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Aberdeen Proving Ground, Maryland

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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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CRITERIA FOR ASSESSING HEARING DAMAGE RISK FROM IMPULSE - NOISE EXPOSURE

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ABSTRACT

This paper presents criteria for assessing damage risk from impulse-noise exposure. The criteria are based on conclusions of independent British and American studies and on the work of other research workers in this field. Most of the studies which led to these criteria were performed with noise from small arms, but the criteria are general enough to permit assessment of most other types of impulse noise. The variables which must be considered in determining the potential hearing hazard and in making practical application of the criteria are presented, and the parameters which must be measured are defined. The measurement technique and type of transducers to be used are discussed.

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CRITERIA FOR ASSESSING HEARING DAMAGE RISK

FROM IMPULSE-NOISE EXPOSURE

INTRODUCTION

For steady-state types of noise, the relationships between the intensity, spectral content, duration of exposure, off-periods, and the extent of the pure-tone hearing loss which results are fairly well known, and a considerable number of relatively similar damage-risk criteria* (DRC) have been published (6, 7, 23, 46, 58, 60, 61, 67). In contrast, there is a lack of information on the effect of impulse noise on hearing.

It has been customary in steady-state noise DRC, ever since the publication of the Benox Report (3) and A.S.A. Z24-X-2 Subcommittee Report (2), to include an upper limit of about 135 dB for unprotected noise exposure for any duration, however short. In most cases it is understood by implication only, rather than by direct statement, that this restriction is not intended to apply to impulse noise, and, in consequence, misunderstandings on this point have arisen. Ward (62), in a study of temporary threshold shift (TTS) from impulses produced by a loudspeaker, gave a caution with regard to impulse noise where the peak level exceeds 135 or 140 dB until more is known about the relative effect of rise time and duration. The CHABA DRC (42, 46) puts 140 dB as the level above which impulse noise may be hazardous. U. S. Army TB Med 251 (60) states that "exposure of personnel to impulse noise below 140 dB may also be hazardous to some very sensitive ears . . ." (p. 4). On the other hand, Murray and Reid (44, 45) list a number of weapons in order of degree of necessity for ear protection according to the peak levels reaching the ears of firer and associated personnel; the .303-inch rifle occupied the lower end of this scale of auditory hazard, when the peak level at the firer's ears was reported as 154-159 dB. More recently, Pfander (49) has suggested that levels of 165 dB are safe, provided duration does not exceed three msec. His data indicate larger permissible durations for lower levels on an equal energy basis. He relates this to either steady-state noise or to impulse noise, when duration is the product of length of time within 10 dB

*The term "damage-risk criterion," unfortunately, has two meanings in the literature. First, it refers to the individual criteria such as allowable temporary threshold shift (TTS), acceptable peak level and duration, etc. Second, it refers to the total document that results as the sum of the individual criteria. Both meanings of the term are implied in this paper, but it is believed that the context will enable the reader to keep the meanings separated.

of the peak value (as measured with a sound level meter) and the number of impulses.

In military spheres, the need for preventing weapon-noise-induced hearing loss is receiving ever-increasing attention. The question as to which impulse noises are hazardous, and which are not, is frequently raised and research is being conducted in a number of countries to obtain data relating to these problems. The approach has to be made along two lines: to find a satisfactory method of measuring and expressing the physical characteristics of the noise, and to assess the potential for auditory damage of various noise sources.

Following simultaneous but independent studies employing the double approach mentioned above, the American and British authors published documents which showed remarkably similar conclusions. Human Engineering Laboratories (HEL) Standard S-1-63B (59) gave methods of impulse-noise measurement and maximum acceptable impulse-noise parameters for U. S. Army Materiel Command small arms, and Garinther and Kryter (21) published data on damage risk from exposure to impulses. A Royal Naval Personnel Research Committee Report (11) outlined the requirements for measuring high-intensity impulse noise, and a paper from the Institute of Sound and Vibration Research (ISVR) (52) published conclusions regarding safe limits for certain types of impulse-noise exposure.

Further discussion between these authors showed that there was such close agreement that publishing their separate results and conclusions together in common terms of method of measuring, of definitions for assessing the noise, and of formulating DRC would be most worthwhile. The outcome of these discussions forms the basis of this report.

DEFINITIONS

There are a number of parameters of a single impulse which may be of importance:

a. Peak pressure level

b. Rise time

c. Pressure wave duration (A-duration)

d. Pressure envelope duration (B-duration)

e. Frequency spectrum.

Each of these will be defined in turn. Parameters a-d are also illustrated in Figure 1.

Peak Pressure Level

This is the highest pressure level achieved (expressed in dB re 0.0002 dyn/sq. cm., or in psi).

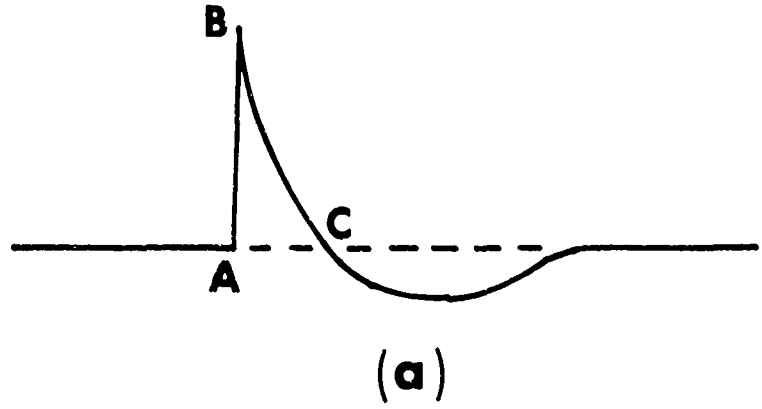
Rise Time

This is the time taken for the single pressure fluctuation that forms the initial or principal positive peak to increase from ambient to the peak pressure level.

Although our experimental data referred to noise sources with rise times that were in most cases virtually instantaneous (i.e., $\leq 1 \mu sec$), the conclusions in terms of auditory hazard from impulses of various peak level and duration are in fair agreement with the data of other workers who have employed laboratory types of impulse noise where the rise times have been relatively long (up to 0.5 msec). Moreover, evidence from loudness studies (54, 69, 70) and from theoretical calculations (Appendix B, Loudness Study 2) suggests that only when the rise time exceeds 0.3-0.5 msec does it have importance with respect to loudness changes and that only then, therefore, does a correction for rise time need to be applied. For these reasons it does not seem to be necessary to include rise time as a parameter in the DRC that follows. However, it should be understood that the proposed DRC presented here applies primarily to impulses having near-instantaneous rise times.

Pressure Wave Duration (A-duration)

This is the time required for the initial or principal pressure wave to rise to its positive peak and return momentarily to ambient. Figure 1A illustrates the method of assessment. In common with Murray and Reid (44, 45) the authors have found that when the point of measurement is close to the noise source, the initial wave is sometimes of smaller amplitude than some of the subsequent waves; in such cases, the A-duration is taken from the largest pressure wave.



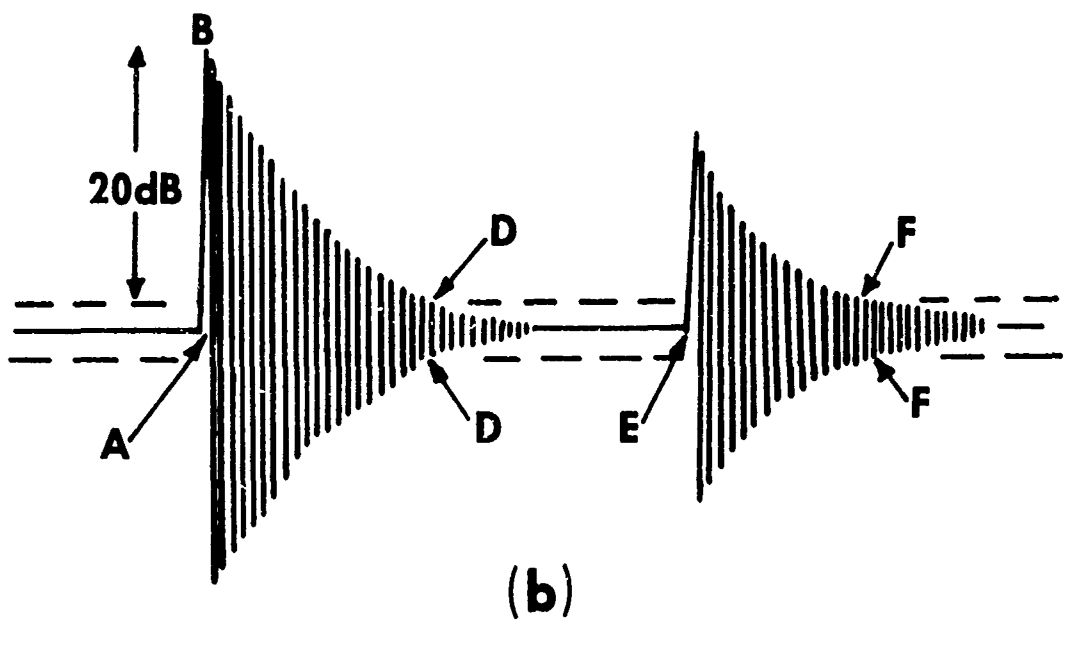


Fig. 1. IDEALIZED OSCILLOSCOPIC WAVEFORMS OF IMPULSE NOISES
(Peak level: pressure difference AB. Rise time: time difference AB.)

A - A-duration: time difference AC.
B - B-duration: time difference AD (+ EF when a reflection is present).

