearing conservation. It is a valuable reference not only for those readers with a technical interest in noise, but also for those who desire an improved general understanding of the subject. Besides addressing noise-related issues within the workplace, this edition has been expanded to also include noise-related problems arising in the community as well.

Many people have worked diligently to develop this manual. The American Industrial Hygiene Association is pleased to acknowledge their contributions in making this new edition possible. We are confident that all readers of this manual will benefit through a better knowledge of noise, and methods for its control.

James R. Thornton
President
American Industrial Hygiene Association

This work is dedicated

*to W. Dixon Ward (1924 – 1996) for his pioneering research
into the effects of noise on hearing, and for his contributions to
this text and to the preceding 4th Edition,*

*to Ross Gardner, Jr. (1933 – 2000) for changing the face of
hearing conservation by his invention of the slow-recovery
foam earplug,*

*and to all of those individuals who have suffered hearing loss
on and off the job as a result of harmful exposure to noise.*

Preface

We, the Editors, are pleased to bring you the revised and expanded fifth edition of the AIHA *Noise Manual*. Many of us were involved with the fourth edition and welcomed the opportunity to update, expand, and perfect an already highly acclaimed and often-quoted reference handbook.

Our intention for this fifth edition of *The Noise Manual* was to be comprehensive in scope and practical in content. The result is a thoroughly referenced and indexed text that will appeal to the novice industrial hygienist, while still providing a detailed reference source for experienced practitioners and for those involved in the regulatory arenas. At the same time, due to the multidisciplinary nature of noise and hearing conservation (hygiene, safety, acoustics, audiology, occupational medicine and nursing, engineering, behavioral, and legal), we feel the Manual should prove valuable to those beyond the industrial hygiene community. It is our hope that it will also continue to serve as a principal or supplemental textbook for courses and seminars in hearing conservation, occupational audiology, and the effects of noise on people.

The fifth edition includes completely new materials in seven chapters (1, 6, and 13–17) and three appendices (II–IV), new authors and hence different treatments in three chapters (9, 11, and 18), complete revisions of the materials in two additional chapters (2 and 10), and revisions and updates to the remaining chapters (3–5, 7, 8, and 12). An original introductory chapter was specifically designed to help the professional promote the value of hearing and the worth of hearing conservation, and an overview chapter was developed to provide the framework for managing an effective hearing conservation program. New areas of great interest to the hygiene and acoustical communities have been incorporated: room noise criteria, speech and signal detection, community noise, prediction of hearing loss due to noise exposure, and standards and regulations. A dramatically expanded and useful table of symbols and abbreviations may also be found at the front of this edition.

The history of the Manual began with the first edition in 1958, and continued through subsequent editions in 1966, 1975, and the fourth edition in 1986. Due to the continuing interest in noise, the excellent sales of the fourth edition (approximately 13,000 copies sold in 8 printings), and the changes in hearing conservation over a period of about a decade, the AIHA Noise Committee began considering preparation of a fifth edition in 1994. Subsequent to initial planning and agreements, work began in earnest in 1997 with the manuscript being completed in the spring of 2000.

Through the five editions, both the contents and the title of this text have changed, as the stature and importance of the book in the noise community continued to grow. For the first three editions the text was called *The Industrial Noise Manual*, changing to *The Noise & Hearing Conservation Manual* for the

fourth edition, and in the current version, *The Noise Manual*. The name changes have reflected the broadening scope of the text from one primarily concerned with industrial/occupational noise, its measurement, effects, and control, to a book that provided a more expansive view of hearing conservation (fourth edition), and finally today, a text that also examines annoyance, the acoustic habitability of spaces, and communication issues.

Each chapter in this edition was primarily written by the author(s) with whose name(s) it is associated. Prior to editing, the chapters received critical peer reviews from the editors as well as the following readers, whose comments are gratefully acknowledged. Subsequently, the editors wheedled, cajoled, persuaded, and nit-picked to strive for accuracy, clarity, completeness, and consistency (both within and among chapters).

