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HAZARDOUS EXPOSURE TO INTERMITTENT AND STEADY-STATE NOISE

Karl D. Kryter

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NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics

Working Group 46

Report of Working Group 46.
Hazardous exposure to
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(Limited distribution)

NAS-NRC Committee on Hearing,
Bioacoustics, and Biomechanics

HAZARDOUS EXPOSURE TO INTERMITTENT AND STEADY-STATE NOISE (U)

Report of Working Group 46

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January 1965

Foreword

The following document was prepared by CHABA Working Group 46. This group was charged, upon request from the Surgeon General of the U. S. Army, to specify damage risk criteria for exposure to sound. The report contains graphs of maximum sound pressure levels and durations of exposures that the Working Group believes would be tolerable and examples of the use of these graphs. This material is followed with background information and a discussion of the rationale, assumptions, limitations, and general problems pertinent to the development and application of a damage risk criterion and related exposure contours.

The report is intended primarily for technical persons working in this problem area in the military services and other government agencies. No attempt is made to interpret or simplify the report or procedures contained therein for special or particular operational situations.

Karl D. Kryter, Chairman
Working Group 46

January, 1965

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HAZARDOUS EXPOSURE TO INTERMITTENT AND STEADY-STATE NOISE

Graphic Representation of Damage Risk Contours[1]

Figures 1 and 2 present damage risk contours for octave bands and one-third octave bands of noise. Figure 3 presents damage risk contours for pure tones. Figures 4 through 11 provide functions showing damage risk contours for interrupted exposures to bands of noise. Figures 1 through 11 are to be applied to diffuse field and, presumably, free field environments.

Although the damage risk contours presented in the following figures are in terms of pure tones or one-third and full octave bands of noise, these figures are to be used in the evaluation of noises that have greater bandwidths, i.e., extend over more than one octave. The level of each one-third or full octave band in a broader band noise of a specified duration is to be compared to the damage risk contours given in the figures which follow.

If any single band exceeds the damage risk contours specified, the noise can be considered as potentially unsafe. As progressively more one-third or octave bands of a broader band noise reach the damage risk contours, the hearing loss will become extended over a wider and wider range of the sound frequencies to which the ear is sensitive. Nevertheless, hearing loss at any one frequency region should not be significantly greater than that expected from exposure to a band of noise located about one-half octave below that particular frequency region (Kryter, 1960; 1963; Ward, Glorig, & Sklar, 1959a).

---

[1]The phrase "damage risk contours" refers to curves showing various relations among sound pressure level, band center frequency of a sound, and the temporal nature of exposures that will provide the damage risk to hearing specified in a criterion. The criterion of what constitutes a tolerable hearing loss or a tolerable damage risk to hearing accepted by the Working Group is given in a later section.

Fig. 1

Purpose: (a) To show the maximum allowable sound pressures for bands of noise of known frequency and duration to which a person is exposed but once per day.

Example: The maximum tolerable sound pressure level allowed for a daily exposure duration of 50 minutes (min) to a 2400-4800 cycles per second (cps) octave band of noise is found by entering Fig. 1 on the vertical line for a 50 min duration. This line crosses the curve for the 2400-4800 cps band at approximately 89 decibels (dB) (left-hand ordinate). Therefore, the maximum tolerable level is 89 dB.

Example: A noise that has a width of one-third octave or less, an approximate band center frequency of 4000 cps and a daily duration of 50 min would have a maximum tolerable level of about 84 dB (right-hand ordinate).

Purpose: (b) To show the maximum allowable durations for bands of noise of known frequency and sound pressure level to which a person is exposed but once per day.

Example: The maximum daily duration for a 2400-4800 cps octave band of noise having a sound pressure level of 100 dB is found by entering Fig. 1 on the horizontal line for an octave band level of 100 dB (left-hand ordinate). This line crosses the curve for the 2400-4800 cps band at 9 min, the maximum allowable duration once per day.

Example: A noise that has a width of one-third octave, an approximate band center frequency of 4000 cps and a sound pressure level of 100 dB (right-hand ordinate) would have a maximum tolerable daily duration of 5 min.

In a similar manner, one can find either maximum sound pressure levels for given durations or maximum once-per-day durations for given sound pressure levels for the octave and one-third octave or narrower bands of noise indicated on Fig. 1.

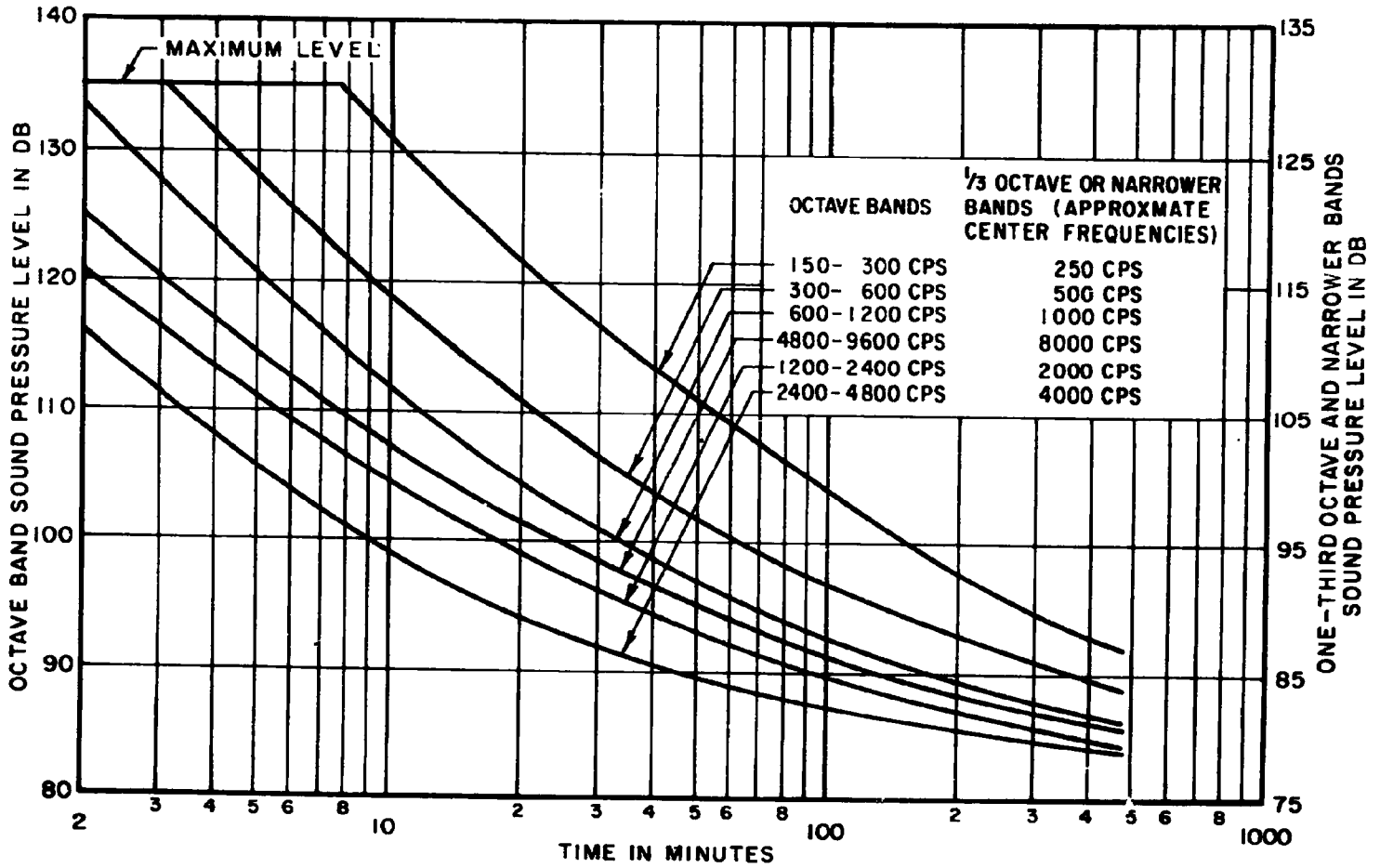

Fig. 1 Damage risk contours for one exposure per day to certain octave (left-hand ordinate) and certain one-third octave or narrower (right-hand ordinate) bands of noise. This graph can be applied to individual band levels present in broad band noise.

Fig. 2

Purpose: To show the maximum tolerable sound pressure levels for various once-per-day durations of exposures to bands of noise having any particular center frequency.[2]

Example: The maximum tolerable sound pressure level of an octave band of noise having a band center frequency of 3000 cps and a daily duration of 3 min is found by entering Fig. 2 on the vertical line for 3000 cps; this line intercepts the 3 min duration contour for an octave band at 110 dB (left-hand ordinate), the maximum tolerable level once per day for that noise.

Example: The vertical line for a one-third octave band of noise having a center frequency of 3000 cps intercepts the 3 min contour at 105 dB (right-hand ordinate), the maximum tolerable level once per day for that noise.

[2]The band center frequencies and cutoff frequencies of filters that are generally used will be found in Table 2 of this report.