Pressure Envelope Duration (B-duration)

This is the total time that the envelope of the pressure fluctuations (positive and negative) is within 20 dB of the peak pressure level. Included in this time would be the duration of that part of any reflection pattern that is within 20 dB of the peak level. When reflections are present, therefore, the pressure envelope duration would be the sum of the incident and reflected pressure envelope durations. The method of assessment is illustrated in Figure 1B.

Frequency Spectrum

There is evidence that different types of impulse noise produce effect at different frequencies. The classical effect of gunfire noise exposure is supposed to be the 4 kHz dip (55, 65) but the greatest hearing loss often occurs around 6 kHz from small arms (26, 27, 47, 52, 56) and was found as high as 12 kHz from certain laboratory-produced spark discharges with A-duration of 40 μsec (18). The spectrum is believed to be important and, while a Fourier analysis can give information regarding the spectral distribution of certain impulse wave forms, in general the spectrum is difficult and time consuming to analyze. For this reason this parameter has not been included in the DRC stated below.

Rice (unpublished data) has noted that noises of two weapons of equal peak pressure level, A-duration and B-duration were not of the same loudness; in the case of the louder one, more high frequency energy appeared within the envelope. This parameter may, however, be of fringe importance only. It has not yet been possible to quantify, and, therefore, define it.

GENERAL CONSIDERATION REGARDING THE TOLERABLE AMOUNT OF IMPULSE-NOISE EXPOSURE

It would be both difficult and cumbersome in practice to express damage risk from noise of heavy weapons, small arms or sporting guns in precise terms of number of rounds fired or repetition rate of exposure. The application of the criteria to be presented is, therefore, restricted to the amounts of impulse-noise exposure commonly experienced by military personnel, members of rifle clubs and users of sporting guns. Even here, the amount of exposure may vary widely from, for example, an annual range course of 50-100 rounds, to weapon-instructing often amounting to well over 5000 rounds per year. In terms of effect on hearing, though, it is probable that the variations in common amounts of exposure from 50 to, say, 1000 rounds per year are no greater than person-to-person variations in susceptibility to impulse-noise-induced hearing loss, i.e., annual 50-round exposures may be more hazardous to some persons than 1000 rounds per year to others.

The relationship between TTS resulting from a single noise exposure and permanent threshold shift (PTS) to be expected from habitual exposure is not known with certainty even for steady-state noise (42, 46). For impulse-noise exposure, there is little such data at all*, but, the present authors are not alone in believing that it is a fair assumption that, on the average, a given TTS repeated often enough may eventually become a PTS of similar magnitude (63). However, variations in type of actual exposure to impulse noise are great compared with that predicted solely by the peak level and duration measurements at the regular exposure position. Therefore, the development of PTS may occur at a considerably greater rate with impulse noise than is the case with steady-state noise. Some grading of average auditory risk with different branches of service or type of impulse-noise exposure activity can, therefore, be expected. For the sake of the most noise-susceptible persons, however, it would be unwise to relax the provisions of the DRC during any form of such noise exposure, however occasional. The only possible exception is when audiograms of the individuals concerned are monitored as part of a hearing conservation program. Even then, unexpected auditory accidents may happen (51).

Where the amounts of impulse-noise exposure are vastly greater than the exposure referred to above, e.g., in persons engaged in proof-firing or frequent weapon training, the auditory hazard must be judged on a different scale. Likewise, the more industrial types of impulse-noise exposure as in riveting, pile driving, drop forging, etc., may require a separate criterion or may be treatable by steady-state noise criteria.

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*It is unlikely that such data can ever be obtained in human subjects from study of their impulse-noise exposure histories because of variations in exposures. For instance, for weapons of the same type, variations in orientation with regard to adjacent weapons, in amount of shooting, and in effect of reflection and reverberation at various firing points make it impossible to judge accurately the actual noise exposure leading to PTS. The relationships between impulse-noise-induced TTS (12, 17, 41) and PTS (10) from the same type of weapon might be interpreted as indicating a more rapid transition from TTS to PTS in impulse noise as compared to steady-state noise exposure. However, a more likely explanation is the fact that the TTS experiments referred to noise from the firer's weapon only (arriving at grazing incidence and capable of exact physical definition) while the men suffering PTS received noise from neighboring rifles also (probably at greater peak levels on some occasions and at more nearly normal incidence -- see page 11).

ACCEPTABLE RISK OF HEARING DAMAGE

In the recent CHABA steady-state noise DRC (42, 46), for reasons discussed there in some detail, it was considered acceptable for the end-of-day TTS_2* (believed to be equivalent to or in most cases greater than the likelihood of eventual PTS from recurrent exposures) to be not more than 10 dB at or below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at or above 3000 Hz in 50 percent of the normal-hearing persons exposed. It is known that, for steady-state types of noise exposure, after the first two minutes the rate of recovery from TTS depends primarily on the amount of TTS with little apparent dependence on how it was acquired (66). Whether this is the case for impulse-noise TTS is not certain, but there is no published evidence to suggest otherwise. The authors have, therefore, accepted for impulse-noise hazard the TTS limits for steady-state noise exposure set forward by the CHABA group.

On the other hand, there appears to be a much larger variation in individual differences in TTS when it is produced by impulse noise then when produced by steady-state noise. Both groups of authors have noticed this difference in the course of a variety of studies and Ward, et al. (68), have commented (p. 785)" . . . that the range in amount of TTS produced by pulses is greater than the range of TTS produced by continuous noise" and that "This fact underscores the necessity for extreme caution in exposing men to impulsive noise." Donley (15) and Carter and Kryter (8) have also found a wider range of sensitivity to impulse noise than to steady-state noise.

In considering a DRC for impulse noise the authors have, therefore, applied the CHABA limits of acceptable TTS to a higher proportion of individuals. The HEL Standard (59) covered the 75th percentile and the Rice and Coles limits (52), adjusted to refer to the CHABA TTS scale, the 90th percentile. For this DRC, only the 75th percentile acceptable exposure limits are given, but an approximation to the 90th percentile can be made by reducing the criterion peak pressure levels by 5 dB.

*Temporary threshold shift measured two minutes after the end of the exposure.

PROPOSED IMPULSE-NOISE EXPOSURE LIMITS

The peak pressure and duration limits proposed are best described in graphic form as shown in Figure 2. Two limits are set, corresponding to the A- and B-durations as defined above. To be acceptable, the noise must be below the relevant limit: usually impulse-noise wave forms fit one or the other pattern shown in Figure 1. Below these limits a majority (75 percent at least) of those exposed to the noise are not likely to suffer hearing loss of a degree that can be considered excessive (as defined in the section on Acceptable Risk of Hearing Damage). The A-duration is primarily an indication of how much energy the noise source emits, while B-duration is determined by a combination of this energy and the characteristics of both the weapon and its surroundings.

In addition to the above basic criteria, the following factors must be considered in making practical applications of the criterion:

a. The criterion is based upon repetition rates in the order of 6-30 impulses per minute (the repetition rates with the greatest hazard [62]), with the total number of impulses limited to around 100 per exposure. Departures from these repetition rates or this total number of impulses would require special consideration.

b. If it is desired to protect the most susceptible persons exposed to impulse noise, the 75th percentile protection limit should be lowered by approximately 10 dB. Even then, there will probably be an occasional person for whom this is insufficient and, in this case, an additional lowering of the limit may be required.

c. The curves in Figure 2 should be lowered by 5 dB where the impulses reach the ear at normal incidence, the noise level being measured at grazing incidence (see section on Impulse-Noise Measurement). For example, when firing on a range, a rifleman's ear receives the noise of his own weapon at grazing incidence (22), whereas it receives the noise of his neighbor's weapon at about normal incidence. The correction of 5 dB is not considered to be applicable to impulse sounds measured in reverberant conditions: while some of the sound waves would reach an ear at normal incidence, other will be from other directions or at grazing incidence. The additional hazard of reverberant conditions is probably expressed adequately by the increased B-duration.

d. Where exposure is to occasional single impulses only, it seems reasonable to raise the limits somewhat, and an estimate of 10 dB has been agreed upon for this. The exact allowances for different numbers of impulses have not been defined, since there are obviously an infinite number of variations in pattern and amount of noise exposure.

e. The authors' best estimate of the amount of attenuation of impulse noise afforded by ear protectors is that good ear plugs -- such as the V-51R or