Jim Banach	Donald Gasaway	Paul Ostergaard
William Cavanaugh	Lee Hager	Charles Pavlovic
Allen Cudworth	Daniel Johnson	Dylan Romo
Robert Dobie	Thomas Lloyd	Paul Schomer
John Earshen	Mary McDaniel	Andrew Stewart
John Franks	Susan Megerson	Noral Stewart
Ross Gardner, Jr.	Deanna Meinke	Laurie Kastner-Wells

We extend our sincerest appreciation to the AIHA Noise Committee for the initiation and support of this project, and to Fran Kuecker, Manager, Publishing, and her staff of the American Industrial Hygiene Association for their extensive and dedicated efforts in the preparation of this manuscript for publication. Additionally, we wish to acknowledge the administrative assistance and research efforts of Cyd Kladden, Technical Secretary, E•A•R.

May, 2000

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Symbols and Abbreviations¹

a	acceleration. Unit: m/s^2 , in/s^2
a_0	reference acceleration ($10 \times 10^{-6} \text{ m/s}^2$, $394 \times 10^{-6} \text{ in/s}^2$)
a	absorption. Unit: m^2 , ft^2
A_{total}	attenuation at each octave band for outdoor sound propagation, composed of A_{div} (geometrical divergence), A_{air} (air absorption), A_{env} (environmental effects) and A_{misc} (miscellaneous other factors). Unit: dB
AAO-HNS	American Academy of Otolaryngology—Head and Neck Surgery
AAOO	American Academy of Ophthalmology and Otolaryngology
ACFM	actual cubic feet per minute. Unit: ft^3/min
ACGIH	American Conference of Governmental Industrial Hygienists
ACOEM	American College of Occupational and Environmental Medicine
ACOM	American College of Occupational Medicine
ADA	Americans with Disabilities Act
ADBA	audiometric database analysis
AI	articulation index. Unit: dimensionless
AIHA	American Industrial Hygiene Association
AMA	American Medical Association
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASA	Acoustical Society of America. Also, until 1966, American Standards Association
ASHA	American Speech-Language-Hearing Association
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BC	bone and tissue conduction
BI	binaural impairment of hearing. Unit: percent
BW	bandwidth as in effective filter bandwidth
c	speed of sound [344 m/s , 1128 ft/s @ 21°C]. Unit: m/s , ft/s

¹ Certain terms in this table may appear both as an abbreviation that can be used in a sentence and as a letter symbol that can be used in an equation. In such cases the letter symbols that are associated with the abbreviations will always appear as a leading capital letter with appended subscripts. Examples are DNL and L_{dn} , and PWL and L_{w} .

C₁..C₂..C_N	OSHA designator for total time of exposure at a stated A-weighted noise level corresponding to allowable exposures T _N . Running subscripts refer to particular noise levels for a range of values from 1 to N. Unit: min, h (also see T ₁ ..T ₂ ..T _N)
CAOHC	Council for Accreditation in Occupational Hearing Conservation
CEC	Council of the European Communities
CF	Correction Factor for metric or English units in equations for sound pressure level. Unit: dB
CFR	Code of Federal Regulations
CHABA	Committee on Hearing, Bioacoustics, and Biomechanics
CNEL	community noise equivalent level. Unit: dBA
cps	cycles per second (also see hertz)
D	noise dose as a percentage of maximum permitted daily noise dose
dB	decibel
dBA	decibel measured using A frequency-weighting (also see L _A)
dBc	decibel measured using C frequency-weighting (also see L _c)
df	degrees of freedom
DI	directivity index. Unit: dB
DIS	draft international standard
DNL	day-night average sound level (A-weighting implicit). Unit: dBA (also see L _{dn})
DOD	Department of Defense
DOL	Department of Labor
DR	dose rate accumulation. Unit: %/min
DRC	damage-risk criteria
e	napierian base = 2.71828 ... (natural logarithms)
E	dynamic modulus. Unit: N/m ²
E_A	A-weighted sound exposure computed with 3-dB exchange rate. Unit: Pa ² h
E_{AT}	A-weighted sound exposure with measurement time period, T. E _{CT} denotes C-weighting. (Note: reporting of T is optional). Unit: Pa ² h
E_C	C-weighted sound exposure. Unit: Pa ² h
ENT	ear, nose, and throat
EPA	Environmental Protection Agency
ER	exchange rate. Unit: dB per time doubling
f	frequency (cycles per second). Unit: hertz (Hz)
f_c	center frequency. Unit: Hz
f_n	natural frequency, also called resonant frequency. Unit: Hz
FDA	Food and Drug Administration
FECA	Federal Employees' Compensation Act