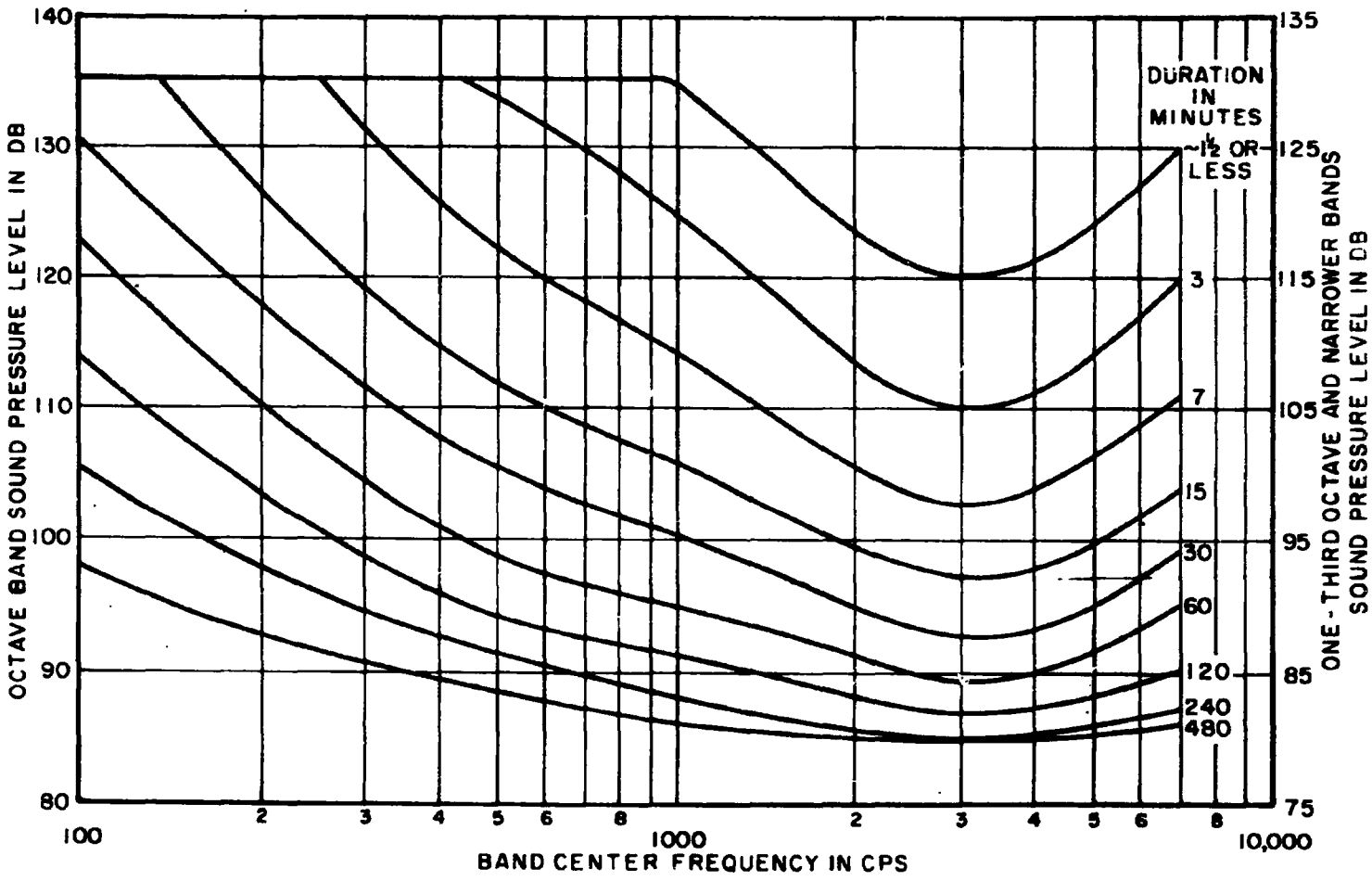

Fig. 2 Damage risk contours for one exposure per day to octave (left-hand ordinate) and one-third octave or narrower (right-hand ordinate) bands of noise. This graph can be applied to individual band levels present in broad band noise.

Fig. 3

Purpose: The purpose and use of Fig. 3 are the same as Fig. 2, except that Fig. 3 should be used only when the sound is predominantly a pure tone.

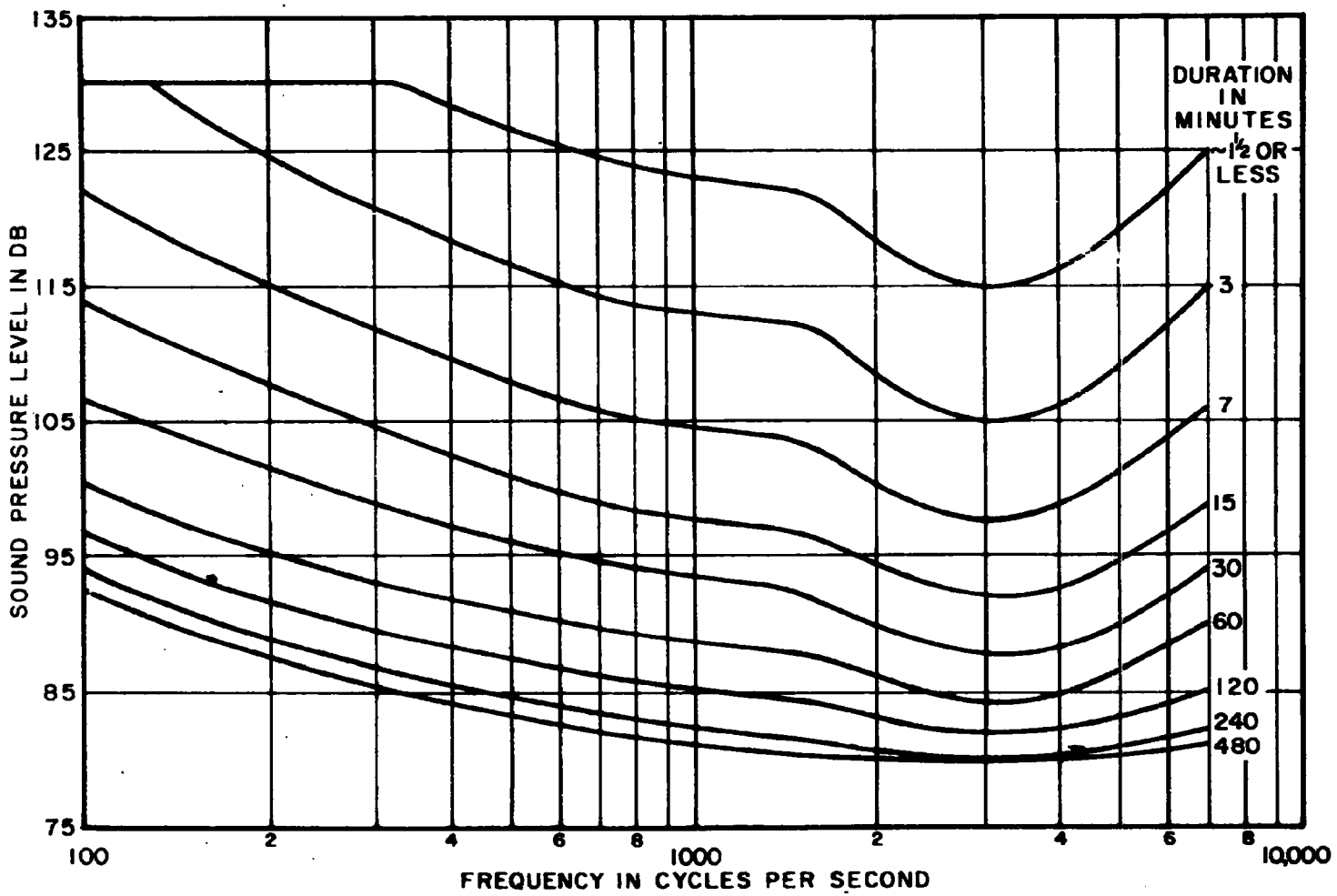

Fig. 3 Damage risk contours for one exposure per day to pure tones.

Use of Figs. 1, 2, and 3 with Sounds Having Fluctuating Level

Figures 1, 2, and 3, for single exposures, apply not only to noises whose level is constant over the exposure period, but also to those with a fluctuating level, provided that (a) the noise does not remain at a single level more than 2 min, and (b) the level never drops below the 480 min curves on Figs. 2 and 3, i.e., the level that can be tolerated for a full work-day. The effective level of such a varying noise is equal to the average sound pressure level (SPL) of the noise over the exposure period.

Example: The level of a noise whose maximum energy is in the 1200-2400 cps octave band varies between 90 and 110 dB, 30 second (sec) bursts of 110 dB alternating with 90 sec intervals of 90 dB. The effective level is, therefore,

$$(30 \text{ sec} \times 110 \text{ dB} + 90 \text{ sec} \times 90 \text{ dB})/(30 \text{ sec} + 90 \text{ sec}) = 95 \text{ dB SPL}.$$

From Fig. 2, the maximum tolerable exposure to this noise is seen to be about 35 min.

Example: A generator with a pronounced whine at 1000 cps varies in output level between 100 and 120 dB. Measurement shows that the time distribution of the levels is as follows: 120 dB 25 per cent of the time, 110 dB 40 per cent, and 100 dB 35 per cent. The average level is, therefore, $120 \times .25 + 100 \times .40 + 100 \times .35 = 109$ dB. Figure 3 indicates that the maximum tolerable exposure to this whine is about 5 min.

Figs. 4, 5, 6, and 7

The use of Figs. 4, 5, 6, and 7 is limited to situations in which (a) there is alternation between noise and effective quiet throughout the duration of daily exposure, and (b) individual noise bursts do not exceed 2 min in duration. "Effective quiet" exists when the noise level drops below the 480 min curves of Figs. 2 and 3; the "duration of daily exposure" consists of the sum of the durations of the noise bursts and the effective quiet. "On-fraction" (the parameter of Figs. 4, 5, 6, and 7) is the ratio of noise burst duration to duration of daily exposure; thus, it is not the ratio of noise time to quiet time, but the noise time divided by the noise-time-plus-quiet-time.

Purpose: (a) To show the maximum tolerable sound pressure levels for bands of noise having certain center frequencies.

Example: The maximum tolerable level of the 300-600 cps octave band of noise that is on for 1 min periods followed by 1 min periods of relative quiet (an on-fraction of 0.5) and a total period of exposure that continues for 60 min is found by entering Fig. 4 on the vertical line for 60 min. This line crosses the curve for an on-fraction of 0.5 at a sound pressure level of approximately 127 dB (left-hand ordinate of Fig. 4), the maximum tolerable level for the 300-600 cps octave band, during the "on" period. The maximum tolerable level in a 300-600 cps octave band of noise would be 89 dB during the "off" period in this case.

Purpose: (b) To show the maximum duration of daily exposure for bands of noise having certain center frequencies and known sound pressure levels and known on-fraction.

Example: A one-third octave band of noise centered at 500 cps (Fig. 4) has a level that follows this sequence repetitively: 30 sec at 110 dB SPL, 30 sec at 100 dB, and 40 sec at 70 dB. The noise is, therefore, "on" for 60 sec at an effective level of 105 dB, and "off" for 40 sec, giving an on-fraction of 60/(60 + 40) = 0.6. The point of intersection of the 0.6 on-fraction contour and the 105 dB right-hand ordinate (since this is a one-third octave band of noise) is at 130 min. Thus, 2 hours (hr) of exposure to this particular sequence can just be tolerated.

The use of Figs. 5, 6, and 7 is the same as that illustrated above for Fig. 4, except, of course, that they should be used only when the sound has the band limits or the band center frequencies indicated on the respective figures.