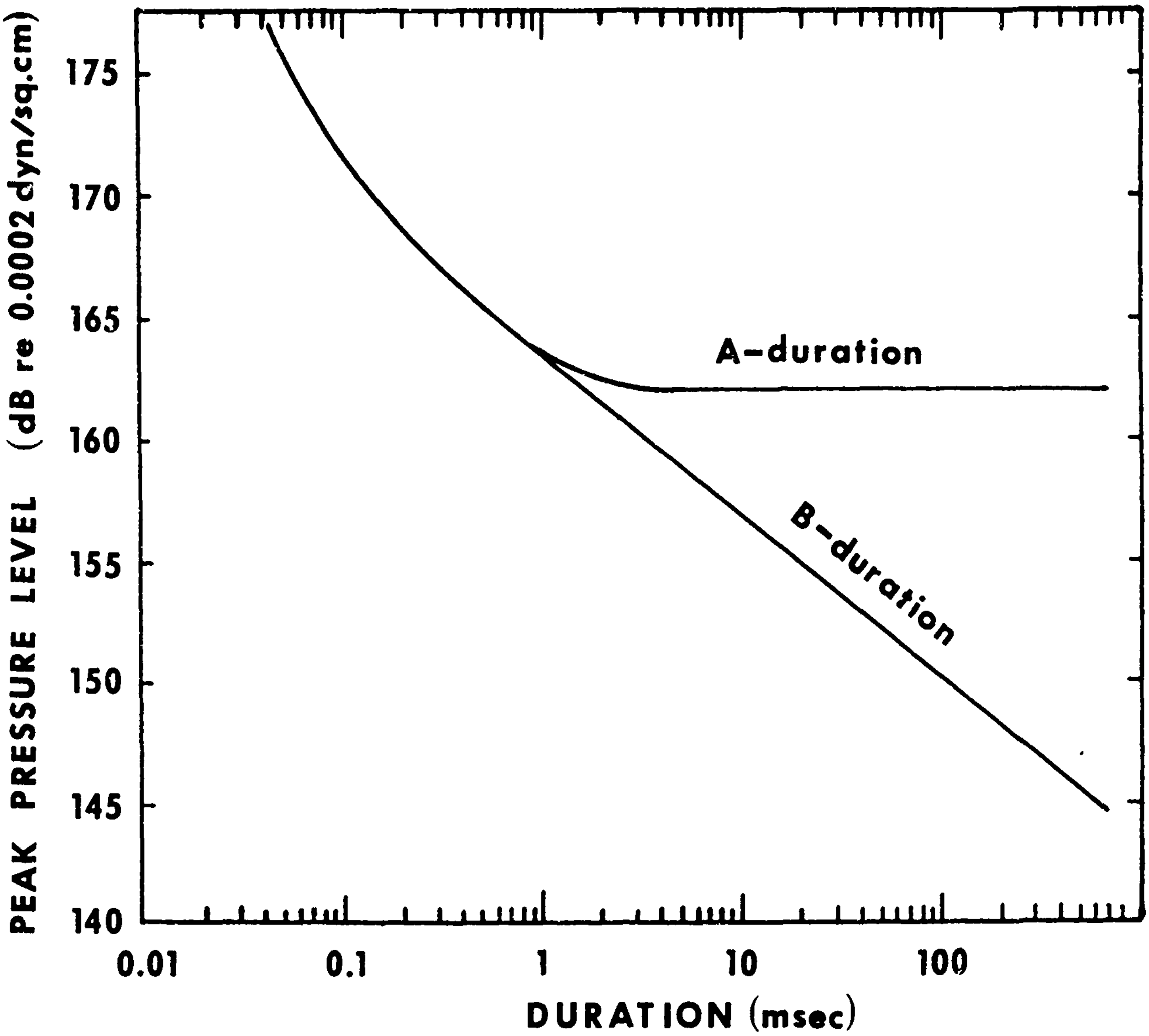

Fig. 2. PEAK PRESSURE LEVEL AND DURATION LIMITS FOR IMPULSES HAVING NEAR-INSTANTANEOUS RISE TIMES, WHICH WILL NOT PRODUCE AN EXCESSIVE RISK OF HEARING LOSS (As defined in Section on Acceptable Risk of Hearing Damage.)

"Glassdown" -- and/or circumaural earmuffs, will reduce the peak level by 20-35 dB depending on their quality and fit.

f. In considering damage risk from small-arms noise, account must be taken of the noise from neighboring weapons, which may often cause peak levels that are higher at a neighbor's ear than at the firer's ear and/or arrive at a more hazardous angle of incidence. Such noise is particularly of concern where sporting guns are fired in pairs at targets moving across the firing point or where terrain dictates that groups of soldiers fire from positions en echelon with respect to the line of fire. In effect, such situations could lead to increases in peak level equivalent to 15 dB (i.e., rifle noise of borderline hazard to the firer becomes a major hazard to his neighbor). Also the reflective or reverberant characteristics of the firing site should be considered. For example, the reflected impulse wave reaching the firer's ear when he fires from the kneeling or seated position, will usually be of a higher intensity than it will be when he fires from the standing position. And firing in a defile or bunker will result in the ear receiving more impulse noise than firing in open terrain.

IMPULSE-NOISE MEASUREMENT

The pressure-versus-time histories of the impulses should be measured by photographing the trace obtained on a cathode-ray oscilloscope. Impact sound level meters necessarily involve use of integration time constants and give results which are, as yet, insufficiently detailed for estimating damage risk. With weapon noises they usually indicate peak levels lower than those indicated by the oscilloscope technique. They are, however, useful for comparing impulse noises of generally similar character. Because hearing loss is at least partially dependent upon the spectral content of the noise, it may be desirable also to analyze these acoustical transients in terms of frequency. At present, however, it is difficult to interpret the results obtained from frequency analysis made with commercially-available filters.

The principal limitations on measuring impulse noise lie in the ability of the transducer and associated equipment to respond accurately to the pressure pulse (12, 19, 22, 31, 41). The minimum qualities of the transducers, apparatus, and environment for such measurements are as follows:

a. A good phase response.

b. A uniform amplitude response characteristic over a wide frequency range. (A band width from 100 Hz to 70 kHz is adequate for most small-arms measurements, but larger caliber weapons and noises such as sonic booms with long

TABLE 1

American and British Comparative Noise Measurements
of Two Standard 7.62mm Rifles

	HEL Data		ISVR Data	
	M-14 (Am)	L1-A1 (Brit)[a]	M-14 (Am)[b]	L1-A1 (Brit)
Peak Level (dB) at firer's left ear	159	160	160.5	161
A-duration (μsec)	270	300	250	330
B-duration (msec)	5	5	4	5

[a] This rifle was, in fact, an American T-48 modification of the Belgian FN-FAL rifle, but was acoustically equivalent to the British L1-A1 version of the Belgian weapon.

[b] This rifle was a standard American M-14 rifle.

DISCUSSION

The slope of the B-duration line (Fig. 2) deserves comment. It is based on the results of TTS studies rather than on any theoretical consideration. From various 7.62mm rifle noise studies (4, 10, 12, 17, 21, 32, 34, 35, 36, 39, 41) (Appendixes A and B) we concluded that the DRC line should run from a point at 159 dB and 5 msec; the other point, at about 150 dB for 100 msec, is a best estimate of the position at which the stated TTS limits are most likely to occur in 25 percent of persons exposed as judged from the data obtained from firing .303-inch and .22-inch rifles in reverberant surroundings (1, 12) (Appendix B, TTS Studies 1, 2, and 6). The straight line drawn between these points has a slope of 2 dB per doubling of duration which is rather less than the 3 dB equal energy increments or the larger increments often recommended for short-duration exposures to steady-state noise. On consideration of the definition of B-duration during which the sound pressure envelope falls by 20 dB, however, it can be seen that a doubling of B-duration may involve considerably less than a doubling of energy and a rate of only 2 dB per doubling may not be surprising.

The criteria presented and the evidence on which they are based (outlined in Appendixes A and B) seem to be in general agreement with the results of studies performed by other groups.

Plomp and his colleagues in the Netherlands have extensively studied both temporary and permanent hearing losses from small-arms noise, and at first glance they might appear to have recorded considerably greater auditory effects than would be expected from our DRC. The serious permanent losses (50) in weapon instructors and considerable TTS found two hours after routine training on rifle ranges (25) are in fact very like those observed on a smaller scale by Coles and Knight (10) in similar circumstances with Royal Marines personnel. As stressed elsewhere in this report, these permanent losses can probably be attributed to the fact that the effective exposures of such personnel are usually considerably greater (perhaps by 15 dB, see section of Proposed Impulse-Noise Exposure Limits .f) than those resulting solely from a man's own rifle. This consideration is, of course, of prime importance in the practical application of our DRC and, indeed, in any consideration of the relationship between TTS and likely eventual PTS; with impulse noise, the vagaries of actual exposure are even greater than is the case with steady-state noise.

Fletcher and Loeb (18) used spark-discharge impulses (at normal incidence) of very short A-duration (about 40 μsec) and high peak level (166 dB). After a +5 dB correction to equivalent peak level at grazing incidence, this exposure would fall close to our A-duration limit for the 75th percentile. Significant TTS resulted from exposure to a series of 1000 such pulses, but the mean TTS exceeded the CHABA (42, 46) limits only at frequencies at and above 8 kHz and had little effect in the 1, 2, and 3 kHz region which is critical for the understanding of speech and which is the primary concern in limitation of damage.

Of the many papers by Fletcher and Loeb on the auditory effects of impulse noise, the one discussed above is the most relevant with regard to the relationship between TTS and impulse noise of known physical characteristics. Their other papers are in most cases concerned with the use of TTS as a means of evaluating other factors influencing auditory hazard, e.g., activity of the middle-ear muscles, effects of earplugs. However, where Fletcher and Loeb have used noise sources similar to our weapon-noise sources, there is no apparent discrepancy between their data and our results with regard to TTS or PTS.

We come now to the TTS experiments carried out in various laboratories (8, 30, 62, 64, 68) with loudspeaker or toy "cricket" impulses where the rise time is relatively long (45 to 500 μsec), and the relevant details and results have been listed together in Table 2. Because of the varying post-exposure intervals we have corrected these TTS results by the method of Kryter (40) to two minutes. Also, all exposures were at normal incidence to the noise source, so a 5 dB correction to equivalent peak level at grazing incidence has been applied to compare those data with our gun and explosion-noise TTS data.

Allowing for the fact that only one ear of each subject was exposed in the case of the laboratory experiments, for the relatively small number of subjects in some cases, and for the large number of impulses used in other cases, there appears to be a considerable measure of agreement on the relationship of impulse noise to TTS_2 between our own data with impulses of very short rise times and the general trend of those obtained in the laboratory with relatively long duration impulses. However, in some cases, unexpectedly large auditory effects from impulses with relatively low peak levels have been recorded (51). It is possible that the latter results represent a limitation on extrapolation from our high-intensity, limited-numbers type of impulse-noise exposure.

