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INTERIM GUIDELINES ON LIMITS OF HUMAN EXPOSURE TO AIRBORNE ULTRASOUND

International Non-Ionizing Radiation Committee of the International Radiation Protection Association

PREFACE

THE International Radiation Protection Association (IRPA) took on the responsibility for activities in the non-ionizing radiation field by forming a working group in 1974. This working group became the International Non-Ionizing Radiation Committee (INIRC) at the IRPA Congress in Paris in 1977. The IRPA/INIRC in cooperation with the Environmental Health Division of the World Health Organization develops criteria documents on all non-ionizing radiations. These documents include thorough reviews of the available scientific literature, studies of existing national and international standards and their rationale, and evaluations of the health risks of exposure to non-ionizing radiations. They then form a scientific basis and rationale for the development of exposure limits and codes of practice.

The first draft of these guidelines was completed at a meeting held in Rockville, Maryland in November 1981. Following approval by the IRPA Executive Council, the draft was distributed to Member Societies of IRPA, and to various Institutions and individual scientists for comments. Many helpful comments and criticisms were obtained, and are gratefully acknowledged. Taking these comments into account, the Committee amended the guidelines and expanded the rationale.

The Committee recognized that when standards on exposure limits are established, various value judgments are made. The validity of scientific reports has to be considered, and extrapolations from animal experiments to effects on humans have to be made. Cost versus benefit analyses are necessary, including the economic impact of controls. The limits in these guidelines were based on the scientific data and no consideration was given to economic impact or other non-scientific priorities. However, from presently available knowledge, the limits should provide a safe, healthy working or living environment from exposure to airborne ultrasound under all normal conditions.

During the preparation of this document, the composition of the IRPA/INIRC was as follows:

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These guidelines were approved by the IRPA Executive Council on 8 July 1983.

INTRODUCTION

Ultrasonic energy is used in a wide variety of industrial processes, including cleaning, drilling, mixing and emulsification. Most of these processes invariably emit airborne acoustic energy, not only at the ultrasonic operating frequency but also at sub-harmonics which, in many cases, are audible. Many industrial applications use high ultrasonic intensities which produce cavitation, observed as a type of boiling action in the liquid, which produces high audible noise levels.

In the industrial environment, many workers have complained of subjective symptoms (nausea, tinnitus, headaches, fatigue, etc.) when operating devices such as ultrasound cleaning tanks. Some data indicate hearing loss from exposure to very high intensities of airborne ultrasound, but no well defined threshold for this effect has been determined.

Effects on the general public of airborne acoustic energy appear to be mediated by nervous reaction. Many people are unable to enter commercial establishments having an intrusion alarm (where the alarm is turned off, but the airborne ultrasound is still radiating) because they immediately suffer headaches or feel nauseated.

There are increasing numbers and varieties of consumer devices that use airborne ultrasound, including door openers, remote controls, intrusion alarms, pest repellers and guidance devices for blind people. In general, these applications employ low intensity ultrasound in the frequency range 20 kHz–100 kHz. Many of these devices also have application in industry and commerce, and most operate predominantly at frequencies below 50 kHz.

The IRPA/INIRC in conjunction with the Division of Environmental Health, World Health Organization, Geneva, drafted a document entitled *Environmental Health Criteria for Ultrasound* (UN82). This document forms the primary scientific data base for the development of the following exposure limits for airborne ultrasound.

PURPOSE AND SCOPE

These guidelines are primarily aimed at protection against exposure from devices emitting limited to frequencies having one-third-octave is provided and guidance given on limits of human exposure to airborne acoustic energy in the ultrasound range. Adverse health effects of exposure to airborne acoustic energy at levels normally encountered have been reported only at frequencies below 100 kHz and nearly all below 50 kHz. Thus, this standard has been limited to frequencies having one third-octave bands with mid frequencies from 20 kHz to 100 kHz.

BASIC CONCEPTS

Airborne ultrasound is usually quantified in terms of sound pressure level (SPL) in decibels (dB), such that:

$$\mathrm{SPL\,(dB)} = 20 \log_{10} (p/p_r),$$

where p is the root mean square acoustic pressure and p_r is the reference pressure. p_r is equivalent to approximately the lowest level of audible sound perceived by humans at the most sensitive frequency (approx. 1 kHz), and is normally taken as equal to 20 micropascals (μPa). 20 μPa is equivalent to an acoustic intensity $I_r = 10^{-12}\,\mathrm{W/m^2}$ in the air.

Since the acoustic intensity (I) is proportional to the square of the acoustic pressure, the sound pressure level can be equivalently expressed by

$$\mathrm{SPL\,(dB)} = 10 \log_{10} (I/I_r).$$

Therefore, doubling the intensity (I) increases the SPL by 3 dB, whereas doubling the pressure (p) increases the SPL by 6 dB.

