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OCCUPATIONAL EXPOSURE TO NOISE

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Health Services and Mental Health Administration
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PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health of workers exposed to an ever increasing number of potential hazards at their workplace. To provide relevant data from which valid criteria and effective standards can be deduced, the National Institute for Occupational Safety and Health has projected a formal system of research, with priorities determined on the basis of specified indices.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on noise by members of my staff and the valuable constructive comments by the Review Consultants on Noise to NIOSH, the ad-hoc committee of the American Industrial Hygiene Association, and Dr. Dixon Ward of the Committee on Hearing, Bioacoustics and Biomechanics. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants and professional societies that reviewed this criteria document on noise. A list of the Review Consultants appears on pages iii and iv.

It should be noted that the majority of the NIOSH Review Consultants recommended an 85 dBA noise limit with mandatory hearing protection and audiometric testing for the most complete protection. Data are provided in this document which indicate that approximately 14% of workers in manufacturing are exposed to noise above 90 dBA, but no data are available relative to the number exposed to 85 dBA or to the technological feasibility of meeting the proposed 85 dBA standard in a given time period. The present recommendations defer the 85 dBA standard until after an extensive feasibility study and limit mandatory audiometric testing to new employees, with a recommendation that employers consider the merits of a full hearing conservation program. A study of the quantity and quality of the health manpower for audiometric testing is needed before further recommendations can be made.

Marcus M. Key

Marcus M. Key, M.D.
Director, National Institute
for Occupational Safety and Health

The Office of Research and Standards Development, National Institute for Occupational Safety and Health, had primary responsibility for development of the criteria and the recommended standard for noise. Mr. Steven A. Coppola served as criteria manager and Messrs. Herbert H. Jones, B. Thomas Scheib, Stephen R. Cordle, Mark E. Schmidek, Barry L. Lempert, and Dr. Terry L. Henderson had NIOSH program responsibility for development of the document.

NIOSH REVIEW CONSULTANTS ON
NOISE

Aram Glorig, M.D.
Director
The Callier Hearing & Speech Center
Dallas, Texas 75235

James Botsford
Contributing Editor
Sound & Vibration
Bethlehem, Pennsylvania 18017

Karl D. Kryter
Director
Sensory Sciences Research Center
Stanford Research Institute
Menlo Park, California 94025

Paul L. Michael
Ordnance Research Laboratory
State College, Pennsylvania 16801

Irving H. Davis
Regional Chief
Division of Occupational Health
State of Michigan - Department of Public Health
Lansing, Michigan 48914

David A. Padden
Industrial Hygienist
International Union, United Auto Workers
of America
Detroit, Michigan 48214

Richard A. Sutter, M.D.
Director
Sutter Clinic, Inc.
St. Louis, Missouri 63101

A. E. Lowe
Senior Industrial Hygiene Engineer
Bureau of Occupational Health & Environmental Epidemiology
California State Department of Public Health
Berkeley, California 94704

Herbert E. Bell
Colonel, USAF BSC
Director for Environmental Management
Washington, D.C. 20301

REVIEW COMMITTEE
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

Robert N. Ligo, M.D.
Division of Technical Services

Vernon E. Rose
Assistant Director for
Health Surveillance & Biometrics

Thomas L. Anania
Division of Technical Services

Paul Caplan
Deputy Director, Division of
Technical Services

Stanley J. Reno
Regional Program Director, Region VIII

Austin Henschel, Ph.D.
Division of Laboratories and
Criteria Development

Alexander Cohen, Ph.D.
Division of Laboratories and
Criteria Development

Francis N. Dukes-Dobos, M.D.
Acting Chief, Physical and
Ergonomics Branch

Ex Officio:

Charles H. Powell, Sc.D.
Assistant Director, for
Research & Standards Development

CRITERIA DOCUMENT: RECOMMENDATIONS FOR AN OCCUPATIONAL EXPOSURE STANDARD FOR NOISE

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I. RECOMMENDATIONS FOR A NOISE STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that employee exposure to noise in the workplace be controlled by requiring compliance with the standard set forth in the following sections. Control of employee exposure to the occupational limits stated and adherence to the precautionary procedures prescribed will improve the protection of the working population from incurring noise induced hearing loss that could impair their abilities to understand everyday speech. Such control and adherence at the workplace is believed sufficiently effective to reduce also the possibility of other forms of occupational injury and illness related to noise.

This standard is amenable to techniques that are valid, reproducible, and presently available. It will be reviewed and revised as additional information becomes available.

Section 1 - Applicability

The provisions of this standard are applicable to occupational noise exposures at places of employment and are intended to apply for all noise even though additional controls may be necessary for certain specific types of noise, such as some impact and impulsive noise. For the purposes of this standard the noise exposure is determined for an 8-hour workday.

Section 2 - Definitions

As used in this standard, the term:

(a) "Administrative control" means any procedure that limits daily exposure to noise by control of the work schedule.

(b) "Audiogram" means a graph or table obtained from an audiometric examination showing hearing level as a function of frequency.

(c) "Baseline audiogram" means an audiogram obtained from an audiometric examination that is preceded by a period of at least 14 hours of quiet.

(e) "Audiometer setting" means a setting on an audiometer corresponding to a specific combination of hearing level and sound frequency.

(f) "Daily Noise Dose" means that value for D derived from the equation:

$$D = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n}$$

where C1, C2 . . . , Cn are the actual durations of exposure for an employee at the various noise levels, T1, T2, . . . , Tn are the respective duration limits obtained from Figure I-1 and D is the Daily Noise Dose.

(g) "dBA - Slow" means the unit of measurement of sound level indicated by a sound level meter conforming as a minimum requirement to the American National Standard Specification for Sound Level Meters, ANSI S1.4 (1971) Type S2A, when used for A-weighted sound level, slow response.

(h) "Engineering control" means any procedure other than administrative control that reduces the sound level either at the source of the noise or in the hearing zone of the employees.

(i) "Hearing level" means the amount, in decibels, by which the threshold of audibility for an ear differs from a standard audiometric threshold.

(j) "Environmental noise level" means the noise level in dBA-Slow as measured in accord with Section 3(c).

(k) "Effective noise level" means (1) for employees not wearing ear protectors, the environmental noise level; (2) for employees wearing ear protectors, the result of subtracting the dBA reduction, R, for the ear protectors (determined as specified in Appendix A) from the measured environmental noise level. Effective noise level is expressed in units of dBA-Slow.

(l) "Noise exposure" means a combination of effective noise level and exposure duration.

Section 3 - Occupational Environment

(a) The unit of measurement shall be "dBA-Slow."

(b) Daily Occupational Noise Exposure

(i) Occupational noise exposure shall be controlled so that no worker shall be exposed in excess of the limit described as line B in Figure I-1. New installations shall be designed with noise control so that the noise exposure does not exceed the limits described as line A in Figure I-1. For noise exposures consisting of two or more periods of exposure at different levels, the Daily Noise Dose, D, shall not exceed unity. Line A or line B, as applicable, shall be used in computing the Daily Noise Dose.

(ii) It is recommended that the limit described as line A become effective for all places of employment after a time period determined by the Secretary of Labor in consultation with the Secretary of Health, Education, and Welfare. This delay in effective date for all places of

LINE A
FORMULA: $T = 16 \div 2^{(L-80)/5}$
RANGE: 80 to 115 dBA-Slow

LINE B
FORMULA: $T = 16 \div 2^{(L-85)/5}$
RANGE: 85 to 115 dBA-Slow

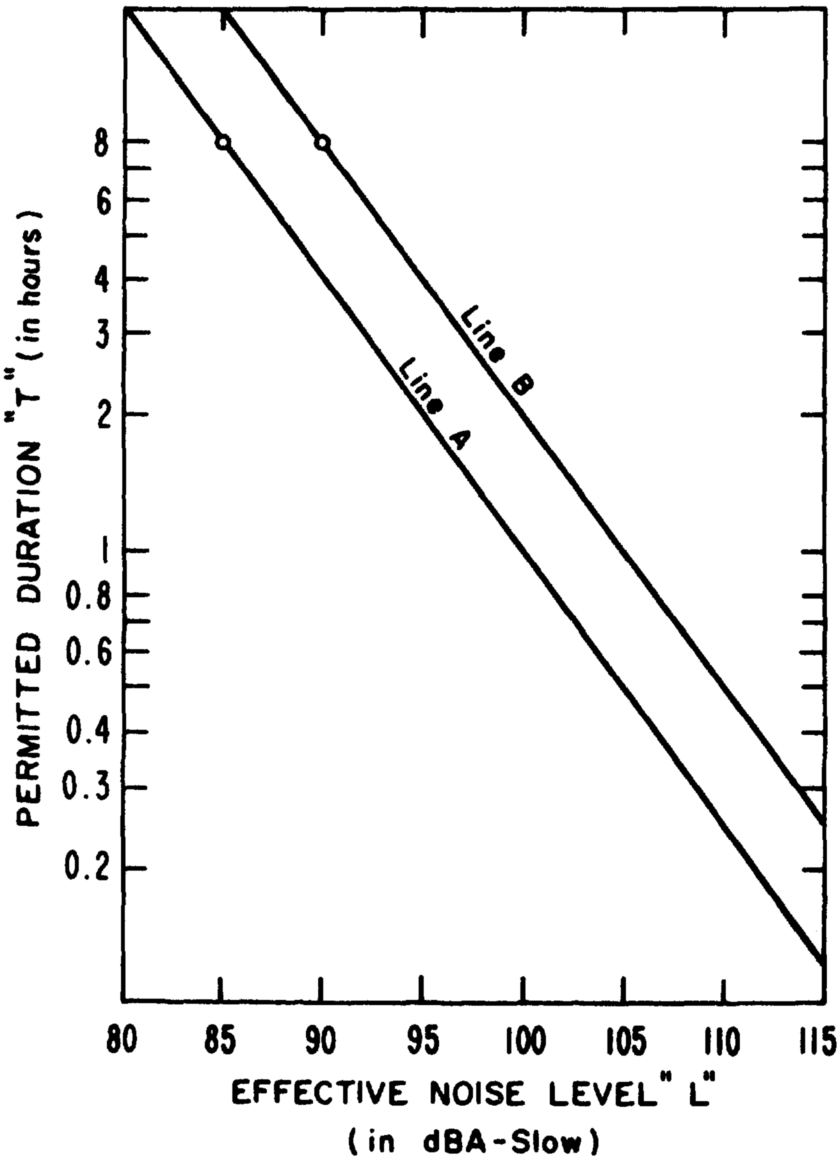

Figure I-1. Permitted duration vs. noise level.*

*The indicated duration limits which exceed 8 hours are to be used only for purposes of computing Daily Noise Dose and are not to be regarded as defining noise exposure limits for work days which exceed 8 hours.

employment is believed necessary to permit the Department of Labor to conduct an extensive feasibility study.

(iii) At no time shall any worker be exposed to effective noise levels exceeding 115 dBA-Slow.

(c) Measurements

(i) Compliance with the permitted daily noise exposures defined by Section 3(b) shall be determined on the basis of measurements made with a sound level meter conforming as a minimum to the requirement of the American National Standard Specification for Sound Level Meters, S1.4 (1971) Type S2A, and set to use an A-weighted slow response.

(ii) All measurements shall be made with the sound level meter at a position which most closely approximates the noise levels at the head position of the employee during normal operations.

(iii) An acoustical calibrator accurate within plus or minus one decibel shall be used to calibrate the sound level meter on each day that noise measurements are taken.

Section 4 - Medical

(a) Medical surveillance in the form of an audiometric testing program shall be provided by the employer when the Daily Noise Dose, D, equals or exceeds the limits specified in Section 3(b), and for all employees whose occupational noise exposure is controlled by personal protective equipment.

(b) The audiometric testing program required by (a) above shall conform to the following schedule:

(i) A baseline audiogram for each employee who is initially assigned or reassigned to work subject to conditions stated in (a) of this section shall be taken within 30 days of assignment to such employment, in the sixth year of such employment, and once every sixth year thereafter. It is recognized that some delay in implementation of this requirement may be necessary for employers with a small work force.

(ii) A baseline audiogram should be taken for each employee presently assigned to work subject to conditions stated in (a) of this section at the time of effective date of this regulation, in the sixth year, and once every sixth year thereafter.

(iii) In addition an audiogram, not necessarily baseline, for all exposed employees should be taken every second year.

(c) Each audiogram shall contain (1) employee's name or identifying number, (2) employee's job location, (3) significant aural medical history of the employee, (4) the examiner's name and signature, (5) the date and time of test, (6) serial number of the audiometer, and (7) last exposure to high level noise: number of hours since exposure; type of exposure; and noise level, if known.

(d) Each employee's audiogram shall be examined to determine whether it indicates for either ear any threshold shift (higher threshold), that equals or exceeds 10 dB at 500, 1000, 2000, or 3000 Hz, or 15 dB at 4000 or 6000 Hz as evidenced by a comparison of that audiogram with the employee's most recent baseline audiogram and with his initial baseline audiogram as corrected to his current age by the method described in Appendix B. If either comparison indicates a shift as described above:

(i) refer the employee for appropriate medical evaluation,

(ii) if the employee needs personal protective equipment or devices, insure that he has the appropriate effective equipment and that he is instructed in the proper use and care of the equipment, and

(iii) if the audiogram was not a baseline audiogram, take a baseline audiogram within sixty days.

(e) Audiometric tests shall be pure tone, air-conduction, hearing threshold examinations, with test frequencies including 500, 1000, 2000, 3000, 4000, and 6000 Hz and shall be taken separately for the right and left ears.

(i) The tests shall be conducted in a room whose ambient noise levels conform to all requirements except that part concerning octave bands whose center frequencies are less than 250 Hz of the American National Standard Criteria for Background Noise in Audiometer Rooms, ANSI S3.1 (1960 R-1971), when measured by equipment conforming to American National Standard Specification for Sound Level Meters, ANSI S1.4 (1971) Type 2 and American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets, ANSI S1.11 (1966, R-1971).

(ii) The tests shall be administered using an audiometer which conforms to the requirements for limited range pure tone audiometers prescribed by the American National Standards Specifications for Audiometers, ANSI S3.6 (1969), and which is of the discrete frequency type. If a pulsed tone audiometer is used, the on-time of the tone shall be at least 200 milliseconds. The instrument used in the testing shall be either a manual audiometer, or a self-recording audiometer which is subject to the following additional restrictions:

(1) The chart upon which the audiogram is traced shall have printed lines at positions corresponding to all multiples of 10 dB hearing level within the intensity range spanned by the audiometer. The lines shall be equally spaced and shall be separated by at least 1/4 inch. Additional graduations are optional. The pen which traces the audiogram shall have a fine point so that the tracing shall not exceed 2 dB in width.

(2) It shall be possible to disable the stylus drive

mechanism so that the stylus can be manually set at the 10-dB graduation lines for calibration purposes.

(3) The slewing rate for the audiometer attenuator shall be 6 dB/sec or less except that an initial slewing rate greater than 6 dB/sec is permitted at the beginning of each new test frequency, but only until the second subject response.

(4) The audiometer shall remain at each required test frequency for 30 seconds (± 3 seconds). The audiogram shall be clearly marked at each change of frequency and the actual frequency change of the audiometer shall not deviate from the frequency boundaries marked on the audiogram by more than ± 3 seconds.

(5) If an audiogram fails to pass the following criteria, the subject shall be retested:

At each test frequency it must be possible to place a horizontal line segment parallel to the time axis on the audiogram, such that the audiometric tracing crosses the line segment at least six times at that test frequency.

(iv) The audiometer shall be maintained in calibration in accordance with the provisions of Appendix C.

Section 5 - Work Practices

When employees are employed under conditions where noise exposures would exceed the limits prescribed in Section 3(b), administrative or engineering controls shall be utilized to reduce exposures to within those limits.

Section 6 - Warning Notice

(a) A warning sign shall be appropriately located at entrances to and/or the periphery of, areas where there exists sustained environmental noise at or in excess of the limit prescribed in Section 3(b).

(b) The notice shall consist of the following:

W A R N I N G

NOISE AREA
MAY CAUSE HEARING LOSS

Use Proper Ear Protection

Section 7 - Personal Protective Equipment

(a) If noise exposures to which employees could be exposed exceed the limits specified, personal protective equipment (i.e., ear protectors) shall be provided by the employer to be used in conjunction with an audiometric testing program, as specified in Section 4, subject to the following requirements:

(i) The use of personal protective equipment to prevent occupational noise exposure of the employer in excess of the prescribed limits is authorized only until engineering and administrative controls and procedures can be implemented to maintain the occupational noise exposures within prescribed limits.

(ii) Any ear protector used by an employee shall reduce the effective noise level to which he is exposed so that his noise exposure is within the limits prescribed in Section 3(b).

(iii) Insert - type ear protectors shall be fitted by a person trained in this procedure.

(iv) Inspection procedures to assure proper issuance, maintenance, and use of personal protective equipment shall be established by the employer.

(b) The employer shall provide training in the proper care and use of all personal protective equipment.

Section 8 - Apprisal of Employees of Hazards from Noise

Each worker exposed to noise shall be apprised of all hazards, relevant symptoms, and proper conditions and precautions for working in noisy areas. The information shall be kept on file and readily accessible to the worker at all places of employment where the noise levels equal or exceed the limits prescribed in Section 3 (b).

Section 9 - Monitoring & Recordkeeping Requirements

(a) Employers will be required to maintain records of:

(i) environmental exposure monitoring for a period of 10 years.

(ii) all audiograms for a period of 20 years.

(iii) all audiometric calibration data for a period of 20 years.

(b) When exposure times of less than 8 hours/day are required in a specific work area or ear protection is used to meet the exposure limits, records of the method of control shall be maintained.

Appendix A - Determination of dBA Reduction R for Ear Protectors

1. The pure tone attenuation vs. frequency characteristics of the ear protector (normally supplied by the manufacturer) shall have been determined in accordance with the American National Standard for Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold, ANSI Z24.22 (1957). Let Q_1, Q_2, . . ., Q_7 be defined (in dB) as follows:

Q_1 = attenuation at 125 Hz, plus 16.2 dB

Q_2 = attenuation at 250 Hz, plus 8.7 dB

Q_3 = attenuation at 500 Hz, plus 3.3 dB

Q_4 = attenuation at 1000 Hz

Q_5 = attenuation at 2000 Hz, minus 1.2 dB

Q6 = average of attenuation at 3000 and 4000 Hz, minus 1.0 dB

Q_7 = average of attenuations at 6000 and 8000 Hz, plus 1.1 dB

2. The following procedure shall be used to determine the dBA reduction R of the ear protector when used for an occupational noise whose octave-band sound pressure levels have been measured.

Let L_1, L_2, L_3, L_4,, L_5, L_6 and L_7 denote the octave band levels in dB at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz respectively; and let L_A denote the dBA-Slow level of the noise. Then the dBA reduction as connected is given by $R = L_A - 10 \log S - 10.0$

where

$$S = \text{antilog}\ (0.1\text{X}\ [L_1 - Q_1]) + \text{antilog}\ (0.1\ \text{X}\ [L_2 - Q_2])$$
$$+\ \text{antilog}\ (0.1\ \text{X}\ [L_3 - Q_3]) + \text{antilog}\ (0.1\ \text{X}\ [L_4 - Q_4])$$
$$+\ \text{antilog}\ (0.1\ \text{X}\ [L_5 - Q_5]) + \text{antilog}\ (0.1\ \text{X}\ [L_6 - Q_6])$$
$$+\ \text{antilog}\ (0.1\ \text{X}\ [L_7 - Q_7])$$

The "-10.0" correction term is to account for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, or various other factors.

3. If the octave band levels of the noise are not known, then the dBA reduction R may be computed simply as

$$R = -10 \log S - 3.0$$

where

$$S = \text{antilog}(-0.1 \times Q_1) + \text{antilog}(-0.1 \times Q_2)$$
$$+ \text{antilog}(-0.1 \times Q_3) + \text{antilog}(-0.1 \times Q_4)$$
$$+ \text{antilog}(-0.1 \times Q_5) + \text{antilog}(-0.1 \times Q_6)$$
$$+ \text{antilog}(-0.1 \times Q_7)$$

This calculation is approximate, and is based upon the assumption that the octave band levels are equal. For most types of noise it will give results close to those obtained by the more accurate method of (2) above.

Example:

Typical Pure-tone Attenuation Characteristics of an Ear Protector

125	250	500	1000	2000	3000	4000	6000	8000	Hz
24	21	23	29	30	35	31	29	27	dB

Thus $Q_1 = 40.2$; $Q_2 = 29.7$; $Q_3 = 26.3$; $Q_4 = 29.0$; $Q_5 = 28.8$; $Q_6 = 31.0$; $Q_7 = 29.1$

If the octave band noise levels are not known, then

$$R = -10 \log S - 3.0$$

where

$$S = \text{antilog}(-4.02) + \text{antilog}(-2.97) + \text{antilog}(-2.63)$$
$$+ \text{antilog}(-2.90) + \text{antilog}(-2.88) + \text{antilog}(-3.10)$$
$$+ \text{antilog}(-2.91)$$

or $S = 0.00811$

So $R = -10 \log. 0.0081 - 3.0 = 20.9 - 3.0 \cong 18$ dBA

Now suppose the ear protector is to be used in an area with an environmental noise level of 95 dBA, for which the octave band noise levels are as follows:

125	250	500	1000	2000	4000	8000	Hz
99	94	94	90	84	82	75	Octave Band Level

In this case the dBA reduction is

$R = L_A = 10 \log S - 10.0$

Where S = antilog (9.9 - 4.02) + antilog (9.4 - 2.97) + antilog (9.4 - 2.63)

+ antilog (9.0 - 2.90) + antilog (8.4 - 2.88) + antilog (8.2 - 3.10)

+ antilog (7.5 - 2.91). So $S = 11{,}090{,}000$

Thus $R = 95.0 - 10 \times 7.05 - 10.0 \cong 85.0 - 70.5$

So $R = 14.5$ dBA

Appendix B - Method for Correcting Initial Baseline Audiograms for Age

Age corrections to initial baseline audiograms shall be made in the following manner:

For each audiometric test frequency:

1. Determine from Table B-1 or B-2 the age correction values for the employee

   (a) for the age at which the most recent audiogram was taken and

   (b) for the age at which the initial baseline audiogram was taken.

2. Subtract the values found in (a) from the values found in (b).

3. Add the difference found in 2 to the employee's initial baseline audiogram to obtain the initial baseline audiogram corrected for age.

EXAMPLE: Employee is 56 years old and male. His initial baseline audiogram was taken at age 26 and his hearing levels at that age were as follows:

Hz	500	1000	2000	3000	4000	6000
Left ear	5	0	10	5	10	10
Right ear	10	0	5	0	5	15

Enter Table B-1 at age 56 and at age 26 and subtract.