The recent paper by Cohen, Kylin, and LaBenz (9) showed median TTS_2 of approximately CHABA-limits magnitude from the noise of a little over 1000 mechanical impacts of 124 to 127 dB peak level, 0.34 to 0.66 msec rise time, and 124 to 150 msec B-duration (measured 15 dB down from peak). These results certainly show that impulse noise below 135 dB can be an auditory hazard and emphasize the possible limitations of our criteria where large numbers of impulses and non-explosive types of waveforms are considered.

It is difficult to relate our criteria to Pfander's (49), since he does not indicate to which percentile his "safe" limit refers. It is understood, however, that his criterion is intended to cover the great majority of those exposed and, on this assumption and allowing for the differences in our definitions of duration ('B-duration' in our case, and 'time within 10 dB of peak multiplied by number of impulses' in his case), it would appear that the criteria may be in substantial agreement.

Although a separate criterion for industrial types of impulse noise may be required, it would seem likely that individual peaks with a peak-to-rms ratio greater

TABLE 2

Extracts from Publications on Laboratory-Type Impulse-Noise TTS

Source of Data	Number of Subjects	Impulse Characteristics: Corrected Peak Level (dB)	Impulse Characteristics: Rise Time (μsec)	Impulse Characteristics: Duration (msec)	Number of Impulses	TTS Characteristics: TTS_2 (dB)	TTS Characteristics: Frequency (kHz)	Percentage showing TTS_2 less than that indicated in previous col.
Carter and Kryter (8)		172	500	1(A-)	120	≥15	Mean of 2 + 4	40
(from Fig. 15, Ref. 30)	15	154	500	1(A-)	20	≥15	Mean of 2 + 4	83
Hecker and Kryter (30)	20	162	250	0.5(A-)	100	10	Mean of 2 + 4	83
(from Tab. III)		162	250	0.5(A-)	200	15	Mean of 2 + 4	83
Ward (62) (from text)	13	150	200	4(B-)	60	ca 17	4	46
Ward (64) (from text & Tab. III)	49	158.5	200	4(B-)	ca 30	≥ 7	4	50
Ward, Selters, & Glorig (68)		143-145	100	>2(B-)	900+900 (double clicks)	M=18	4	50
		148-150	100	>2(B-)	900+900 (double clicks)	M=21	4	50
(from Fig. 4)	13							
		150	45	1.5(B-)	900+900 (single impulses)	M=10	4	50
		155	45	1.5(B-)	900+900 (single impulses)	M=13	4	50
(from Fig. 7 3' @ 25 C/M data)	14	148	200	4(B-)	75	M=17	4	50

than 10 dB would have to exceed about 135 dB for them to carry much hazard in them-selves. On the other hand, industrial impulse noises are very often repeated several times a second and in reverberant surroundings. The noise then becomes more or less continuous, with a smaller peak-to-rms ration than for single, nonreverberant impulses. Such noise may be reliably measured by rms-reading sound level meters, in which case conventional steady-state-noise DRC would apply (42, 46). However, whether a more general continuity between impulse and steady-state-noise criteria can ever be achieved seems very uncertain in view of the evident differences in their ranges of TTS and in view of opinions such as that of Kryter and Garinther (41) that PTS from impulse noise may follow a different pattern from PTS due to steady-state noise.

REFERENCES

1. Acton, W. I., Coles, R. R. A., & Forrest, M. R. Hearing hazard from small bore rifles. Rifleman, 1966, 74, 9-12.

2. American Standards Association. The relation of hearing loss to noise exposure. (Report of subcommittee Z24-X-2.) 10 E. 40th St., New York, N. Y., 1954.

3. BENOX Report. An exploratory study of the biological effects of noise. University of Chicago, Ill., 1953.

4. Bragg, T. S. Unpublished data. U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1964.

5. British Standards Institution. Normal equal loudness contours for pure tones and normal threshold of hearing. British Standard 3383, 1961.

6. Burns, W. Noise as an environmental factor in industry. Trans. Ass. industr. med. Offrs., 1965, 15, 2-11. (Also embodied in Defence Council Instruction [Royal Navy] 283, 1965.)

7. Burns, W., & Littler, T. S. "Noise," in Schilling, R. S. F. (Ed.), Modern Trends in occupational health. London: Butterworth, 1960. Chap. 17, Pp. 249-267.

8. Carter, N. L., & Kryter, K. D. Studies of temporary threshold shift caused by high intensity acoustic transients. Report No. 949, Bolt Beranek and Newman, Inc., Cambridge, Mass., 1962.

9. Cohen, A., Kylin, B., & LaBenz, P. J. Temporary threshold shifts in hearing from exposure to combined impact/steady-state noise conditions. J. acoust. Soc. Amer., 1966, 40, 1371-1380.

10. Coles, R. R. A., & Knight, J. J. Unpublished studies on PTS from 7.62mm rifle noise. London: Royal Navy Personnel Research Committee, 1962, 1965.

11. Coles, R. R. A., & Rice, C. G. The pure-tone, speech and impulse-noise attenuating properties of Selectone-K and V-51R ear plugs. Report R. N. P. 65/1049, Medical Research Council, London, 1965.

12. Coles, R. R. A., & Rice, C. G. Speech communications effects and temporary threshold shift reduction provided by V-51R and Selectone-K earplugs under conditions of high intensity impulsive noise. J. Sound Vib., 1966, 4, 172-186.

13. Crocker, M. J. Measurement of sonic boom with limited frequency response instrumentation: A theoretical study. Report WR 66-20, Wyle Laboratories, Huntsville, Ala., 1966.

14. Davies, R. J. Personal communication, 1966.

15. Donley, R. Unpublished data. U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1962.

16. Ellis, R. M. Subjective reaction to simulated N-waves. M. Sc. Thesis, University of Southampton, England, 1964.

17. Elwood, M. A., Brasher, P. F., & Croton, L. M. A preliminary study of sensitivity to impulsive noise in terms of temporary threshold shifts. Paper presented to British Acoustical Society meeting on impulse noise, Southampton, England, 1966.

18. Fletcher, J. L., & Loeb, M. Relationships for temporary threshold shifts produced by three different sources. J. Auditory Res., 1965, 5, 41-45.

19. Forrest, M. R. The effects of high intensity impulsive noise on hearing. M. Sc. Thesis, University of Southampton, England, 1967.

20. Friedlander, F. G. The diffraction of sound pulses: I. Diffrection by a semi-infinite plane. Proc. Roy. Soc. A., 1941, 186, 322-344.

21. Garinther, G. R., & Kryter, K. D. Auditory and acoustical evaluation of several shoulder-rifles. Technical Memorandum 1-65, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1965.

22. Garinther, G. R., & Moreland, J. B. Transducer techniques for measuring the effect of small arms' noise on hearing. Technical Memorandum 11-65, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1965.

23. Glorig, A., Ward, W. D., & Nixon, J. Damage risk criteria and noise-induced hearing loss. Arch. Otolaryngol., 1961, 74, 413-423.

24. Golden, P. M., & Clare, R. The hazards to the human ear from shock waves produced by high energy electrical discharge. Report No. E-1/65, United Kingdom Atomic Energy Authority, Atomic Weapons Research Establishment, Aldermaston, Berks., England, 1965.

25. Gravendeel, D. W., Bouman, M. A., & Plomp, R. Het gehoorverlies tengevolge van een eerste expositie aan schietlawoai het effect van gehoorbeschermers. Report No. WW 1957-5, Institute for Perception RVO-TNO, Soesterberg, The Netherlands, 1957.

26. Gravendeel, D. W., & Plomp, R. The relation between permanent and temporary noise dips. Arch. Otolaryngol., 1959, 69, 714-719.

27. Harbold, G. J., & Greene, J. W. A study of the effect of gunfire and other infantry combat training noises on the hearing acuity of U. S. Marine Corps recruits. Project MR005, 13-2005, Subtask 1, Report No. 10, U. S. Naval School of Aviation Medicine, Pensacola, Fla., 1961.

28. Harel, J. R. P. Objective response to simulated N-waves and rectangular pulses. M. Sc. Thesis, University of Southampton, England, 1964.

29. Hawkins, S. J., & Hicks, J. A. Sonic bang simulation by a new explosives technique. Nature (London), 1966, 211, 1244-1245.

30. Hecker, M. H. L., & Kryter, K. D. A study of auditory fatigue caused by high-intensity acoustic transients. Report No. 1158, Bolt Beranek and Newman, Inc., Cambridge, Mass., 1964.

31. Hilton, D. A., & Newman, J. W., Jr. Instrumentation techniques for measurement of sonic-boom signatures. J. acoust. Soc. Amer., 1966, 39, S31-S35.

32. Hodge, D. C. Reliability of temporary threshold shifts resulting from repeated exposure to impulse noise. J. acoust. Soc. Amer., 1965, 37, 1194(A).

33. Hodge, D. C., Gates, H. W., Helm, C. P., Soderholm, R. B., & Blackmer, R. F. Preliminary studies of the impulse-noise effects on human hearing (Project HumIN). Technical Memorandum 15-64, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1964.

34. Hodge, D. C., & McCommons, R. B. Relation between hearing level and TTS from impulse-noise exposure. J. acoust. Soc. Amer., 1965, 38, 938(A).