It should be noted that commonly used sound level meters have an effectively complete cut-off above about 20 kHz. Thus special sound level meters are needed for measurements above this frequency.

An octave band contains a range of fre-

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†From previous page.

quencies, the upper frequency limit being twice the lower frequency limit. The centre or mid frequency used to designate each octave is twice the centre frequency of the preceding octave band. In this document, one-third octave bands are used to geometrically split an octave band into three parts and the mid frequency is used to designate each band.

EXPOSURE LIMITS

Limits of exposure to airborne ultrasound for occupational exposure are given in Table 1. The limits apply to continuous exposure to workers for an 8 hour working day. The limits in Table 1 may be increased in accordance with corrections given in Table 2, provided the total duration of exposure per day does not exceed 4 hours.

Exposure limits to airborne ultrasound for the general public are given in Table 3. The limits apply to continuous exposure to the general public for up to 24 hours per day.

National or local noise regulations or standards should incorporate limits of occupational and general public exposure to the auditory component of the airborne acoustic energy emitted from ultrasound devices.

Measurement of the sound pressure levels to determine adherence to the guidelines should be made at the normal height of the ears of exposed persons.

A brief rationale for the exposure limits is given in Appendix 1. Measures needed to ensure compliance with these limits are given in Appendix 2.

EXCLUSIONS

The limits recommended in these guidelines may be exceeded for occupational exposure, if workers are provided with ear protectors that reduce the ultrasound levels at their ears to the sound pressure levels given in Table 1. No exclusions to these limits are recommended for exposure of the general public (Table 3).

Table 1. Limits for continuous occupational exposure to airborne ultrasound

Mid frequency of one-third octave band (kHz)	Sound pressure level (dB re: 20 μPa)
20	75
25	110
31.5	110
40	110
50	110
63	110
80	110
100	110

Table 2. Modification to occupational exposure limits given in Table 1 for exposure durations not exceeding 4 hours per day

Total exposure duration (h)	Correction to SPL (dB)
2-4	+3
1-2	+6
0-1	+9

Table 3. Limits for continuous exposure of the general public to airborne ultrasound

Mid frequency of one third-octave band (kHz)	Sound pressure level (dB re: 20 μPa)
20	70
25	100
31.5	100
40	100
50	100
63	100
80	100
100	100

CONCLUDING REMARKS

Since the data on the effects of human exposure to airborne ultrasound are presently limited, these guidelines will be subject to periodic revisions and amendments with advance of knowledge.

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APPENDIX 1

RATIONALE FOR EXPOSURE LIMITS

The biological effects of exposure to airborne ultrasound have recently received a thorough review (UN82). They have previously been reviewed by various authors and organizations (Ac67; Ac74; Ac77; He81; Hi82; HW80; Re81).

Much less than 1% of the airborne ultrasound is absorbed by human skin, the rest is reflected. Hair strongly absorbs sound and ultrasound in the frequency range of interest. The ear, being a more efficient coupler of airborne acoustic energy than any other part of the human body, is considered the most sensitive organ.

Acton and Carson (Ac67) failed to detect either temporary or permanent losses of hearing in industrial workers exposed to levels of airborne ultrasound of approximately 120 dB. On the other hand, temporary threshold shifts were detected in hearing of subjects exposed to frequencies of 18 kHz at 150 dB for approximately 5 minutes (Ac67).

The more sensitive indicator of potential harm from airborne ultrasound exposure comes from reports of subjective effects—nausea, headaches, fatigue, tinnitus, or an unpleasant sensation of fullness or pressure in the ears. Workers with good hearing at the upper frequencies of the audible range were reported to complain of these subjective effects (Ac67; Ac74; Ac77; Cr77; He81; Hi82; Re81; Sk65). It was suggested that these effects were produced by audible components of the ultrasonic frequency (Ac67; Ac74; Ac77). Airborne sound at levels of approximately 78 dB at 16 kHz was reported to cause subjective symptoms, while levels of 100 dB at 20 kHz and 25 kHz did not cause these effects. However, Crabtree and Forshaw (Cr77) reported subjective symptoms in Canadian Forces personnel working around ultrasonic cleaning tanks. The SPL in the 20 kHz, one-third octave band did not exceed 105 dB at the operator's position.