Hz	500	1000	2000	3000	4000	6000
Age 56	16	10	11	20	28	34
Age 26	11	5	4	5	7	10
Difference	5	5	7	15	21	24

Add the differences to his initial baseline audiogram to obtain his corrected initial baseline audiogram as follows:

Hz	500	1000	2000	3000	4000	6000
Left ear	10	5	18	20	31	34
Right ear	15	5	13	15	26	39

TABLE B-1

Age Corrections Values to be Used for Age Correction of Initial Baseline Audiograms for Males

Age Years	Audiometric Test Frequencies (Hz) 500	1000	2000	3000	4000	6000
20 or younger	10	5	3	4	5	8
21	10	5	3	4	5	8
22	10	5	3	4	5	8
23	10	5	3	4	6	9
24	10	5	3	5	6	9
25	11	5	3	5	7	10
26	11	5	4	5	7	10
27	11	5	4	6	7	11
28	11	6	4	6	8	11
29	11	6	4	6	8	12
30	11	6	4	6	9	12
31	12	6	4	7	9	13
32	12	6	5	7	10	14
33	12	6	5	7	10	14
34	12	6	5	8	11	15
35	12	7	5	8	11	15
36	12	7	5	9	12	16
37	13	7	6	9	12	17
38	13	7	6	9	13	17
39	13	7	6	10	14	18
40	13	7	6	10	14	19
41	13	7	6	11	15	20
42	14	8	7	11	16	20
43	14	8	7	12	16	21
44	14	8	7	12	17	22
45	14	8	7	13	18	23
46	14	8	8	13	19	24
47	14	8	8	14	19	24
48	15	9	8	14	20	25
49	15	9	9	15	21	26
50	15	9	9	16	22	27
51	15	9	9	16	23	28
52	15	9	10	17	24	29
53	16	9	10	18	25	30
54	16	10	10	18	26	31
55	16	10	11	19	27	32
56	16	10	11	20	28	34
57	16	10	11	21	29	35
58	17	10	12	22	31	36
59	17	11	12	22	32	37
60 or older	17	11	13	23	33	38

TABLE B-2

Age Corrections Values to be Used for Age Correction of Initial Baseline Audiograms for Females

Age Years	Audiometric Test Frequencies (Hz) 500	1000	2000	3000	4000	6000
20 or younger	15	7	4	3	3	6
21	16	7	4	4	3	6
22	16	7	4	4	4	6
23	16	7	5	4	4	7
24	16	7	5	4	4	7
25	16	8	5	4	4	7
26	16	8	5	5	4	8
27	17	8	5	5	5	8
28	17	8	5	5	5	8
29	17	8	5	5	5	9
30	17	8	6	5	5	9
31	17	8	6	6	5	9
32	17	9	6	6	6	10
33	18	9	6	6	6	10
34	18	9	6	6	6	10
35	18	9	6	7	7	11
36	18	9	7	7	7	11
37	18	9	7	7	7	12
38	18	10	7	7	7	12
39	19	10	7	8	8	12
40	19	10	7	8	8	13
41	19	10	8	8	8	13
42	19	10	8	9	9	13
43	19	11	8	9	9	14
44	20	11	8	9	9	14
45	20	11	8	10	10	15
46	20	11	9	10	10	15
47	20	11	9	10	11	16
48	20	12	9	11	11	16
49	21	12	9	11	11	16
50	21	12	10	11	12	17
51	21	12	10	12	12	17
52	21	12	10	12	13	18
53	21	13	10	13	13	18
54	21	13	11	13	14	19
55	22	13	11	14	14	19
56	22	13	11	14	15	20
57	22	13	11	15	15	20
58	22	14	12	15	16	21
59	22	14	12	16	16	21
60 or older	23	14	12	16	17	22

Appendix C - Procedures for Calibration of Audiometers

The accuracy of an audiometer shall be determined by (1) a biological calibration, (2) a periodic calibration, and (3) an exhaustive calibration.

A. A biological calibration shall be made at least once each month and shall consist of (1) testing a person having a known stable audiometric curve that does not exceed 25 dB hearing level at any frequency and comparing the test results with the known curve and (2) registering the subject's response to distortions and unwanted sounds from the audiometer. If the results of a biological calibration indicate hearing-level differences greater than ±5 dB at any frequency, if the signal is distorted, or if there are attenuator or tone switch transients, then the audiometer shall be subjected to a periodic calibration within thirty days.

B. A periodic calibration shall be performed at least annually or as indicated by results of a biological check and shall include the following:

(1) Set audiometer to 70 dB hearing threshold level and measure sound pressure levels of test tones using an NBS-9A-type coupler, for both earphones and at all test frequencies.

(2) At 1000 Hz, for both earphones measure the earphone decibel levels of the audiometer for 10 dB settings in the range 70 to 10 dB hearing threshold level. This measurement may be made acoustically with a 9A coupler, or electrically at the earphone terminals.

(3) Measure the test tone frequencies with the audiometer set at 70 dB hearing threshold level, for one earphone only.

(4) In making the measurements in (1) - (3) above the accuracy of the calibrating equipment shall be sufficient to prove that the audiometer is within the tolerances permitted by ANSI S3.6-1969.

(5) A careful listening test, more extensive than that required in the biological calibration, shall be made in order to ensure that the audiometer displays no evidence of distortion, unwanted sound, or other technical problems.

(6) General function of the audiometer shall be checked, particularly in the case of a self-recording audiometer.

(7) All observed deviations from required performance shall be corrected.

C. An exhaustive calibration shall be performed at least every five years. This shall include testing at all settings for both earphones. The test results must prove unequivocally that the audiometer meets for the following parameters the specific requirements stated in the applicable sections of ANSI-S.3-1969 as noted in parenthesis.

(1) Accuracy of decibel level settings of test tones (Sections 4.1.4.1 and 4.1.4.3).

(2) Accuracy of test tone frequencies (Section 4.1.2).

(3) Harmonic distortion of test tones (Section 4.1.3).

(4) Tone-envelope characteristics, i.e., rise and decay times, overshoot, "off" level (Section 4.5).

(5) Sound from second earphone (Section 4.4.2).

(6) Sound from test earphone (Section 4.4.1).

(7) Other unwanted sound (Section 4.4.3).

II. INTRODUCTION

The sounds of industry, growing in volume over the years, have heralded not only technical and economic progress, but also the threat of an ever increasing incidence of hearing loss and other noise related disturbances to exposed employees. Noise is not a new hazard. Indeed, noise-induced hearing loss was observed centuries ago. Ramazzini in "De Morbis Artificium Diatriba" in 1700 described how those hammering copper "have their ears so injured by that perpetual din.....that workers of this class became hard of hearing and, if they grow old at this work, completely deaf." Before the Industrial Revolution, however, comparatively few people were exposed to high level workplace noise. It was the advent of steam power in connection with the Industrial Revolution that first brought general attention to noise as an occupational hazard. Workers who fabricated steam boilers were found to develop hearing loss in such numbers that such a malady was dubbed "boilermakers disease." Increasing mechanization in all industries and most trades has since proliferated the noise problem.

Federal efforts to effectively regulate occupational noise in the United States were begun about 1955. The military was first to establish such regulations for members of the armed forces. Under the Walsh-Healey Public Contracts Act of 1936, as amended, safety and health standards had been issued that contained references to excessive noise, but they prescribed neither limits nor acknowledged the occupational hearing loss problem. A later regulation under this act (41 CFR 50-204.10) promulgated in 1969, defined noise limits for occupational exposure for purposes of hearing conservation. These limits were applicable to only those firms having supply contracts with the government in excess of $10,000; similar limits were made applicable to work under Federal Service contracts of $2,500 or more under the Service Contract Act. The noise rule in the Walsh-Healey Act regulations was adopted under the Coal Mine Health and Safety Act of 1969 and thereby became applicable to underground and surface coal mine operations as amended on July 7, 1971 (Federal Register, Vol. 36, No. 130, p. 12739).

In 1970, the Occupational Safety and Health Act was enacted which stipulated that the Secretary of Health, Education, and Welfare would on the basis of available data develop criteria for harmful physical agents that describe exposure levels safe for various periods of employment. In compliance with this provision, it is the intent of this document to present the criteria and a recommended standard based thereon for preventing occupational hazards arising from workplace noise. The recommended limits for safe exposure are primarily designed to conserve hearing since this is recognized as the most serious physical problem that noise may cause in humans. For other disturbances connected with noise such as stress related illness and performance losses, there is insufficient or inconclusive evidence upon which to base a standard. It should be emphasized, however, that adherence to noise limits for hearing conservation will also reduce risks of any other noise related problems.

Currently NIOSH reluctantly concurs with the generally acceptable 90 dBA occupational exposure level for an 8 hour day. The need for reducing this 8 hour exposure level to 85 dBA, as supported by the material contained in this document is also recognized. It is recommended that the 85 dBA, 8 hour exposure level be applicable to all newly designed occupational exposure environments after 6 mos. from the effective date of this standard. However, due to the unavailability of sufficient data relating to the technological feasibility of meeting the 85 dBA level, NIOSH is unable to recommend a specific time period after which the 85 dBA, 8 hour occupational exposure level might become effective for all occupational noise environments.

In accord with other provisions of the Occupational Safety and Health Act of 1970, this document also presents prescribed methods for measuring noise, calculating noise exposure, providing medical services and a hearing conservation program, environmental monitoring, and recordkeeping.

III. ACOUSTICAL TERMS AND METHODS

Definitions[4]

Ambient Noise - Ambient noise is the all-encompassing noise associated with a given environment, being usually a composite of sounds from many sources near and far.

Band Pressure Level - The band pressure level of a sound for a specified frequency band is the sound pressure level for the sound contained within the restricted band. The reference pressure must be stated. The band may be specified by its lower and upper cut-off frequencies, or by its geometric center frequency and bandwidth. The width of the band may be indicated by a prefatory modifier; e.g., octave band (sound pressure) level, half-octave band level, third-octave band level, 50-cps band level.

Cycle - A cycle is the complete sequence of values of a periodic quantity that occur during a period.

Damping - Damping is the dissipation of energy with time or distance.

Decibel - the decibel is a unit of level whenever the base of the logarithm is the tenth root of ten and the quantities concerned are proportional to power. The logarithm to the base the tenth root of 10 is the same as ten times the logarithm to the base 10; e.g., for a number X^2, $\log_{10}{}^{1/10} X^2 = 10 \log_{10} X^2 = 20 \log_{10} X$. This last relationship is the one ordinarily used to simplify the language in definitions of sound pressure level.

Effective Sound Pressure (Root-Mean-Square Sound Pressure) - The effective sound pressure at a point is the root-mean-square value of the instantaneous sound pressures over a time interval at the point under consideration. In the case of periodic sound pressures, the interval must be an integral number of periods or an interval that is long compared to a period.

Frequency - The frequency of a function periodic in time is the reciprocal of the primitive period. The unit is the cycle per unit time and must be specified. The unit cycle per second is commonly called Hertz (Hz).

Level - In acoustics, the level of a quantity is the logarithm of the ratio of that quantity to a reference quantity of the same kind. The base of the logarithm, the reference quantity, and the kind of level must be specified.

Noise - (1) Noise is any undesired sound; and, by extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. (2) Noise is an erratic, intermittent, or statistically random oscillation. Since the definitions of noise are not mutually exclusive, it is usually necessary to depend upon context for the distinction.

Noise Level - (1) Noise level is the level of noise, the type of which must be indicated by further modifier or context. The physical quantity measured (e.g., voltage), the reference quantity, the instrument used, and the bandwidth or other weighting characteristic must be indicated. (2) For airborne sound, unless specified to the contrary, noise level is the weighted sound pressure level called sound level; the weighting must be indicated.

Oscillation - Oscillation is the variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference.

Period – The period of a periodic quantity is the smallest increment of the independent variable for which the function repeats itself.

Periodic Quantity - A periodic quantity is an oscillating quantity whose values recur for certain increments of the independent variable.

Sound - (1) Sound is an oscillation in pressure, stress, particle displacement, particle velocity, etc., in a medium with internal forces (e.g., elastic, viscous), or the superimposition of such propagated oscillations. (2) Sound is an auditory sensation evoked by the oscillation described above.

Sound Absorption - Sound absorption is the change of sound energy into some other form, usually heat, in passing through a medium or on striking a surface.

Sound Level (SL) - Sound level is a weighted sound pressure level, obtained by the use of metering characteristics and the weightings A,B, or C as specified in the American National Standard Specification for Sound Level Meters, ANSI-S1.4-1971. The weighting employed must be stated.

Sound Pressure - The sound pressure at a point is the total instantaneous pressure at that point in the presence of a sound wave minus the static pressure at that point.

Sound Pressure Level (SPL) - The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure must be stated. The following reference pressure is in common use for measurements concerned with hearing and with sound in air and liquids: 2×10^{-5} N/M^2. Unless otherwise explicitly stated, it is to be understood that the sound pressure is the effective (rms) sound pressure.

Spectrum - (1) The spectrum of a function of time is a description of its resolution into components, each of different frequency and (usually) of different amplitude and phase. (2) Spectrum is also used to signify a continuous range of components, usually wide in extent, within which waves have some specified common characteristic; e.g., "audio-frequency spectrum."

Adding Sound Pressure Levels

Since the decibel is a logarithmic unit, sound pressure levels from different, independent sources cannot be combined by simple addition. The correct procedure is to convert the sound pressure level to ratios of sound intensities add the ratios, and then reconvert to decibels. This procedure is given by the equation:

Effective sum of SPL, SPL_2, . . ., and SPL_n =

$$10 \log \left[10^{\frac{(SPL_1)}{10}} + {\frac{(SPL_2)}{10}} + \ldots 10^{\frac{(SPL_n)}{10}} \right]$$

For example:

where

SPL_1 = 95 dB and SPL_2 = 94 dB

Then the effective sum is:

$= 10 \log \left[10^{9.5} + 10^{9.4} \right]$

$= 10 \log \left[(3.16 + 2.50)\ (10^9) \right]$

$= 10 \log \left[5.66 \times 10^9 \right]$

$= 10\ (0.75 + 9.0)$

$= 97.5$ dB

This is a time-consuming procedure, hence graphs and tables are available to aid in the addition of decibels.

Response of the Ear

Upon inspection of the definition of sound pressure level, it is evident that there is no reference to frequency. In actuality, the ear does not show equal response to all frequencies, and in fact, it is more sensitive to the middle frequencies than to the low or high ones. Studies have been made which determine the sound pressure levels of simple tones at various frequencies which sound just as loud to an observer as a 1000 Hz tone of a particular SPL. The results of such comparisons are given as equal loudness curves in Figure 1. The number of each curve, loudness level in phons, is the SPL of the 1000 Hz tone used for comparison in determining the curve.[3]

Measurement Scales

These equal loudness contours have been taken into account in the standardization of several frequency weighting networks which are included on most sound measuring equipment. The frequency characteristics of these networks are given in Figure 2. The A scale corresponds approximately to the 40-phon equal loudness contour, the B-scale corresponds to 70-phons, and the C-scale corresponds to the 100-phon contour. With these weighting networks, which modify sound pressure level to approximate the ear's response, the term to be used is sound level, and the weighting used must always be stated. ("The A-sound level is 36 dB" or "36 dBA" are appropriate expressions.) The reference pressure is 2×10^{-5} N/M^2).

The A scale is commonly used in measuring noise to evaluate its effect on people, and the A-weighted sound level is considered an adequate number to indicate or rate the hazard of a certain noise. Explanation of these measurements is given in Part IV.

Correction of Original Baseline Audiograms for Age

To determine whether there has been a significant change in an employee's hearing due to noise exposure by comparing an audiogram taken since the original baseline audiogram with that audiogram it is necessary to make a correction for difference in age.

The best way to make this correction is to use data from a non-noise exposed group from the same area tested in the same manner as the group under consideration. Quite often this is not possible; therefore, it is necessary to establish an age correction that can be used universally.

Data are presented in Table B-1 of Appendix B for non-noise exposed males from studies by NIOSH, which are described in Part VI. These data represent workers who received no significant noise exposure ($<$ 80 dBA-Slow) on the job, off the job or during military service, have no history of ear problems, and from otoscopic examination appear to have normal ears. The hearing study of the National Health Survey,[5] represents a random sample of the United States adult population tested during 1960-1962. No screening was done in this study to exclude those with significant noise exposure or questionable medical histories. Current Eastman Kodak Company[6] hearing data and the ISO Draft Proposal for hearing levels of non-noise exposed people at various ages are two studies which excluded members of the population with otological abnormalities or significant noise exposure.

The data from these four studies with respect to differences in hearing level from age 20 are quite similar. However, the greater changes apparent in the National Health Survey data at the upper frequencies could be expected because this population was not screened for significant noise exposure.

Thus, to provide a uniform correction, tables B-1 and B-2 (Appendix B) derived from the NIOSH data, will be used as specified in the standard.

<u>Conversion of Octave Band Levels to dBA Levels</u>

When the octave-band sound pressure levels of a noise have been measured it is often desirable to compute the A-weighted sound pressure level from them. This can be done as follows:

1. From each octave band level, subtract (or add) the A-weighting correction value shown in Table III, corresponding to the frequency of the octave band.

2. Let K_1, K_2, . . ., K_N denote the corrected octave band levels obtained from 1 above. The dBA level L_A is then L_A = 10 log S where S = antilog (K_1/10) + antilog (K_2/10)

+ . . . + antilog (K_N/10)

(logarithms are base 10)

This method is quite accurate although it does involve some approximation.

<u>Calculation of dBA Reduction R for an Ear Protector</u>

Calculation of dBA reduction R for ear protectors can be done as follows:

1. When the octave band levels of the noise are known: If the dB attenuation levels of the ear protector were known for each octave band, then the dBA reduction of the ear protector could be determined by subtracting these attenuation levels from the original octave band noise levels, and then calculating the dBA level of the resulting attenuated octave band levels using the method described in the previous section. One would then subtract this dBA level from the original dBA level to obtain the dBA reduction.

However, the American National Standard for Measurement of Real-Ear Attenuation of Ear Protectors at Threshold, ANSI Z24.22 (1957), prescribes pure-tone tests at 125, 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. We shall also assume that the 4000 Hz octave band attenuation level can be obtained by averaging the pure tone attenuation levels at 3000 and 4000 Hz, and that the 8000 Hz octave band attenuation level can be obtained by averaging the pure tone attenuation levels at 6000 and 8000 Hz.

This method has been formulated concisely in Appendix A of the Recommended Noise Standard, also including a factor of 10 which is to be subtracted to account for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, or various other factors. It ignores noise in the 31.5 Hz, and 16,000 Hz bands, but these rarely contribute substantially to the dBA level.

2. When the octave band levels are not known it is assumed that the noise has a uniform "pink" spectrum, i.e., equal levels in each octave band. This type of noise is representative of "average" occupational noise, and the error introduced by making this approximation is usually small. The assumption results in a simplified formula for calculation, as presented in Appendix A of the recommended Noise Standard. It is recommended, however, that the more exact method described in (1) above be used whenever octave band noise levels are available.

IV. REVIEW OF EFFECTS OF NOISE ON MAN

Exposures to noise levels found at the workplace, particularly in mechanized industries, are likely to be the most intense and sustained of any experienced in daily living. As such, they represent the severest form of acoustic insult to man and therein pose the greatest harm to human function. Real or alleged effects of occupational noise exposures include the following:

- Temporary and permanent losses in hearing sensitivity.
- Physical and psychological disorders.
- Interference with speech communications or the reception of other wanted sounds.
- Disruption of job performance.

These different listed effects of noise can be classified in various ways. For example, the first two effects can be treated in the context of health or medical problems owing to their underlying biological basis. That is, noise-induced hearing loss, as will be described later, involves damage to the cell structures of the hearing organ, and physical or psychological disorders due to noise presume alterations in normal physiologic or nervous system responses. In contrast, the remaining two effects, interference with sound reception and performance loss, are deemed annoyance or economic problems since they involve no pathology or physical dysfunction to the organism.

The aforementioned noise effects can also be classified as "auditory" and "extra-auditory" in nature. In this regard, hearing loss and speech interference caused by noise are deemed auditory effects since they both involve disturbance to the hearing organ and/or its functional processes.

Noise effects on physical and psychological health states and/or performance represent extra-auditory effects in that they extend beyond or are apart from auditory experience per se.

The intent of this part is to summarize current knowledge of these various adverse effects of noise as it relates to occupational noise conditions, and to establish their importance relative to needs for noise control in industry.

Hearing Loss

The ear is the organ structure of the body especially adapted and most responsive to the pressure changes underlying airborne sounds or noise. Anatomically, it is divided into three subdivisions - the outer, middle, and inner ear. Some key structures within these subdivisions are shown in Figures 3 and 4. The principal functions of the outer and middle ear are to collect and transmit sound pressure to the inner ear where the hair cell receptors for hearing are located. The latter are arranged in several rows along the entire length of the basilar membrane, one of two partitions which spiral around the bony axis of the cochlea. These hair cells together with their supporting cells comprise the Organ of Corti, the auditory sense organ.

Outer and middle ear structures are rarely damaged by exposure to intense noise, although explosive sounds or blasts can rupture the eardrum and possibly dislodge the ossicular chain.[7] These disorders prevent or reduce the normal passage of sound energy from the outer to the inner ear and therein create a conductive-type of hearing loss. More commonly, excessive noise exposure produces hearing loss of a neural type involving injury to the hair cells of the inner ear. Histological studies of animal ears subjected to a high level noise have confirmed the site and extent of damage to the cell structures of the Organ of Corti.[8,9] These observed lesions closely resemble those in post-mortem specimens of ears of humans known to have had prolonged high level noise exposure. Figure 5 illustrates different degrees of injury that excessive noise might cause in a section of the Organ of Corti. For proper perspective it is important to realize that the degree of hearing loss actually produced by noise not only depends upon the severity of damage at one location but also on the extent of such damage along the length of the Organ of Corti. "In this regard, the upper part of the cochlea is broadly responsive to low frequency stimulation and loss of hair cells here can be quite extensive without showing a corresponding change in low frequency sensitivity. On the other hand, much more localized portions of the basal region of the cochlea are responsible for high frequency sound sensation. Hence, less extensive losses of hair cells in these lower portions are reflected in sensitivity changes for such sounds."[10]

Many theories have been proposed to explain noise-induced injuries to the Organ of Corti. One is that vigorous stimulation of the hair cell structures by high level sounds subjects them to shearing forces or other mechanical stresses that may jar them loose from their supporting cells or otherwise damage them.[10] Another is that constant intense sound stimulation forces the hair cell receptors to high metabolic levels that cannot be maintained. As a result, the metabolic processes essential for cellular life become exhausted or poisoned, leading to the death of the cells involved.[11,12]

Since direct observation of the cell structures of the intact ear on a live human is impossible, injury to these parts are inferred from audiograms which show losses in threshold hearing levels for certain pure tone frequencies relative to some reference value. Such losses, when due to noise, may be of a temporary or permanent nature. Temporary hearing loss, more usually called temporary threshold shift or TTS, can be produced by brief exposures to high level sound and shows recovery following a period of time in quiet. Figure 6 describes an example of TTS caused by a two-hour exposure in the laboratory to a broad-band noise of fairly high level (103 dBA). In this instance an audiogram was taken on the listener just before and at various times after the cessation of the noise exposure. Differences between pre- and post-exposure threshold levels for the specified test frequencies display the amount of TTS induced by the noise. TTS is greatest immediately after exposure and progressively diminishes with increasing time in the quiet, reflecting ear recovery from the apparent noise overstimulation.

As a general rule, a noise capable of causing significant TTS with brief exposures is probably capable of causing significant permanent losses in hearing, given prolonged or recurrent exposures. In fact, some limited evidence from animal studies suggests the presence of minor hair cell damage even in those ears showing complete recovery from noise-induced temporary threshold shift.[13] In any case, daily exposures to TTS-producing noises for several hours per day for months or years would pose a risk of permanent hearing loss. That is, the ear is not likely to recover completely with recurrent exposures of this type. Rather, only partial recovery may occur in due course with new resting thresholds established, poorer than those found at the beginning of the overall noise experience. This residual loss is indicative of permanent hearing damage. Figure 7 describes these permanent losses in one group of employees as a function of their years of exposure to workplace noise levels appoximating the level used in the TTS example above.[14] The TTS component in the losses evident in these hearing data was eliminated by allowing sufficient time after the workshift ended before taking audiograms on the worker group. Deductions have also been made in the hearing levels to remove those hearing changes related to aging (i.e., presbycusis).

Figure 7 indicates that the most significant noise-induced hearing losses occur first in the high frequency range, most prominently at 4,000 cycles per second or Hertz (Hz). Decreased sensitivity to these high frequency sounds may go unnoticed by the listener since they are relatively unimportant to speech reception. With increasing exposure years, however, the losses grow and also broaden to involve other frequencies which are more critical to speech reception, namely, those in the range 500 to 3,000 Hz. In actuality, in the United States, generally accepted procedures for rating hearing handicap for speech consider losses only at frequencies 500, 1000, and 2000 Hz on the audiogram.[15] Controversy centers around the need to include 3000 Hz in these judgments since consonant discrimination may depend on hearing sensitivity for sounds higher than 2000 Hz.[16,17,18]

The pattern of permanent hearing loss shown in Figure 8 seems typical of noise-induced hearing damage as revealed in noise and hearing surveys in assorted industries (see Table IV). Why high frequency hearing, particularly around 4000 Hz, shows most vulnerability to noise is not altogether clear. One possible explanation is that the resonant frequency of the ear canal is in region 2000 - 5000 Hz which, in effect, adds strength to corresponding frequencies in an incoming noise signal.[19,20]

Complicating evaluations of hearing loss due to industrial noise are a number of factors. First, hearing sensitivity normally decreases with age, and these losses (presbycusis) are quite similar to those caused by excessive noise, i.e., differentially greater losses at the higher frequencies.[21,22] Consequently, how much of an employee's hearing loss is due to occupational noise exposure? - - and how much due to his age? Hearing data for different age and sex groups with negligible noise exposure can be used to supply correction factors to remove the aging component from audiograms collected on noise exposed employees. These presbycusis corrections are also incorporated in workman's compensation formulae used by different states in rating hearing loss disability from occupational noise exposure.