FFT	fast Fourier transform
g	acceleration of gravity [9.81 m/s ² , 32.2 ft/s ²]. Unit: m/s ² , ft/s ²
h	hour
H^a	actual duration of workshift. Unit: min, h
HCA	Hearing Conservation Amendment (OSHA CFR 1910.95, paragraphs c – p)
HCP	hearing conservation program
HH	hearing handicap
HL	hearing level. Unit: dB
HPD	hearing protection device
HRTF	head-related transfer function
HTL	hearing threshold level. Unit: dB
HTLA	hearing threshold level associated with age. Unit: dB
HTLAN	hearing threshold level associated with age and noise. Unit: dB
HVAC	heating, ventilation, and air conditioning
Hz	hertz (cycles/second; also see cps)
HML	High, Medium, Low, hearing protector rating. Unit: dB
I	sound intensity. Unit: watts/m ²
I₀	reference sound intensity (10 ⁻¹² w/m ²)
IEC	International Electrotechnical Commission
I-INCE	International Institute of Noise Control Engineering
IHC	inner hair cells
IL	insertion loss. Unit: dB
INCE	Institute of Noise Control Engineering
INEP	industrial-noise-exposed population
ISO	International Organization for Standardization
k	dynamic stiffness, as in a spring constant. Unit: N/m, lb/ft
k	Constant used in various equations relating sound power and sound pressure. The value differs for metric and English units, and is specific to each equation.
K	values used for determining tolerance limits as listed in Table 7.11. Unit: dimensionless
kg	kilogram
L_a	acceleration level (vibration). Unit: dB
L_A	A-weighted sound level. Unit: dBA
L_{A8hn}	A-weighted average sound level with 3-dB exchange rate, normalized to 8 hours. Same as L _{EX,sh} as defined in ISO 1999. Contrast with L _{eq,T} which is a non-normalized quantity. Unit: dBA
L_{AE}	sound exposure level with A-weighting. Unit: dBA (also see SEL)
L_{Aeq,T}	see L _{eq,T}

$L_{AF}(t)$	A-weighted and fast response sound level as a function of time. Use of S instead of F denotes slow response. Unit: dBA
L_{Apk}	peak sound level with A-weighting. L_{Cpk} denotes C-weighting, and lack of either an A or a C denotes no frequency weighting. Unit: dBA
L_{AS}	sound level with A-weighting and slow response. Similarly L_{AF} denotes fast response. Unit: dBA
L_{ASmax}	maximum sound level with A-weighting and slow response. Unit: dBA
L_{ASX}	level exceeded X% of the time, measured using A-weighting and slow response. L_{AFX} denotes fast response. The total measurement duration must be stated. Unit: dBA
$L_A(t)$	A-weighted sound level as a function of time. Unit: dBA
L_{Awkn}	A-weighted weekly average sound level, computed by energy averaging (3-dB exchange) the daily TWAs (5-dB exchange), normalized to a 5-day exposure. Unit: dBA
L_{Ayrn}	A-weighted yearly average sound level, computed by energy averaging (3-dB exchange) either the weekly TWAs or values of L_{Awkn} , normalized to a 48- or 50-week exposure, as appropriate. Unit: dBA
L_c	criterion level (A-weighted). Exposure at L_c for the criterion time generates 100% noise dose. Unit: dBA
L_C	C-weighted sound level. Unit: dBC
L_{Cdn}	day-night average level, C-weighting used. Unit: dBC (also see L_{dn})
L_{CE}	sound exposure level with C-weighting. Unit: dBC (also see SEL)
L_{CS}	sound level with C-weighting and slow response. L_{CF} denotes fast response. Unit: dBC
L_{dn}	day-night average sound level (A-weighting implicit), use of L_{Adn} is optional. Unit: dBA (also see DNL).
$L_{eq,T}$	equivalent-continuous sound level, also called average sound level, during time period T, using a 3-dB exchange rate. Weighting must be specified separately as in $L_{Aeq,T}$. Contrast to L_{A8hn} for normalized average sound level, but note that for an 8-hr measurement, $L_{A8hn} = L_{Aeq,8h}$. Unit: dB, dBA, or dBC.
L_F	sound levels or sound pressure levels measured with fast time constant; 125-ms exponential weighted time average instrument response, often called “fast response.” (also see L_S .)
L_{mt}	masked threshold. Unit: dB
$L_{OSHA,T}$	A-weighted average sound level, during the time period T, with 5-dB exchange rate and slow meter response, applied in OSHA/MSHA practice. The time period over which the average is computed should be stated, but in most contemporary instruments and in common usage the averaging time is reported separately, hence the “T” in the subscript does not appear. The equivalent metric based on a 3-dB exchange rate is $L_{Aeq,T}$; the 8-hr normalized quantity, with a 5-dB exchange rate, is TWA. Unit: dBA