A recommended occupational exposure limit of 110 dB for frequencies with mid frequencies of one-third octave bands above 20 kHz seems well justified from the available data (UN82). What seems to differ in many standards is the exposure limit at 20 kHz, mid frequency of one-third octave band (UN82). Presently available data do not provide a threshold for effects in this frequency band. Acton (Ac75) recommends an SPL of 75 dB for the one-third octave band with mid frequency of 20 kHz. His rationale was that the nominal frequency limits of the one-third octave band centered on 20 kHz are 17.6 kHz to 22.5 kHz and the lower end is within the upper end of the audible frequency range of many people who operate industrial ultrasonic devices. The SPL of 75 dB seems appropriate from presently available data. Sound pressure levels of 100 dB at frequencies in the range 17.6 kHz to 20 kHz may produce severe auditory and subjective effects, although permanent hearing loss is unlikely (Ac67).

When considering exposure limits for the general public, a number of additional factors must be taken into account.

(a) Exposure may occur for up to 24 hours per day.

(b) There is no medical surveillance as is possible for a controlled occupational group.

(c) It would be undesirable to require hearing protectors or other protective devices to keep levels at the ears within the limits.

(d) Noise-related effects such as annoyance, stress, etc., must be considered in addition to other possible auditory effects.

(e) The general public is a population containing a broad range of sensitivities to insult from physical agents.

Existing data suggest that exposure of the general public to airborne ultrasound (one-third octave band mid frequencies above 20 kHz) at levels up to 110 dB is not known to cause untoward health effects. However, noting that the general population can potentially be exposed 24 hours per day and for the other considerations noted above, an added safety factor should be incorporated, at least as an interim measure until more definite data on adverse health effects of exposure to airborne ultrasound become available. Thus an SPL of 100 dB is recommended. For similar reasons, an added safety factor should be incorporated into the exposure limit for frequencies in the range of the one-third octave band centred on 20 kHz. An SPL of 70 dB is recommended, although it is noted that noise exposure limits in each country (HW79; IL77; UN80) may cover audible frequencies up to 20 kHz.

APPENDIX 2

PROTECTIVE MEASURES

Adoption of exposure limits constitutes the first step in protection. Equipment performance and emission standards should then be derived from the exposure limits.

Standardized measurement techniques and survey procedures should be introduced and adhered to. Determination of sound pressure levels at given locations in an airborne acoustic field is normally made using a device consisting of a capacitor microphone having a flat response over the frequency range of interest, associated electronics, and a set of one-third octave filters. The audible component of an acoustic field can be measured using a sound level meter with a low-pass filter to reject frequencies above 20 kHz.

In air, ultrasound at a frequency of 40 kHz has a wavelength of about 8.5 mm, is quite directional (depending on the ratio of the source diameter and the wavelength), is easily attenuated barriers, and loses about 0.06 dB for every 30 cm the wave travels due to absorption by the air. At lower frequencies, lower attenuation occurs due to air absorption and vice versa. In addition, the acoustic intensity radiating from a point source reduces 6 dB for each doubling of distance in the far field. The airborne acoustic field can be extremely complex and careful mapping of the field should be made during surveys since levels can vary significantly over a short distance. Preliminary measurements should be made to assess the acoustic field present. As most acoustic sources vary in intensity level and frequency spectrum, careful consideration of each measurement situation is essential to obtain meaningful data.

Measurement of SPLs should be made with the microphone positioned at the ear height of exposed persons where possible. For making these measurements, it is highly desirable to use a small diameter microphone with adequate response at high frequencies and good directional properties.

Microphones and filters can have frequency-dependent errors, and so must be calibrated before use. Complete calibration of the measurement equipment is complex and should be conducted by a qualified laboratory or the equipment manufacturer. Before and during measurements in the field, checks on the accuracy of the equipment should be made. Such checks are normally made using a field calibrator, which generates a known acoustic signal. The highest frequency of a field calibrator is normally limited to 2 kHz. However, such a calibrator should still be used because the equipment normally performs correctly either at all frequencies or at none. Thus the calibrator will allow the detection of malfunctions related to frequency. The accuracy of measurement instruments should be within ±2 dB for frequencies up to 25 kHz and ±5 dB above 25 kHz to the upper frequency limit of the instrument (HW80).

Responsibility for protection and safety should be clearly assigned to appropriate regulatory agencies, health departments and individuals. Where possible and needed, principles of medical and environmental surveillance should be developed and appropriate responsibilities assigned (HW80; IL77).

Responsibility for the evaluation of protection from emissions from newly designed equipment and installations should be assigned and implemented. This should also allow for the development of safe use guidelines or codes of practice. These should constitute an integral part of instructions for the user and for the development of an emission standard (where applicable), before such equipment is mass-produced. One might consider pre-market approval of these devices on the basis of safety. Wherever possible, exposure controls should be built into mass-produced equipment to avoid dependence for safety on instructions and labels alone.

Guidelines on measures for protecting humans against exposure to acoustic energy have recently been published (HW80; IL77). Both these documents are good references for persons or institutions developing their own codes of safe practice.