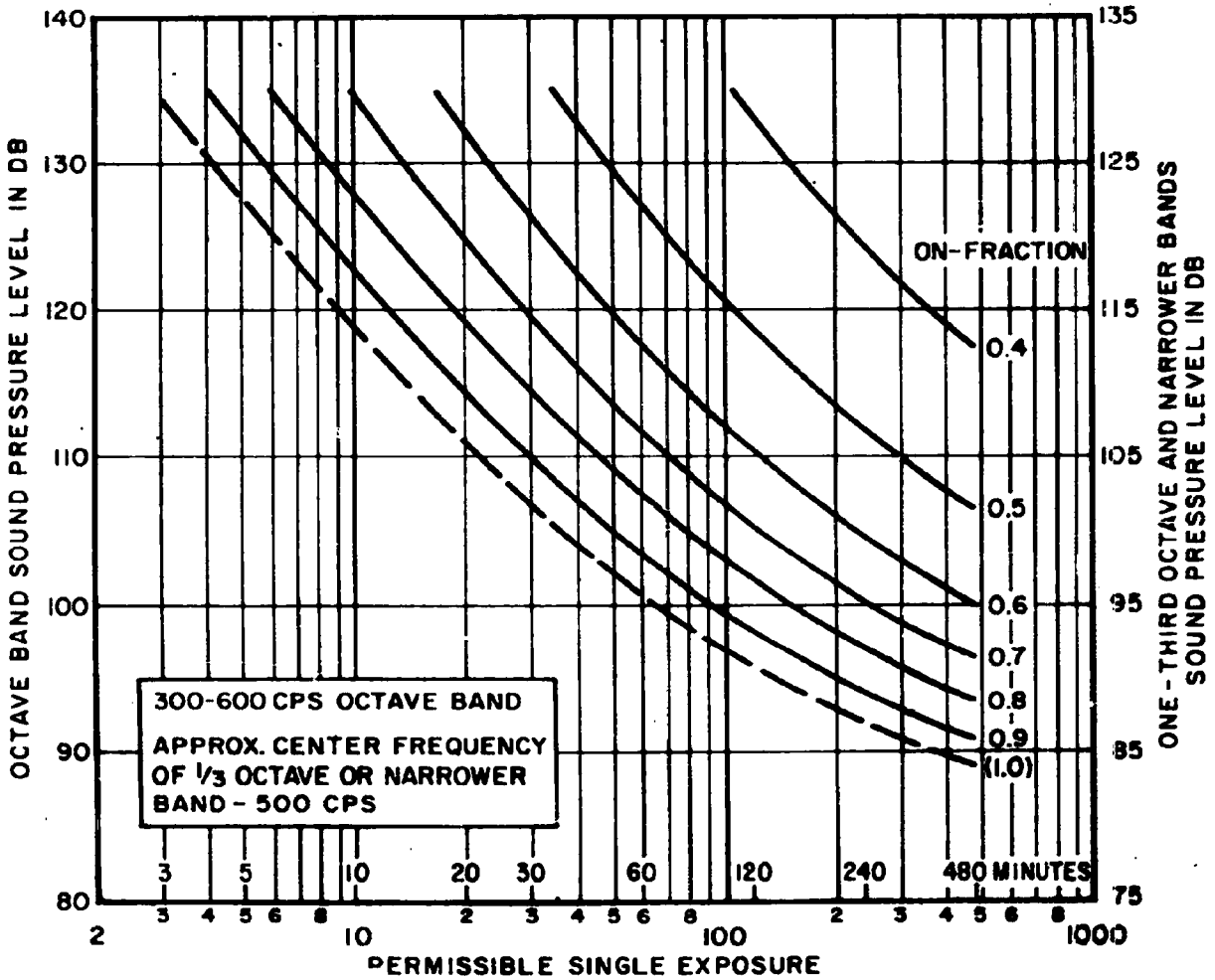

Fig. 4 Damage risk contours for short-burst-duration intermittent noise (noise bursts 2 minutes or less in duration).

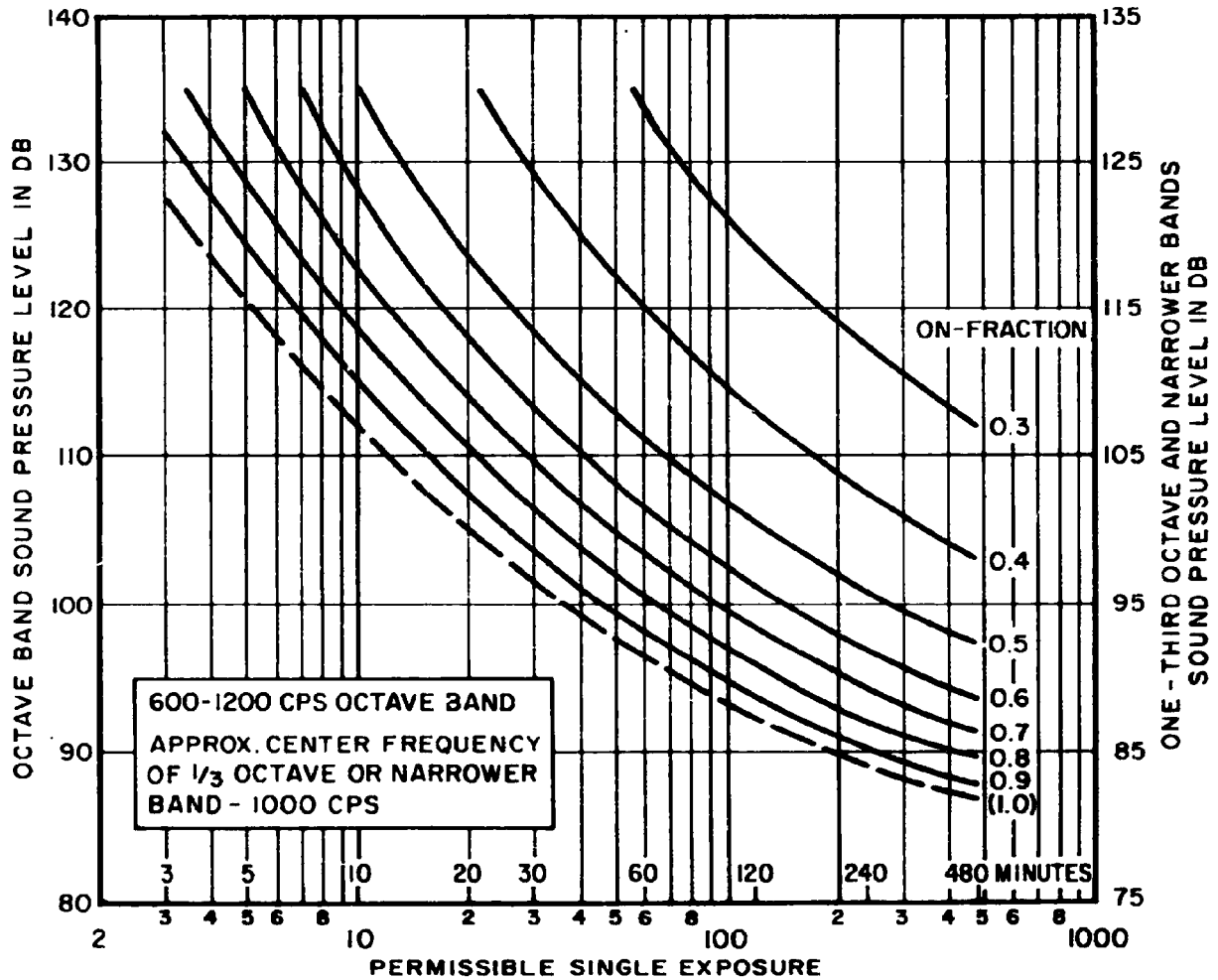

Fig. 5 Damage risk contours for short-burst-duration intermittent noise (noise bursts 2 minutes or less in duration).

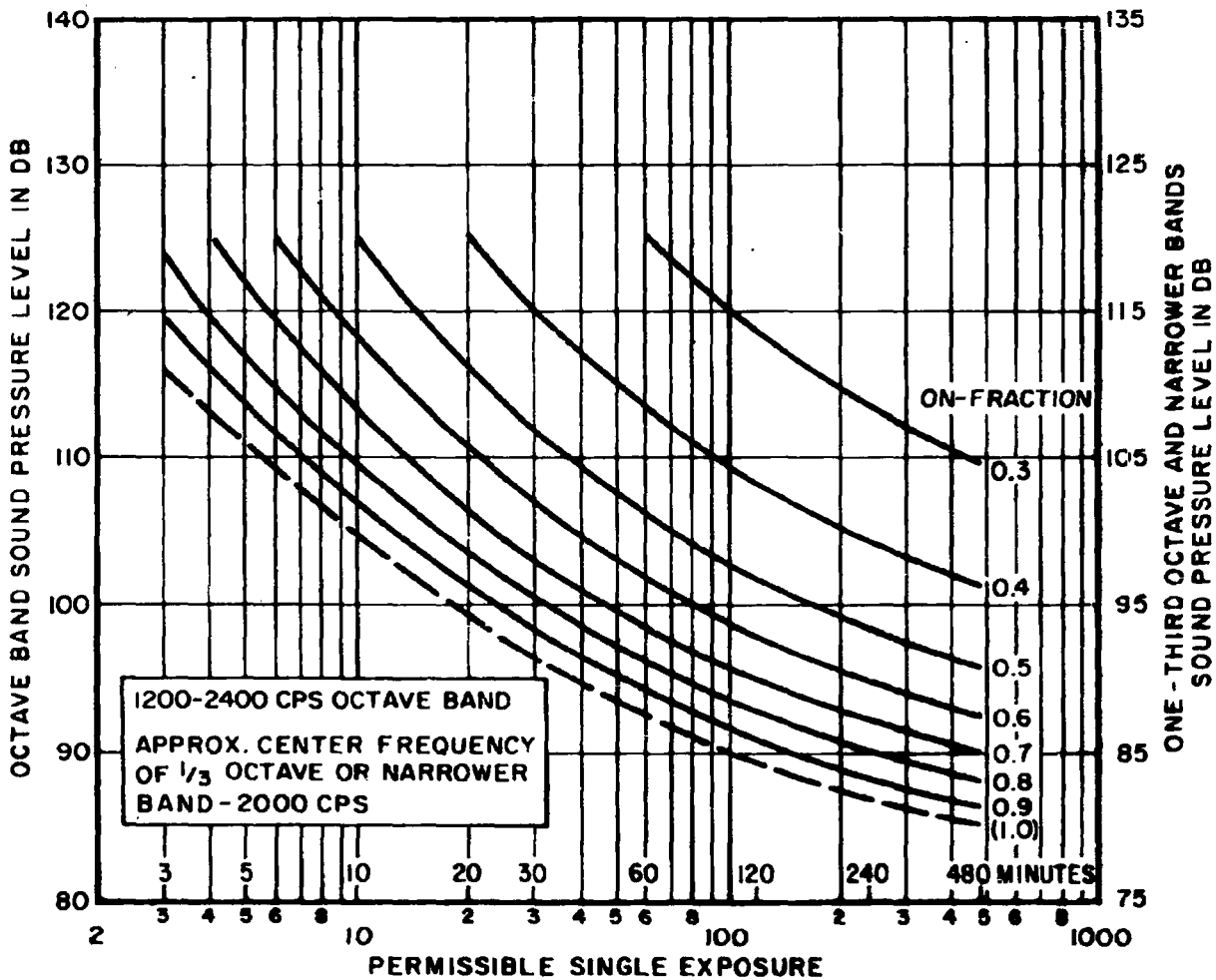

Fig. 6 Damage risk contours for short-burst-duration intermittent noise (noise bursts 2 minutes or less in duration).