Other causes of hearing loss besides noise and age include use of drugs, illness and disease processes, blows on the head.[23] Special audiometric procedures are sometimes necessary to diagnose a given case of hearing loss in order to determine the likelihood that it may have been caused by excessive noise rather than other agents.

Even when there is clear audiometric evidence of noise-induced hearing loss, questions may be raised as to whether such damage was produced entirely by workplace noise. It is apparent that off-job noise conditions, particularly in recreation, can pose some risk of hearing change by themselves or can exacerbate the acoustic insult associated with the job situation.[24]

While indicating the need for close appraisal of audiometric results, the aforementioned complicating factors should not be construed as minimizing the seriousness of noise and hearing loss problems in industry. As will be noted in subsequent section, noise surveys in assorted manufacturing, construction, mining, transportation and farm operations indicate exposure conditions potentially harmful to millions of workers. Indeed, the population at risk with regards to noise-induced hearing loss may be greater than any other hazard in the work environment. Audiometric data already collected on samples of employees in many of the jobs surveyed above for excessive noise show them to have poorer hearing relative to other groups of workers not so exposed. Composite reviews of published occupational noise and hearing studies are found in Bell,[25] and Passchier-Vermeer,[26] and the Intersociety Guidelines.[27] A number of individual survey studies are listed in Table IV.

Recognition of industrial noise hazards to hearing have spurred research to identify noise exposure factors and other variables of consequence to the development of temporary and permanent threshold changes. These variables are cited below together with some summary statements describing their implications to threshold shift in hearing.

a. Overall sound level: Sound levels must exceed 60 - 80 dBA before a typical person will experience TTS even for exposures that last as long as 12 - 24 hours.[13] Other things equal, the greater the intensity over 60 - 80 dBA, the greater the amount of TTS. Relationships between permanent threshold loss and noise exposure at work suggest that such losses could occur under conditions comparable to those noted for TTS above, given long-term, repeated exposures.[26,27]

b. Noise Spectra: Most common sounds and noises are each composed of many different frequencies within the audible frequency range. The spectrum of these sounds refers to the manner in which their acoustic energy is distributed across the component frequencies. In general, noises having most energy above 1500 Hz are more potent in causing threshold shift than are those with most energy below this frequency.[28,29] Also, strong pure tones are potentially more noxious to hearing than broader bands of sound stimulation of equal sound level.[30-32]

c. Total Duration: Other things equal, the longer the time in noise, the greater the amount of threshold shift. With regard to TTS, exposure durations beyond 8 - 16 hours may not produce further increase in the magnitude of the shift measured within a few minutes after cessation of the exposure.[13] However, it does result in a slower recovery. The amount of permanent threshold shift at the most noise sensitive hearing, 4000 Hz, seems to reach an asymptote after about 10 to 12 years of exposure to the same noise.[26,32] Further losses at this frequency with continuing exposure appear to be due to the aging process. For test frequencies below 4000 Hz this is not true.

d. Temporal Distribution of Noise Exposure: Interruptions in noise exposure (intermittency) reduces the amount of temporary as well as permanent threshold shift over that obtained with continuous noise at equal levels during on-periods.[33] The increased ear tolerance to intermittent noise exposure may depend on the sound level present during the quiet intervals as well as during the noise segments. The number and length of quiet periods relative to the amount of noise on-time also influences the potentiality of threshold shift.

e. Individual Differences in Ear Tolerance to Noise: Susceptibility to TTS and permanent threshold losses from noise may vary greatly among individuals. This has prompted attempts to develop techniques for identifying those persons with tender ears. Such tests have largely involved TTS measurements following certain test exposure conditions, the notion being that persons displaying the greatest amount of TTS would be most vulnerable to permanent hearing loss.[34] Unfortunately, differences in TTS suceptibility are not uniform across the audible range of frequencies. That is, vulnerability to TTS from low, middle, and high frequency noise may be relatively independent. Even more important, data actually validating relationships between TTS and permanent threshold loss for the same subject group are lacking.

f. Type of Noise: Most of the discussion here has dealt with steady-state noise or sounds which predominate in industrial operations. Another class of sounds are those produced by explosive discharge of gases, termed an impulse, or by objects being struck together, called an impact. Individual impulse and impact sounds can be characterized in terms of their rise time, peak sound level, and pulse duration. Available data from TTS studies indicate that ear tolerance to impact peak sound pressures is greatly reduced by increasing the rise time and/or burst duration of the sound.[35,36] Obviously, the rate and number of such impact sounds constituting an exposure period are also factors in making hazard judgments for these types of sounds. Noise and hearing surveys in industry dealing with these types of exposure conditions are just beginning. Most permanent hearing loss data reflecting impulse noise hazards have been based on military studies involving gunfire.

Physical and Psychological Disturbances

Aside from hearing loss, noise may trigger changes in cardiovascular, endocrine, neurologic, and other physiologic functions,[35,37-39] all of which are suggestive of a general stress reaction. These physiologic changes are produced typically by intense sounds of sudden onset, but can also occur under sustained high level or even moderately strong noise conditions. Whether repeated noise induced reactions of this type can ultimately degrade one's physical and mental health is still uncertain. For example, the aforementioned physiologic changes tend to subside with recurrent exposures to the same sounds, suggesting adaptation and presumably no health difficulty. These observations, however, may not have been conducted over a sufficiently long time period to judge the possible long-term cost of this adaptation to the health of the organism.[40]

There are some reports which show that prolonged exposure to high level noise may lead to physiologic disorders in animals. For example, Anthony and Ackerman reported that guinea pigs presented with intense siren-type noises for fairly long periods of time eventually revealed endocrine and metabolic deficits which reduced their ability to cope with the noise stress.[41] Additional siren exposure here resulted in gastro-intestinal ailments, cardiovascular disease and even tissue damage in the kidneys and liver. Reproductive dysfunction and reduced resistance to infectious disease have also been reported in animals subjected to recurrent or prolonged high level noise conditions.[42,43] The results of these studies have not been without criticism.[10,37] In some instances, they have lacked for certain controls, e.g., handling of test animals in noise but not in non-noise groups, or not differentiating the groups. Also, rodents have often been used as subjects, and these animals are known to have special susceptibility to the effects of certain sounds. Furthermore, the sound levels used in many of these experiments have usually been well above those normally encountered by man even in the noisiest environmental situations.

With regard to human exposures, there are indications in the foreign literature which suggest that routine exposures to intense industrial noise might lead to chronic physical disturbances. A German study, for example revealed a higher incidence of circulatory and neurologic irregularities among steel workers in noisy jobs as compared with other worker groups in less noisy plant areas.[44] Neurological examinations of Italian weavers exposed daily to intense noise showed their reflexes to be hyperactive, and in a few cases, electroencephalography traced a pattern of desynchronization similar to that seen in personality disorders.[25] A study in the Russian literature showed workers in noisy ball-bearing and steel plants to have a relatively greater prevalence of cardiovascular irregularities such as bradycardia.[45] Complaints of fatigue, irritability, and social conflicts in many noise exposed workers have also been reported in connection with several of the investigations just noted.[25,44]

The fact that those who work in high noise levels show greater medical difficulties than those who work under quieter conditions is not conclusive evidence that noise is the <u>crucial causal</u> factor. In each case, it is possible that the differences in the specified health parameters may be explained by other factors such as age, other environmental contaminants, work load and job habits. In any case, replication of these findings seems indicated with attempts being made to statistically isolate and better control factors that could confound possible noise effects on a variety of health indicators.

Concern may be raised as to whether excessive noise poses any added hazards to persons with preexisting health problems. The literature references individual cases where noise has provoked seizures in certain persons with epilepsy or caused headaches in those suffering from migraine problems.[46,47] The generality of these findings remains to be demonstrated. In fact, little systematic information is available describing the stress tolerance of persons with chronic neurologic, cardiovascular, and gastrointestinal ailments. Presumably, it would be lower than that for individuals in normal health. There is also a great likelihood that those unduly distressed by noise or other stress-producing conditions would remove themselves from the sources of such disturbances.

It is evident from this discussion that no statements can be offered in terms of dose-response relationships between noise and the occurrence of physical and psychological disturbances. It must be emphasized, however, that noise limits designed to provide hearing protection should also reduce the possibility of any extra-auditory health disturbance. That is, the ear owing to its sensitivity to acoustic energy is most vulnerable to damage from overexposure to sound. Other bodily functions, less sensitive to sound stimuli, would not appear as prone to noise-induced alterations or damage.

Interference with Sound Reception

The most demonstrable effect of noise is masking or the interference with the reception of wanted auditory signals, notably speech. Noise conditions not intense enough to cause hearing damage may still interfere with desired sound transmissions. Table V describes the nature of speech communications possible under different ambient noise levels. Even moderate noise levels would require use of a loud voice or shouting to communicate effectively, especially for distances of 10 feet or more between talker and listener. Telephone use can also be affected.

In industry, lack of adequate speech reception due to noise masking can degrade efficiency in those jobs dependent on such functions.[48] Inability to hear warning signals or shouts of caution because of noise have also been implicated as a causal factor in worker accidents.[49] While this is plausible, data to support the latter contention are not available.

Special measures for rating or predicting the masking effects of noise have been developed which take account of the acoustic energy found within those frequency bands of noise which encompass the critical speech frequency range.[3] These measures are used in defining acoustic requirements for offices or other living spaces where speech and other forms of sound reception serve important functions.

Interference with speech reception by noise or masking can take place under noise conditions which may be safe for hearing. This problem is specific to offices or other work areas where communication needs can be critical to job functions. Acoustical design criteria for assuring the adequacy of speech reception in these workplaces are available.

Disruption of Job Performance

The effects of noise on performing tasks for which voice communications are unnecessary are quite variable and appear to depend on the acoustic conditions present, features of the task being performed, and the attitude or make-up of the performing person.[38,50-52] With regard to acoustic factors, repeated impulse and intermittent sounds of high level appear more likely to disrupt performance than continuous or steady sounds of comparable level.[53,54] Impulsive sounds have the more notable effects which are largely confined to the brief periods during or immediately following their occurrence. Intermittent noise exposure may cause losses in performance that are not specific to the on-times of the noise.[38] That is, losses in performance may occur when the noise appears and also when it disappears. Apparently, change in noise levels is the degrading factor. Of interest here is that sound levels required to cause notable performance changes may exceed hearing conservation limits for routine workday exposure. Thus, noise standards for safeguarding hearing could also offset possible noise effects on job efficiency.[38]

More moderate levels of noise may actually benefit task performance relative to quiet conditions. The presence of such noise may provide for a more uniform acoustic background, masking stray sounds which could be otherwise audible in a quiet work area and cause distraction. Also on the positive side, pulsating-type sounds may pace or drive performance and, in effect, reduce fatigue on tasks that are trying. The rhythm component in music may serve this purpose too.[55]

Not all performance capacities suffer equally from the disruptive effects of noise. In fact, noise may aid performance on simple, well-practiced or repetitive tasks through causing increased arousal in an otherwise boring job. There are indications in fact, that only those tasks which require unremitting attention (e.g., vigilance in machine monitoring, product inspection) or which place extreme mental demands on the employee (short-term high-memory loads) may be most vulnerable to the degrading effects of noise.[51] In short, tasks which by themselves tax the total capacity of the individual do not permit any accommodation to noise and consequently show loss. In some instances, noise seems more inclined to disturb the quality rather than the quantity of work. That is, noise might not change work output, but may cause more errors. Along these lines, performance under noise may be subject to worker fluctuations, with periods of poor performance being interwoven with periods of heightened effort.[56] These performance swings, when averaged across the total work session, may yield little or no overall performance decrement.

Individual differences are quite commonly found in investigations of noise effects on performance. Attitudes toward noise are a basic factor in this variance. A recent laboratory study found subjects sensing that they had no control over randomly occurring noise intrusions to perform poorer than those who could terminate such sounds.[57] Personality factors also seem to underlie performance variations in noise. Tense, anxious persons, as defined by personality inventories and certain physiologic indicators, seemed less able to cope with certain laboratory tasks as compared with those who were more relaxed.[58]

The importance of attitude factors in noise-performance studies is even more evident in field investigations. For example, morale and ego-involvement in one's job can override stresses imposed by noise.[59] Other employees dissatisfied with their job situations can use noise as a "scape-goat" for poor performance. It should be mentioned, too, that through a process of self-selection, only the more noise tolerant employees probably stay at a noisy job. The more noise sensitive persons would remove themselves from these situations. Measures of absenteeism and labor turnover could reflect the latter occurrences, but could be difficult to relate causally to noise.

The numerous factors that can influence noise effects on performance make for highly qualified conclusions and conservative predictions. Generally speaking, intense sounds, preferably impulsive, and a taxing task performed by a tense person offer the combination of conditions most likely to display a noise-induced decrement in performance.

Cumulative Effect

This discussion has separately treated different adverse effects of noise that may result from occupational exposures. It is unrealistic, however, to conceive of employees in their everyday job routines experiencing one form of noise disturbance to the exclusion of the others. Indeed, one's daily encounters with workplace noise may degrade hearing, mask reception of desired sounds, heighten emotions and physiologic activity, disrupt concentration , or otherwise hinder job efficiency or safety. The collective impact of these noise effects clearly poses a significant challenge to the employee's health, productivity, and well-being.

The establishment of noise exposure limits for safeguarding the employee's hearing will in the main prevent the occurrence of the worst physical defect that noise can have in humans. Adherence to these limits may also have other benefits. Specifically, physical and psychological disturbances from occupational noise exposures will be less likely to arise under more controlled exposure conditions. Of course, the question remains as to whether excessive noise by itself can cause physical and mental disorders. Nevertheless, noise levels which meet hearing conservation requirements may also be within limits that do not cause losses in job performance.

V. PROCEDURES FOR REDUCING EXPOSURES

The information in this part (1) substantiates the existence of a considerable number of industrial employees who are exposed to potentially hazardous noise levels; (2) presents noise levels for selected industrial operations; and (3) describes procedures for reducing hazardous noise exposures in the industrial setting.

Survey Data for Estimating Noise Exposed Population

In response to a questionnaire survey conducted by the NIOSH 341 plants in 24 states involved in 18 different types of manufacturing procedures reported the information listed in Table VI.[60] The table is not an attempt to present exact figures as to how many employees are exposed to hazardous noise levels; rather it substantiates that noise is indeed a common occupational hazard which could affect a large number of employees. The companies were asked to answer the following question: "How many of your employeees are located in areas where noise levels are 90 dBA or above?"

When this question was asked in August 1971, the recommended level for an 8-hour exposure limit was still 90 dBA, however, it can be assumed that a greater population is at risk. In interpreting the answers to the question stated in the preceding paragraph and the results which appear in Table VI the following points must also be considered:

1. The answers from this question cannot be used to determine how many employees are incurring hazardous noise exposures because information concerned with length of exposure time and the exact level of the exposure is not available.
2. The 341 plants volunteered this information, and the information is based upon their own noise level evaluations.
3. Many other plants involved in the questionnaire survey could not or did not answer the question.
4. The table does not contain information concerned with the 4,511,000 transportation workers, the 3,502,000 construction workers, the 626,000 miners, or the 4,746,000 agricultural workers.

The projected numbers of employees located in areas of noise 90 dBA or higher were computed by multiplying the number in the total work force of a particular industry by the percentage of work force reported to be exposed to 90 dBA. The total work force populations were based on August 1, 1971, Department of Labor figures.[61]

Noise Levels for Selected Industrial Operations

Over the past twenty-five years, numerous noise surveys have been made in a wide variety of occupational settings. A listing of selected surveys that included both noise and hearing is presented in Table IV.

Table VII presents samples of noise levels actually measured for a variety of industrial operations. In each case the noise was generated by operating machinery, and each dBA level listed represents observations taken in operation areas.

The list is intended only to give a general impression of industrial noise levels. For many of the noise sources listed one could expect variations over a range of 20 dBA, or even more, due to such factors as machine type, make, and age; acoustical characteristics of location; design of supporting structure; type of raw material being worked by the machine; idiosyncrasies of operator; location of operator with respect to machine; condition and lubrication of machine.

The data contained in the list have been taken from several Public Health Service surveys and other sources in acoustical and industrial hygiene literature.[62-65]

<u>Noise Control</u>

Abatement of environmental noise such as that listed in Table VI is afforded by engineering controls which reduce the intensity of the noise either at the source or in the immediate exposure environment. A number of these procedures will require consultation, and it is recommended that employers avail themselves of the services of a competent acoustical engineer in development of their noise abatement program. However, several controls may be implemented by company personnel at relatively little expense. The following are some examples:

1. In ordering new or replacement equipment, the exposure limits should be taken into consideration. In those areas where several pieces of equipment are to be operated at the same time, it may be desirable to specify individual equipment operating noise levels lower than the limits set by the standard in order to insure compliance with the standard.

2. Maintenance

   A. Replace worn or unbalanced parts in existing equipment.

   B. Maintain proper adjustment of equipment.

   C. Secure all covers or safety shields on machines.

   D. Lubricate all moving parts on equipment.

   E. Use proper coolants.

   F. Use sharp and properly shaped cutting and drilling tools.

3. Substitution of Machines

   A. Substitute belt drives for gears.

4. Vibration Dampening

   A. Increase mass.

   B. Increase stiffness.

   C. Use rubber or plastic linings to dampen noise.

   D. Improve supports.

5. Reduction of Solid-Borne Transmission

   A. Flexible mounts for motors and other types of machinery.

   B. Flexible hose in pipes or electrical conduits.

   C. Flexible coupling on shafts.

6. Reduction of Noise Caused by Fluid Flow

   A. Install or replace intake and exhaust mufflers on internal combustion engines and compressors.

7. Isolate Noise Source

   A. Construct sound reduction enclosures around equipment or parts of equipment.

8. Isolate Operator

   A. Provide a relatively sound-proof enclosure for the operator or attendant of one or more machines.

Of the items listed above, the preferred procedures for reducing environmental noise are those which are directed at reducing the noise at its source (Items 1 - 7). Generally, these procedures have proven to be far more efficient in terms of actual noise reduction than the procedure listed as Item 8. Furthermore, source noise controls provide protection for both the operators of the equipment as well as workers in the immediate exposure environment.

Administrative Controls

Another effective approach to reducing the hazard of excessive noise exposure is to limit the daily amount of exposure which each employee receives, by means of strict control of the work schedule. The following are several methods suggested by the Department of Labor:[66]

"1. Arrange work schedules so that employees working the major portion of a day at or very close to the criteria limit are not exposed to higher noise levels.

2. Ensure that employees who have reached the upper limit of duration for a high noise level, work the remainder of the day in an environment with a noise level well below criteria limit.

3. Where the man-hours required for a job exceed the permissible time for one man in one day for the existing sound level, divide the work among two, three, or as many men as are needed, either successively or together, to keep individual noise exposure within permissible time limits.

4. If less than full-time operation of a noisy machine is needed, arrange to run it a portion of each day, rather than all day for part of the week.

5. Perform occasional high level noise producing operations at night or at other times when a minimum number of employees will be exposed."

When personnel are rotated, extreme care must be taken to insure that no single employee is exposed to a high level noise for a period longer than is allowed by the noise exposure limits.

VI. DEVELOPMENT OF THE STANDARD

Attempts at limiting human exposure to noise have been based on damage risk criteria. The purpose of such criteria is to define maximum permissible levels of noise for stated durations which, if not exceeded, would result in an acceptably small effect on hearing levels over a working lifetime of exposure.

Previous Damage Risk Criteria

a. Damage Risk Criteria Before 1950

Early efforts at determining the maximum safe level of exposure relied heavily on over-all levels of sound pressure. A listing of criteria developed prior to 1950 is presented in Table VIII. As may be seen from the table, there was, even at that time, quite a diversity of opinion with regard to the limit of safe exposure to noise. Estimates ranged from a low of 75 dB SPL[67] to a high of 100 dB SPL.[68-71] This situation was further complicated in 1945 by Goldner's suggestion that a nominal daily exposure for at least two years to a noise having an overall sound pressure level of 80 dB could be hazardous to hearing.[72]

In tracing the possible sources of error in these pre-1950 criteria, Kryter[73] suggested that one problem inherent in most of the studies was the high ambient noise levels-which characterized the hearing testing-environments. It was thought that such high ambient noise levels could account for an over-estimation of the degree of hearing loss by as much as 10 to 15 dB. Probably the greatest source of error, however, was the fact that exposures were characterized using overall sound pressure level and no other factors.

b. Damage Risk Criteria Since 1950

It was apparent by 1950 that proposed limits must consider, in addition to intensity, other physical dimensions and characteristics of noise exposure. In 1953, Rosenblith and Stevens[74] published an extensive document entitled "Noise and Man" in which they delineated the following variables important to the development of damage risk criteria:

1. Measurement of spectral distribution (Noise Spectrum).

2. Determination of the temporal characteristics of exposure (Noise Duration).

3. Identification of a protection goal (Biologic Response).

In the discussion which follows, selected damage risk criteria listed in Table IX, will be compared and contrasted with respect to the above variables. The table represents a compilation of most criteria developed between 1950 and 1971, and where appropriate, criteria expressed in octave band levels have been converted to equivalent dBA. For purposes of performing these conversions a "pink" noise spectrum (i.e., equal sound pressure level in each octave band), typical of many common industrial noises, was assumed.

c. Criteria Based on Octave Band Levels

Beginning with Kryter[73] in 1950, concern shifted from measurement of noise based solely on overall sound pressure to measurements which are more indicative of the response of the hearing mechanism. Consistent with this thinking, several modern damage risk criteria have emphasized limit setting by frequency bands, usually one octave in width. Two lines of evidence were responsible for this shift in thought. First of all, data on minimum audible field sensitivity[75] and measurements of equal loudness[76] indicated that the ear was not equally sensitive at all frequencies. It was found that the ear is most sensitive to acoustic stimuli in the frequency range 2000 - 4000 Hz, and less sensitive to frequencies both below and above this range. Shown in Figure 8 are several damage risk criteria (DRC) developed between 1952 and 1966. For comparison, the 40 phon equal loudness curve[76] is presented in the lower part of this figure As may be seen from this figure, although the DRC differ in estimates of safe sound pressure level per octave, they all weight the spectrum similarly.

The second major impetus for measurement of noise based on octave band analysis came from research which indicated that, at least for most audiometric frequencies, the amount of threshold shift observed (either temporary or permanent) was closely related to the frequency or spectrum of the stimulus. Results of "stimulation deafness" (temporary threshold shift) studies indicated that for pure tone stimuli the maximum shift in hearing appears to be about one-half octave above the frequency of total stimulation.[77-79] Similar findings were reported for octave bands of noise and broadband noise by Davis et al.,[77] Kylin,[29] and Ward.[30] However, for these latter stimuli there was some difference of opinion as to the exact location of maximum effect. Davis et al.[77] and Kylin[29] suggested that the maximum effect occurs one-half octave to one octave above the center frequency of the octave band, whereas, more recently Ward[30] found that the maximum change in hearing occurs one-half octave to one octave above the upper cut-off frequency of the noise.

Prior to 1956 damage risk criteria set as a goal for protection (see Protection Goal), the prevention of hearing loss at all frequencies. This necessitated assessment of the noise at each octave band. After this time, however, much more qualified protection goals were established (usually protection of loss in the so-called "speech frequencies") such that only knowledge of the sound pressure in certain critical octave bands (not to be confused with aural critical bands) was required in order to assess the risk of noise exposure to hearing. This approach characterized the damage risk criteria developed by the Air Force in 1956, The American Academy of Ophthalmology and Otolaryngology in 1957, the International Standards Organization in 1961, and the American Academy of Ophthalmology and Otolaryngology in its revision of the 1957 criteria in 1964 (see Table IX).