L_p	sound pressure level. Unit: dB (also see SPL)
L_{pb}	band pressure level, i.e., the sound pressure level for sound contained within a restricted band of frequencies (e.g., octave, 1/3 octave). Unit: dB
L_{ps}	spectrum sound pressure level. Unit: dB/Hz
L_S	sound levels or sound pressure levels measured with slow time constant; 1-s exponential weighted time average instrument response, often called “slow response.” (also see L_F)
L_W	sound power level. Used with A or C subscript (e.g., L_{WA}) denotes use of A- or C-weighting. Unit: dB (also see PWL)
$L_1..L_2..L_N$	OSHA designator for a specific A-weighted noise level at which there is a permissible time of exposure (also called reference duration). Running subscripts refer to particular noise levels for a range of values from 1 to N. Unit: dBA
LCL	lower confidence limit. Unit: dimensionless
log	logarithm. When no subscript appears, base 10 is assumed.
m	meter
<i>m</i>	mass. Unit: kg, lb
MAF	minimum audible field. Unit: dB
MAP	minimum audible pressure. Unit: dB
ms	1/1000 s (millisecond)
MSHA	Mine Safety and Health Administration
N	newton (Kg-m/s ²)
<i>N</i>	rotational speed. Unit: rpm
NASED	National Association of Special Equipment Distributors
NBS	National Bureau of Standards. Current name has been changed to NIST
NC	noise criterion level. Unit: dB
NCB	balanced noise criteria. Unit: dB
NCPF	noise control priority factor.
NHCA	National Hearing Conservation Association
NIHL	noise-induced hearing loss. Unit: dB
NINEP	non-industrial-noise-exposed population
NIOSH	National Institute for Occupational Safety and Health
NIPTS	noise-induced permanent threshold shift. Unit: dB
NIST	National Institute of Standards and Technology
NR	noise reduction. Unit: dB (in Chapter 13 NR is used to mean Noise Rating)
NRC	noise reduction coefficient. Unit: dimensionless
NRN	Noise Reduction Rating. Often a trailing subscript, as in NRN_{84} , is used to indicate the percentage of the population that is protected. Unit: dB

NRR(SF)	Noise Reduction Rating (Subject Fit). Unit: dB
NSC	National Safety Council
NVLAP	National Voluntary Laboratory Accreditation Program
OAE	otoacoustic emissions
OB	octave band. Often preceded by 1/1 or 1/3 to indicate octave or one-third octave band.
OHC	occupational hearing conservationist (in Chapter 4 also used for outer hair cells)
ONIPPTS	occupational-noise-induced permanent threshold shift
OPM	Office of Personnel Management
OSHA	Occupational Safety and Health Administration
p	sound pressure. Unit: Pa
p_o	reference sound pressure (20μPa)
p_{rms}	root-mean-square sound pressure. Unit: Pa
Pa	pascal
PEL	permissible exposure limit. A-weighted sound level at which exposure for a stated time, typically 8 hrs., accumulates 100% noise dose. Unit: dBA
PNC	preferred noise criteria. Unit: dB
PNR	predicted noise level reduction. Unit: dB
PSIL	preferred speech interference level. Unit: dB
PTS	permanent threshold shift. Unit: dB
PU	polyurethane
PVC	polyvinyl chloride
PWL	sound power level. Unit: dB (also see L _w)
%B_b	percent of employees showing a shift of 15 dB or more toward better hearing at any test frequency (500 – 6000 Hz) in either ear relative to their baseline audiogram. Unit: %
%W_b	percent of employees showing a shift of 15 dB or more toward worse hearing at any test frequency (500 – 6000 Hz) in either ear relative to their baseline audiogram. Unit: %
%BW_s	percent of employees showing a shift of 15 dB or more toward either better or worse hearing at any test frequency (500 – 6000 Hz) in either ear between two sequential audiograms. Unit: %
%W_s	percent of employees showing a shift of 15 dB or more toward worse hearing at any test frequency (500 – 6000 Hz) in either ear between two sequential audiograms. Unit: %
q	nondimensional parameter that determines the exchange rate in computing noise dose. For 5-dB exchange rate, q = 16.61; for 3-dB exchange rate, q = 10.
Q	directivity factor. Unit: dimensionless
QAI	quality assessment index, used in conjunction with RC Mark II method for rating a noise spectrum. Unit: dB