35. Hodge, D. C., & McCommons, R. B. Further studies of the reliability of temporary threshold shift from impulse-noise exposure. Technical Memorandum 3-66, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1966.

36. Hodge, D. C., & McCommons, R. B. Reliability of TTS from impulse-noise exposure. J. acoust. Soc. Amer., 1966, 40, 839-846.

37. Hodge, D. C., & McCommons, R. B. Growth of TTS from impulse-noise exposure: A methodological study. Technical Memorandum 10-67, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1967.

38. Hodge, D. C., & McCommons, R. B. A behavioral study of the sound-shadow effect in impulse noise. Technical Memorandum 12-67, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1967.

39. Hodge, D. C., McCommons, R. B., & Blackmer, R. F. Reliability of temporary threshold shifts caused by repeated impulse-noise exposure. J. Auditory Res., 1966, 6, 121-128.

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

41. Kryter, K. D., & Garinther, G. R. Auditory effects of acoustic impulses from firearms. Acta Otolaryng. (Stockh.), 1965, Suppl. 211.

42. Kryter, K. D., Ward, W. D., Miller, J. D., & Eldredge, D. Hazardous exposure to intermittent and steady-state noise. J. acoust. Soc. Amer., 1966, 39, 451-464.

43. Kylin, B. Temporary threshold shift and auditory trauma following exposure to steady-state noise: An experimental and field study. Acta Otolaryng. (Stockh.), 1960, Suppl. 152.

44. Murray, N. E., & Reid, G. Experimental observations on the aural effects of gun blast. Med. J. Australia, 1946, 1, 611-617.

45. Murray, N. E., & Reid, G. Temporary deafness due to gunfire. J. Laryng., 1946, 60, 92-130.

46. National Research Council Committee on Hearing, Bioacoustics, and Biomechanics. Hazardous exposure to intermittent and steady-state noise. (Report of working group 46.) Washington, D. C., 1965.

47. Ogden, F. W. Effect of gunfire upon auditory acuity for pure tones. Project 315, Report No. 1, U. S. Army Air Force School of Aviation Medicine, Randolph Field, Texas, 1944.

48. Pease, C. B. Personal communication, 1966.

49. Pfander, von F. Uber die Toleranzgrenze bie Akustischen Einwirkungen. H. N. O., 1965, 13, 27-28.

50. Plomp, R., Gravendeel, D. W., & Bouman, M. A. Gehoorverliezen ten gevolge van het schieten met Lichte vuurwapens. Report No. WW 1956-9. Institute for Perception RVO-TNO, Soesterberg, The Netherlands, 1956.

51. Reid, G. Further observations on temporary deafness following exposure to gunfire. J. Laryng., 1946, 60, 609-633.

52. Rice, C. G., & Coles, R. R. A. Impulsive noise studies and temporary threshold shift. Paper B67 in Proceedings of the Fifth International Congress on Acoustics, Liege, Belgium, 1965.

53. Rice, C. G., & Coles, R. R. A. Auditory effects of sonic booms? Internal. Audiol., in press.

54. Rice, C. G., & Zepler, E. E. Loudness and pitch sensations of an impulsive sound of very short duration. J. Sound Vib., 1967, 5, 285-289.

55. Schuknecht, H. F., & Tonndorf, J. Acoustic trauma of the cochlea from ear surgery. Laryngoscope, 1960, 70, 479-505.

56. Smith, M. G., & Goldstone, G. A pilot study of temporary threshold shifts resulting from exposure to high-intensity impulse noise. Technical Memorandum 19-61, U. S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1961.

57. Thurner, M. A sonic boom simulator for subjective testing. M. Sc. Thesis, University of Southhampton, England, 1963.

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

59. U. S. Army Human Engineering Laboratories. Maximum noise level for Army Materiel Command equipment. HEL Standard S-1-63B, Aberdeen Proving Ground, Md., 1965.

60. U. S. Army, Office of the Surgeon General. Noise and conservation of hearing. TB Med 251, Washington, D. C., 1965.

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

62. Ward, W. D. Effect of temporal spacing on temporary threshold shift from impulses. J. acoust. Soc. Amer., 1962, 34, 1230-1232.

63. Ward, W. D. The concept of susceptibility to hearing loss. J. Occupational Med., 1965, 7, 595-607.

64. Ward, W. D. "Susceptibility to auditory fatigue," in Neff, W. D. (Ed.), Advances in sensory physiology. (Vol. 3) New York: Academic Press, in press.

65. Ward, W. D., Fleer, R. E., Glorig, A. Characteristics of hearing losses produced by gunfire and by steady-noise. J. Auditory Res., 1962, 1, 325-356.

66. 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.

67. 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.

68. Ward, W. D., Selter, W., & Glorig, A. Exploratory studies on temporary threshold shifts from impulses. J. acoust. Soc. Amer., 1961, 33, 781-793.

69. Zepler, E. E., & Harel, J. R. P. The loudness of rectangular pulses. Paper presented at Fachtagung Larmschutz, Dresden, Germany, 1965.

70. Zepler, E. E., & Harel, J. R. P. The loudness of sonic booms and other impulsive sounds. J. Sound Vib., 1965, 2, 249-256.

APPENDIX

APPENDIX A

RELEVANT DATA FROM AMERICAN SOURCES

BASIC RESEARCH

The Human Engineering Laboratories have conducted a number of basic studies (4, 32, 33, 34, 35, 36, 37, 38, 39, 56) of TTS from impulse-noise exposure to gain an understanding of the effect of impulses, as a class of acoustical stimuli, on the human hearing mechanism. The results and conclusions of some of these studies are summarized below. With two exceptions, subjects have always been exposed to noise with their ear normally incident to the oncoming shock wave. Thus, in some cases, the TTS exceeded the amounts allowed by the foregoing DRC when the firer's ear is in a more nearly grazing orientation.

Temporary Threshold Shift Study 1

During 1963-1964 experiments were carried out by Hodge et al. (33) to select impulse-noise exposure conditions to be used in later studies. The goal was to find exposure conditions which would produce a measurable TTS in most subjects, but without risk of permanently damaging the most susceptible subjects. The exposure conditions and resulting TTS are summarized in Table 1A.

Conclusions

1. To protect 90 percent of ears exposed at normal incidence, the peak level should be reduced below 153 dB.

2. The range of susceptibility to TTS from impulse-noise exposure was much greater than previously found for steady-state noise.

3. It is probably not possible to find exposure conditions that will produce a measurable positive TTS in most subjects without risk of permanent hearing loss in the most susceptible subjects.

TABLE 1A

TTS_2[a] (dB) Equalled or Exceeded in 50%, 25%, and 10% of Ears Exposed at Normal Incidence to Gunfire

Exposure[b]			Test Frequency (Hz)																	
			500			1000			2000			3000			4000			6000		
Peak Level (dB)	Number of Imrulses	N	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
153	25	13							5	10	25				5	10	15			
153	25	20							0	5	15				0	0	5			
153	50	16							10	13	17				5	7	10			
155	50	12	6	8	14	5	7	9	6	13	20	1	11	20	8	24	30	5	27	40
158	50	7	5	10	15	0	12	15	10	22	30	10	32	40	2	45	55	22	48	55

[a] Blank spaces indicate that TTS_2 cannot be obtained from available data.

[b] B-duration, 4 msec

Temporary Threshold Shift Study 2

In 1964 an experiment (33) was conducted to determine the effect of ear orientation on TTS. Subjects were exposed to 50 impulses at peak levels of 155 dB and 158 dB (B-duration, about 4 msec), with their ear oriented either normal to, or at grazing incidence to, the oncoming shock-wave impulse. Table 2A shows the results.

Conclusions

Normal ear orientation resulted in substantially more TTS than did the grazing orientation. The differences were especially marked at frequencies of 2 kHz and above. Temporary threshold shift resulting from the grazing-incidence exposures did not exceed the 10-15-20 dB "safe" limits of the DRC, even at 158 dB peak level, whereas the limits were exceeded even at the 155 dB peak level for the normally-oriented ears.

Temporary Threshold Shift Study 3

Experiments conducted by Hodge et al. during 1965 were devoted primarily to the establishment of the reliability (consistency; repeatability) of individual subject's, and group mean, TTS. The results of these studies have been reported elsewhere in detail (32, 34, 35, 36, 39), and they support the conclusion that group measures of TTS are much more reliable than individual subject's TTS. More relevant to the present discussion are the amounts of TTS demonstrated by the subjects on the occasion of the first noise exposure for each of the experiments. Subjects with normal hearing in the 0.5 to 6 kHz range were tested in two of the experiments, while in a third the subjects' hearing levels exceeded 15 dB (re USASI audiometer zero) at one or more of the six test frequencies and were therefore called "subnormal." The TTS is shown in Table 3A.

Conclusion

The safe peak level for the most susceptible 10 percent of ears should be reduced below 155 dB for normal-incidence exposures. TTS did not exceed the 10-15-20 dB "safe" limits at any test frequency in 75 percent of the subjects.