The procedure for rating noise hazards by this mehtod consists of measuring the octave band levels in the critical octaves, and then comparing the measured levels with damage risk contours. This is best exemplified by the use of the "Noise Rating" curves developed by the International Standards Organization.[80] The octave band levels of the noise are measured and then compared with the noise rating curve (Figure 9). The highest curve which is exceeded by the level of these bands yields the noise rating number (N). For this particular scheme, a noise rating of 85 was suggested as the protection criterion.

<u>The Use of A-weighted Sound Level</u>

Since the publishing of the first Intersociety "Guidelines for Noise Exposure Control,"[81] a relatively new approach, A-weighted sound level measurement, has become a popular measure for assessing overall noise hazard. As stated in Part III, the weighting on the A-scale approximates the 40-phon equal loudness contour (Figure 8). Use of the A-weighting is thought, therefore, to insure the rating of noises in a reasonably similar manner as would the human ear.

Several studies have been conducted in order to evaluate the efficacy of using A-weighted sound levels in rating hazardous exposures to noise. In a study of 580 industrial noises, Botsford[82] showed that the A-weighted sound level indicated the hazard to hearing as accurately as did limits expressed as octave band sound pressure levels in 80% of the cases and was slightly more conservative than octave band measures in 16% of the noises. Passchier-Vermeer[26] found that, except in one noise condition, sound level in dBA was as accurate as Nose Rating (NR) in estimating noise induced hearing loss. In a study of hearing loss in 759 subjects, Robinson[83] concluded that the error incurred from using dBA in predicting hearing level was within ± 2 dB, even for noises ranging in slope from + 4 dB/ octave to -5 dB/octave. A recent study[84] found that even though dBA perhaps discounted too much low frequency energy, in all cases but one it predicted TTS_2 resulting from exposures to noises of different spectra (slopes of -6 dB/octave, 0 dB/octave, and 6 dB/octave) as well as or better than other noise rating schemes which employed spectral measurements in octave-bands.

As a result of its simplicity and accuracy in rating hazard to hearing, the A-weighted sound level was adopted as the measure for assessing noise exposure by the American Conference of Governmental Industrial Hygienists (ACGIH)[85] and by an Intersociety Committee[27] consisting of representatives from the American Academy of Occupational Medicine, American Academy of Opthalmology and Otolaryngology, ACGIH, Industrial Hygiene Association, and the Industrial Medical Association. A-weighted sound level measurement was also adopted by the U.S. Department of Labor as part of the Occupational Safety and Health Standards[86] and by the British Occupational Hygiene Society in its Hygiene Standard for Wide-Band Noise.[87]

In keeping with the several precedents which have been established for its use in rating the hazard resulting from industrial noise exposure, and because it has been shown to be a reasonably accurate measure of such hazard, the A-weighted sound level measurement has been recommended for use in rating noise hazard in the Recommended Standard.

Protection Goal

The limit of noise exposure that is established ultimately depends upon the degree of hearing which is to be protected and the number of persons in an exposed population to be protected. If a very strict protection criterion is contemplated such that no person exposed to noise will develop hearing loss at any frequency, the maximum permissible noise level governing a daily, or near daily, exposure would be quite low. Conversely, if the protection goal were to permit a certain amount of hearing loss in a small percentage of workers over a working lifetime, then the permissible exposure level would be raised accordingly. For example, Figure 10 compares the permissible levels of exposure for an eight-hour day recommended by the National Academy of Sciences, National Research Council Committee on Hearing, Bioacoustics and Biomechanics (NAS-NRC) CHABA Working Group 46 with the damage risk criterion recently proposed by Kryter[88] for the same amount of exposure. Although both criteria are based upon either the same or similar types of data, the damage risk level is much higher in the CHABA criterion than in that proposed by Kryter. The major reason for this difference is that CHABA established as its protection goal attainment and no more than 10 dB of permanent threshold shift at 1000 Hz, 15 dB at 2000 Hz, and 20 dB at 3000 Hz in 50% of the people exposed to noise; whereas, Kryter set as his protection goal attainment of "0" dB of threshold shift at the frequencies

2000 Hz and below, and 10 dB of shift in the frequencies above 2000 Hz in 75% of the people exposed to noise.

The problem is further illustrated by a comparison of the protection criteria developed by the Intersociety in the Guidelines for Noise Exposure Control with the Hygiene Standard for Wide Band Noise[87] developed by the British Occupational Hygiene Society. Both standards established 90 dBA as the limit for a near daily 8-hour-per-day continuous exposure. However, as the following quotations indicate, there is quite a difference of opinion as to how much protection is actually afforded by 90 dBA:

1. "In the poplulation exposed to 90 dBA to age 50 - 59, the amount of impairment is increased 10 percentage points (ten more persons per 100 exposed) as compared to the population with no occupational exposure." (Intersociety, 1970)

2. "A noise emission of 105 dB (equivalent to 90 dBA for a working lifetime) is acceptable exposure on the basis that no more than 1 percent of exposed persons will experience handicap due to noise after lifetime exposure." (British Occupational Hygiene Society, 1971)

The difference here, as in the previous example, follows from a difference in the definition of the protection goal, specifically, the definition of hearing impairment or hearing handicap. The first critieria (Intersociety, 1970) adopted the AAOO-AMA definition of hearing impairment.[15] This definition states that hearing impairment begins as the average hearing level at 500, 1000, and 2000 Hz exceeds 15 dB re ASA S3.6 1951 (25 dB re ANSI S3.6-1969). Conversely, The British Occupational Hygiene Standard defined as its "low fence" of impairment an average permanent noise induced threshold shift (not to be confused with hearing level) of 40 dB in the six frequency range 0.5 - 6.0 KHz for 30 years of exposure. Recently, Robinson[89] computed hearing impairment risk values on the British data using the AAOO-AMA definition of hearing impairment. His figures indicate that near daily 8-hour exposure to continuous noise at a level of 90 dBA for 40 years would result in an increase in hearing impairment in between 13 to 15 persons per 100, depending upon the incidence figure of the non-noise exposed control population used for comparison. This "risk" value is comparable to the one presented by the Intersociety Committee[27] but about 6 - 8% below the International Standards Organization value for the same exposure.[90]

The question of how much hearing should be protected and in what percentage of the people hearing losses of certain magnitudes should be permitted has long been an issue of much controversy. The ultimate decision, according to Eldredge,[91] must be based on social and humane values.

Historically, the most common protection goal has been one directed at the preservation of hearing for speech. Direct measures for evaluating hearing for speech have been, and are being, developed. These tests generally fall into two classes: those which measure the threshold of speech or the ability to hear speech and those which measure discrimination, or the ability to understand speech. Although speech tests have been widely accepted for use in aural diagnostics, several objections have been raised as to their use and validity in industrial testing. These are: (1) Speech test items are sometimes unfamiliar to the listener; (2) Speech tests frequently measure the size of one's vocabulary as well as hearing impairment for speech; (3) Several speech tests or different forms of a single test designed to measure the same speech hearing function may yield different results; and

(4) Considerable training is required on the part of the examiner to administer and score speech tests. It has become, therefore, a common practice to measure pure tone sensitivity and relate hearing levels at certain specific frequencies to the ability to hear and understand speech.

In 1929, Fletcher[92] proposed what has now become known as his "Point 8" formula whereby the ability to hear everyday speech was estimated by multiplying the hearing levels at 500, 1000, and 2000 Hz by 0.8 and then computing the average over these three frequencies. The major contribution of this formula was the introduction of the concept that hearing loss for speech could be estimated by the average hearing levels at what has now become known as the "speech frequencies"-500, 1000, and 2000 Hz.

The American Medical Association[93] in 1947 recommended that hearing loss for speech be determined by the pure tone hearing losses at 500, 1000, 2000, and 4000 Hz. The four frequencies were given a weighting in accordance with what was presumed to be the importance of each frequency in hearing for speech (i.e., 15% at 500 Hz, 30% at 1000 Hz, 40% at 2000 Hz, and 15% at 4000 Hz). This guideline further suggested that hearing loss for speech does not begin until the weighted average hearing loss equaled 10 dB, and total loss for speech hearing occurred when the loss at 500 Hz reached 90 dB or the losses at the other 3 frequencies reached 95 dB.

In a later article which reviewed the assumptions in computing hearing loss for speech, the AMA[94] made the following observations and recommendations:

(1) The 1947 formula was inadequate for calculating hearing loss for speech in sensorineural hearing loss. (This is particularly interesting in that the method used today for computing hearing loss for speech, developed by the AAOO in 1959 and accepted by the AMA in 1961, eliminated the most

sensitive indicator of sensorineural hearing loss (i.e., losses at 4000 Hz.))

(2) Everyday communication should be the basis for evaluation of hearing disability.

(3) Losses greater than 15 dB (re ASA, 1951 Zero Audiometric standard) at 500, 1000, and 2000 Hz are abnormal and usually noticeable by the individual in everyday communications. Furthermore, a loss greater than 30 dB at 4000 Hz can be considered abnormal.

A new formula was developed by the Subcommittee on Noise of the American Academy of Ophthalmology and Otolaryngology (AAOO). This formula was subsequently adopted by the AAOO Committee on Conservation of Hearing[95] in 1959 and by the American Medical Association[15] in 1961. The bases of this formula are explained by the following excerpts taken from the "Guides to the Evaluation of Hearing Impairment" published in the _Journal of the American Medical Association_.[15]

> "Estimated hearing level for speech is the simple average of hearing levels at the 3 frequencies of 500, 1000, and 2000 cycles per second (cps).
>
> "Ideally, hearing impairment should be evaluated in terms of ability to hear everyday speech under everyday conditions. The ability to hear sentences and to repeat them correctly in a quiet environment is taken as satisfactory evidence for correct hearing of everyday speech. Because of present limitation of speech audiometry, the hearing loss for speech is estimated from measurements made with a pure tone audiometer. For this estimate, the simple average of the hearing levels at the 3 frequencies 500, 1000, and 2000 cps is recommended.

"In order to evaluate the hearing impairment, it must be recognized that the range of impairment is not nearly so wide as the audiometric range of human hearing. Audiometric zero, which is presumably the average normal threshold level is not the point at which impairment begins. If the average hearing level at 500, 1000, and 2000 cps is 15 dB or less, usually no impairment exists in the ability to hear everyday speech under everyday conditions."

The only major change in this formula from 1959 to the present time has been the result of the change in audiometric reference for hearing level (HL). The 15 dB average hearing level at 500, 1000, and 2000 Hz referenced to the 1951 ASA standard[96] corresponds to a 25 dB average hearing level at the same frequencies according to the recent reference pressure adopted by the American National Standards Institute.[97]

On the basis of the results of recent research which has investigated the relationship between pure tone hearing loss and hearing loss for speech, a slightly different definition of "hearing impairment" has been adopted for the purposes of this document. Simply stated, hearing impairment for speech communication begins when the average hearing level at 1000, 2000, and 3000 Hz exceeds 25 dB re ANSI (1969). The principle reasons for this definition are as follows:

1. The basis of hearing impairment should be not only the ability to hear speech, but also the ability to understand speech.

2. The ability to hear sentences and repeat them correctly in quiet is <u>not</u> satisfactory evidence of adequate hearing for speech communication under everyday conditions.

3. From (1) and (2) above, the ability to understand speech under everyday conditions is best predicted on the basis of the hearing levels at

1000, 2000, and 3000 Hz.

4. The point at which the average of hearing losses in the stated three frequency range of 1000 - 3000 Hz begins to have a detrimental effect on the ability to understand speech is 25 dB re ANSI (1969).

With reference to the determination of hearing impairment (1. above), the ability to "hear" speech, measured in terms of the lowest intensity at which a listener can barely identify speech materials, provides little information concerning communication difficulties under everyday conditions. As Sataloff[98] states, "It [occupational deafness] implies the presence of obvious difficulties in hearing speech. Actually, the difficulty more often lies not so much in 'hearing' speech as in 'understanding' it." Furthermore, Davis and Silverman[99] observed that ". . . a man with severe high-tone nerve deafness (as is seen in occupational noise induced hearing loss), will always fail to hear certain sounds and will never make a perfect articulation score. On the other hand, the same man may hear some words, the easy low-frequency words, as well as anyone else does. He may have a normal threshold for speech."

This issue is further clarified if one compares the "typical" clinical picture of a person having a conductive hearing loss versus a person having a sensorineural hearing loss resulting from noise exposure. Both cases would be expected to have elevated speech reception thresholds (a measure of hearing for speech); however, in the case of the conductive loss, speech discrimination (measure of understanding) would be approximately the same as that for a person having normal hearing, provided that the presentation level is sufficiently above the speech reception threshold level. The person with occupational hearing loss (sensorineural), on the other hand, would have relatively poor discrimination scores, and the effect of raising the presentation level to higher levels often serves to reduce the articulation score[100] (see example in Figure 11). In applying the AAOO-AMA formula to the cases shown in Figure 11 it is possible that both would be rated identically in terms of hearing impairment, yet the sensorineural case has much more difficulty in understanding speech than does the conductive case. It is apparent, therefore, that the formula applied to compute hearing impairment should consider discrimination ability and that the pure tone frequencies used in the formula should be highly correlated with this latter function.

With reference to <u>speech communication under everyday conditions</u> (see 2 above), it has been assumed by the AAOO - AMA formula that the "ability to hear sentences and repeat them correctly in a quiet environment is taken as satisfactory evidence for correct hearing of everyday speech."[15,95] According to Kryter[88] this definition of everyday speech employs a type of speech material and a listening condition which is not indicative of everyday conditions and one which is "least likely to show any impairment in the deafened person."

Actually, everyday communication is placed under a wide variety of environmental stresses. Estimates of the amount of time that everyday speech is distorted range from a conservative figure of 50%[100] up to about 100%.[101] Furthermore, everyday speech rarely takes the form of complete sentence communications; thus, the number of speech cues available for accurate speech perception under everyday conditions is greatly reduced.[88] From this discussion, it may be concluded that an appropriate predicting scheme for determination of hearing impairment must include some consideration for an actual daily communication environment rather than some optimum condition as suggested by the AAOO - AMA.

With reference to predicting ability to understand speech on the basis of heavy levels at the pure tone average at 1000, 2000, and 3000 Hz (point 3 above), results of several studies indicate that hearing levels at these three frequencies predict hearing loss for speech under mild conditions of distortion better than the three frequency average at 500, 1000, and 2000. Mullins and Bangs,[102] investigating the relationship between speech discrimination and several indices of hearing loss, found that the pure tone hearing losses at 2000 and 3000 Hz had the highest correlation with speech discrimination. Harris, Haines, and Myers[103] studied the effect speeded speech had on discrimination in subjects with high frequency sensorineural hearing loss. They concluded that a nearly normal audiogram at 3000 Hz was essential for high sentence intelligibility if the speech material is distorted by increasing the speech rate. It was further concluded that once hearing losses progressed to include 2000 Hz, the effect on discrimination of speeded speech was quite devastating.

Kryter, Williams, and Green,[17] in a study of the effects of background noise on speech discrimination, found that in 114 adult male soldiers who had varying degrees of sensorineural hearing loss, threshold levels at 2000, 3000, and 4000 Hz correlated best with speech discrimination loss. They concluded, however, that the average hearing loss at 1000, 2000, and 3000 Hz should be used to predict speech hearing loss since this average represented a "reasonable compromise" for the results of the various studies which have dealt with the topic.

In a comparison of normal hearing subjects and subjects with sensorineural hearing losses on several different measures of hearing acuity, Ross et al.[104] found that in the impaired hearing group: (1) Speech discrimination scores in quiet tended to be poorer as the losses at 2000 and 4000 Hz increased and (2) neither pure tone threshold at 500 Hz nor speech reception threshold levels were related to speech discrimination in quiet.

Furthermore, in 1965 Harris[16] conducted an investigation to explore the effects of audiometric losses on discrimination scores for speech which was mildly and severely distorted. The results of this study indicated the frequency regions of greatest impact on intelligibility were somewhat different depending upon the severity of the distortion. However, Harris concluded that ". . . the region 2000 Hz and below is inadequate for predicting intelligibility of speech in noise, and that a point of vanishing returns is reached by adding anything beyond 3000 Hz."

Recently, Acton[105] investigated the effect of different signal-to-noise ratios on speech discrimination in a group of industrial workers who had incurred characteristic noise induced hearing losses. Results indicated that a significant loss in speech intelligibility occurred when high frequency hearing loss involved the 2000 Hz audiometric test frequency, and quite profound effects upon intelligibility once the loss had progressed to 1 KHz. In another recent investigation[106] of speech discrimination in industrial employees, it was found that hearing level at 2000 Hz had the highest correlation with speech discrimination (0.769, P 0.0001) under the most favorable condition of signal-to-noise (S/N = +10).

In summary, it is evident that in order to accurately assess hearing loss for speech under everyday conditions by means of pure tone hearing loss, a modification in the three frequency average recommended by the AAOO and the AMA is warranted. Such a modification should include the elimination of 500 Hz from the formula, and the addition of 3000 Hz in its place.

With reference to the level of beginning hearing impairment for speech (see 4 above), it would appear that an average hearing level of 25 dB re ANSI(1969) at 1000, 2000, and 3000 Hz signals the beginning of speech communication difficulties in everyday situations. In a comprehensive review of the topic of hearing impairment, Kryter[88] constructed several curves (see Figure 12) which related pure tone hearing level average to speech impairment for various samples of speech presented at different levels in quiet. As may be seen from this figure, the AAOO-AMA definition of impairment (Avg. HL at 500, 1000, and 2000 Hz of 25 dB re ANSI(1969)) allows for negligible impairment for sentences presented at an "everyday" level or normal conversational level, and only 15% impairment in the perception of isolated words presented at the weak conversational level.

Kryter, Williams, and Green[17] found that in subjects with sensorineural hearing losses, a dramatic change in perception of speech occurred as the average hearing level at 1000, 2000, and 3000 Hz shifted from approximately 18 dB re ANSI(1969) to about 31 dB re ANSI(1969). Corresponding to these shifts in average hearing level, sentence intelligibility in a mild background of noise (S/N = +5) dropped from 90 to 78% whereas PB work intelligibility, with slightly less noise (S/N = +10), decreased from 75 to 58%.

Results of the study conducted by Acton[105] concerned with speech intelligibility in a group of industrial workers indicated that a significant, although slight, shift in speech intelligibility (compared with normals) occurred when the hearing level (group mean) at 2000 Hz had reached 25.3 dB. At this point the average hearing level at 1000, 2000, and 3000 Hz was 25 dB re ANSI(1969).

Temporal Characteristics of Exposure

The damage risk criteria in Table IX are specifically concerned with limits of safe exposure to continuous noise for five hours or more. It has long been recognized that the ear can tolerate greater amounts of energy provided that the exposure time is limited.[73,74,107] Furthermore, research indicates that noises which are interrupted on a regular or irregular basis are much less hazardous to hearing.[109-111]

The decision as to how much noise can be tolerated for daily short-duration continuous exposures and interrupted exposures ultimately depends upon how the ear integrates noise over time. Probably the two most popular theories on how the ear responds to such stimulation are the equal energy and the equal pressure rules.

The equal energy rule states that equal quantities of acoustic energy entering the ear canal are equally injurious, regardless of how they are distributed in time. This rule dictates that, as exposure time doubles, the level of noise must be reduced by 3 dB in order to maintain an equal degree of hazard. The equal pressure rule, on the other hand, hypothesizes that the ear integrates noise on a pressure, rather than an energy basis. Such a rule maintains that for each doubling of the exposure time the level of noise must be reduced by 6 dB to maintain an equal degree of hazard.

Research attempting to determine which rule is appropriate has generally been inconclusive. Spieth and Trittipoe,[112] investigating the effects of high level, short duration exposures in human subjects, found that two different exposures would produce the same TTS if one exposure were 6 dB lower and twice the duration of the other. Conversely, Ward and Nelson[113] recently found that four separate exposure conditions, equated in terms of equal energy, all caused about the same amount of temporary threshold shift in chinchillas. However, they cautioned that their findings were only applicable to continous exposures and not to intermittent exposures.

Variables that are germane to interrupted exposures but do not play a significant role in limiting hazard from short-term continuous exposures further complicate the problem of how the ear responds and integrates noise over time. One such variable is the "acoustic" or "middle ear" reflex. When the ear is exposed to loud noise, the middle ear muscles contract, thus altering the impedance of the middle ear. This reflex, which serves to attenuate the noise reaching the inner ear, adapts out or disappears quickly if the noise is continuous and relatively unchanging over time. However, if the noise level varies considerably or is interrupted on a regular or irregular basis, then the reflex is sustained.

A second variable which plays an important role in reducing the hazard of interrupted noises relative to short-term continuous noises concerns the off-time of the exposure cycles. Depending upon the over-all level of the noise and the nature of the relationship between on-time and off-time, a considerable reduction in the degree of temporary hearing threshold shift may be observed.

To date, the only empirical data available on permanent hearing losses resulting from intermittent exposures comes from a study of iron ore miners conducted by Sataloff et al.[114] Their findings indicated that intermittent noises had to be some 15 dB more intense than continuous noises to cause the same additional hearing impairment in men ages 30 to 50 years. Although this evidence confirms the general notion that intermittent exposures are less hazardous than continuous steady-state exposures of the same duration and noise level, the applicability of this rule to other schedules of intermittency must await further investigation.

Since 1960, several damage risk criteria have been proposed to limit exposure to intermittent noise.[82,107,115] For the most part, these criteria, like the rules for assessing intermittent noise exposure discussed below, have been based predominantly upon evidence collected from studies of temporary threshold shift.

At least three different rules have been proposed in order to assess the hazard of exposures to intermittent noise. The first of these rules, developed by Ward et al.[28] was called the "on-fraction" rule. This rule states that the amount of temporary threshold shift resulting from a given intermittent exposure can be determined on the basis of noise level and average on-fraction (the time the noise is on divided by the total duration of exposure). This procedure assumes that levels below 75 dB SPL are not hazardous to hearing; thus, the amount of on-time is taken as the total time the noise is above 75 dB SPL. In a critical test of the on-fraction rule, Selters and Ward[111] found that this rule was invalid when the regular on-off times exceeded two minutes.

For burst durations longer than two minutes, a second rule has been suggested. This second rule, developed by Ward et al.,[109] is called the "exposure equivalent" rule. According to the concept of exposure equivalency, the amount of hearing change observed at the end of the day may be computed as follows:

a. Calculate the amount of TTS resulting from the exposure to the first bursts of noise.

b. Using generalized recovery curves, compute the residual TTS remaining at the end of the "off-time."

c. Determine how much exposure (time) to the noise causing the initial TTS in (a) above is necessary to cause the residual TTS.

d. Add the time in (c) above to the time of the subsequent noise burst and predict the TTS_2 at the end of the second exposure.

e. Repeat steps (b), (c), and (d) for each cycle in the daily exposure. The essential feature of this approach is that residual TTS is translated into exposure time.

One of the crucial assumptions of the "exposure-equivalent" rule is that the course of recovery from TTS is independent of the type of noise that produce the TTS. In a recent article, Ward[33] has presented data that question the validity of this assumption. It appears that intermittent exposure to high level, high frequency noise causes a considerable delay in the recovery of TTS relative to intermittent low frequency exposures.

A third approach in determining hazard from interrupted noise has been to determine the total on-time of the noise, regardless of how the noise bursts are distributed in time, and to consider the intermittent exposure in terms of an equivalent continuous exposure. This approach attempts to take into consideration the reduced hazard of interrupted noise by adjusting the rule which relates noise level and exposure duration. Although possibly not as scientifically rigorous as the previously mentioned procedures, the "equivalent continuous" rule is not constrained by the assumption concerning the regularity of exposure cycles which is basic to the other rules.

Intermittent noise exposure criteria based upon the first and/or second rules include those developed by Glorig, Ward, and Nixon,[115] CHABA Working Group 46,[107] and Botsford.[82] Botsford's intermittency criteria reflect a simplification and consolidation of the CHABA continuous exposure, long-burst intermittent, and short-burst intermittent contours into one general figure relating dBA level, total on-time (noise level above 89 dBA), and number of exposure cycles (see Figure 13). The limits of intermittent exposure expressed in these contours (shown in Table X) have recently been adopted by the Second Intersociety Committee.[27] Similar limits have been adopted as part of a revision of the German document concerned with assessment of industrial noise in working areas.[116]

Recent research designed to investigate the efficacy of the limits proposed in Table X have generally shown that the limits do not accurately predict risk to hearing, at least so far as temporary threshold shift is concerned. In a laboratory study[117] designed to evaluate selected exposure conditions from Table X, it was found that (1) the table shows concentrations of noise exposure within an eight-hour workday than can cause excessive amounts of temporary threshold shift and (2) the conditions did not yield equal effects on hearing, thus not affording equal protection. Conversely in a study of forestry employees[118] it was found that although the noise exposures were rated as hazardous according to Table X, the audiometric results indicated that the exposures did not pose a risk to hearing.