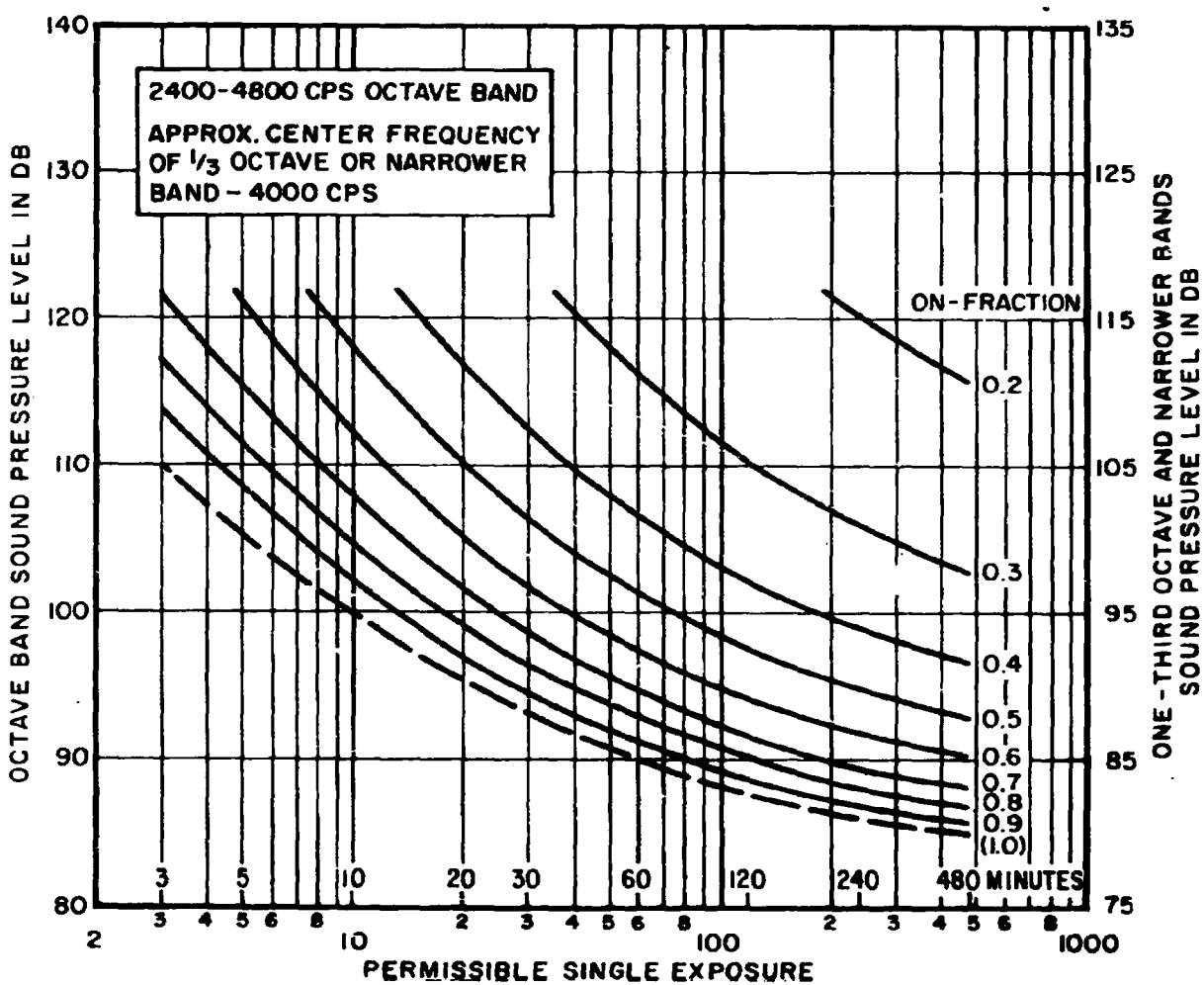

Fig. 7 Damage risk contours for short-burst-duration intermittent noise (noise bursts 2 minutes or less in duration).

Figs. 8, 9, 10, and 11

Purpose: To show the interval of effective quiet that must follow an exposure to an octave band or one-third octave or narrower band of noise having a specified sound pressure level and duration, before the exposure can be repeated during the work day. Effective quiet, again, exists whenever the noise level drops below the contour in Fig. 2 for 480 min. These figures are to be used when the noise bursts are longer than 2 min in duration.

Example: A 300-600 cps octave band of noise (Fig. 8) having a sound pressure level of 115 dB (fourth contour from the left, as indicated by the top row of numbers on Fig. 8), and a duration of 10 min would require 45 min of effective quiet following the noise burst before a person could be exposed again to the noise, throughout the 480 min work day. Thus, an individual could be exposed eight or nine times to this 10 min noise during the work day, provided he was given a 45 min rest between each exposure.

Example: A one-third octave band of noise with a center frequency of 2000 cps displays the following time course. For 10 min the noise level alternates regularly between 90 and 100 dB, then drops to 70 dB (effective quiet) for 30 min. The effective level of the noise during the 10 min is thus 95 dB; Fig. 10 indicates that a 10 min exposure to 95 dB (third contour from the left, indicated by the second row of numbers at the top of Fig. 10), need be followed by only about 16 min of effective quiet. Therefore, the observed pattern (10 min noise, 30 min quiet) is tolerable over the 8 hr work day.

Example: A noise having its maximum energy in the octave band 2400-4800 cps has an effective level of 100 dB and must be on for 10 min. The intersection of the 100 dB octave band contour in Fig. 11 and the 10 min burst duration (abscissa) cannot be found on the graph, suggesting that a single 10 min exposure will probably exceed the criterion. This is verified by consulting Fig. 1, which shows that a single 9 min exposure is all that can be tolerated in a single day.

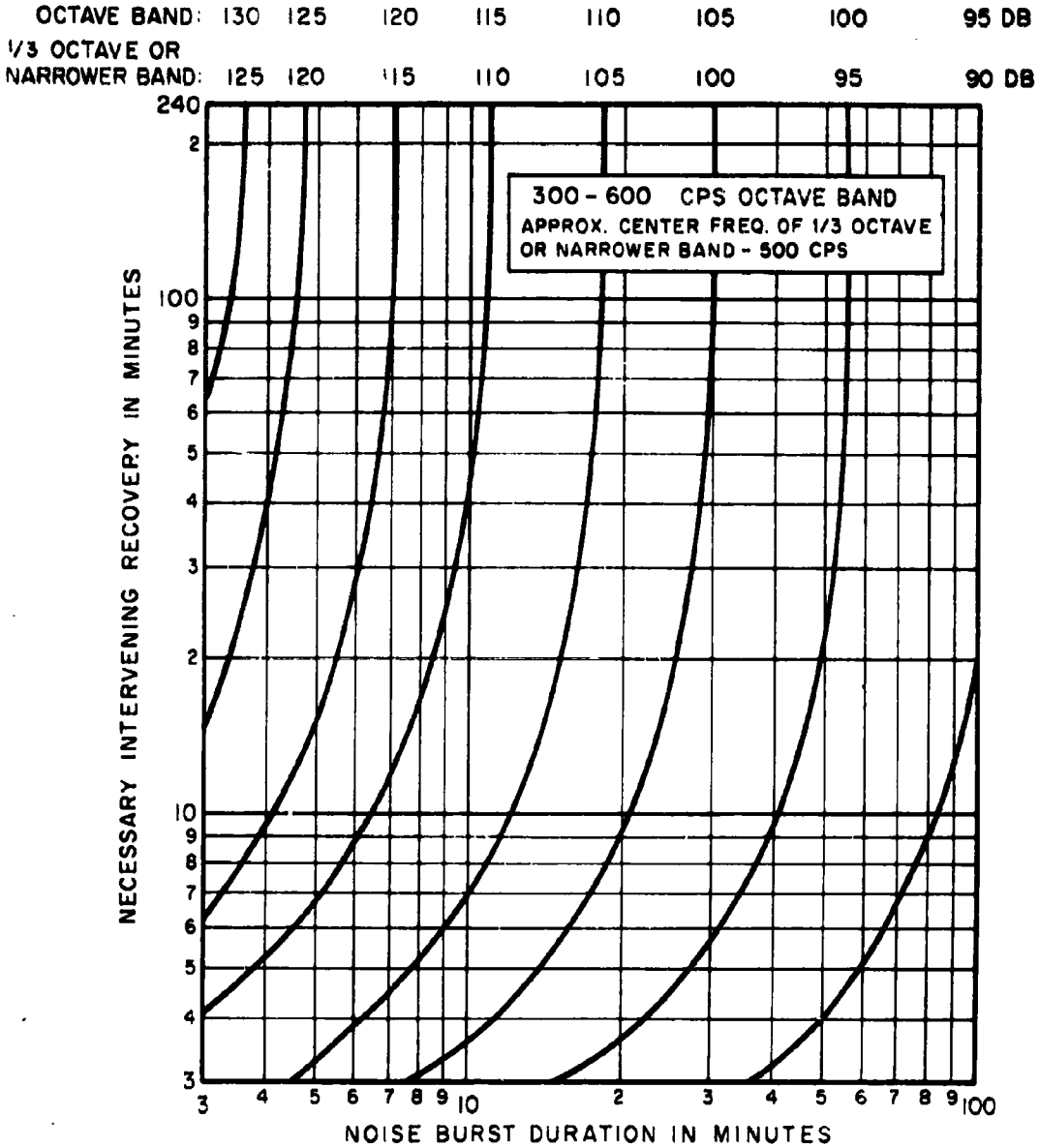

Fig. 8 Damage risk contours for long-burst-duration interrupted noise parameter: Band SPL.