TABLE 2A

TTS_2 (dB) Equalled or Exceeded in 50%, 25% and 10% of Ears Exposed at Normal and Grazing Incidence to 50 Gunfire Impulses

Exposure[a]		Test Frequency (Hz)																	
		500			1000			2000			3000			4000			6000		
Peak Level (dB)	Ear Orientation	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
155	Normal	6	8	14	5	7	9	6	14	20	1	11	20	8	24	30	5	27	40
155	Grazing	0	0	8	0	5	10	1	9	15	0	4	10	0	4	8	0	0	13
158	Normal	5	10	15	0	12	15	10	22	30	10	32	40	2	45	55	23	48	55
158	Grazing	0	3	10	0	6	10	2	7	10	1	7	20	1	12	15	8	14	20

[a] A-duration, 350 μsec; B-duration, 4 msec

TABLE 3A

TTS_2 (dB) Equalled or Exceeded in 50%, 25%, and 10% of Normal- and Subnormal-Hearing Ears Exposed at Normal Incidence to Gunfire

Exposure[a]			Test Frequency (Hz)																	
			500			1000			2000			3000			4000			6000		
Peak Level (dB)	Number of Impulses	Type of Ears	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
155	50	Normal	1	5	9	5	7	11	7	12	25	5	13	26	7	16	43	5	14	49
155	50	Subnormal	1	5	9	0	7	10	4	10	15	5	15	23	0	8	24	1	7	11
158	25	Normal	3	6	10	2	5	11	2	12	15	2	6	13	3	9	13	3	13	39

[a] B-duration, 4 msec

Temporary Threshold Shift Study 4

A fourth TTS-reliability experiment (35, 36) was conducted using normal-hearing subjects in which pre- and post-exposure audiometry was conducted at frequencies of 8 to 18 kHz in addition to the usual testing at 0.5 to 6 kHz. The TTS from the first exposure is shown in Table 4A. Measurable amounts of TTS occurred in some subjects at frequencies up to 18 kHz. The largest median TTS occurred at 2, 6, and 10 kHz.

Conclusion

The "safe" amounts of TTS should not be relaxed at the higher frequencies, particularly in cases where personnel who fire weapons may also be assigned other duties requiring acute high-frequency hearing sensitivity.

Temporary Threshold Shift Study 5

In 1964, Bragg (4) performed a study in which TTS was measured in 36 soldiers after they were exposed to impulses of varying peak levels and numbers. All test ears were positioned at grazing incidence with regard to the shock wave. The TTS for 50, 25, and 10 percent of ears is shown in Table 5A.

Conclusions

Peak levels of 160 dB or less will not produce excessive TTS in 75 percent of ears exposed to 50 impulses. Up to 100 impulses below 150 dB do not cause excessive TTS in 90 percent of ears. As the number of impulses and their peak levels increase above these values, TTS becomes excessive. Fifty impulses at 165 dB will produce excessive TTS even in 50 percent of the population.

TABLE 4A

TTS_2 (dB) Equalled or Exceeded in 50%, 25%, and 10% of Ears Exposed at Normal Incidence to 25 Gunfire Impulses at 158 dB Peak Level[a]

Test Frequency (Hz)																							
500			1000			2000			3000			4000			6000			8000			9000		
50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
3	6	10	3	6	10	6	10	16	2	6	20	2	8	40	4	10	35	0	13	30	1	9	30

Test Frequency (Hz)																							
10,000			11,000			12,000			13,000			14,000			15,000			16,000			18,000		
50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
7	16	21	0	1	25	0	14	37	0	13	30	1	9	20	0	16	25	1	10	15	0	3	17

[a] B-duration, 4 msec

TABLE 5A

TTS_2 Equalled or Exceeded in 50%, 25%, and 10% of Ears Exposed at Grazing Incidence to an M-14 Rifle

Exposure[a]			Test Frequency (Hz)														
			1000			2000			3000			4000			6000		
Peak Level (dB)	Number of Impulses	Ears	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
140	100	64	0	0	6	0	0	6	0	0	9	0	0	16	0	6	24
150	100	66	0	5	11	0	7	12	0	7	16	0	6	19	0	10	27
160	25	20	0	7	9	6	10	11	6	9	27	6	12	22	8	19	37
160	50	20	4	7	13	8	11	20	3	10	20	6	19	36	10	15	30
163	25	26	4	7	9	7	12	21	11	16	29	17	40	40	18	35	50
165	25	26	5	8	14	6	19	32	6	14	28	7	13	45	3	24	51
165	50	8	23	56	89	20	44	68	29	59	89	26	58	90	39	71	103

[a] B-duration, 4 msec

HEARING LOSS EVALUATION OF SEVERAL SHOULDER RIFLES

In 1964 Garinther and Kryter (21, 41) performed a study in which the threshold of audibility of each ear of 178 soldiers was measured before and after they fired various types of shoulder rifles at the rate of one trigger pull every five seconds. The acoustical impulses from each type of weapon were measured (peak pressure, time history, and spectrum). The peak pressures (172.5, 168.5, 167.5 and 159.0 dB) of the acoustical impulses from firing the weapons highly correlated with threshold shifts caused by exposure to the gun noise. From these and related data, estimates were made of the expected permanent hearing level in the frequency region 1-6 kHz to be equaled or exceeded in 50, 25 and 10 percent of ears repeatedly exposed to gun noise at various peak pressure levels, and these are shown in Table 6A.

Conclusion

Peak pressure levels of 160 dB or less with A-duration of 250 μsec and B-duration of 4 msec will not produce excessive hearing levels in 75 percent of the people exposed. If protection for 90 percent of the population is desired, Table 6A indicates that exposures should be below 160 dB peak level.

TTS FROM IMPULSE VS. STEADY-STATE NOISE

Donley (15) conducted a study in 1962 to determine the relative effects of impulse and steady-state noises on hearing thresholds. Thirteen subjects were exposed to (a) 100 impulses from rifle fire, nine seconds apart, each having a peak level of 161 dB and a B-duration of 4 msec, and (b) 10 minutes of 110 dB SPL 1.2-2.4 kHz, steady-state noise. For the impulse-noise condition, the subject's ear was at normal incidence to the shock wave. TTS_2 was determined at 2 and 4 kHz and is shown in Table 7A. The ranges of TTS_2 for the impulse-noise exposure were 0-75 dB at 2 kHz and 0-55 dB at 4 kHz, compared with 10-30 dB at 2 kHz and 10-20 dB at 4 kHz for the steady-state noise exposure.

TABLE 6A

Predicted Permanent Hearing Level (USASI Standard) Equalled or Exceeded in 50%, 25%, and 10% of Ears After Repeated Daily Firing of Shoulder Rifles[a]

	Test Frequency (Hz)														
	1000			2000			3000			4000			6000		
Peak Level (dB)	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
160	0	7	15	0	8	16	0	18	25	15	35	45	25	45	60
165	0	9	16	0	10	20	12	32	42	25	45	60	47	52	67
170	0	15	25	10	25	35	35	55	70	45	65	85	50	70	90

[a] 100 rounds, at 5 second intervals. A-duration, 200 μsec; B-duration, 4 msec

Conclusion

Susceptibility to TTS from impulse noise varies over a much wider range than that for steady-state noise. There was no correlation between TTS from the two types of noise exposure. Maximum TTS from impulses occurred at 4 kHz for about one-half the subjects, and at 2 kHz for the other half.

TABLE 7A

TTS_2 (dB) Equalled or Exceeded in 50%, 25%, and 10% of Ears Exposed to Impulse and Steady-State Noise

Type of Noise	Test Frequency (Hz)					
	2000			4000		
	50%	25%	10%	50%	25%	10%
Impulse[a]	10	37	72	20	35	55
Steady-State	15	20	28	15	20	20

[a] Ears at normal incidence.

TRANSDUCER TECHNIQUES FOR MEASURING THE EFFECTS OF SMALL ARMS' NOISE ON HEARING

Garinther and Moreland (22) investigated different types of transducers and the techniques which might be used when evaluating the hearing hazard of the pressure waves that small-arms produce. In measuring the small-arms' peak pressure level, error was directly proportional to the measured rise time and inversely proportional to the positive pressure duration (A-duration) of the wave. For example, when measuring a rifle with an A-duration of 250 μsec using a transducer with a rise time capability of 10 μsec, the error will be four percent or 0.35 dB. Conversely, if the duration of the impulse noise is shorter, the error will be greater. One of the transducer's most important characteristics is its rise-time capability. Although no present-day commercial transducer can follow the pressure rise of small-arms accurately, the device chosen must be able to reach a peak before significant pressure decay occurs. Care must be taken to measure only the incident pressure wave, i.e., the pressure that would be measured by a transducer with negligible size and perfect response. Orienting a transducer of small diameter ($\leq$ 1/4 inch) at 90° incidence approaches this condition.

In summary, there were four recommendations for measuring small-arms pressure waves:

1. Use a transducer which has a rise-time capability of 10 μsec or less at the pressure being measured.

2. Transducer ringing and overshoot should be less than 1.5 dB at the pressure being measured.

3. The measuring system should have enough sensitivity to allow a signal-to-noise ratio of 25 dB or greater.

4. In relation to the weapon, the transducer should be where the left ear of a right-handed firer would be (firer not present). It should be oriented (a) at 90° incidence, and (b) with its sensitive surface approximately parallel to the ground.

APPENDIX B

RELEVANT DATA FROM BRITISH SOURCES

The two British authors have collected data both from their own studies and by association with projects of others. Summaries of the principal features and results are given below.