Considerably more data must be collected to evaluate present criteria which attempt to designate safe levels of exposure to intermittent noise. Furthermore, additional research is needed to define the relationship of exposure level and duration. Until such information is made available, a change in the present 5 dB rule for halving or doubling of exposure time and a change in the assessment of intermittent noise in terms of equivalent continuous exposure is unwarranted.

One variable which does warrant alteration concerns the lower level or "off" level of noise in intermittent exposures. The designation of such a level implies (1) noises below this level do not of themselves cause any significant temporary or permanent hearing threshold shift and (2) in combination with intermittent high levels of noise, optimum recovery may take place between noise bursts.

Various noise "cut-off" levels have been suggested. As mentioned previously, Glorig, Ward, and Nixon,[115] based on results of continuous noise exposure on temporary threshold shift, designated 75 dB SPL in any octave band as the level at which no TTS_2 would develop. The CHABA Working Group 46,[107] on the other hand, suggested that the "off" level was frequently dependent. For example, the safe level of exposure for the octave band 300 - 600 Hz was seen to be 89 dB SPL, whereas it was approximately 85 dB SPL for octave band 1200 - 2400 Hz.

Recently, Botsford[82] computed a dBA equivalent from the octave band damage risk criteria developed by CHABA. The results of this computation suggested that the "off level" based upon one-third octave or octave band sound pressure level will, in many cases, be below the level designated by Botsford (particularly in the case of strong narrow band components in the noise). Both the CHABA and Botsford criteria do not appear to be in accord with the intended meaning of a safe intermittent level in that present data suggest that there is a significant increase in the proportion of the population having hearing impairment in those groups exposed to continuous noise levels at and slightly below 85 dBA as compared with a non-noise exposed population.

Two lines of evidence suggest that the lower limit of interrupted exposure is considerably below the levels mentioned above. In a review of much of the available TTS and PTS data, Kryter[88] stated that a level of 65 dBA would cause "(a) no more temporary threshold shift than 0 dB for frequencies up to 2000 Hz and 10 dB for frequencies above 2000 Hz, measured two minutes after initial exposure for the average normal ear, and (b) a like amount of permanent noise-induced threshold shift following 20 years of nearly eight hours of daily exposure to noise in the hearing of no more than 25% of the population." Furthermore, results of a study[119] which investigated interrupted exposures using three different quiet levels indicated that the interval level of 57 dBA had a significant effect on the resultant TTS_2, TTS_{30}, and 30 minute recovery rate when compared with 67 dBA and/or 77 dBA interruption levels. It was concluded that recovery from intermittent noise exposure is maximized in quiet levels below 67 dBA.

It would appear from the foregoing discussion that a level of approximately 65 dBA meets the requirements of criteria established for a true "off-level" for intermittent exposure.

Support of the Standard

To comply with the protection goal of the NIOSH standard (see Part VI), hearing impairment for an individual is considered to occur when the average of hearing threshold levels at the three audiometric frequencies 1000, 2000, and 3000 Hz for both ears exceeds 25 dB (Thresholds re ANSI S3.6 (1969)). As described below, NIOSH noise and hearing study data relevant to hearing impairment were analyzed, and the incidence of hearing impairment of noise exposed employee groups was compared with that of exposed employee groups of comparable age and work experience. For the purposes of this part, noise-exposed employees are those exposed to 80 dBA-Slow to 102 dBA-low and non-noise-exposed employees are those exposed to less than 80 dBA-Slow. These comparisons resulted in the risk values applicable to the NIOSH standard (incidence of hearing impairment of exposed group minus incidence of hearing impairment of unexposed group).

Data collected from 1968 to 1971 by NIOSH, represented the steelmaking, paper bag processing, aluminum processing, quarrying, printing, tunnel police, wood working, and trucking employees included in 13 noise and hearing surveys. Audiometric data from non-noise exposed employees were collected in 12 of these 13 surveys. The audiometric data were analyzed using the current "fence" of hearing handicap, 25 dB average hearing threshold level at 0.5, 1, and 2 kHz (thresholds re ANSI S3.6 (1969), as well as the fence appropriate to this document, 25 dB average hearing threshold level at 1, 2, 3 kHz (thresholds re 1969 audiometric zero). The total sample of more than 4000 audiograms, however, could not be used to represent a qualitative measure of hearing loss. Employees not exposed to a specified continuous noise level in dBA-Slow over their working lifetime and those with abnormal hearing levels as a result of their medical history and a variety of otological problems were eliminated from the sample. Thus, 1172 audiograms were used which represented 792 noise-exposed and 380 non-noise exposed employees. The distribution of employees with respect to noise exposure, age, and experience is listed in Table XI.

The audiometric van used for the hearing tests was capable of testing six individuals at one time. All employees were tested before the beginning of their work shift, and, due to scheduling problems, the number of employees in a test session ranged from one to six. When less than six employees were present at a testing session, an attempt was made to randomize the assignment of audiometers. It was also necessary to use headphones with otocups to properly shield the employees from the possible effects of interference caused from hearing the other test tones in the van. However, it was found from the results of two independent studies in the NIOSH laboratory that there was no significant difference in measured thresholds between headphones fitted with otocups and those fitted with standard MX-41/Ar type ear cushions.

Before data analysis could be done, it was necessary to check the calibration data accumulated during the respective survey. Calibration of the audiometeres used to take the audiograms was usually performed before and after each survey. The data were corrected where necessary to the appropriate values given in the American National Standard Specifications for Audiometers, ANSI S3.6 (1969).

Used for purposes of data analysis were the three-frequency averages mentioned above in the definitions of hearing impairment. HLI $(\overline{0.5, 1, 2})$ and HLI $(\overline{1, 2, 3})$ are used to denote these averages performed over both ears. (HLI stands for "hearing level index.")

The samples were grouped into age and experience ranges to assure equal numbers per cell and a consistent spread of the data across the various dBA levels.

The following lists the steps made in the data analysis:

1. Hearing level indices for 87 and 94 dBA noise exposed individuals were grouped into 31 samples for three-way cross-classification with respect to dBA level, age group, and experience group. The data were transformed by taking natural logarithms, and the resulting variances of log HLI $(\overline{0.5, 1, 2})$ and log HLI $(\overline{1, 2, 3})$ were computed for each sample. For each of the two dBA levels, Bartlett's tests for homogeneity of variances were performed over all age and experience combinations. Separate tests were performed for HLI $(\overline{0.5, 1, 2})$ and HLI $(\overline{1, 2, 3})$ average noise indices. Of the four Bartlett's tests, three showed no suggestion of nonhomogeneity of variance, but the fourth was significant at the 0.05 probability level. However, only one atypical variance was found within the "nonhomogeneous" group, and this was believed to be caused by an improbable combination of purely random variations and not indicative of a real elevation of variability for the cell in question. Thus, the conclusions were that variability of log HLI $(\overline{0.5, 1, 2})$ and log HLI $(\overline{1, 2, 3})$ for replicate subjects was stable over all cells defined by the cross-classification.

2. Fifth-degree orthogonal polynomial regression curves were fitted to log HLI vs. dBA for each age and experience cell using data for <u>all</u> dBA levels. Significance tests for nullity of regression coefficients were performed. For most of the curves which exhibited any significant trend, a straight line fitted the data within the limits of unexplained variability.

In several cases, fourth or fifth degree coefficients showed significance, but examination of the plotted points revealed these to be artifacts due to clustering of the dBA levels for those plots, i.e., too few levels of the independent variable so that the polynomial tended to "fit the random errors."

3. Histograms of pooled deviations of log HLI values from the respective regression lines for HLI$(\overline{0.5,\ 1,\ 2})$ and HLI $(\overline{1,2,3})$ were constructed by fitting normal distribution curves. Chi-square goodness-of-fit tests were performed. The tests revealed that the log HLI deviations from the means were normally distributed over the full range of variability to a very significant degree of approximation as shown in Figures 14 and 15 Means were found to be zero, and pooled variances were calculated for use in later stages of the analysis.

4. Regression lines for different age groups within an experience-level were tested for parallelism, and in every case, the lines were found to be parallel within the limits of error in the slope estimates. Pooled slopes were calculated, and the intercepts were revised to reflect the small differences between the separate and pooled slopes. Families of parallel lines were plotted. Tests for coincidence of sets of parallel lines were then made by the method of covariance analysis. This revealed significant difference at the 0.01 probability level in all cases.

5. Regression lines for different experience levels within an age group were not found to be parallel, and, for each age group, the intercepts were compared by means of Student's t-tests. The "intercepts" were defined as ordinates of the regression lines at a dBA of 79, which represented the control group exposed to less than 80 dBA. These regression lines were found to be significantly different families of nonparallel lines from common intercepts.

6. For each age and experience combination, the normal distribution of pooled variation in replicate subjects was distributed about the regression line with its zero mean centered at the ordinate of the line. This model was then used to calculate a predicted percentage of subjects whose hearing levels exceeded a "fence". Thus, such percentages could be tabulated as a function of dBA for each age and experience category. Furthermore, risk values were then derived as the percentage difference between employees exposed to noise levels 80 dBA or greater and those exposed to less than 80 dBA (Table XII and XIII).

This analysis indicates that the 85 dBA-Slow noise limit for an eight-hour day, in conjunction with the medical program prescribed in the standard, will improve the protection of the working population from hearing loss that could impair their abilities to understand everyday speech. The reliability of the analysis is evidenced by homogeneity of the variance and normality of the population distributions. In other words, the evaluation is repeatable and is representative of a random sample.

Comparison of NIOSH Data with Other Published Data

Three analyses comparable to the NIOSH analysis use a definition of hearing impairment different from that used in the NIOSH standard. In order to compare NIOSH data with these analyses, the NIOSH data was analyzed using the following definition: hearing impairment is considered to occur when the average of the hearing threshold levels at the audiometric frequencies 500, 1000, and 2000 Hz for both ears, HLI $(\overline{0.5, 1,2})$, exceeds 25 dB (thresholds re ANSI S3.6 (1969)). Again, risk is defined as the additional incidence of hearing impairment of noise exposed worker groups when compared with that of equivalent nonnoise exposed groups, or the difference between the two incidences.

NIOSH risk data for retirement age groups are compared in Tables XIV, XV, and XVI with the following sets of risk data: (1) that used by the American Conference of Governmental Industrial Hygienists,[85] the OSHA Federal Standard,[86] as well as the Intersociety Committee;[27] (2) that used by the International Organization for Standardization (ISO); and (3) that developed by the National Physical Laboratory (U.K.).[89] In all cases, the age grouping and sound levels are similar to those of the NIOSH data.

The Intersociety Committee, composed of representatives from the American Academy of Occupational Medicine, American Academy of Opthalmology and Otolaryngology, American Conference of Governmental Industrial Hygienists, Industrial Hygiene Association, and Industrial Medical Association, in 1970, published an analysis similar to the NIOSH analysis. It studied a combination of several noise and hearing studies[120-124] in order to determine risk from noise exposure. There are several features of this analysis, however, which differ from that by NIOSH.

First, most of the Intersociety data consisted of hearing levels for only the right ear. Although the right ear may statistically be better than the left, both ears were used in the NIOSH analysis in order to obtain a more realistic incidence of hearing impairment since a person hears with both ears, not one. This same feature of the Intersociety analysis is discussed by Botsford[125] who determined that the use of the average of the two ears produces a higher risk factor.

Also, the Intersociety data were not separated into experience groups within each age group. The NIOSH analysis found that work experience ranged from 0 to 40 years in the older age groups, and thus, it was necessary to classify employees by experience as well as by age.

Moreover, some of the studies used in the Intersociety analysis used Speech Interference Level SIL: the average of octave band levels with center frequencies 500, 1000, and 2000 Hz) as the measure of exposure in analyzing the noise levels encountered by the employees. NIOSH considers this unsatisfactory since the conversion of SIL to dBA is generally inaccurate and is based on tenuous assumptions.

Finally, the Intersociety analysis used the noise-exposed populations from a variety of different studies with one non-noise exposed population and one "general" population (including both noise exposed and non-noise exposed individuals) for their composite determination of risk. Furthermore, the different investigations used in this analysis were each unique with respect to screening (or excluding) criteria, audiometric equipment, and data analysis. The NIOSH study used a non-noise exposed population which consisted of a pool of employees similar in these respects to each other and to the noise exposed population under study.

Thus, the Intersociety analysis differs from that of NIOSH in several characteristics: use of one ear only, nonseparation of experience groups, use of SIL in noise levels, and use of a dissimilar composite population. Some of these characteristics tend to produce lower risk values and considerably more uncertainty than the NIOSH analysis, as evidenced in Table VII-3.

Another study whose analysis determined risk is published in ISO Recommendation R1999 (1971).[90] This analysis differs from the NIOSH analysis in three ways. The first is that only the right ear was used. The second is that no separation of age groups into work experience groups was done. The third is that no screening for otological abnormalities was done in the ISO study. On the other hand, the entire sample of data used in this analysis is homogeneous in that all members of the sample were taken from one comprehensive examination.[126] The lack of otological screening has some effect on incidence of hearing impairment for both the noise exposed and the non-noise exposed groups, but, when risk is calculated by subtracting the two incidences, the effect is essentially cancelled. Thus the NIOSH risk values are very similar to the ISO values, as evidenced in Table XV.

Another study, by the British National Physical Laboratory,[127] developed an equation for calculating hearing levels of the populations exposed to noise. This equation was used by Robinson[89] to develop risk tables for various groups and noise levels.

In comparing the British risk values with those of the NIOSH, shown in Table XVI, it can be seen that the British risk values are much lower. The nature of this discrepancy is difficult to determine; however, it may result from the severity of the British screening for otological abnormalities and previous noise exposure. It is also possible that the reason for the discrepancy is the baseline, or reference level, used in this analysis. The British used a baseline (which they considered to be audiometric zero), determined by a non-noise exposed industrial group of people 18-25 years of age, which was actually lower than audiometric zero (thresholds re ANSI 1969 (or ISO R389)). It has been found, however, in many United States studies[5,21,22,126,128,129] including the NIOSH analysis, that the average hearing threshold level over the audiometric frequencies 500, 1000, and 2000 Hz (HLI($\overline{0.5, 1, 2}$)) is 5 - 10 dB (thresholds re ANSI S3.6-1969) for non-noise exposed employees 18-25 years of age, which is approximately 10 dB higher than that of the 97 non-noise controls used by the British. Thus, if the British data are used to calculate risk with a 10 dB correction, which brings the baseline of their data into coincidence with the baseline appropriate to the protection goal of this standard and which is representative of the baseline found in occupational environments in many U.S. studies, then the risk values using the British data are, in fact, very similar to those found in both the NIOSH and ISO risk tables, as shown in Table XVI.

The "Hygiene Standard for Wide-Band Noise" of the British Occupational Hygiene Society[87] is based on assumptions radically different from those of the NIOSH standard. As mentioned previously, the British consider hearing impairment to occur when the average hearing loss at the audiometric frequencies 500, 1000, 2000, 3000, 4000, and 6000 Hz for both ears exceeds 40 dB [(threshold re ISI R389-1964)] (48 dB minus 8 dB for presbycusis or aging effects). This 48 dB "fence" is comparable to an HLI ($\overline{0.5, 1, 2}$) of approximately 39 dB for thresholds re ANSI S3.6 (1969). Such a high fence is not in line with the protection goal of the NIOSH standard.

<u>Effect of Hearing Impairment Definition on Risk</u>

The NIOSH standard was based on risk calculated using the definition of hearing impairment as the condition when the average of the hearing threshold levels at the three audiometric frequencies 1000, 2000, and 3000 Hz, HLI

$(\overline{1, 2, 3})$ for both ears exceeds 25 dB [(thresholds re ANSI S3.6 (1969)]. Another definition was used to compare the NIOSH risk data with other data. This definition was that hearing impairment for an individual is considered to occur when the average of the hearing threshold levels for the audiometric frequencies 500, 1000, and 2000 Hz, HLI $(\overline{0.5, 1, 2})$ for both ears exceeds 25 dB re ANSI S3.6 (1969). Some of the NIOSH risk values calculated using both definitions are shown in Table XVII. Although the incidences of hearing impairment are higher for the definition using HLI $(\overline{1, 2, 3})$, the risks due to noise are, in fact, quite similar. Thus, even though the two definitions reflect the incidence of hearing impairment in the population differently, the different definitions have little effect when risk is calculated.

Comparison of the NIOSH Standard with Other Standards

The present Federal standard for occupational noise exposure,[86] which is based on the same data as that of the Intersociety Committee, ACGIH, and Walsh Healey Public Contract Act mentioned above, differs in several respects from that of the NIOSH standard, and the analysis shows lower risk than does NIOSH for the same noise levels. Indeed, industrial employee data more recent than the Intersociety data, published as ISO R1999,[90] has shown trends comparable to those of the NIOSH analysis. Thus, the 85 dBA-Slow noise exposure level for a nominal eight-hour day should allow no more than an increase of 10-15 percentage points in the incidence of hearing impairment, as compared to the non-noise exposed population. (This statistic is for employees aged 50-65 years, having a minimum of 20 years noise exposure.)

The recommended occupational exposure level of 85 dBA for an eight hour day will be applicable to all newly designed installations six months after the effective date of the standard. However, the level of 85 dBA is not applicable to established installations until such time as determined by the Secretary of Labor in consultation with the Secretary of Health, Education and Welfare. Such a provision was necessary because of the lack of sufficient available evidence upon which to determine a reasonable time period for the development of technologically feasible methods to meet the 85 dBA level.

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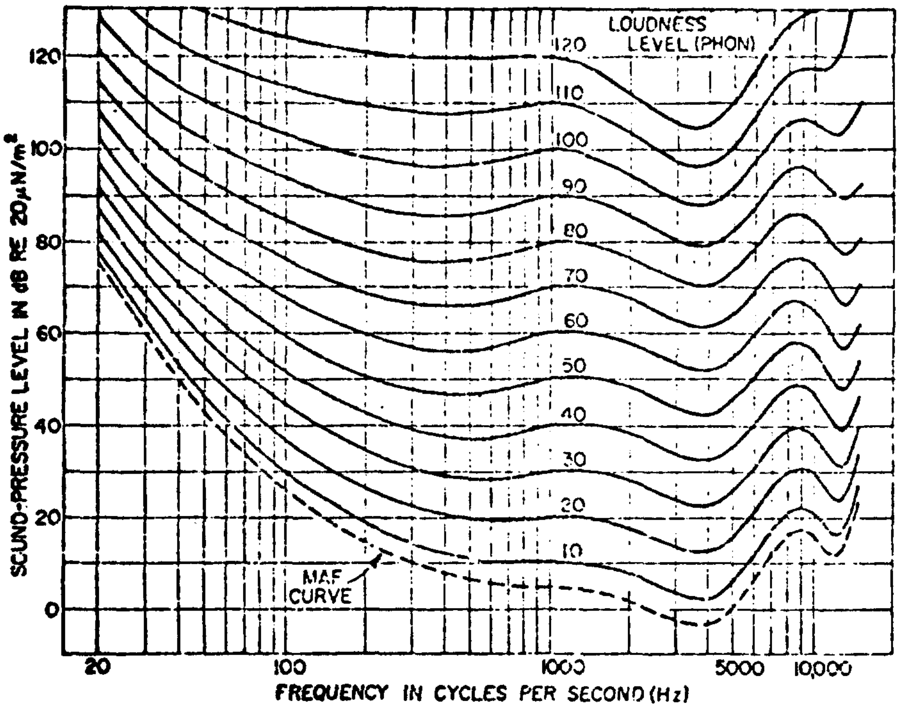

Figure 1. Normal Equal Loudness Contours for Pure Tones

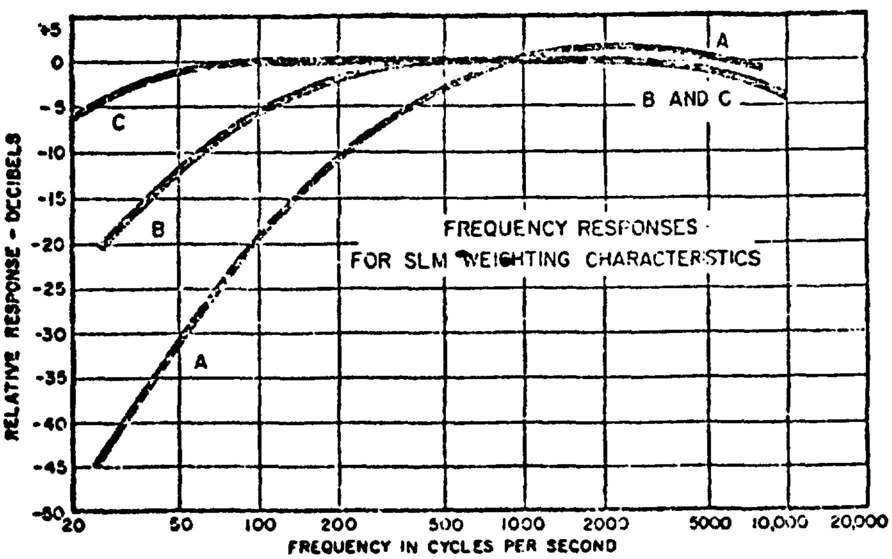

Figure 2. Standard Frequency Weighting Curves for Sound Level Meters

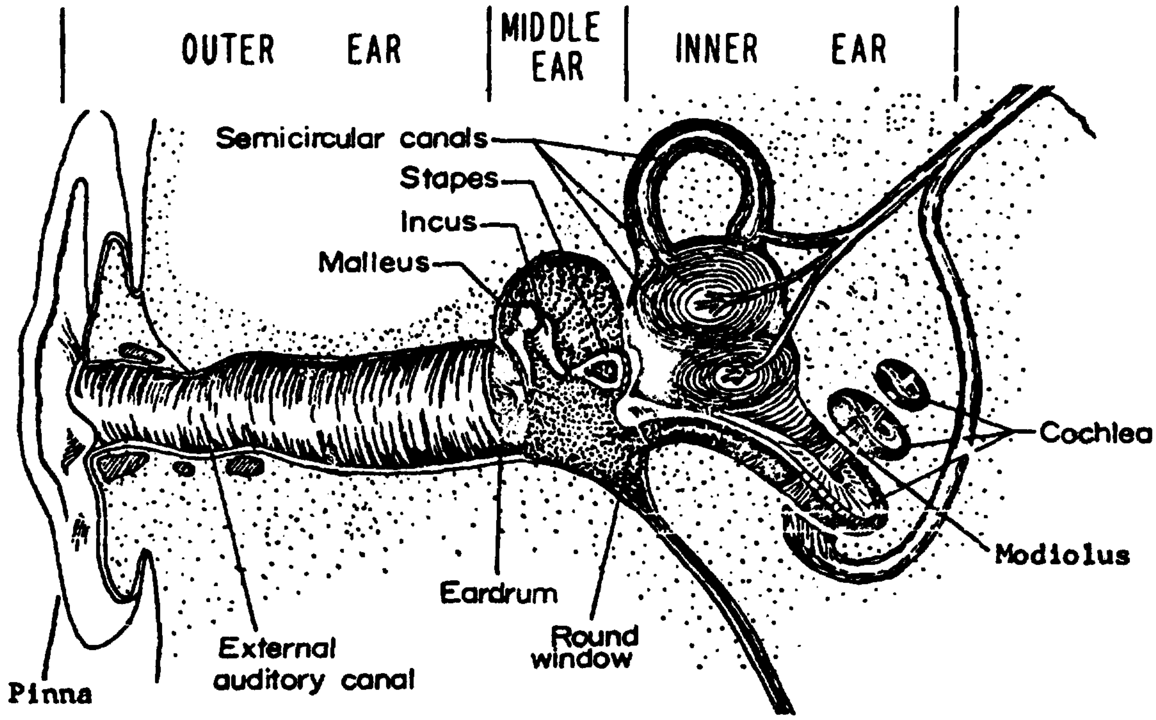

Figure 3. Cross-section of outer, middle, and inner ear structures.