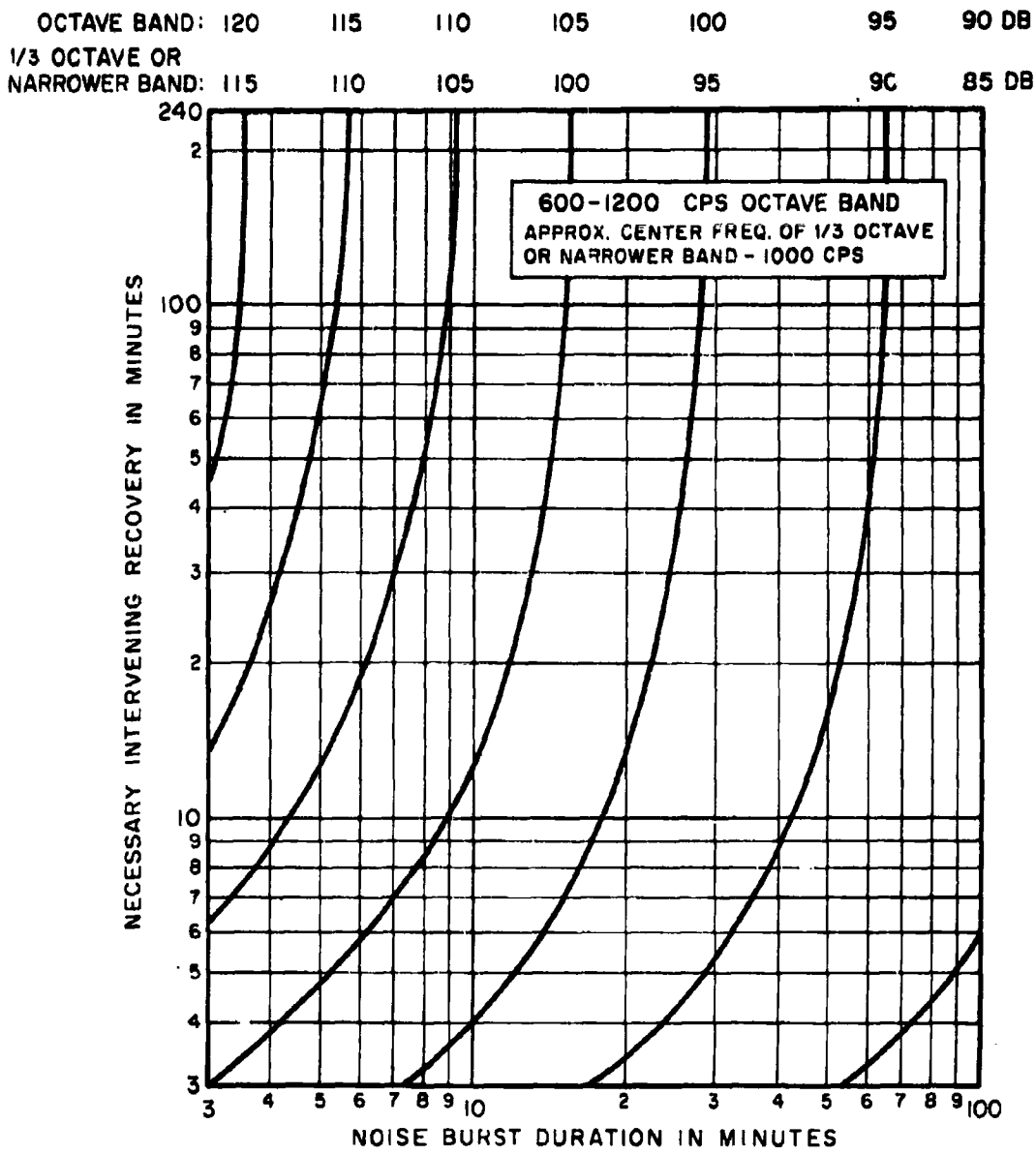

Fig. 9 Damage risk contours for long-burst-duration interrupted noise parameter: Band SPL.

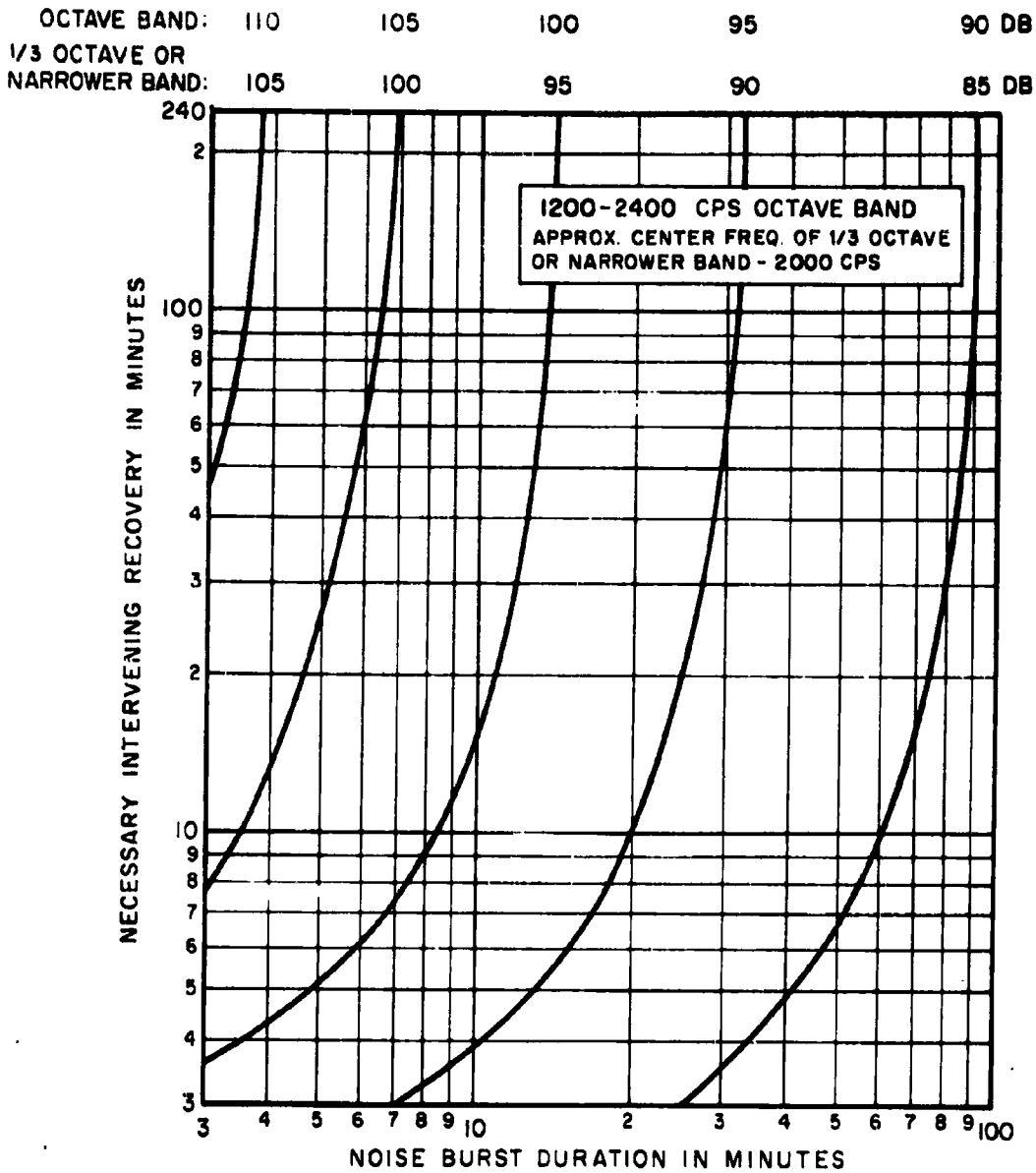

Fig. 10 Damage risk contours for long-burst-duration interrupted noise parameter: Band SPL.