PERMANENT THRESHOLD SHIFT STUDIES

Permanent Threshold Shift Study 1

In 1960-62, Coles and Knight (10) carried out an otological and audiometric survey of groups of men at intervals during training of Royal Marines, a survey similar to that of Harbold and Greene (27) with U. S. Marine Corps recruits. Elevations of threshold greater than 15 dB at 3 kHz, 20 dB at 4 or 6 kHz, or 25 dB at 8 kHz were considered to constitute a significant deterioration. During Part-A training, in which each man fired about 350 rounds of 7.62mm rifle ammunition (peak level at L/R ears = 161/159 dB, A-duration = 330μsec, B-duration = 5 msec) but also, of course, was exposed to noise from neighboring rifles, three men (10%) in one group of 30 and six men (11%) in another group of 57 had significant deteriorations. Reported use of V-51R earplugs averaged 62 percent and 14 percent, respectively, of men-times-occasions of exposure. During Parts B, C and D training, in which there are much further rifle-noise exposures and a few firings of heavier weapons, e.g., the 2-inch mortar (see PTS Study 2), a further five (18%) of the group of 30 men suffered significant deteriorations. Reported use of ear protection had been 24 percent. Five (23%) of another group of 22 men during this stage of training suffered such hearing changes with seven percent reported use of ear protection.

Conclusion

Noise of the types and amounts described is a significant auditory hazard. It should be noted, however, that where several persons fire on the same range, the noise hazard from neighboring weapons may be considerably greater than that measured from a man's own weapon. This is because (1) firers may be separated by insufficient distances, (2) although firers on marksmanship (classification) ranges are in line abreast, in field-firing they will usually be sited according to the shape of the terrain and may frequently be en echelon, and (3) noise from neighboring weapons arrives at the ear at incidences nearer to 0^{o} (normal incidence). In addition, firing sometimes takes place in somewhat reverberant conditions (e.g., a roof over the firing point) which increase the auditory hazard from each weapon.

Permanent Threshold Shift Study 2

In 1964-65, a further group of 34 Royal Marine recruits was surveyed (10). On this occasion, from start to finish of training, only one (3%) of the recruits suffered a significant deterioration of hearing, probably because the men used V-51R earplugs more frequently. The reported usage averaged 90 percent of men-times-occasions of exposure. The hearing loss in the one man affected was quite certainly related to noise of firing of 40 2-inch mortar bombs. Whether this indicated an upper limit of V-51R earplug efficiency or a poor fit of his earplugs was not certain, but the evidence available supported the former supposition. Another man showed a small, just below CHABA-limit, threshold shift which could also be related to this noise, in spite of ear protection. Murray and Reid (44, 45) recorded peak pressure levels equivalent to 173 to 176 dB at 2-inch mortar crewmen's ears.

Conclusion

Noise of 2-inch mortars may be a borderline hazard even when V-51R earplugs are worn. V-51R earplugs give complete protection against the usual levels of rifle noise fired on open ranges.

TEMPORARY THRESHOLD SHIFT STULIES

Temporary Threshold Shift Study 1

Coles and Rice (11, 12) have reported TTS reduction studies of V-51R and Selectone-K earplugs in two types of impulse noise situations. Of the five men out of 20 exposed who showed a definite effect, the mean TTS_2 was as tabulated in Table 1B. [In order to compare these results with those from HEL and the end-of-day TTS_2 limits used in the CHABA DRC (42, 46), these TTS data have been converted to TTS_2 using the method of Kryter (40). However, the authors do not necessarily accept the basic interpretation of Kryter, i.e., that of an average TTS_2 correction for any random group or frequency; rather, they feel that if the subjects were split into three groups (e.g., highly sensitive, normally sensitive, and relatively insensitive to impulse-noise exposure, as suggested by Rice and Coles (52) and Elwood, et al. (17) different TTS_2 corrections for each group might then be found necessary. Further, from their own experience (52), they would agree with Kryter that his corrections are not applicable to TTS values in excess of 35 dB when recovery is nc always proportional to log time.]

V-51R earplugs gave protection to all five men for both types of noise. Selectone-K earplugs were adequate for the short impulses (at grazing incidence) but allowed some TTS in the long-impulse (reverberant) condition.

Conclusion

The short impulses were a significant hazard. If TTS from impulses is indeed proportional to the number of impulses (25, 68) then the TTS_2 at 1, 2 and 3 kHz would exceed 10, 15 and 20 dB, respectively, in over 25 percent of persons exposed to 100 rounds. The longer impulses are distinctly a more severe hazard, thus indicating the importance of duration.

TABLE 1B

Mean TTS_2 as a Function of Exposure
to Long- and Short-Duration Impulses
(5 subjects of marked impulse noise susceptibility)

	TTS_2 (dB)	
Frequency (Hz)	Short Impulses[a]	Long Impulses[b]
500	2	4
1000	5	7
2000	7	11
3000	6	13
4000	10	18
6000	20	31

[a] No. of rounds, 10-50; Peak level, 160 dB; A-duration, 330 μsec; B-duration, 5 msec

[b] No. of rounds, 5-20; Peak level, 156 dB; B-duration, 160 msec

Temporary Threshold Shift Study 2

In an extension of the previous study (12), the authors have shown the following TTS (Table 2B), here corrected to TTS_2, in four noise-sensitive subjects (upper quartile of noise-sensitivity range) firing identical numbers of rounds from the weapons described in TTS Study 1. Later exposure of two of these men to noise of blank ammunition fired in the open (159 dB peak level, 2 msec B-duration) caused little TTS.

Conclusion

This lends further support to TTS Study 1 and to the importance of duration.

Temporary Threshold Shift Study 3

In a development of the technique employed by the authors for estimating the impulse-noise sensitivity of experimental subjects, Elwood, et al. (17) have shown in a group of 110 men that sensitivity to the short-impulse noise (at grazing incidence) mentioned in PTS Study 1 and TTS Studies 1 and 2, can be sub-divided into four categories:

1. Highly sensitive (25% of subjects). Significant TTS_{2-6} (20 dB or more at 3, 4, 6 or 8 kHz in one or both ears, or 15 dB at two frequencies) from 20 rounds.

2. Moderately sensitive (15% of subjects). Significant TTS after a further 40 rounds.

3. Slightly sensitive (10% of subjects). Significant TTS after a further 60 rounds.

4. Insensitive (50% of subjects). No significant TTS after 120 (20 + 40 + 60) rounds of firing.

Conclusion

Although these data cannot be related exactly to the CHABA TTS_2 limits (42, 46), they further emphasize that the 7.62mm rifle noise at the firer's ears is an auditory hazard for at least 25 percent of the population.

TABLE 2B

Mean TTS_2 Resulting from Equal Numbers[a]
of Short and Long Impulses
(4 subjects of marked impulse noise susceptibility)

	TTS_2 (dB)	
Frequency (Hz)	Short Impulses	Long Impulses
2000	7	19
3000	8	26
4000	11	29
6000	23	34
8000	14	26

[a] No. of rounds, 20-50 according to susceptibility.

Temporary Threshold Shift Study 4

The authors cooperated in the second part of the study by Elwood, et al. (17) in which 12 men, fairly representative of the normal range of impulse-noise sensitivity, but probably not spreading far into the upper quartiles of susceptibility, were exposed to single impulses (at grazing incidence) which took the form of Friedlander waves (20) similar in form to that shown in Figure 1a on page 4 of this report. Peak levels varied between 165 and 185 dB, and the A-duration was 1 msec. Different levels of exposure and numbers of subjects having TTS_{2-6} of 20 dB at any one frequency or 15 dB at two frequencies in the 3 to 8 kHz range are shown in Table 3B.

Conclusion

Single exposures at peak levels of 170 - 175 dB appear to be hazardous to 25 percent or more of persons exposed.

Temporary Threshold Shift Study 5

With Elwood, et al. (17), the authors further exposed most of the same 12 men used in TTS Study 4 to single exposures in a free field of two other types of stimuli, both at grazing incidence, one being a conventional type of explosion and the other being a simulated sonic boom derived from a specially shaped line charge (29). The results are shown in Table 4B.

Conclusion

Single exposures to simulated sonic booms (N-waves) of 154 dB peak level were considered (53) to be harmless to hearing, but an explosion of 171 dB peak level would be hazardous to perhaps 25 percent of persons in a sample more representative of the noise distribution than used in this experiment.

TABLE 3B

Proportion of Persons Affected by Single Impulses as a Function of Peak Level (12 subjects)

Peak Level (dB)	No. of subjects with 20 dB or more TTS_{2-6}
165	0 (0%)
171	2 (17%)
174	6 (50%)
177	9 (75%)
180	11 (92%)
185	11 (92%)

NOTE: If a subject gave 20 dB or more TTS from one level, he was not further exposed, but it was assumed that he would suffer "significant" TTS for each of the higher levels also.

TABLE 4B

Comparison of TTS Produced by Various Impulse Noises with the Same 12 Subjects

Stimulus	No. of Impulses	Peak Level (dB)	Rise Time	A-duration	B-duration	No. of Subjects with 20 dB TTS_{2-6}
Complex waveform (see Fig. 1B)	20 - 120[a]	160	Instantaneous	330 μsec	5 msec	5 (42%)
N-wave	1	154	2 msec	45 msec[b]	-	nil
Friedlander wave (see Fig. 1A)	1	171	Instantaneous	8 msec	-	1 (8%)

[a] Based on individual data from TTS Study 3, but the subjects used probably did not extend far into the upper quartile of susceptibility.

[b] Because rise time exceeded 0.5 msec in the special case of the N-wave, the auditory hazard has been calculated (Loudness Study 3) to be at least 5 dB less for the given peak level.

Temporary Threshold Shift Study 6

The authors have recently been associated with a study, by W. I. Acton and M. R. Forrest (1), of the auditory effects of the noise of the .22-inch rifle when fired outdoors and in enclosed, reverberent ranges (see Table 5B).

In a series of exposures to the noise of 100 rounds each, 19 marksmen firing in pairs four feet apart were examined for TTS. In the reverberant ranges, effects which might be considered a borderline hazard for subjects at the extreme of noise sensitivity were recorded, whereas on the open range, TTS was negligible.