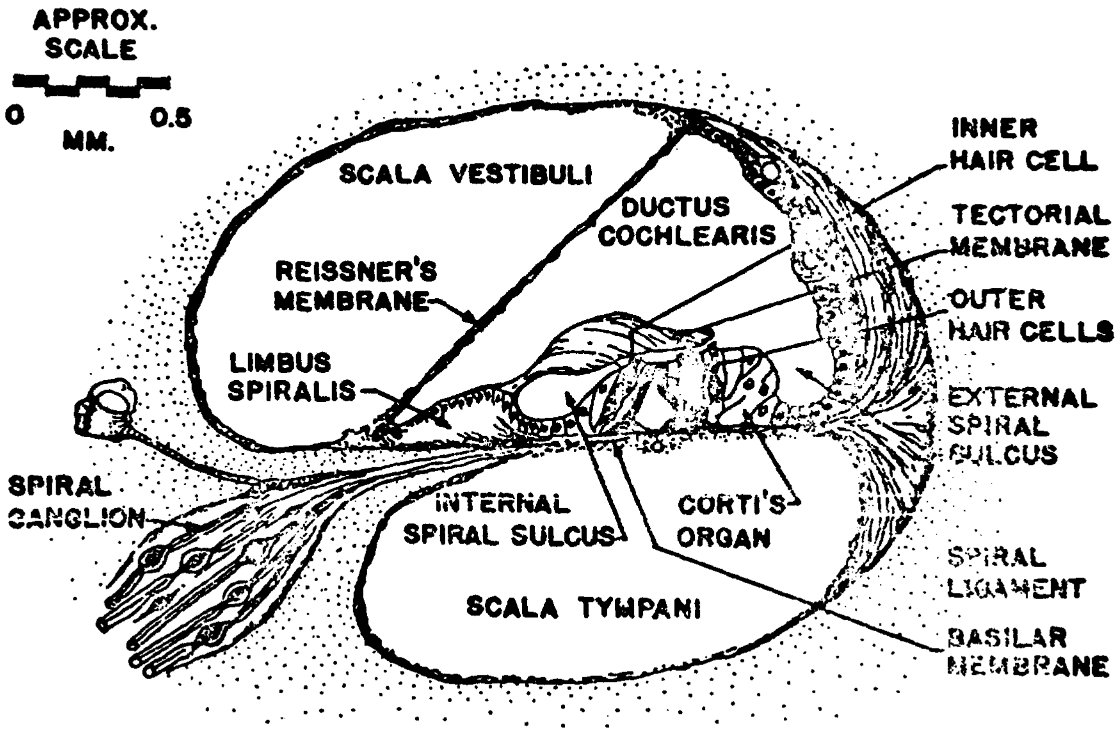

Figure 4. Cross-section of the Organ of Corti.

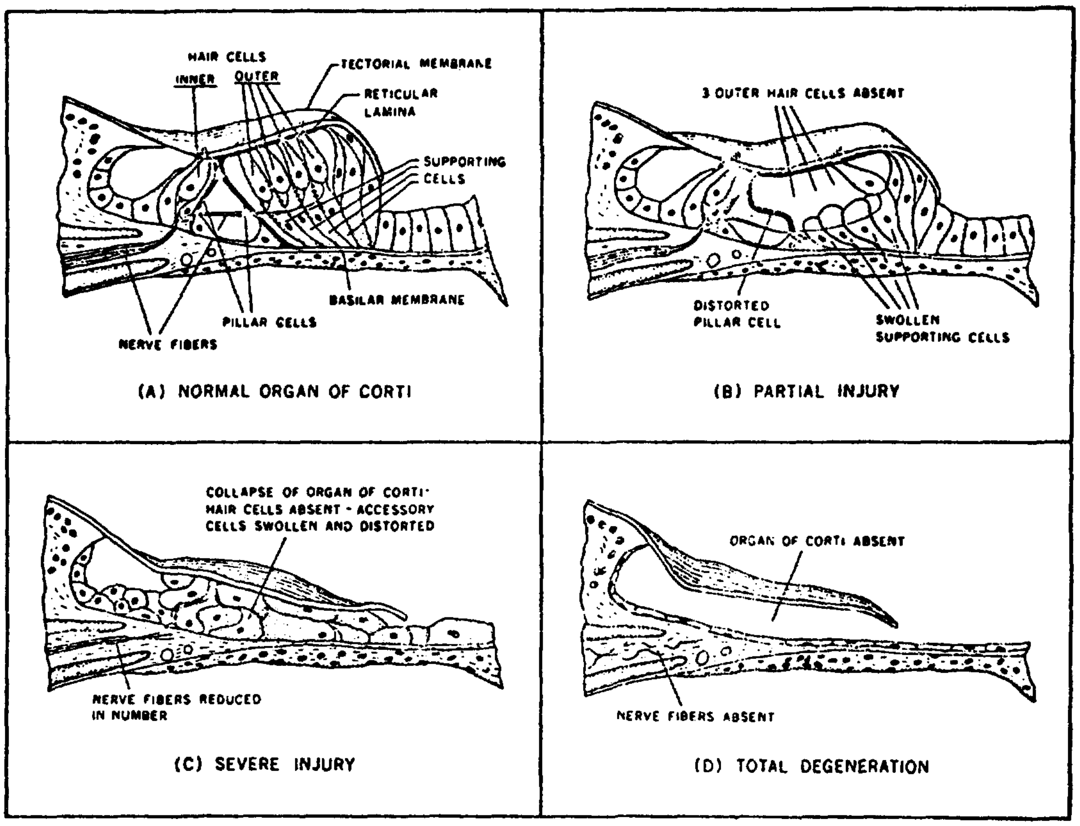

Figure 5. Cross-section of the basilar membrane revealing the normal state and progressive degrees of damage likely to be inflicted by high level noise. (Material reproduced from J. D. Miller, Central Institute of the Deaf, St. Louis, Missouri, as noted in Ref. 10).

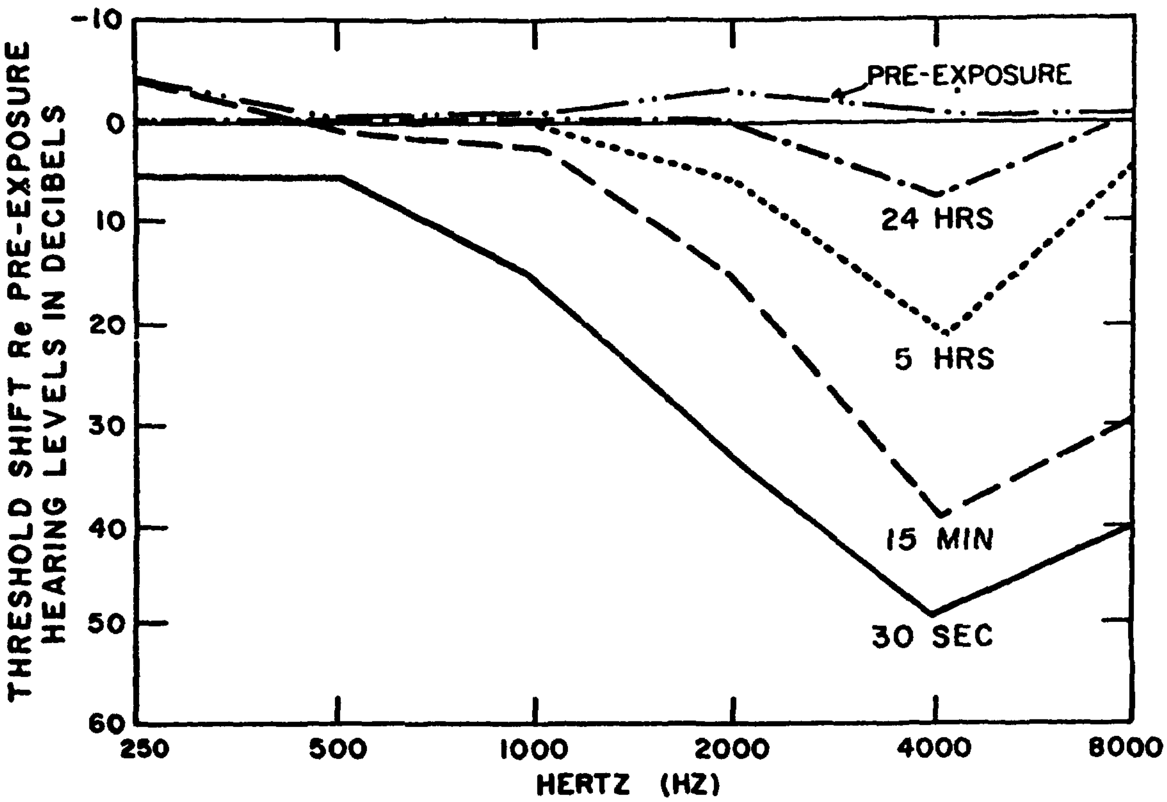

Figure 6. Hearing levels measured at various times after a 2-hour exposure to a broad-band noise at 103 dBA as compared with pre-exposure determinations. (Single subject data taken from the Public Health Service laboratory in Cincinnati, Ohio).

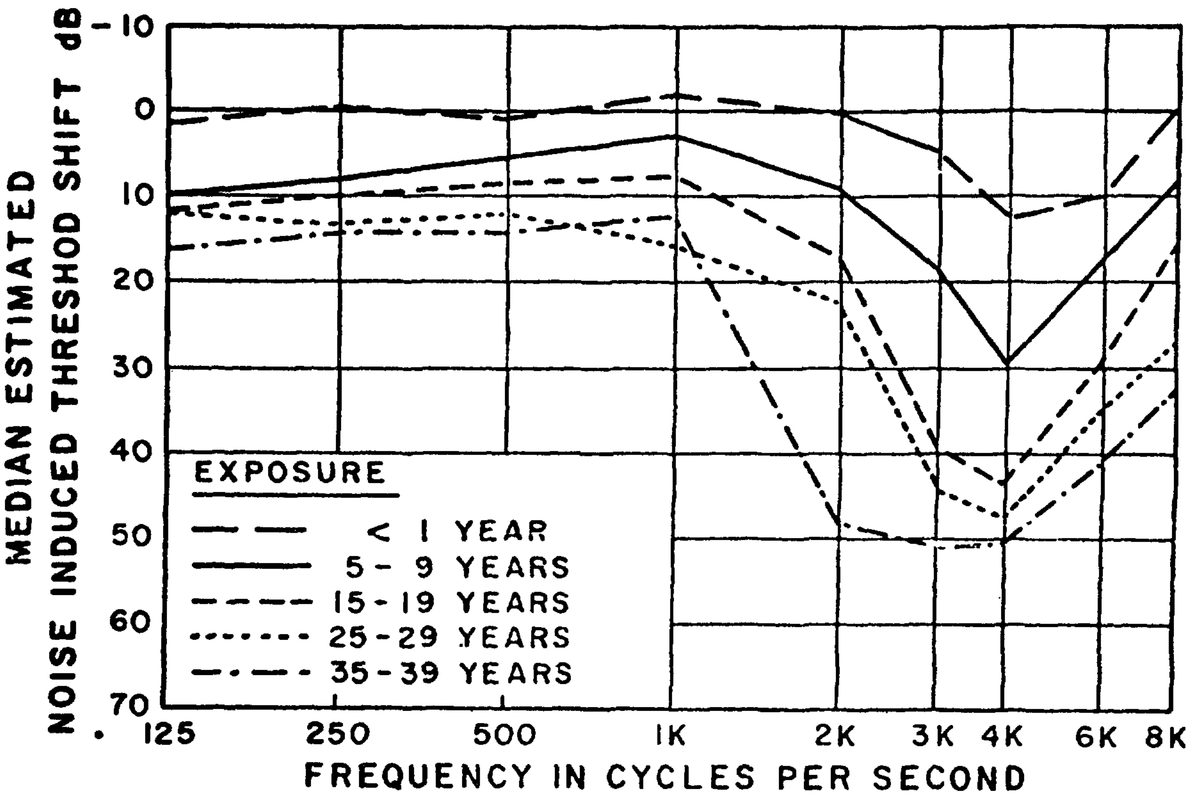

Figure 7. Median permanent threshold shifts in hearing levels as a function of exposure years to jute weaving noise. (Data taken from Taylor, et. al. [Ref. 10]).

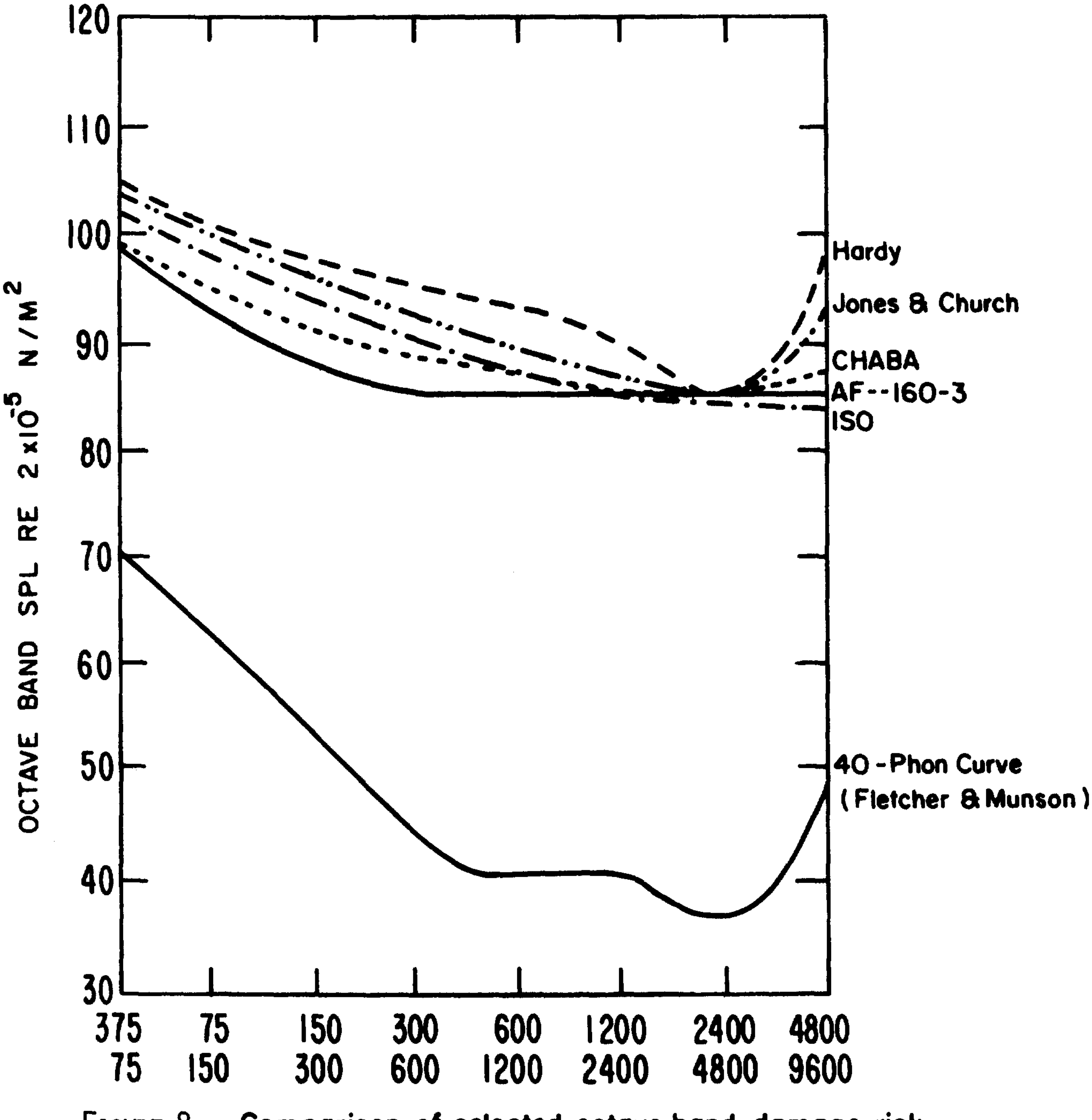

FIGURE 8. Comparison of selected octave band damage risk criteria with 40 phon loudness curve.

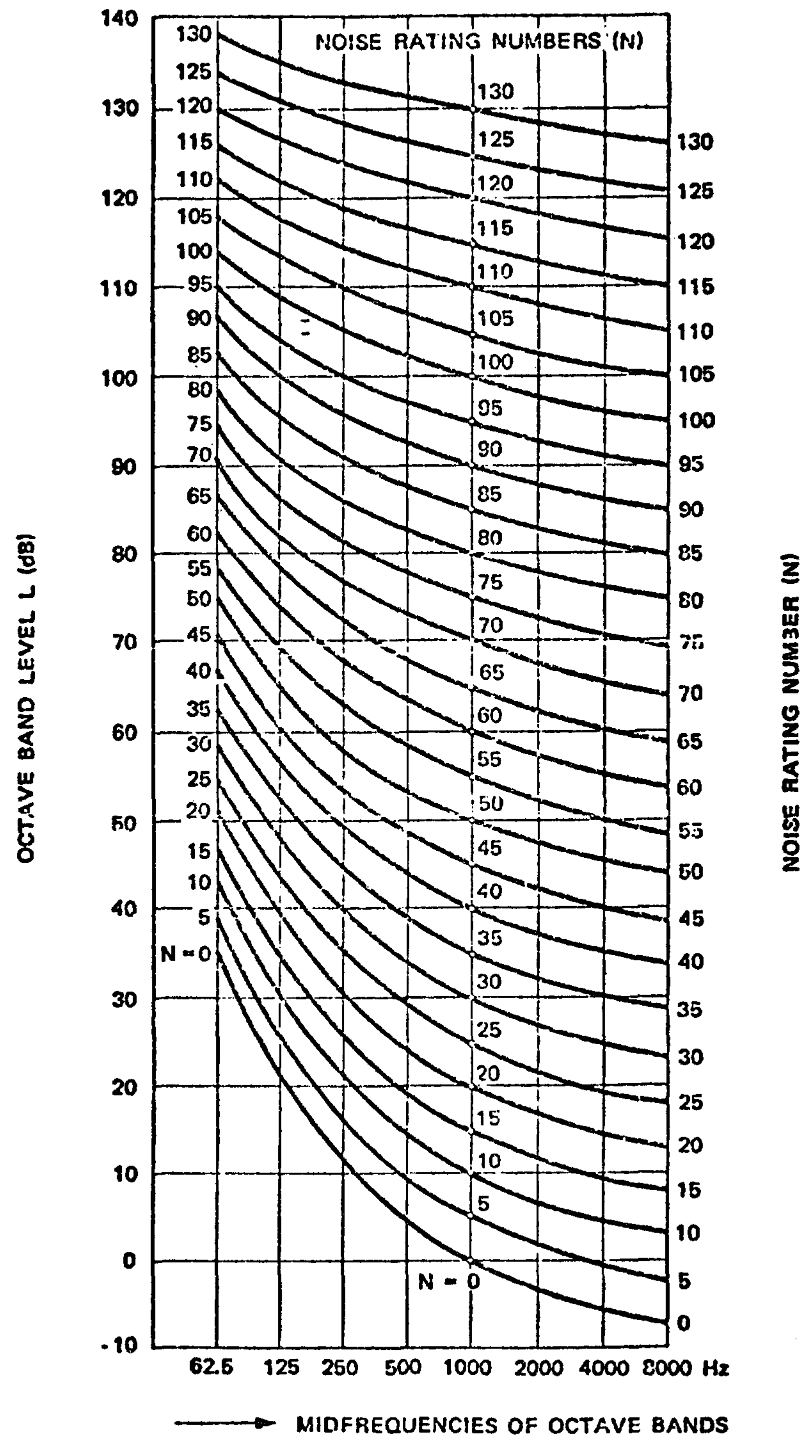

Figure 9. Noise Rating Curves

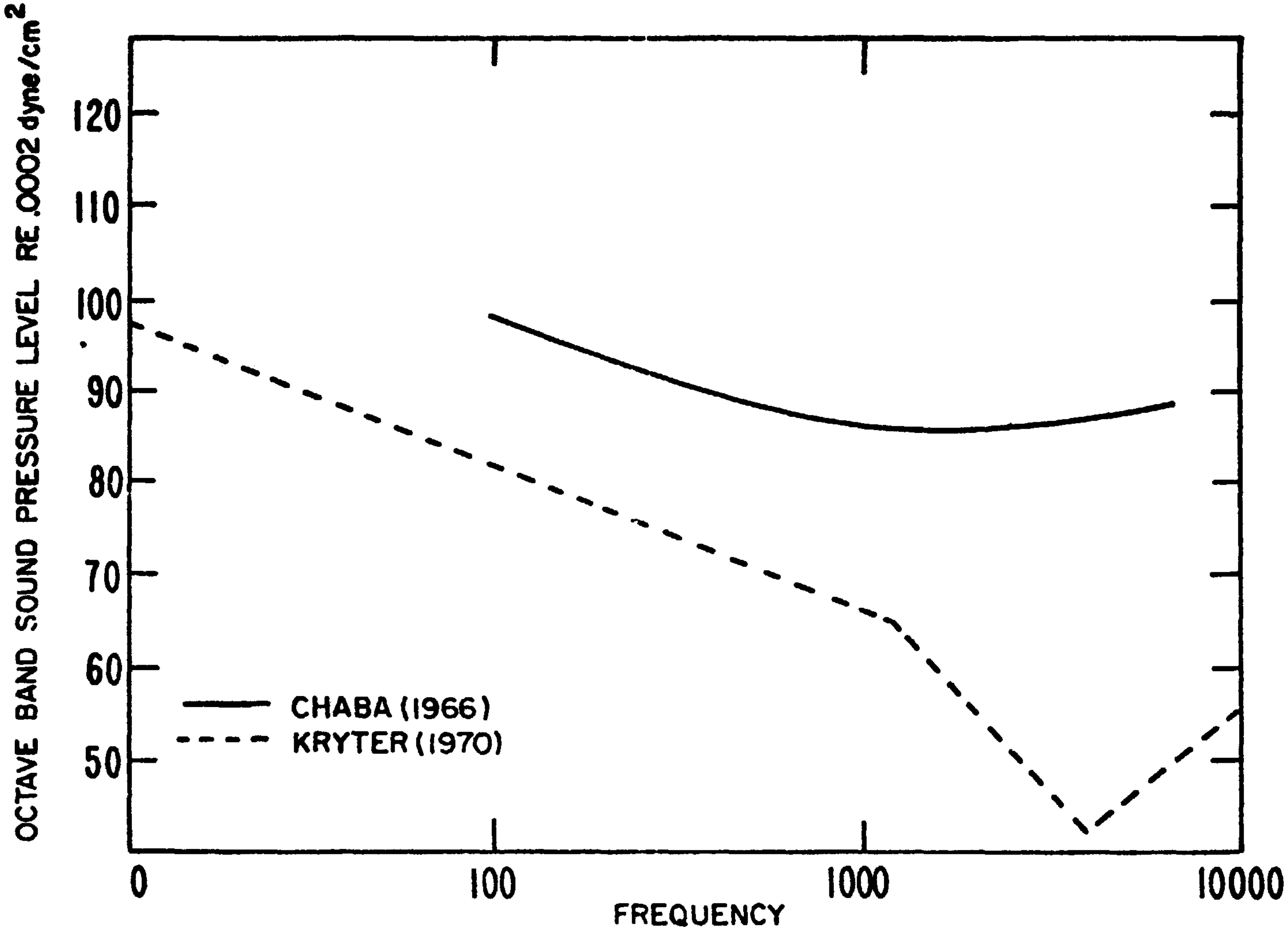

FIGURE 10. Difference between two damage risk criteria based on protection goal recommended by CHABA (1966) and Kryter (1970).