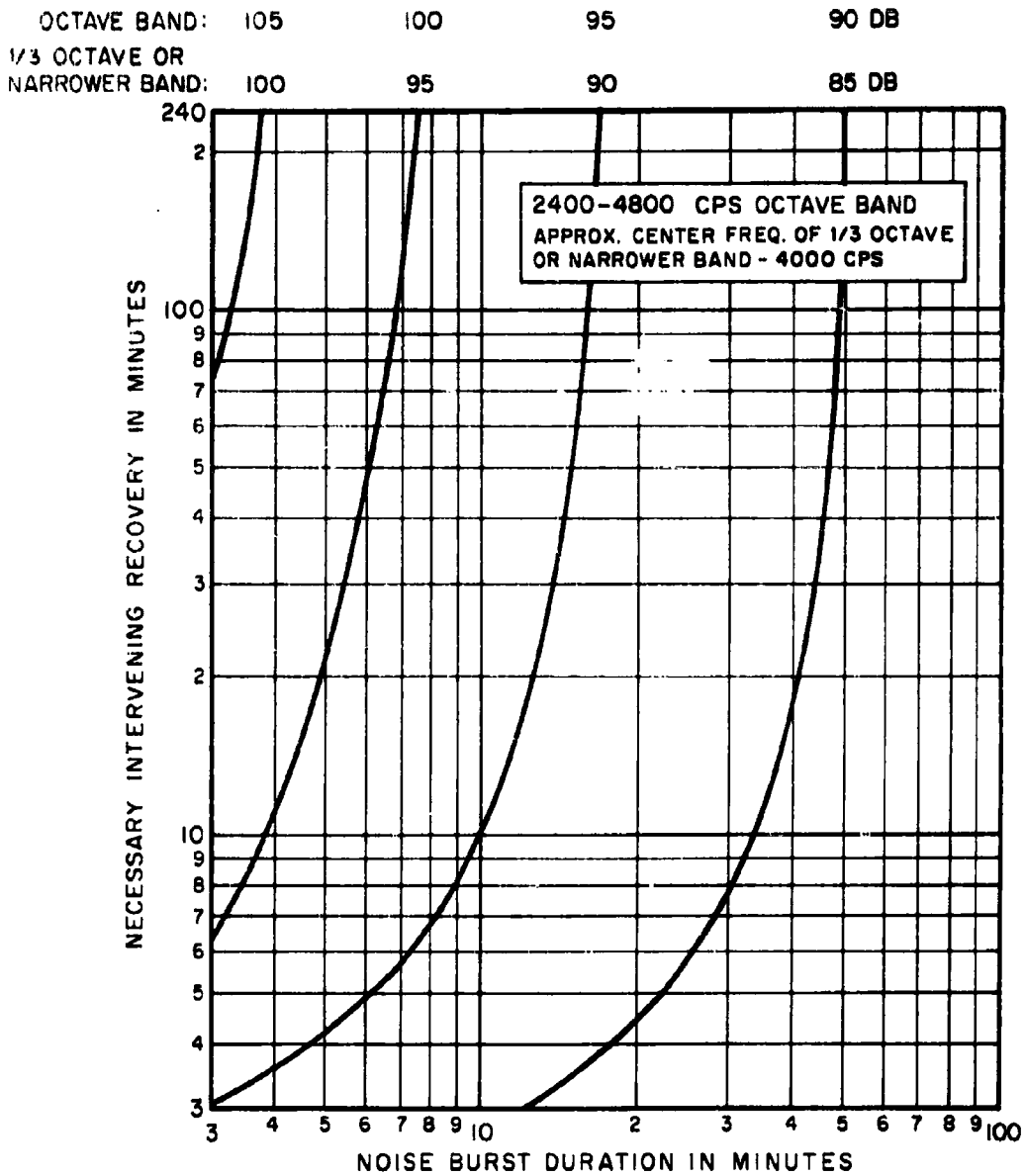

Fig. 11 Damage risk contours for long-burst-duration interrupted noise parameter: Band SPL.

Discussion of Damage Risk Contours

Relations shown in Figs. 1 through 11 are based either upon direct measures of temporary threshold shifts or permanent noise-induced losses in hearing resulting from exposure to sound or extrapolations from such data, as will be discussed later. In general, there has been a sufficient amount of research in this problem area so that both the data points and extrapolations have been verified to a reasonable extent by one or more independent investigations. However, some of the relations are based on less evidence than others. For example:

1. The maximum levels to be allowed regardless of duration (the top curves of Figs. 1 and 3) are estimates that are not supported by direct experimental data.

2. The data supporting the damage risk contours for pure tones are not as extensive as those for the octave or one-third octave bands of noise, and as such may be subject to change. Because of the extensiveness and similarity of results found with bands of noise by various investigators, it is felt that the damage risk contours for bands of noise are valid.

3. As yet, there are very few data on the effects of sounds below 100 cps and above about 7000 cps. In the opinion of the Working Group there is at the present time insufficient evidence to warrant extrapolating the damage risk contours as a function of frequency beyond the frequencies mentioned.

4. It is found that noises that are one octave in width will provide a degree of shift in threshold of audibility similar to that resulting from exposure to a one-third octave band having the same center frequency, but 5 dB less intense than the octave band of noise (Carter & Kryter, 1962; Kryter, 1963). Further verification of this result is needed, however, before this difference between the effect on hearing of one-third and octave bands of noise having the same center frequency can be considered as proven.

As will be seen from a comparison of Figs. 2 and 3, the ear is less tolerant of low-frequency pure tones than it is to narrow bands of noise in the same frequency region. The explanation for this difference is apparently to be found in the actions of the aural reflex (Ward, 1962a; 1962b). This reflex is such that when the ear is exposed to intense bands of noise it can provide, depending on the level, as much as 15 dB or so of effective protection for low-frequency sounds being transmitted to the inner ear. However, the reflex is not maintained by pure tones, and as a result the tolerable sound pressure level for low-frequency tones below 1000 cps is much less than it is for bands of noise with frequencies below 1000 cps.

Background

For the past 20 years or so there has been considerable interest in "damage risk criteria" for sounds, the maximum levels and durations of sounds of different spectra to which people can be safely exposed without endangering their hearing.[3] The establishment of damage risk criteria and contours is required because in many industries and in military services persons are exposed to sounds that lead to permanent and significant impairment in the hearing of some of those persons.

CHABA, now the NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics, was asked by the Armed Services in 1955 for advice with respect to damage risk criteria and contours, the advice to be based on research data available at that time. On the basis of CHABA recommendations, the Air Force prepared a document which prescribed both damage risk criteria for hearing and hazardous noise exposure (U. S. Air Force, 1956). Recently, CHABA was asked by the Office of the Surgeon General, U. S. Army, to re-evaluate, on the basis of new knowledge in this field, the question of damage risk criteria for exposure to sound. To this end, CHABA Working Group 46 was established. This Working Group has analyzed the research data and problems in this general area and has concluded that a new set of rules and recommendations can be prescribed with respect to damage risk criteria and contours for exposure to steady sound. These new rules and recommendations take into account research data that were not available when Air Force Regulation 160-3 was published (1956).

Tolerable exposures, in terms of sound pressure levels, spectrum characteristics and durations, can, it was found, be specified at the present time only for approximately steady sound (noise and pure tones) as distinct from impulsive sound, and the recommendations made herein are directed towards steady sound. By "steady" sound is meant sound that remains steady over at least several seconds as would be required for measurement of overall level with a typical sound level meter. By "noise" is meant that the spectrum of the sound is complex, i.e., does not consist of merely a single or even several pure tones. This definition allows for intermittent exposures to steady sound, but is intended to exclude short bursts of sound that reach a maximum level and then decline in level within less than 1 or 2 sec.

In their approach to this task, the Working Group attempted to follow two principles.

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[3] It has been general practice in the past to label tables or graphic curves showing the maximum sound pressure levels and durations of sound that can be tolerated in accordance with a criterion such as that to be given in a following section as "damage risk criteria." In this report, the phrase "damage risk contours" is applied to such curves, and the phrase "damage risk criterion" is reserved for the specification of the degree of the risk and damage to hearing to be considered as acceptable or practical.

1. The criteria, contours, and conclusions would be based on data concerned with either temporary or permanent effects on hearing from exposure to sound. No attempt was to be made to "average" or give preference to any previous estimates of damage risk contours; accordingly, the extrapolations and assumptions found to be necessary to develop general damage risk contours were made only with respect to actual data.

2. The damage risk criteria should take some cognizance of the fact that more protection should be provided in the lower frequency regions (where a major portion of the energy in the speech spectrum falls) than in the higher frequency regions because of the extreme importance of preserving man's ability to communicate by speech. At the same time, these criteria should include as much of man's audible frequency range as present data will permit, so that one can estimate the impact upon hearing of as wide a frequency range of sounds as is presently possible.

The Working Group also evaluated the knowledge available with regard to the effects of impulsive sounds, such as gunfire, upon hearing. The group concluded that further research data must be acquired with respect to such physical parameters as peak sound pressure level, repetition rate, number of exposures, spectrum, etc., before damage risk contours for impulsive sounds can be specified. It is estimated that in the near future it may be possible to formulate damage risk contours for impulsive sounds that approach the generality to be found in the relations given for steady sound. While exact limits cannot be set, the Working Group did find evidence that repeated exposure to some types of acoustic impulses exceeding 140 dB in the ear canal of the listener can result in significant losses of hearing in some persons.

Damage Risk Criterion

The basic criterion adopted by the Working Group is that a sound environment will be deemed acceptable if it produces, on the average, a permanent sound- or noise-induced hearing loss in people after ten years or more of near-daily exposure of no more than 10 dB at 1000 cps or below, nor more than 15 dB at 2000 cps, or no more than 20 dB at 3000 cps or above. The present criterion is concerned only with the range of frequencies from 100 to 7000 cps. This criterion allows less hearing loss at lower frequencies than at higher frequencies in order to provide greater protection for hearing in the frequency region containing the major portion of the energy found in the normal speech signal.

The phrase "sound- (or noise-) induced permanent hearing loss" means that a person has suffered a shift or depression in his threshold of audibility as a result solely of exposure to the sound environment under question. Aging or other factors affecting the hearing mechanism are presumably eliminated from consideration.

The problem, of course, is to specify the maximum durations and spectra of sound that will result, on the average, in permanent hearing losses that just meet this criterion. Exposures that exceed these maxima may be considered as potentially unsafe for a significant portion of human listeners; exposures that are less than, or meet, these maxima may be considered safe for the majority of people exposed to them. Estimates of the statistical distribution of hearing losses to be expected in a large population of persons exposed to sounds that meet the criterion are given in Table 1.

Bases for Specification of Tolerable Exposure to Sound

In attempting to specify the maximum tolerable exposure that would meet the criterion in the previous section, the Working Group used data from (a) studies of permanent losses of hearing incurred by workers in industries (Kylin, 1960; Nixon & Glorig, 1961; Rosenwinkel & Stewart, 1957; Rudmose, 1957), and (b) studies of temporary threshold shift (TTS) conducted in research laboratories (Carter & Kryter, 1962; Davis, Morgan, Hawkins, Galambos, & Smith, 1950; Kryter, Weisz, & Wiener, 1962; Kryter, 1963; Kylin, 1960; Miller, 1959. Ward et al., 1958; 1959a; 1959b; 1959c; Ward, 1960; 1962a; 1962b). In the absence of truly adequate data, a practical approximation for a solution to the problem was required, and the recommendations of the Working Group depend on a somewhat indirect approach. The approach taken is described below.

Permanent losses of hearing are usually described in terms of permanent threshold shift (PTS). Noise-induced permanent threshold shifts (NIPTS) are the losses that should be determined in order to define maximum tolerable exposures to sound. NIPTS presumably excludes threshold shifts associated with increased age, diseases, etc. Unfortunately, studies of the hearing of industrial workers do not provide direct measures of NIPTS, i.e., pre-exposure hearing sensitivity vs. post-exposure hearing sensitivity in the same persons. However, the magnitudes of NIPTS have been estimated in most of the industrial studies cited by correcting the post-exposure hearing levels of the industrial workers for the average effects of aging or presbycusis. There have been systematic differences in methods of calibrating audiometers and of correcting thresholds for the effects of age among the various studies from which NIPTS was estimated. Accordingly, the NIPTS values deduced from these studies may be in "error" with respect to "true" NIPTS, but the amount of the error is almost certainly less than 10 dB (Kylin, 1960; Nixon & Glorig, 1961; Rosenwinkel & Stewart, 1957; Rudmose, 1957).