r	radius, effective radius, or distance from source. Unit: m, ft
rad	radians
R	room constant. Unit: m^2 , ft^2 (also called metric sabins or sabins)
R	mechanical vibration isolation. Unit: dimensionless
RC	room criterion level. Unit: dB
REAT	real-ear attenuation at threshold. Unit: dB
REL	recommended exposure limit. NIOSH recommended 8-hr time-weighted average limit (85 dB), using a 3-dB exchange rate, which if equaled or exceeded, indicates a hazardous exposure. Unit: dBA
rms	root-mean-square
s	second
S	surface area of room. Unit: m^2 , ft^2
SCFM	standard cubic feet per minute. Unit: ft^3/min
SD	standard deviation. Unit: same units as measured quantity
SEL	sound exposure level. Unit: dB (also see L_{AE})
SII	speech intelligibility index. Unit: dimensionless
SIL	speech interference level. Unit: dB
SLC	Sound Level Conversion. Often a trailing subscript, as in SLC_{80} , is used to indicate the percentage of the population that is protected. Unit: dB
SLM	sound level meter
SN	serial number
S/N	speech-to-noise or signal-to-noise ratio. Unit: dB
SNR	Single Number Rating. Unit: dB
SPL	sound pressure level. Unit: dB (also see L_p)
SRT	speech recognition threshold (previously called speech reception threshold). Unit: dB
STC	sound transmission class. Unit: dB
STS	standard threshold shift in hearing, as defined in OSHA HCA. Unit: dB
t	time. Unit: s, min, h
t	refers to values of Student's t-distribution as found in Table 7.10. Unit: dimensionless
T_c	criterion sound duration. In OSHA/MSHA practice, $T_c = 8$ h. Unit: h
T_p	Permissible time of exposure, with any defined exchange rate, at a stated A-weighted sound level which accumulates 100% noise dose. Compare to OSHA permissible time, T_N . Unit: min, h

$T_1..T_2..T_N$	OSHA designator for permissible time of exposure (also called reference duration) with a 5-dB exchange rate, at a stated A-weighted sound level which accumulates 100% noise dose. Running subscripts refer to particular noise levels for a range of values from 1 to N. Unit: min, h (compare to T_p for permissible time with other than 5-dB exchange rate, and also see $C_1..C_2..C_N$)
T_{60}	reverberation time. Unit: s
T^*	Actual measurement time for worker exposure to noise. Unit: min, h
TL	transmission loss. Unit: dB
TLV [®]	threshold limit value.
TR	transmissibility, also called transmission ratio. Unit: dimensionless
TTS	temporary threshold shift. Unit: dB
TTS ₂	temporary threshold shift measured 2 minutes post-exposure. Unit: dB
TWA	A-weighted average sound level with 5-dB exchange rate and slow meter response, applied in OSHA/MSHA practice. The TWA is normalized to 8 hours. Contrast with L_{OSHA} for a non-normalized quantity. Unit: dBA
UCL	upper confidence limit. Unit: dimensionless
v	velocity. Unit: m/s, in/s
w	watt
W	sound power. Unit: watts
W_0	reference sound power (10^{-12} acoustic watts)
WC	workers' compensation
WHO	World Health Organization
Z	standard scores for the normal distribution as listed in Table 7.8. Unit: dimensionless
α	sound absorption coefficient. Unit: dimensionless
α'	air attenuation coefficient. Unit: dB/km
δ	static deflection. Unit: cm, in
η	loss factor. Unit: dimensionless
λ	wavelength. Unit: m, ft
μPa	micropascal (10^{-6}Pa)
ρ	density of air. Unit: kg/m^3
τ	transmission coefficient. Unit: dimensionless
ω	angular frequency = $2\pi f$. Unit: rad/s
ω_n	angular natural frequency. Unit: rad/s
ζ	ratio of viscous damping constant to critical damping value. Unit: dimensionless
%B, %W	see definitions alphabetized under "p" for percent

*Quiet places
are the think tank of the soul.*

Gordon Hempton
The Sound Tracker