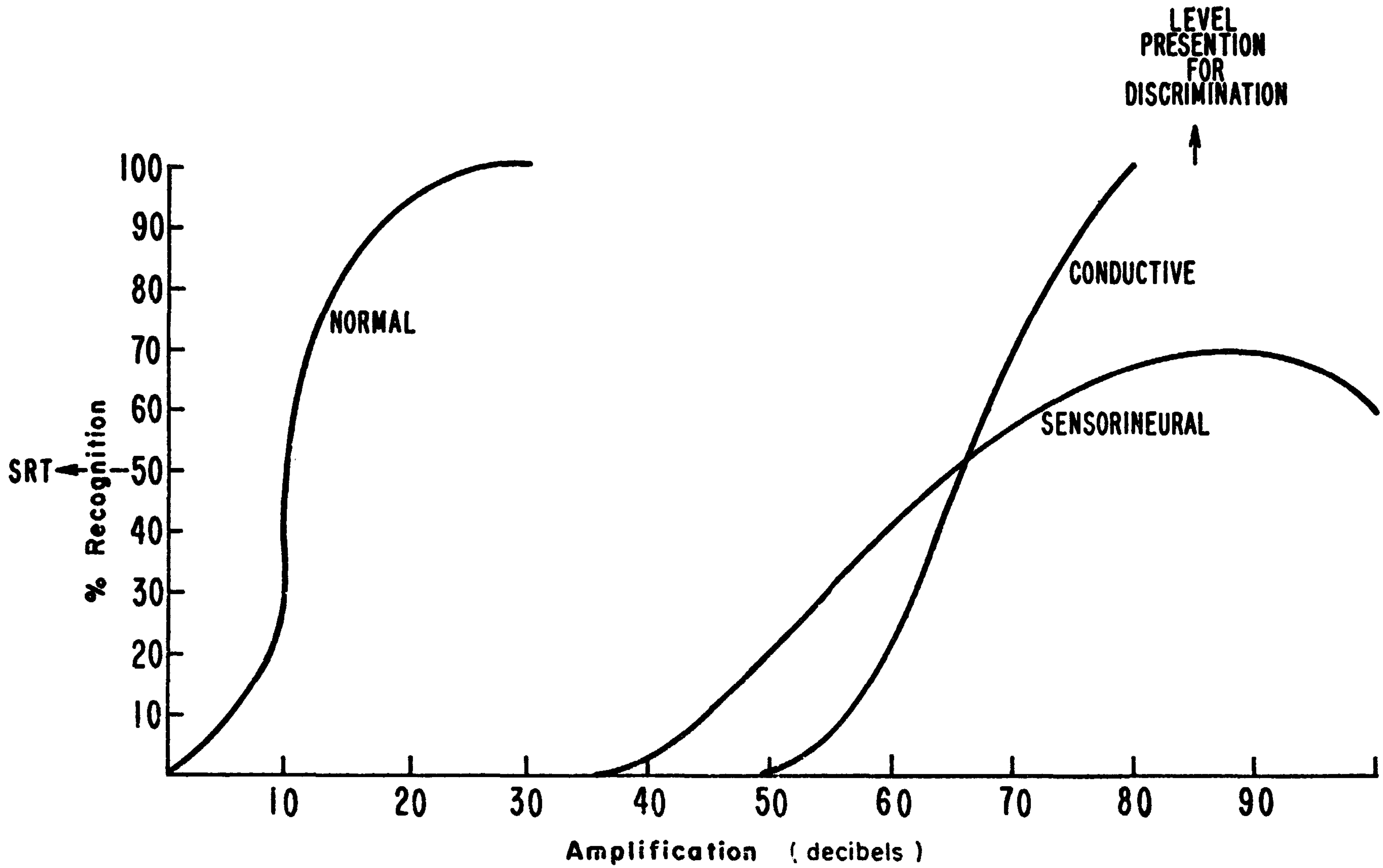

FIGURE 11. Articulation Indices Representing Normal, Conductive and Sensorineural Cases (from Hood, 1971)

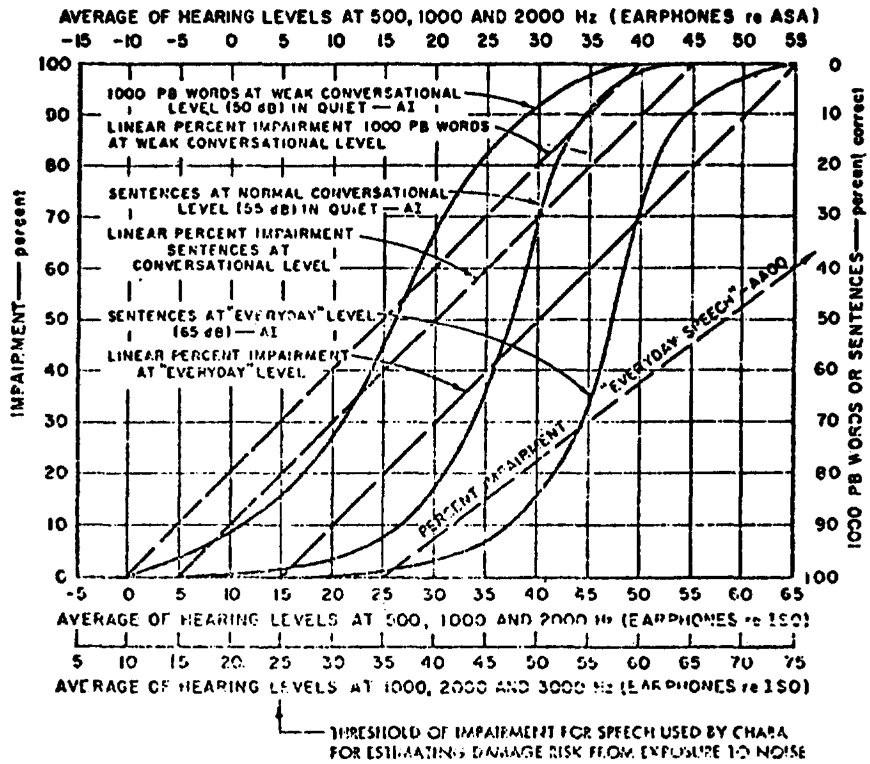

Figure 12. **Relation between impairment of speech intelligibility and HL, as calculated by AI and as proposed by AAOO. (From Kryter, 1970)**

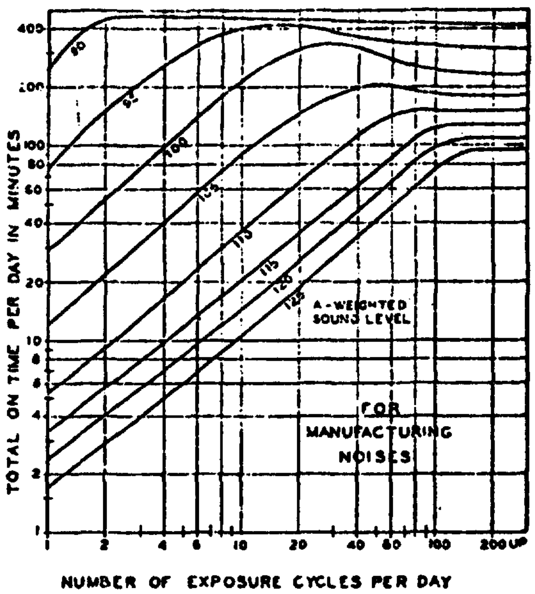

Figure 13. **Total duration of a noise allowable during an 8-hour day as a function of the number of periodic interruptions. An exposure cycle is completed each time the A-weighted sound level decreases to or below 89 dB.** (From Botsford, 1967)

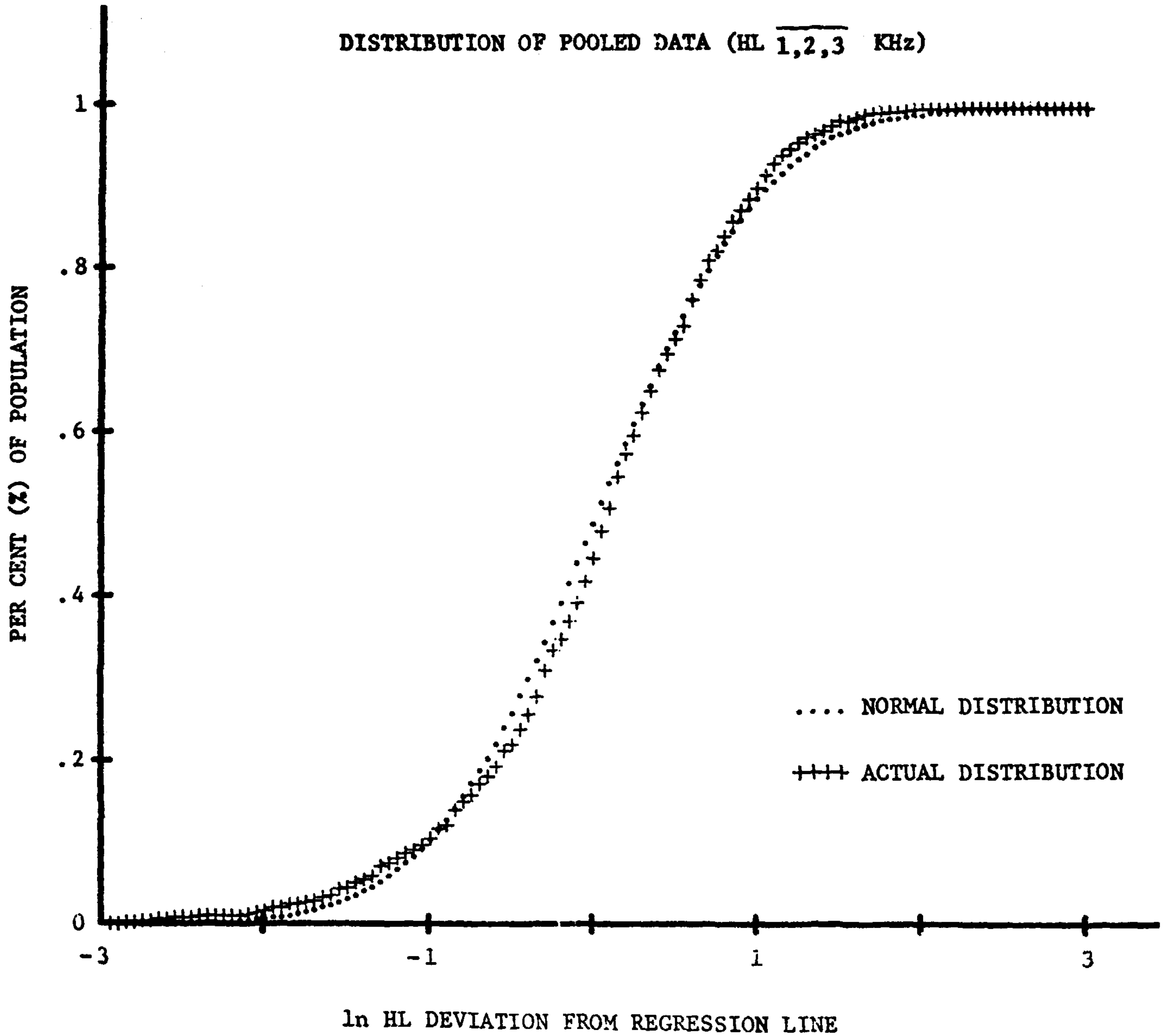
DISTRIBUTION OF POOLED DATA (HL $\overline{1,2,3}$ KHz)
PER CENT (%) OF POPULATION
1
.8
.6
.4
.2
0
-3
-1
1
3
.... NORMAL DISTRIBUTION
++++ ACTUAL DISTRIBUTION
ln HL DEVIATION FROM REGRESSION LINE

Figure 14.

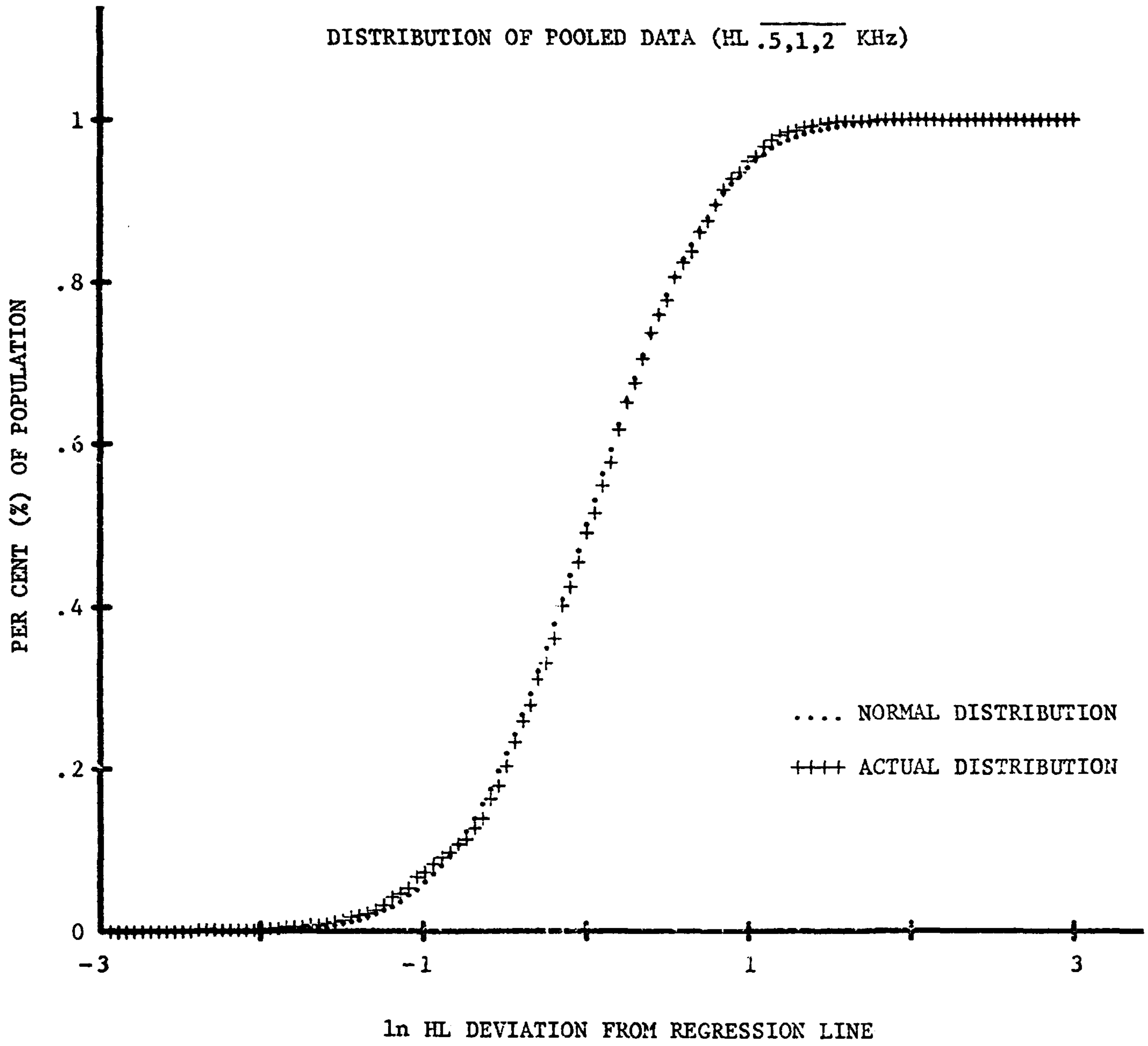
DISTRIBUTION OF POOLED DATA (HL $\overline{.5,1,2}$ KHz)
PER CENT (%) OF POPULATION
1
.8
.6
.4
.2
0
-3
-1
1
3
.... NORMAL DISTRIBUTION
++++ ACTUAL DISTRIBUTION
ln HL DEVIATION FROM REGRESSION LINE

Figure 15.

TABLE I

CHANGES IN MEDIAN HEARING LEVELS OF MALES FROM AGE 20:
NIOSH,* NATIONAL HEALTH SURVEY, ISO DRAFT PROPOSAL,
EASTMAN KODAK COMPANY

STUDY	AGE	Audiometric Test Frequencies (Hz) 500	1000	2000	3000	4000	6000
NIOSH	30	1	1	1	2	4	4
NHS	25-34	0	0	1	3	6	5
ISO	30	0	0	1	2	3	4
E.K.Co	25-34	0	1	2	-	7	-
NIOSH	40	3	2	3	6	9	11
NHS	35-44	3	2	4	9	14	12
ISO	40	2	2	4	7	10	12
E.K.Co.	35-44	0	2	6	-	18	-
NIOSH	50	5	4	6	12	17	19
NHS	45-54	5	4	8	16	24	20
ISO	50	4	6	8	13	18	22
E.K.Co.	45-54	2	6	9	-	26	-
NIOSH	60	7	6	10	19	28	30
NHS	55-64	6	6	14	26	37	36
ISO	60	8	8	15	22	29	34
E.K.Co.	55-64	5	8	16	-	40	-

*See Table B-1. Appendix B

TABLE II

CHANGES IM MEDIAN HEARING LEVELS OF FEMALES FROM AGE 20:
NIOSH,* NATIONAL HEALTH SURVEY,
ISO DRAFT PROPOSAL, AND EASTMAN KODAK COMPANY

STUDY	AGE	Audiometric Test Frequencies (Hz) 500	1000	2000	3000	4000	6000
NIOSH	30	2	1	2	2	2	3
NHS	25-34	1	0	2	2	2	4
ISO	30	1	2	1	1	2	2
E.K.Co.	25-34	1	1	1	-	5	-
NIOSH	40	4	3	3	5	5	7
NHS	35-44	2	2	4	4	4	7
ISO	40	2	2	4	5	6	8
E.K.Co.	35-44	2	3	4	-	11	-
NIOSH	50	6	5	6	8	9	11
NHS	45-54	6	5	7	8	9	12
ISO	50	5	5	7	9	11	16
E.K.Co.	45-54	3	5	6	-	14	-
NIOSH	60	5	7	8	13	14	16
NHS	55-64	10	9	12	15	18	22
ISO	60	8	9	12	16	19	25
E.K.Co.	55-64	9	8	12	-	22	-

*See Table B-2. Appendix B

TABLE III

A-WEIGHTING CORRECTIONS FOR OCTAVE BAND LEVELS

Octave Band Frequency (HZ)	Correction
31.5	Subtract 39.5 dB
63.0	Subtract 26.2 dB
125.0	Subtract 16.2 dB
250.0	Subtract 8.7 dB
500.0	Subtract 3.3 dB
1000.0	No Correction
2000.0	Add 1.2 dB
4000.0	Add 1.0 dB
8000.0	Subtract 1.1 dB
16000.0	Subtract 6.7 dB

TABLE IV

AUDIOMETRIC SURVEYS CARRIED OUT IN THE YEARS 1960 to 1970
IN THE UNITED STATES AND OTHER COUNTRIES

Reference and country	Nature of work investigated	Findings
Bonati (1960) Rass. Med. Indust. 29: 127. Italy	103 shipyard workers (riveters, caulkers, and fitters and testers of diesel engines and turbines)	Every riveter and caulker affected.
Coles & Knight (1960) Ann. Occup. Hyg. 2, 267. United Kingdom	Workers in diesel-engine test-house	Maximum noise level 116 dB. Of six men who worked continuously in the intense noise of the two-stroke test-House (average period 3-1/2 years) all had losses of 45-60 dB in one or both ears at 3.4 and 6 kHz and none could be accounted for by an aging factor.
Yaffe and Jones (1961) Public Health Publication No. 850, Wash. D.C. U.S.A.	1952 Federal penitentiary workers (textile mills; wood products and sheet metal products manufacturing; brush, shoe, and clothing factories; and printing) were tested periodically from 1953-59. Octave band noise levels ranged from 75-110 dB.	Those levels which exceeded octave band criteria produced significant hearing threshold shifts at 3,4, and 6 kHz after 24 month exposures. The locations producing the largest shifts were cotton mill twist and weaving departments, woolen mill weaving departments, and furniture mills.

TABLE IV Continued (p.2)

Reference and country	Nature of work investigated	Findings
Schneider, Peterson, Hoyle, Ode, and Holder (1961) Amer. Ind. Hyg. Assoc. J. 22:245. U.S.A.	294 jobs in thirty chemical company departments and 691 screened individuals	Data divided into 4 noise exposure groups based on octave band criteria indicated that the group exceeding criteria more than 10% of the time experienced a permanent threshold shift of 1dB per year at 2, 3, and 4 KHz. For the group near criteria exposure most of the hearing loss occurred within the first 5 or so years.
Waal (1961) Ann. Otol. 70:208 Netherlands	Engine-room personnel	"...out of 234 threshold curves of 117 persons from engine room, 197 curves of 107 persons revealed a threshold shift of 15 dB or more in the frequency range of 1000-8000 Hz...in 69% the center of the threshold shift lies between 3600 Hz and 5600 Hz."
Brohm & Zlamal (1962) Cas. Lek ces. 101:300 Czechoslovakia	Noise in cabins of heavy trucks 90-110 dB	Examinations made on 51 truck drivers and in each case a loss of hearing was determined.

Reference and country	Nature of work investigated	Findings
Mancini & Stancari (1962) Rass. Med. Indust. 31:239. Italy	50 fettlers	Men worked in 9 foundries with noise levels of 92-110 dB. In men who had been working for more than 5-6 years in noisy conditions almost all frequencies were involved; those who had worked less than 2-3 months in noisy conditions showed a loss varying from 30 to 50 dB at 4000 Hz.
Piesse, Rose & Murray (1962) Rept. No. 19, Commonwealth Acoustics Laboratory, Dept. of Health. Australia	5127 skilled and unskilled workers of all ages	Results of initial hearing tests on 5127 skilled and unskilled workers of all ages, performed during reference audiometry, showed 33% of the total number of ears had hearing losses in excess of 45 dB. The hearing losses of 786 tradesmen were as follows (approximate percentage of ears with losses of 45 dB or more at 4000 Hz): boiler-makers 65%, drop forge operators 62%, plumbers 42%, sheet-metal workers 38%, joiners 25%, fitters 22%, electrical mechanics 19% and painters 18%.

TABLE IV Continued (p.4)

Reference and country	Nature of work investigated	Findings
Amelotti & Bandini (1963) Artis Medicae Studia No. 18, 17. Italy	Shipyard workers	6930 audiometric examinations in 38 different occupations. Hyperacousia is characterized by swifter development, and by definite after-effects, even after a few years' exposure to harmful sound levels.
Chadwick (1963) Jour. Laryngol. 77: 467 United Kingdom	12 men exposed to noise from industrial gas-turbine (jet) engine noise	Noise levels reached as high as 113 dB flat. "...the low-tone loss in just over two years was in the region of 10 dB and from 2000 Hz to 4000 Hz was in the order of 20 dB... the average loss for the speech frequencies was...eight times more than that to be expected in a more conventional industry with a known noise hazard."
Filin (1963) Gig. Tr. prof. Zabol 7:3. U.S.S.R.	Drivers of self-propelled jumbos in underground ore mining	Noise levels of 127 dB at frequencies between 1000 Hz and 8000 Hz. Hearing loss in 91 of 135 miners examined; after 10 years' work loss at 4000 Hz was 53 dB; after only 1-2 years' work, 28 dB loss at 4000 Hz.

TABLE IV Continued (p.5)

Reference and country	Nature of work investigated	Findings
Weston (1963) J. Aust. Inst. Agric. Sci. 29:15. Australia	Agricultural tractor drivers	53 drivers of tractors of different horse-power; audiograms showed greater impairment in inland drivers where the tractors are of higher power and exposure is for longer periods than on coastal-plain farms. Noise levels ranged from 92 dB to 106 dB, occasionally as high as 114 dB.
Taylor, Pearson, Mair, and Burns (1964) J. Acoust. Soc. Amer. 38:113 United Kingdom	251 working and retired jute weavers subjected to wide band continuous noise of 99-102 SPL (overall) with "transients of peak amplitude 15-18 dB above the mean noise level".	"The most conspicuous feature is an initial deterioration (in hearing) in the first 10-15 years of exposure, followed by a period of about 10 years where deterioration attributable to noise is small. Thereafter, after 20-25 years of exposure, further deterioration occurs, especially marked at 2000 CPS".