Studies of the hearing of industrial workers provide insight into the general relations among NIPTS, the spectrum of the noise, level of noise, duration of daily exposures, and number of years of exposure. In particular, there are good data relating NIPTS to exposures to broadband, steady noises incurred daily, 8 hr per day for years. Maximum tolerable exposures to the same noises can be specified for the NIPTS criterion directly from the data. Comparable data do not exist for many shorter exposures to noise, for exposures to intermittent noise, or for repeated short exposures with intervening rest periods; but an assessment of these classes of exposures can be made in terms of temporary threshold shift produced in young normal ears by noise exposures that are comparable to those encountered in a single working day in the industrial studies of NIPTS.

Temporary threshold shift (TTS), the difference in the threshold of audibility measured before and after exposure to sounds, is characterized by the fact that after a period away from intense sound, usually a matter of hours, the person's threshold of audibility that was elevated by the exposure to noise has returned to its pre-exposure

level. To provide a uniform reference for this changing threshold shift, the TTS 2 min after the end of exposure (TTS_2) is commonly used to describe the amount of TTS produced by any particular exposure to noise.

Studies of TTS, conducted under controlled laboratory conditions, have provided knowledge of the relations among variations in spectrum, level, duration, repetition rate, and other characteristics of sound to TTS to a degree not possible for NIPTS. The tolerable noise exposure contours that cannot be specified for a criterion NIPTS, can be specified for a criterion TTS. At present, the relations between NIPTS and TTS are not precisely known, but the prospect of equating a great variety of noise exposures in terms of some common dimension of hearing, such as TTS, is both rational and inviting. As a practical matter, the Working Group agreed to use damage risk contours derived from TTS_2 values that are equal in decibels to the criterion values for PTS. In effect, the Working Group adopted a secondary criterion; that is, TTS_2 of no more than 10 dB at 1000 cps or below, no more than 15 dB at 2000 cps, and/or no more than 20 dB at 3000 cps or above, as measured in young adults with normal hearing. It is postulated that TTS_2 will rank the various kinds of exposures encountered in a single day's assignment in the same manner as would TTS measured at any later time after exposure. This assumption is supported by evidence that TTS's maintain their rank order during recovery, and by evidence that recovery from TTS_2 does not depend on how the TTS_2 was produced (Ward, 1960).

For these reasons, TTS_2 is postulated to be a consistent measure of the effects of a single day's exposure to noise. (Postulate I)

The second postulate is that TTS is not only a consistent measure of a single day's exposure to noise, but also a measure of the hazard associated with years of such exposures. Postulate II can be stated, "all exposures that produce a given TTS_2 will be equally hazardous."

This is a key assumption in the Working Group's reasoning. There is little direct evidence to support this assumption. Indeed, it is recommended that future groups approaching this task should carefully re-evaluate Postulate II. It may be, for example, that exposures producing the same TTS_2 will have to be separated into distinct classes in order that this postulate be exactly correct.

Nonetheless, at present, members of the Working Group believe that the TTS_2 from a single day's exposure to noise is a measure which will correlate with ability of a single day's exposure to produce NIPTS, if it is repeated on a near-daily basis, over a course of about ten years.

A third and stronger postulate concerns the quantitative relation between TTS_2 and $NIPTS_{10\ yr}$. There is evidence (Glorig, Ward, & Nixon, 1962; Kylin, 1960; Nixon & Glorig, 1961; Rosenwinkel & Stewart, 1957; Rudmose, 1957) that the NIPTS eventually produced after many years of habitual exposure, 8 hr per day, is about numerically equal to the TTS_2 at 1000 cps produced in young normal ears by an 8 hr exposure to the same noise; the NIPTS at 2000 cps produced after many years of habitual exposure, 8 hr per day, is about 5 dB less than the TTS_2 at 2000 cps produced in young normal ears by an 8 hr exposure to the same noise; while the NIPTS at 4000 cps eventually produced after many years of habitual exposure, 8 hr per day, is about

3 dB greater than the TTS_2 at 4000 cps produced in young normal ears by an 8 hr exposure to the same noise. Although the correspondence between NIPTS and TTS_2, as measured in these experiments, is not as precise as would be desirable, it should be noted that there was reasonable agreement among the results of the various studies made of NIPTS and TTS_2 (Kryter, in press).

A broad generalization that might be made from data is that mean $NIPTS_{10\ yr}$ in a given population has linear regression on TTS_2 with slope one and intercept zero. If this generalization is correct for all test frequencies and all classes of exposures, then $NIPTS_{10\ yr}$ would, on the average, be equal to TTS_2. It is, however, for present purposes not necessary to generalize to this extent from the NIPTS and TTS_2 data; it is sufficient for the drawing of the contours given in this report to postulate (Postulate III) that $NIPTS_{10\ yr}$ is approximately equal to the TTS_2 set of criteria.

It would not surprise the members of the Working Group if, in the future, the relation between TTS_2 and $NIPTS_{10\ yr}$ is found to be curvilinear, or of slope different from one, or intercept different from zero, and, furthermore, it is possible that slightly differing curves relating TTS_2 to $NIPTS_{10\ yr}$ will be required for various classes of exposures. Nevertheless, Postulate III was used as stated as the best available engineering approximation to the facts as they are now available.

These postulates, which will need periodic review, provide a rational way to arrive at damage risk contours for short, intermittent, and interrupted exposures to noise. The criteria provided by this method seem to be more realistic than the equal-energy assumption employed by Air Force Regulation 160-3 (U.S. Air Force, 1956). In that document, the potential hazard of a noise exposure was assumed to depend on the total energy in a given octave band entering the ear, regardless of the temporal pattern. Thus, a steady 4-hr exposure at 88 dB SPL was taken to be as dangerous as a steady 8-hr exposure at 85 dB SPL, or as an intermittent exposure in which the 88-dB noise was on only half the time during the day, say, on 30 sec, off 30 sec. The main shortcoming of this system was that it failed, in effect, to consider recovery of the ear between noise bursts, and was, it appears, overly conservative. When noise control is very expensive, a more precise estimate of a hazardous noise contour can avoid the cost of unnecessary degrees of noise control. The contours based on TTS_2 allow some more intense, short exposures than does AFR 160-3, and, it is believed, provide a guide for noise control which, in the light of current information, is more reasonable and realistic. The contours based on TTS_2 are complex and their use may sometimes require personnel with special experience not found at most field installations. However, the Working Group assumes that there will be many occasions when the cost of providing the necessary special experience or expert advice will be much less than the cost of unnnecessary noise control.

One additional warning concerning the use of the proposed damage risk contours is in order. It is not safe to extrapolate or to scale proportionately from the contours given in Figs. 1 through 11 in an attempt to meet other sets of conditions of exposure (for a limited number of years of military service, for example), or for the protection of different amounts of hearing. In order to derive damage risk contours for other conditions of exposure and hearing than those specified in this document, one must return to and use the original data on TTS and NIPTS, as well as make certain calculations regarding the effects of relatively brief intermittent exposures upon TTS.

Variability in Susceptibility to Threshold Shift

The variation around an average NIPTS is an important aspect of the practical problem of hazardous exposure to noise. The true risk to individuals is described as much by measures of variation as it is by measures of central tendency. Description of variations of NIPTS around the criterion adopted by this Working Group is difficult since the noise exposure contours in the report were written to secondary criteria of specified amounts of mean TTS_2 and, in addition, there are only few data that allow direct estimation of the variability of NIPTS around the mean NIPTS set as the primary criteria. There are, however, isolated sets of data on (a) the variability of TTS_2 (Kryter, et al., 1962; Kylin, 1960; Miller, 1959), (b) recovery from TTS_2 (Ward et al., 1959b; Ward, 1960), and (c) the variability of the NIPTS (Glorig, et al., 1962; Kylin, 1960; Nixon & Glorig, 1961; Rosenwinkel & Stewart, 1957; Rudmose, 1957) presumed from the hearing levels measured on noise-exposed persons in industry. Strictly speaking, each set of data is valid only in isolation, but taken together they provide some clues to the probable order of magnitude of the variabilities to be expected.

When mean TTS_2 is 20 dB, the standard deviation of the distribution of TTS_2's for individual ears is 6 dB to 7 dB (Kryter, et al., 1962; Kylin, 1960).[4] For similar conditions, the standard deviation of the distribution of TTS_2's from a given ear that has been given repeated but widely spaced exposures to noise is about 4 dB (Lightfoot, 1955; Miller, 1959).

A TTS_2 that approaches or exceeds 40 dB can be taken as a signal that danger to hearing is imminent. This statement is supported as follows.

1. There is a rapid increase in the time to recover from TTS as TTS_2 approaches and exceeds 40 dB; recovery to pre-exposure threshold requires about 16 hr if TTS_2 is less than 40 dB, but more than 16 hr and even several days or weeks may be required if TTS_2 exceeds 40 dB (Ward, 1960).

2. Prolonged cases of TTS with initial values of about 40 dB have been observed in laboratory cats after exposures to noise that were only slightly shorter than exposures that produced acute traumatic NIPTS (Miller, Watson, & Covell, 1963).

Now, fewer than 1 per cent of young, normal ears exposed on one occasion to a noise exposure on the contours of this report would sustain TTS_2's that exceed 40 dB. For these conditions and ears, the probability of TTS_2's that exceed 40 dB becomes negligible for those frequencies at which mean TTS_2 is only 10 dB or 15 dB. Thus, it is nearly certain that only a very small proportion of the population would exhibit clear signs of possible danger to hearing if the exposures on the contours were widely spaced in time and limited to young, normal ears.

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[4] Ward, W. D. Personal communication to Working Group 46, 1963.

In the actual field situation, however, it is recognized that other factors may be important contributors to NIPTS. Variability in the threshold shifts can be produced by variability in the actual exposures encountered in the work environment and outside of the work environment (for example, when hunting with a gun), as well as by possible cumulative effects of repeated, near-daily exposures to noise. Furthermore, while recovery is initially complete in 16 hr from TTS_2's that are less than 40 dB, it is possible that recovery may fail to be complete as such exposures are repeated over a period of years.