Conclusion

Noises with a peak level of about 133 dB of short duration do not constitute an auditory hazard. In reverberant conditions where the B-duration is prolonged the noise approached an auditory hazard for about the 5th percentile.

LOUDNESS STUDIES

Although exact relationships between loudness and auditory hazard are uncertain, there may be some similarity. For impulse noise, theoretical prediction and experimental loudness judgments are believed to provide a useful tool in comparing one noise with another, in terms which are probably closely related to their potentiality for auditory damage. The authors, therefore, believe that it is relevant to consider data from two recent studies of loudness of transient sounds.

Loudness Study 1

Rice and Coles (52) have studied the physical characteristics of six small-arms noises at three different situations; in addition, comparative loudness judgments were made by a 16-man jury for two of the conditions. These are shown in Table 6B.

TABLE 5B

Noise at Ears of Persons Firing
a .22-inch Rifle

	Peak Level[a] (dB)	A-duration (μsec)	B-duration (msec)
Open Range	138 (left) 130 (right)	<45	3.5
Reverberant Range	138 (left) 130 (right)	<45	60

[a] In this case the noise field at the firer's ear position was measured with the firer's head in situ and with him firing from the right shoulder; in absence of the head, the left-right ear position peak levels would have been about 132-134 dB, with a B-duration in the reverberant range of 140 msec.

TABLE 6B

Comparative Loudness Judgments of Several Small Arms

Weapon (and Ammunition)	Peak Level (dB) at Firer's Left Ear	Rank Order of Loudness Judged 15 ft at 180° to Line of Fire	Peak Level (dB)	B-duration (msec)	Rank Order of Loudness Judged 20 ft at 135° to Line of Fire	Peak Level (dB)	B-duration (msec)
7.62mm rifle (live)	161	7.62mm rifle (live)	148	4	7.62mm rifle (live)	149	3.5
.303-inch rifle (live)	161	.303-inch rifle (live)	147	4	.303-inch rifle (live)	147	3.5
.303-inch rifle (blank)	159	12-bore shot-gun (live)	141	5	.303-inch rifle (blank)	144	3.5
.38-inch pistol (live)	157	.303-inch rifle (blank)	140	4.5	7.62mm rifle (blank)	142	3.5
12-bore shot-gun (live)	155	7.62mm rifle (blank)	139	4.5	12-bore shot-gun (live)	143	2.5
7.62mm rifle (blank)	150	.38-inch pistol (live)	142	1.3	.38-inch pistol (live)	144	1.2

NOTE: When a subject in the open fired live rounds from the 7.62mm rifle and blanks from the .303-inch rifle (peak levels at his left ear were 161 and 159 dB, respectively) the noise of the 7.62mm rifle was judged much louder. It also caused much more TTS in the two subjects tested (see TTS Study 2). On the other hand, noise from .303-inch blanks fired by another person in a reverberant hut was judged louder, and produced more TTS, than the noise of live rounds fired from the 7.62mm rifle in the open (11, 52). In the reverberant hut, the blanks produced a peak level of only 156 dB at the subject's ear due to a different firing arrangement, but the envelope duration was much longer than that for the more intense noise of live rounds fired in the open (12). In these situations, loudness and TTS followed the same rank ordering and were somewhat independent of peak level. Similarly, the results tabulated above gave further indication that loudness is not dependent on peak level alone.

Conclusion

A damage-risk criterion for impulse noise must include considerations of envelope duration as well as of peak level.

Loudness Study 2

Experimental results obtained over recent years (14, 16, 28, 57, 69) within the Institute of Sound and Vibration Research have enabled a great deal of evidence to be accumulated regarding the loudness of acoustic transients. From this evidence a theory has evolved (54, 70) which allows the subjective impressions of loudness and pitch of short-duration acoustic transients to be predicted with a high degree of accuracy.

The theory uses the modulus of the Fourier transform $|F(\omega)|$ of the waveform, and a weighting factor K determined by the frequency sensitivity of the hearing mechanism from consideration of the phon curves (5), such that a weighted energy density curve of $K|F(\omega)|^2$ can be plotted. From the area under this curve, the absolute loudness level is expressed by the empirical formula (54)

$$\text{loudness level (phons)} = 102 + 10 \log(A \times 10^4)$$

where A is the area in $lb^2\ sec/ft^4$. To facilitate calculation a computer program has been evolved (48).

Assuming a triangular waveshape to be an idealized approximation to the A-duration of many types of impulse noise, then the relative loudness for high-intensity triangular impulses as a function of duration and rise time is shown in Table 7B and Figure 1B. The A-duration curve shown in Figure 2 (main text) is the inverse of Figure 1B.

Conclusion

If loudness is a correlate of likely auditory damage then rise times of less than about 0.3-0.5 msec for impulse types of noise can be treated in a single group, particularly as many potentially hazardous impulse noises have near instantaneous rise times. For such impulses, theoretical evidence suggests that the hazard increases with increasing duration up to a limit of 3 msec and remains at a steady level thereafter. Inclusion of this data into the DRC effects a satisfactory bridge between short-duration pressure changes and more prolonged ones, such as with Friedlander waves and nuclear explosions. When the rise times exceed 0.5 msec, the hazard might decrease by the amounts shown in Table 7B. However, it is not recommended that such corrections be used without careful consideration and in any case should not exceed 5 dB.

TABLE 7B

Relative Loudness in Phons as a Function of Rise Time and Duration

Duration (msec)	Rise Time (μsec)						
	1	100	500	1000	2000	3000	5000
0.05	0						
0.1	4.8						
0.2	7.8	8.7					
0.3	8.5	9.0					
0.5	10.2	10.1					
1	13.0	12.9	12.7				
2	14.7	14.7	14.7	14.8			
3	15.1	15.1	15.0	15.0	15.0		
5	15.2	15.2	14.8	14.6	14.0	14.0	
10	15.1	15.1	14.5	13.9	12.6	11.6	10.8
20	15.0	14.8	14.2	13.4	11.7	10.1	7.8
30	14.9	14.8	14.1	13.3	11.4	9.6	6.7
50	14.9	14.8	14.1	13.3	11.4	9.6	6.7
100	14.9	14.8	14.0	13.2	11.2	9.3	6.2

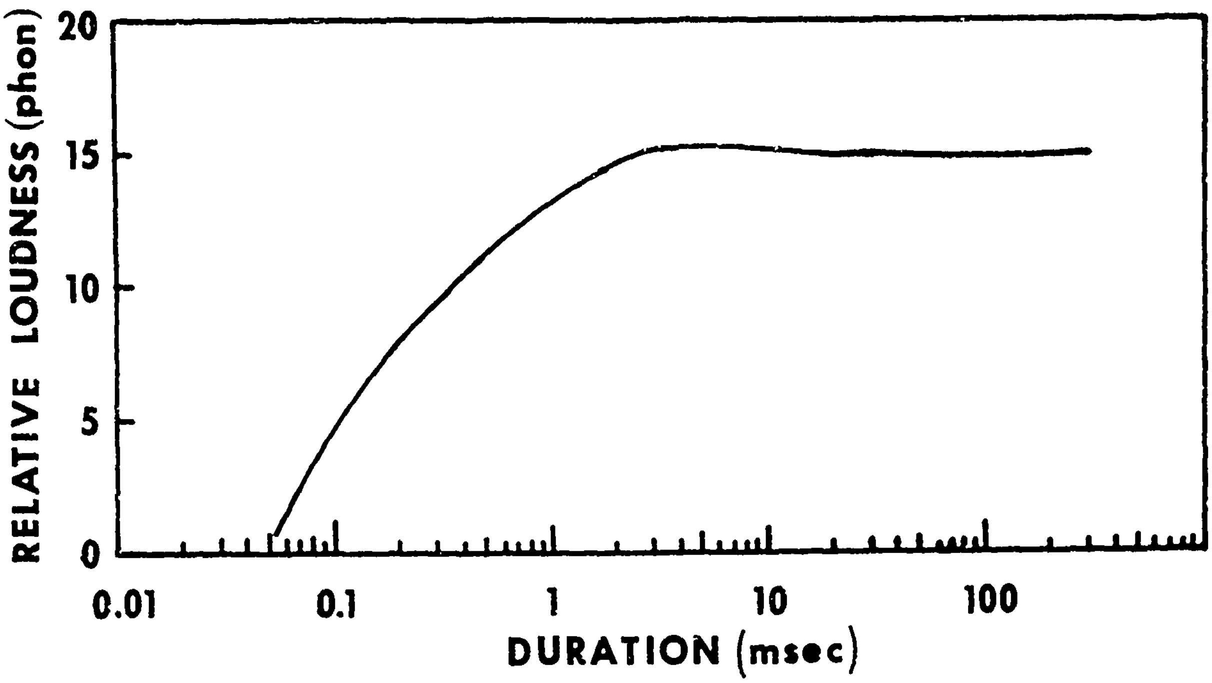

Fig. 13. CALCULATED RELATIVE CHANGE OF LOUDNESS OF A TRIANGULAR PULSE AS A FUNCTION OF DURATION

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13. ABSTRACT

This paper presents criteria for assessing damage risk from impulse-noise exposure. The criteria are based on conclusions of independent British and American studies and on the work of other research workers in this field. Most of the studies which led to these criteria were performed with noise from small arms, but the criteria are general enough to permit assessment of most other types of impulse noise. The variables which must be considered in determining the potential hearing hazard and in making practical application of the criteria are presented, and the parameters which must be measured are defined. The measurement technique and type of transducers to be used are discussed.

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