TABLE IV Continued (p.6)

Reference and country	Nature of work investigated	Findings
Burns, Hinchcliffe, and Littler (1964) Ann. Occup. Hyg. 7: 323 United Kingdom	174 textile workers (spinners and weavers), 53 of whom were retested after 3 years overall SPL for weaving was 100 dB and for spinning was 101 dB.	Occupational hearing loss occurs in textile workers, "to a greater extent in weavers than in spinners." Over 3 years, "significant threshold shifts occurred in weavers at 2000 c/s and 8000 c/s." At 4000 c/s the deterioration was inversely related to the hearing level."
Harris (1965) Jour. Acoust. Soc. Amer. 37: 444 U.S.A.	Several hundred diesel-engine-room personnel.	About 15% of ears had permanent thresho[illegible] shifts of more than 20 dB at any frequency.
Antherly, Noble, and Sugden (1967) Ann. Occup. Hyg. 10: 255 United Kingdom	Iron foundry and manganese bronze foundry workers. Octave band noise levels at 0.5, 1, 2, 3 and 4 KHz ranged from 100-115 dB in the dressing and trimming shops.	The hearing levels of the trimmers at 1, 2, 3, and 6 KHz were from 15 to 35 dB higher than other comparable (age, sex, etc.) occupational groups exposed to less intense noise such as bus drivers, printers, boiler makers, and iron molders.

TABLE IV Continued (p.7)

Reference and country	Nature of work investigated	Findings
Cohen, Anticaglia, and Jones (1970) Arch. Environ. Health 20:614. U.S.A.	Hearing levels for heavy earth-moving equipment operators, paper-bag workers, and airport ramp workers were compared with those of non-noise exposed groups. Noise encountered ranged from 80-120 dB (A weighted sound level).	The hearing levels of the heavy earth equipment operators were found to be significantly higher than the non-noise exposed groups. The paper bag workers had higher hearing levels but not as high as the earth equipment operators. The airport ramp personnel, however, had the lowest hearing levels, probably due to the intermittency of their exposures.
Burns and Robinson (1970) Hearing and Noise in Industry, Her Majesty's Stationery Office, London United Kingdom	759 employees in 32 various industrial factories. Noise levels ranged from 78 to 109 dBA.	A relationship between noise, level, exposure duration, and hearing level was defined with two parameters: audiometric frequency and percentage of persons expected to exceed a specified hearing level. A weighted sound level was found to be adequate for estimating hearing level for the industrial noises measured.

TABLE IV Continued (p.8)

Reference and country	Nature of work investigated	Findings
Stone, Freman, and Craig (1971) <u>Amer. Indus. Hyg. Assoc. J</u>. 32:123 U.S.A.	3,116 employees of 9 steam electric generating plants and 2 hydroelectric plants were tested. Noise levels from assorted equipment ranged from 91 to 127 dBA, the more intense values associated with coal hoppers, turbine generators and pumps, and forced draft fans.	Prevalence of hearing impairment (defined by hearing levels averaging more than 15 dB (re ASA 1951) at test frequenices of 0.5, 1, and 2 KHz) varied from 4.7 percent for the younger workers having less than two years of service to 31.9 percent for the oldest workers with 26 years or more experience. Boilermakers, heavy equipment operators, and conveyor car operators as classes had high incidences of hearing impairment.

TABLE V

NATURE OF SPEECH RECEPTION POSSIBLE UNDER NOISE CONDITIONS RATED IN dBA*

Noise Level in dBA	Voice Level and Distance	Nature of Communication	Telephone Use
55	Normal Voice at 10 ft.	Relaxed communication	Satisfactory
65	Normal Voice at 3 ft. Raised Voice at 6 ft. Very Loud Voice at 12 ft.	Continuous communication	Satisfactory
75	Raised Voice at 2 ft. Very Loud Voice at 12 ft. Shouting at 8 ft.	Intermittent communication	Marginal
85	Very Loud Voice at 1 ft. Shouting at 2-3 ft.	Minimal communication (restricted, prearranged vocabulary desirable)	Impossible

* Table adopted in part from Bioacoustics Data Book, NASA Report SP-3006 National Aeronautics and Space Administration, Washington, D.C., Page 301, 1964.

TABLE VI

NOISE EXPOSURES ABOVE 90 dBA IN MANUFACTURING

CODE	NUMBER OF PLANTS IN SAMPLE	TOTAL NUMBER OF EMPL. IN SAMPLE	NUMBER LOCATED IN AREAS 90 dBA AND ABOVE	PERCENT OF WORK FORCE EXPOSED	TOTAL WORK FORCE	NUMBER PROJECTED TO BE LOCATED IN AREAS 90 dBA AND OVER
Textile Mill Products	23	12,764	5,634	44.1	963,300	424,815
Petroleum and Coal Products	16	20,493	5,875	28.6	192,800	55,140
Lumber and Wood Products	14	5,654	1,460	25.8	601,000	155,058
Food and Kindred Products	17	23,690	5,959	25.1	1,898,600	476,549
Furniture and Fixtures	11	10,374	1,849	17.8	465,400	82,841
Fabricated Metal Products	56	41,371	7,079	17.1	1,335,000	228,285
Stone, Clay and Glass Products	5	2,502	416	16.6	643,800	106,870
Primary Metal Industries	51	71,208	11,001	15.4	1,190,000	183,260
Rubber and Plastic Products	4	7,671	1,105	14.4	589,500	84,888
Transportation Equipment	46	199,212	23,445	11.7	1,705,500	199,543
Electrical Equipment and Supplies	7	8,790	973	11.0	1,778,100	195,591
Chemicals and Allied Products	8	3,081	324	10.5	1,014,400	106,512
Apparel and Other Textile Products	1	50	5	10.0	1,353,100	*
Paper and Allied Products	21	14,997	1,385	9.2	687,400	63,240
Ordnance and Accessories	12	39,403	3,480	8.8	193,900	17,063
Instruments and Related Products	6	3,254	193	5.9	433,800	25,594
Machinery Except Electrical	38	25,016	1,144	4.5	1,768,000	79,560
Printing and Publishing	5	5,597	237	4.2	1,085,900	45,607
Total	341**	504,427	71,564	14.1	16,999,500	2,533,416

* Insufficient data for projection

**2709 questionnaires were sent to the manufacturing industries listed, of which 1559 were returned. 341 of these respondents answered this question.

TABLE VII

MEASURED NOISE LEVELS FOR SELECTED INDUSTRIAL OPERATIONS*

Textile Mill
1. loom - 106 dBA
2. cotton spinning - 83 dBA

Lumber and Wood Products
1. planer - 106 dBA
2. molder - 100 dBA
3. router - 93 dBA
4. shaper - 104 dBA
5. boring machine - 94 dBA

Furniture Products
1. cut-off saw - 112 dBA
2. sander - 97 dBA
3. radial arm saw - 98 dBA

Paper Products
1. paper cutter - 96 dBA
2. bag and handle former - 89 dBA

Printing and Publishing
1. newspaper press - 97 dBA
2. mona-casting - 91 dBA
3. postcard press - 91 dBA
4. keyboard mono-type - 84 dBA
5. offset press - 88 dBA
6. small offset press - 82 dBA
7. folding machines - 85 dBA
8. binder - 86 dBA

Petroleum Refining
1. can seaming - 96 dBA
2. furnace heating distilling columns - 100 dBA
3. steam let down - 130 dBA
4. furnace high speed rotating equipment - 100 dBA
5. furnace pumps - 103 dBA

Transportation
1. 1-ton truck - 70 dBA
2. 5-ton truck - 73 dBA
3. 20-ton truck - 92 dBA

*Noise measurements for the specified operations were taken from assorted Public Health Service surveys and references in acoustical and Industrial Hygienists literature. See References 62-65.

TABLE VII Continued

Glass Products
1. inflation of containers - 106 dBA
2. corrugated band saw - 99 dBA

Steel products
1. coke oven - 83 dBA
2. blast furnance - 100 dBA
3. basic oxygen furnace - 91 dBA
4. electric furnance (150 tons) 112 dBA
5. 160" mill - 98 dBA

Various Metal Products
1. milling machine - 90 dBA
2. turret lathe - 90 dBA
3. 4" hand grinder - 85 dBA
4. riveting machine - 110 dBA
5. forge drop hammer - 105 dBA
6. automatic punch press - 95 dBA
7. pneumatic chisel - 101 dBA

Canning Food Products
1. canning punch press - 97 dBA
2. can making body operation - 95 dBA
3. can filling machine - 100 dBA

Mining, Underground
1. axial vane fan - 107 dBA
2. stoper drill - 115 dBA
3. Jackhammer drill - 113 dBA
4. roof bolter - 103 dBA
5. loader (gathering arm) - 96 dBA
6. conveyor belt - 93 dBA
7. continuous miner - 99 dBA

Mining, Open Pit
1. jumbo drill - 107 dBA
2. rotary drill - 93 dBA
3. crusher - 96 dBA
4. locomotive - 85 dBA
5. oxygen torches - 120 dBA

Heavy Equipment (earth moving)
1. double scraper - 92 dBA
2. scraper - 117 dBA
3. bull dozer - 110 dBA
4. road grader - 95 dBA

TABLE VII Continued

Farm Equipment

1. tractor - 98 dBA
2. grain roller mill - 85 dBA
3. pneumatic conveyor - 100 dBA
4. one-row beet puller - 94 dBA
5. two-row corn picker - 106 dBA

TABLE VIII

DAMAGE RISK CRITERIA PRIOR TO 1950

Author	Overall Sound Pressure Level		
	Safe	Borderline	Harmful
McKenzie (1934)			90
Rosenblith (1942)	75-80		
Bunch (1942)		80-90	
McCoy (1944)	80-85	90-100	110-130
Davis (1945)		100	115-120
Goldner (1945)			80
Schweishmer (1945)		80-90	
MacLaren (1947)		100	
Fowler (1947)		100	
Canfield (1949)	80		100-110
Grave (1949)	90		
Guild (1950)	<90 dB above hearing threshold		

Adapted from Jones (Reference 130)

TABLE IX

DAMAGE RISK CRITERIA FOR 5 - 8 HOUR EXPOSURES
AS PROPOSED FROM 1950 - 1971

Author & Year	Ref. No.	Basis of Criteria	Protection Goal	Actual or Computed* Octave Band SPL 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600	Actual or Computed** dB(A)
Kryter (1950)	73	No "critical band"[1] >85 dB SPL (re: 0.0002 MB)	No PTS or TTS	81	85	90	93	96	97	96	95[2]	88**
		No "critical band" >85 dB SPL (re: MAF)	No PTS or TTS	125	115	108	101	100	92	87	102[2]	94**
Hardy (1952)	131	100 Sones[3] per octave	Upper limit, above which definite hazard to hearing exists	115	112	108	106	104	95	91	102	98**
		50 Sones per octave	Lower limit below which no hazard to hearing exists	104	100	97	95	92	87	85	95	92**
Rosenblith & Stevens (1953)	74	Octave Band SPL with respect to the sensitivity of the ear-Wide Band Noise	Prevention of permanent damage due to noise	110	102	97	95	95	95	95	95	102**

CONTINUATION (2) OF TABLE IX

Author & Year	Ref. No.	Basis of Criteria	Protection Goal	Actual or Computed* Octave Band SPL 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600	Actual or Computed** dB(A)
Rosenblith & Stevens (1953)	74	Same as above except for pure tones and critical bands of noise	Prevention of permanent damage due to noise	100	92	87	85	85	85	85	85	Not Applicable
Lindman (1955)	132	Interpolation between sound pressure of sorting octaves[4] & allowance for less sensitivity in lower frequencies	Protects most, but not all persons with unprotected ears	110	105	100	90	90	85	85	85	92**
CFR 160-3 (1956)	108	Octave Band Levels at or above which ear protection must be used	Preservation of hearing of 15 dB or better at the frequencies 500, 1000, 2000 cps.	---	---	---	95	95	95	95	---	102**
		Octave Band Levels at or above which the use of ear protection is recommended	Same as above	---	---	---	85	85	85	85	---	92**

CONTINUATION (3) OF TABLE IX

Author & Year	Ref. No.	Basis of Criteria	Protection Goal	Actual or Computed* Octave Band SPL 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600	Actual or Computed** dB(A)
AAOO (1957)	133	Octave Band SPL at these bands most likely to have an effect on the frequency listed in a protection goal	Protect man's hearing for speech (i.e. losses at 500, 1000, 2000 Hz)	---	---	---	---	-85	85	---	---	92**
Jones & Church (1960)	134	Octave Band SPL	Allowable weekly exposure dose, determining when hearing conservation is mandatory	100	91	87	86	85	85	85	92	92**
ISO (1961)	80	Octave Band Levels Primary Emphasis on those with center Frequency 500, 1000, 2000, NR Curve 85	Protect against TTS_5 or PTS_5 greater than 12dB at 500, 1000, 2000 for 50% of the persons exposed	102	95	91	87	85	82	80	79	86**
Kryter (1963 & 1965)	135 136	Octave Band Levels-Broad Band Noise	Protect against normal ears producing TTS_2 of 10 dB at 1000 Hz, 15 dB at 2000 Hz, & 20 dB at 3000 Hz.	---	98	92	89	86	85	85	86	92**

CONTINUATION (4) OF TABLE IX

Author & Year	Ref. No.	Basis of Criteria	Protection Goal	Actual or Computed* Octave Band SPL 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600	Actual or Computed** dB(A)
Kryter (1963 & 1965)	135 136	Narrow Band Levels	Protect against normal ears producing TTS_2 of 10 dB at 1000 Hz, 15 dB at 2000 Hz, & 20 dB at 3000 Hz	---	93	87	84	81	80	80	81	Not applicable
AAOO (1964)	137	Octave Band Levels encompassing "Speech Frequencies"	Prevention of hearing loss in those people who are "normally" susceptible at the frequencies 500, 1000, 2000 Hz	---	---	---	85	85	85	---	---	92**
CHABA (1966)	107	Octave Band Levels	No permanent or temporary loss greater than 10 dB at 1000 Hz, 15 dB at 2000 Hz, and 20 dB at 3000 Hz in 50% of the people exposed	---	98	92	89	86	85	85	86	98**
		Narrow Band Levels			92	88	84	81	80	80	81	Not applicable
		Pure Tones		---	92	88	84	81	80	80	81	Not applicable

CONTINUATION (5) OF TABLE IX

Author & Year	Ref. No.	Basis of Criteria	Protection Goal	Actual or Computed* Octave Band SPL 20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600	Actual or Computed** dB(A)
Intersociety (1970)	27	dB(A)	An increase of 10 percentage points (10 more people per 100) in the number of people who develop hearing impairment[5] by retirement age due to exposure									90
British Occupational Hygiene Society (1971)	87	Noise immision based on dB(A) and total duration of exposure	Protect 99% of the exposed population from developing an average NIPTS of 40 dB or average hearing level of 48 dB for the freeuencies .5, 1, 2, 3, 4, & 6 KHz									90
Kryter (1970)	88	Octave Band Level	Maximum allowable TTS or PTS for 75% of those exposed limited to 0 dB below 2 KHz and 10 dB above 2 KHz	91	83	78	73	68	61	52	53	65

* Damage risk criteria not given in octave band levels, but computed by author referenced by number following OBL 4800-9600 Hz.

CONTINUATION (6) OF TABLE IX

** Computed, assuming a "pink" noise spectrum (equal energy in each octave band).

1. Critical band -- ". . . is that frequency band of sound, being a portion of a continuous-spectrum noise covering a wide band that contains sound power equal to that of a simple (pure) tone centered in the critical band and just audible in the presence of the wide-band noise." (Reference 4)

2. From Eldredge, D. H. (Reference 91)

3. Sone -- ". . . a unit of loudness. By definition, a simple tone of frequency 1000 cycles per second, 40 decibels above a listener's threshold, produces a loudness of 1 sone. The loudness of any sound that is judged by the listener to be _n_ times that of the 1-sone tone is _n_ sones." (Reference 4)

4. Levels selected by Z24-X-2 sorting octaves (Reference 138)

5. Average hearing level at 500, 1000, and 2000 Hz of 15 dB re ASA (1951) or 25 dB re ANSI (1969). (References 15 and 95)

TABLE X

Acceptable exposures to noise in dBA as a function of the number of occurrences per day. (From Guidelines for Noise Exposure Control, 1970)

Daily Duration		Number of times the noise occurs per day						
Hours	Min	1	3	7	15	35	75	160 up
8		90	90	90	90	90	90	90
6		91	93	96	98	97	95	94
4		92	95	99	102	104	102	100
2		95	99	102	106	109	114	
1		98	103	107	110	115		
	30	101	106	110	115			
	15	105	110	115				
	8	109	115					
	4	113						

To use the table, select the column headed by the number of times the noise occurs per day, read down to the average sound level of the noise and locate directly to the left in the first column the total duration of noise permitted for any 24 hour period. It is permissible to interpolate if necessary. Noise levels are in dBA.

TABLE XI

Distribution of NIOSH Data Over
Noise Exposure Level, Age, and Experience

Age Groups (in yrs.)	17-27	28-35	36-45	46-54	55-70
Number of Workers	228	292	287	215	150
Experience Groups (in yrs.)	0-1	2-4	5-10	11-20	21-41
Number of Workers	133	154	308	314	263
Exposure Groups* (in dBA-Slow)	<80	80-84	85-89	90-94	95-102
Number of Workers	380	51	387	314	40

*In the data analysis, noise exposure levels were not grouped.

TABLE XII

DEPENDENCE OF HEARING IMPAIRMENT ON AGE,
EXPERIENCE, AND NOISE EXPOSURE -- HLI (0.5, 1, 2)

	Noise Exposure in dBA-Slow					
	80*	80	85	90	95	100
Experience: 2 - 4 years						
Age (in years)						
17-27	1.3	1.5	2.4	3.9	6.0	9.0
28-35	3.2	3.5	5.5	8.2	11.9	16.6
36-45	4.9	5.3	8.0	11.6	16.2	--
46-54	9.1	9.8	14.0	19.2	25.4	32.6
Experience: 5-10 years						
Age (in years)						
17-27	1.3	1.5	2.8	4.9	--	--
28-35	3.3	3.7	6.2	10.0	15.2	22.0
36-45	5.0	5.5	9.0	13.8	20.2	28.2
46-54	9.3	10.2	15.4	22.3	30.6	--
Experience: 11-20 years						
Age (in years)						
28-35	3.3	3.8	6.8	11.5	--	--
36-45	5.0	5.7	9.7	15.7	23.6	33.3
46-54	9.4	10.4	16.6	24.7	34.6	45.7
55-70	20.0	21.7	31.0	41.8	--	--
Experienced: 21-41 years						
Age (in years)						
36-45	5.2	6.0	11.7	20.4	32.2	--
46-54	9.6	10.9	19.3	30.8	44.6	59.0
55-70	20.4	22.6	34.9	49.0	63.3	75.9

*Non-Noise Exposed

TABLE XIII

DEPENDENCE OF HEARING IMPAIRMENT ON AGE,
EXPERIENCE, AND NOISE EXPOSURE -- HLI ($\overline{1, 2, 3}$)

	Noise Exposure in dBA-Slow					
	80*	80	85	90	95	100
Experience: 2-4 years						
Age (in years)						
17-27	1.4	1.6	2.7	4.4	6.8	10.2
28-35	7.4	8.0	11.8	16.7	22.8	29.9
36-45	8.3	9.0	13.1	18.3	24.7	--
46-54	16.9	18.0	24.4	31.7	39.9	48.5
Experience: 5-10 years						
Age (in years)						
17-27	1.5	1.8	4.0	8.0	--	--
28-35	7.7	8.8	15.7	25.5	37.7	51.3
36-45	8.7	9.8	17.2	27.5	40.1	53.8
46-54	17.5	19.4	30.3	43.3	57.0	--
Experience: 11-20 years						
Age (in years)						
28-35	7.9	9.1	17.6	29.7	--	--
36-45	8.8	10.2	19.2	31.9	47.2	62.9
46-54	17.8	20.0	32.9	48.3	64.0	77.6
55-70	27.6	30.4	45.7	61.6	--	--
Experience: 21-41 years						
Age (in years)						
36-45	8.7	9.8	17.2	40.0	--	
46-54	17.5	19.4	30.2	43.2	56.9	69.9
55-70	27.3	29.6	42.7	56.5	69.7	80.6

*Non-Noise Exposed

TABLE XIV

COMPARISON OF RISK* FOR RETIREMENT AGE POPULATIONS
AS DETERMINED BY INTERSOCIETY COMMITTEE AND NIOSH

	dBA	80	85	90	95	100
	Total Percent Impaired	23	26	33	43	56
Intersociety**	Normal Percent Impaired	22	22	22	22	22
	Risk	1	4	11	21	34
	Total Percent Impaired	11	19	31	45	59
NIOSH*** (Age 46-54)	Normal Percent Impaired	10	10	10	10	10
	Risk	1	9	21	35	49
	Total Percent Impaired	23	35	49	63	76
NIOSH*** (Age 55-70)	Normal Percent Impaired	20	20	20	20	20
	Risk	3	15	29	43	56

*Where impairment is defined as average threshold level in excess of 15 dB re ASA 1951 (25 dB re ANSI (1969)) at 500, 1000, 2000 Hz.

**Age group 50-59, assumes monotonic growth of exposure with age.

***Age groups 46-54 and 55-70, respectively, experience 21-41 years. (See Table VII-2a)

TABLE XV

COMPARISON OF RISK* FOR RETIREMENT AGE POPULATIONS
AS DETERMINED BY INTERNATIONAL ORGANIZATION
FOR STANDARDIZATION AND NIOSH

		Age 50 Years				
	dBA	80	85	90	95	100
	Total Percent Impaired	14	22	32	45	50
ISO**	Normal Percent Impaired	14	14	14	14	14
	Risk	0	8	18	31	44
	Total Percent Impaired	11	19	31	45	59
NIOSH*** (Age 46-54)	Normal Percent Impaired	10	10	10	10	10
	Risk	1	9	21	35	49

		Age 60 Years				
	dBA	80	85	90	95	100
	Total Percent Impaired	33	43	54	62	74
ISO**	Normal Percent Impaired	33	33	33	33	33
	Risk	0	10	21	29	41
	Total Percent Impaired	23	35	49	63	76
NIOSH*** (Age 55-70)	Normal Percent Impaired	20	20	20	20	20
	Risk	3	15	29	43	56

*Where impairment is defined as average threshold level in excess of 15 dB re ASA 1951 (25 dB re ANSI(1969)) at 500, 1000, 2000 Hz.

**Ages 48 and 58 years, respectively, experience is equal to Age - 18 years.

***Age groups 46-54 and 55-70, respectively, experience is 21-41 years.

TABLE XVI

COMPARISON OF RISK* FOR RETIREMENT AGE POPULATION
AS DETERMINED BY ROBINSON AND NIOSH

Age 50 Years

	dBA	87	92	97	102
	Total Percent Impaired				
	a) thresholds re:97 British controls	3	8	17	33
	b) thresholds re:+10 dB correction	16	26	40	59
Robinson**	Normal Percent Impaired				
	a) thresholds re:97 British controls	1	1	1	1
	b) thresholds re:+10 dB correction	3	3	3	3
	Risk				
	a) thresholds re:97 British controls	3	8	17	33
	b) thresholds re:+10 dB correction	13	23	37	56
	Total Percent Impaired	24	36	50	65
NIOSH***	Normal Percent Impaired	10	10	10	10
	Risk	14	26	40	55

*Where impairment is defined as average threshold level in excess of 15 dB re ASA 1951 (25 dB re ANSI(1969)) at 500, 1000, 2000 Hz.

**Based on 30 years exposure. Risk computed by Robinson[87] using a fence of 25 dB re ANSI (1969).

***Age group 46-54, experience is 21-41 years.

TABLE XVII

COMPARISON OF NIOSH RISK VALUES FOR TWO DEFINITIONS OF HEARING IMPAIRMENT

Age 46-54 Experience 21-41

	dBA	80	85	90	95	100
	Total Percent Impaired	11	19	31	45	59
HLI $(\overline{0.5,1,2})$	Normal Percent Impaired	10	10	10	10	10
	Risk	1	9	21	35	49
	Total Percent Impaired	19	30	43	57	70
HLI $(\overline{1,2,3})$	Normal Percent Impaired	18	18	18	18	18
	Risk	1	12	25	39	52

Age 55-70 Experience 21-41

	dBA					
	Total Percent Impaired	23	35	49	63	76
HLI $(\overline{0.5,1,2})$	Normal Percent Impaired	20	20	20	20	20
	Risk	3	15	29	43	56
	Total Percent Impaired	30	43	56	70	81
HLI $(\overline{1,2,3})$	Normal Percent Impaired	27	27	27	27	27
	Risk	3	16	29	43	54

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