The empirical distribution of NIPTS's in a population of noise-exposed industrial workers is much broader than that for TTS_2. Examples of this variation of NIPTS are shown in Table 1. Discussion of plausible hypotheses to explain the greater variations around the mean of NIPTS than the variation around the mean of TTS for a given noise condition is beyond the scope of this report. The practical consideration is that when exposures to noise lead to some average NIPTS, there will always be a few ears that show rather large NIPTS.

Table 1

Estimated Percentage of People Having Various Degrees of Presumed NIPTS Following Years of Exposure to a Given Industrial Noise Environment[1]

Column 1 Test frequency	Column 2 Median NIPTS (50 percentile)	Column 3 20 percentile	Column 4 10 percentile
1000 cps	10 dB	20 dB	30 dB
2000 cps	15 dB	30 dB	45 dB
3000 cps	20 dB	40 dB	60 dB

1. Based on Nixon & Glorig, 1961; Rudmose, 1957.

Hearing Conservation and Monitoring Program

Table 1 shows that in industrial situations, one can expect some portion of a group of people to have rather large hearing losses, even though the average hearing losses for the group, according to some criterion, may be acceptably small. It is highly probable, of course, that the variability in hearing losses exhibited by industrial workers is partly due both to variations in the noise exposure reportedly present in their work situations, and to exposure to noises outside of their occupations.

If the hearing losses allowed in the criterion adopted by this Working Group are judged to be acceptable, it is clear that the tolerable exposures given will be unsafe for a certain portion of a given population. It is believed that it is well nigh impossible to specify practical maximum tolerable sound levels and exposures that are safe for 100 per cent of the population; where to draw the line is a matter of judgment. For this reason, when environmental noise conditions are such that the above damage risk contours (DRC's) might be equalled or exceeded, hearing conservation programs, when feasible, are desirable in order to forestall the development of sound-induced hearing losses in ears having a relatively great susceptibility to hearing loss.

Such a program would consist of periodically measuring or monitoring the auditory sensitivity of people exposed to an intense noise or sound, and removing from the noise environment those persons who are first to show significant changes in hearing sensitivity. This monitoring procedure is part of the hearing conservation program of some industries and the Armed Services, where persons are regularly exposed to high-intensity noise.

The Working Group wishes to emphasize the fact that for many noise environments the wearing of devices such as earplugs or earmuffs can prevent the development of significant hearing losses in people exposed to noise. The use of such devices should be considered whenever noise exposures approach, equal, or exceed the damage risk criteria given in this report.

Physical Measurement of Sound

Measurements of octave band spectra may be used if the sound being analyzed is broad-band and does not contain sharp peaks in its spectrum that are narrower than one octave band in width.

When filters with bandwidths no wider than one-third octave are used to measure the noise spectra, the maximum tolerable levels for different band center frequencies and different durations are then found by reference to the right-hand ordinates of Fig. 1 and Fig. 2, respectively. It is noted that the same right-hand ordinate can be used regardless of the total bandwidth or spectrum of the noise, provided one-third octave or narrower filters are used for making the spectrum analysis.

A "rule of thumb" that can be used for determining whether a sound contains a strong narrow band of energy that is less than one octave in width is: if the level of the octave band immediately above and the octave band immediately below are each less than the middle octave band by five or more decibels, it is likely that the sound in question contains one or more strong bands of energy that are narrower than one octave wide. If this is true, then the right-hand ordinate of Figs. 1 and 2 should be consulted to determine maximum tolerable level, even though the sound spectrum under question is expressed in octave band levels.

This rule is a rough guide and is not infallible. For example, if a strong narrow-frequency band of energy less than, say, one-third octave wide falls in the region of the crossover frequencies of adjacent octave band filters, the measured sound pressure level would be the same for both octave bands and would thus give a measured spectrum that had the appearance of being "flat" over those two adjacent octave bands.

The same general rule (with the same general shortcomings) could be applied to the use of either octave or one-third octave band filters for determining the spectrum of a sound containing strong pure-tone components. If very narrow bandpass filters, only a few cycles wide, are not available for making spectral analysis, it is recommended that one-third octave filters, the "5 dB rule" mentioned above, and the detection of pure tones by listening be used to determine if, and at what frequencies, strong pure-tone components are present.

As a matter of possible convenience to the reader, particularly with respect to the interpretation of the abscissa of Fig. 2, the center and cut-off frequencies of some commercially available filters that are often used for making spectral analyses of noise are given in Table 2.

Table 2

Center and Cut-off Frequencies of Some Commercially Available Filters

One-third octave band filters			Octave band filters		
One-third octave	Center frequencies	Cut-off frequencies	Octave	Center frequencies	Cut-off frequencies
1	50	44-55	1	63	44-87
2	63	55-71	2	125	87-175
3	80	71-90	3	250	175-350
4	100	90-112	4	500	350-700
5	125	112-140	5	1000	700-1400
6	160	140-179	6	2000	1400-2800
7	200	179-224	7	4000	2800-5600
8	250	224-280	8	8000	5600-12000
9	320	280-353			
10	400	353-448	1	39	20-75
11	500	448-560	1A	53	37-75
12	630	560-706	2	106	75-150
13	800	706-896	3	212	150-300
14	1000	896-1120	4	425	300-600
15	1250	1120-1400	5	850	600-1200
16	1600	1400-1790	6	1700	1200-2400
17	2000	1790-2240	7	3400	2400-4800
18	2500	2240-2800	8	6800	4800-9600
19	3200	2800-3530			
20	4000	3530-4480	1	71	50-100
21	5000	4480-5600	2	141	100-200
22	6300	5600-7060	3	283	200-400
23	8000	7060-9080	4	506	400-800
24	10000	9080-11020	5	1131	800-1600
			6	2263	1600-3200
			7	4525	3200-6400
			8	9050	6400-12800

References

Carter, N., & Kryter, K. D. Equinoxious contours for pure tones and some data on the "critical band" for TTS. Bolt, Beranek & Newman, Inc., 1962, Rep. No. 948. (Contract No. DA49-007-MD-985, OSG, U. S. Army, Washington, D. C.)

Davis, H., Morgan, C. T., Hawkins, J. E., Jr., Galambos, R., & Smith, L. W. Temporary deafness following exposure to loud tones and noise. Acta Oto-Laryngol., 1950, Suppl. 88, 1-57.

Glorig, A., Ward, W. D., & Nixon, J. Damage risk criteria and noise-induced hearing loss. Arch. Oto-Laryngol., 1961, 74, 413-423. (Also in The control of noise. NPL Symposium No. 12, Her Majesty's Stationary Office, London, England, 1962, Paper No. E-2.)

Kryter, K. D., Weisz, A. Z., & Wiener, F. M. Auditory fatigue from audio analgesia. J. acoust. Soc. Amer., 1962, 34, 383-491.

Kryter, K. D. Exposure to steady-state noise and impairment of hearing. J. acoust. Soc. Amer., 1963, 35, 1515-1525.

Kryter, K. D. Damage risk criterion and contours based on permanent and temporary hearing loss data. Amer. industr. Hyg. Assoc. J. In press.

Kylin, B. Temporary threshold shift and auditory trauma following exposure to steady-state noise. Acta Oto-Laryngol., 1960, 51-6, Suppl. 152.

Lightfoot, C. Contribution to the study of auditory fatigue. J. acoust. Soc. Amer., 1955, 27, 356-364.

Miller, J. D. On the relationship between temporary hearing loss and masking. Unpublished doctoral dissertation, Indiana Univer., 1959.

Miller J. D., Watson, G. S., & Covell, W. P. Deafening effects of noise on the cat. Acta Oto-Laryngol., 1963, Suppl. 176.

Nixon, J. C., & Glorig, A. Noise-induced permanent threshold shift at 2000 cps and 4000 cps. J. acoust. Soc. Amer., 1961, 33, 901-908.

Rosenwinkel, N. E., & Stewart, K. C. The relationship of hearing loss to steady state noise exposure. Amer. industr. Hyg. Assoc. Quart., 1957, 18, 227-230.

Rudmose, W. Hearing loss resulting from noise exposure. C.M. Harris (Ed.), In Handbook of noise control. New York: McGraw-Hill, 1957. Chp. 7. (Also, W. A. Rosenblith, chairman, The relations of hearing loss to noise exposure, a report by Subcommittee Z24-X-2. 1954. Amer. Stand. Assoc. Inc., 70 E. 45th St., N. Y.)

U. S. Air Force, Medical Service. Hazardous noise exposure (AF Reg. No. 160-3), 1956. Washington, D. C.

Ward, W. D., Glorig, A., & Sklar, D. L. Dependence of temporary threshold shift at 4 kc on intensity and time. J. acoust. Soc. Amer., 1958, 30, 944-954.

Ward, W. D., Glorig, A., & Sklar, D. L. Temporary threshold shift from octave-band noise: applications to damage risk criteria. J. acoust. Soc. Amer., 1959, 31, 522-528. (a)

Ward, W. D., Glorig, A., & Sklar, D. L. Relation between recovery from temporary threshold shift and duration of exposure. J. acoust. Soc. Amer., 1959, 31, 600-602. (b)

Ward, W. D., Glorig, A., & Sklar, D. L. Temporary threshold shift produced by intermittent exposure to noise. J. acoust. Soc. Amer., 1959, 31, 791-794. (c)

Ward, W. D. Recovery from high values of temporary threshold shift. J. acoust. Soc. Amer., 1960, 32, 497-500.

Ward, W. D. Studies on the aural reflect. II reduction of temporary threshold shift from intermittent noise by reflex activity; implications of damage-risk criteria. J. acoust. Soc. Amer., 1962, 34, 234-241. (a)

Ward, W. D., Damage-risk criteria for line spectra. J. acoust. Soc. Amer., 1962, 34, 1610-1619. (b)

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13. ABSTRACT

This report specifies damage risk criteria for exposure to sound, and contains graphs of maximum sound pressure levels and durations of exposures that are considered tolerable along with examples of the use of these graphs. Also included is background information and a discussion of the rationale, assumptions, limitations, and general problems pertinent to the development and application of damage risk criteria and the related exposure contours. This report is intended primarily for technical persons working in this problem area in the military services and other government agencies. No attempt is made to interpret or simplify the report or procedures contained herein for special or particular operational situations.

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