A Review of Current Ultrasound Exposure Limits

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Abstract

Research has indicated that airborne ultrasonic sound impinging on the ear drums of humans has the potential to cause undesirable effects. The United States of America's Occupational Health and Safety Administration have changed their guidelines to permit an additional 30dB increase in the acceptable ultrasonic amplitudes under certain conditions. This paper contains a review of current recommended acceptable exposure limits from standards organisations around the world.

1 Introduction

Exposure limits for ultrasonic noise were developed in the late 1960s and one standards organisation in the United States of America has recently changed their recommended exposure limits. This paper contains a review of the current recommended noise exposure limits from standards organisations around the world. The limits are set based on current knowledge, so as to ensure the safety of people from the potential hazards of exposure to high levels of ultrasonic sound.

Ultrasonic sound is beyond the range of normal human hearing and is usually described as sound that has a frequency above 20kHz. There are no reports of hearing loss due to ultrasound exposure [1, 2], although there is a report of temporary threshold shift in subjects exposed to frequencies of 18kHz at 150dB for about 5 minutes [1]. Research has shown that airborne ultrasound has the potential to cause nausea, fatigue, and headaches [3–8].

Recently, devices have become commercially available, which indirectly generate audible sound by initially generating ultrasound. The details of the method by which

audible sound is generated from ultrasound can be found in Refs [9–12]. The potential use of these devices to act as focussed control sources in an active noise control system was the impetus to conduct a review of the literature to find current recommendations for the exposure limits of airborne ultrasound impinging on the human ear.

There is a general consensus amongst standards organisations on the exposure limits for ultrasound. The limits were derived by three independent research groups who arrived at very similar findings for acceptable exposure limits [5]. The exception to the general consensus are the guidelines from the US Occupational Health and Safety Administration (OSHA), which in 2004 voted to adopted the recommendations from The American Conference of Governmental Industrial Hygienists, which permit an increase in the exposure limits by 30dB under certain conditions [4] that are described later in this paper.

The general consensus is embodied in a Health Canada report [13], which is based on the findings from the International Radiation Protection Agency (IRPA) [8], which provides recommendations to the World Health Organisation, listed in Table 1. These limits are applicable for continuous occupational exposure to airborne ultrasound. The IRPA guidelines allow for an increase in the exposure limits if the exposure duration is less than 4 hours per day; however Health Canada [13] does not support this recommendation and it should be noted that the IRPA recommended limits for continuous exposure for airborne ultrasound to the public are lower than those shown in Table 1.

Table 1: Recommended ultrasound exposure limits in octave bands.

Frequency (kHz)	Sound Pressure Level (dB re 20μPa)
8	-
10	-
12.5	-
16	-
20	75
25	110
31.5	110
40	110
50	110

2 Standards on Ultrasound Exposure

2.1 Effects

There are many medical products that use ultrasound in the mega-Hertz frequency range for such purposes as imaging, destruction of kidney stones, and others. There is a great deal of literature available that discusses the occupational risks of using such equipment and the possible damage that can occur to practioners, patients or foetuses [14]. This research is not relevant to the current discussion as typically the frequency range is higher than the frequency range of interest here, the amplitudes are much greater than proposed here, and the method of conduction is with direct skin contact travelling through water or the body. The literature review discussed here is focused on the effects of ultrasound that is less than 50kHz, travels through air, and impinges on the ear drums.

Parrack found that slight heating of the skin could occur when exposed to sound pressure levels of 140-150dB at ultrasonic frequencies [15]. Parrack has also calculated theoretically that a dose of more than 180dB would be lethal to humans [16].

Von Gierke and Nixon [5] have a concise description of the effect of ultrasound; the effects of "... ultrasonic energy at frequencies above about 17kHz and at levels in excess of about 70dB may produce adverse subjective effects experienced as fullness in the ear, fatigue, headache, and malaise".

The National Occupational Health and Safety Commission's Annual Safety Report [3] says that "... there is less evidence on the specific adverse affects of ultrasound. However, it is becoming a suspect factor in harmful effects on the human genome, spontaneous abortion, congenital malformation, chromosomal aberrations, and even cancers."

Schust [17] wrote that "The human ear may perceive auditory sensations up to at least 40kHz. In laboratory experiments a temporary threshold shift by ultrasound could be demonstrated. Some epidemiologic studies point to the fact that an impairment of high-frequency hearing above 8kHz may not be excluded by long-term ultrasound exposure".

The generation of ultrasound is often accompanied by high amplitude sound pres-

sure levels of sub-harmonic frequencies in the audible frequency range. In addition, research has shown that the ear drum vibrates non-linearly and can generate sub-harmonic vibration when exposed to sound pressure levels in the range from 110-130dB [18]. The amplitude of the sub-harmonics was the same order as the amplitude at the fundamental frequency and could possibly damage the ear.

The subjective effects that are attributed to ultrasound are usually caused by the sound energy in the audible frequency range. When the sound energy in the audible frequency range is reduced, it is usually accompanied by a reduction in the subjective symptoms [3]. Criteria have been developed to limit the levels of ultrasound to control auditory and subjective effects. The criteria were developed from the independent investigations of three scientists [5], and are discussed in the next section.

2.2 Exposure Limits

Several standards exist that specify acceptable ultrasound exposure limits. The prescribed limits vary between countries and a summary of the exposure limits is shown in Table 2, which was adapted from a table in a Health Canada report [13].

Table 2: Guidelines for the safe use of ultrasound [13].

	Proposed By*						
Frequency (kHz)	1	2	3	4	5	6	7
8	90	75	-	-	-	-	-
10	90	75	-	-	80	-	-
12.5	90	75	75	-	80	-	-
16	90	75	85	-	80	-	75
20	110	75	110	105	105	75	75
25	110	110	110	110	110	110	110
31.5	110	110	110	115	115	110	110
40	110	110	110	115	115	110	110
50	110	-	110	115	115	110	110

*Legend: 1. Japan (1971); 2. Acton (1975) [19]; 3. USSR (1975); 4. Sweden (1978); 5. American Conference of Governmental Industrial Hygienists (ACGIH 89) [20] and US Department of Defense (2004) [21]; 6. International Radiation Protection Agency (IRPA 1984) [8]; 7. Canada (1991) [13].

The International Commission on Non-Ionising Radiation Protection (ICNIRP) is an independent scientific organisation responsible for providing guidance and advice

on the health hazards of non-ionising radiation exposure. ICNIRP provides recommendations to the World Health Organisation (WHO) for ultrasound exposure limits, and are listed in column 6 of Table 2.

Note that for the data listed in Table 2, some have exposure time limits and others do not. The amplitude limits prescribed by Health Canada [13] in column 7 are independent of time as the subjective effects of high amplitude ultrasound can occur immediately.

The exposure limits proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) have recently changed the permissible levels, and hence it is worthwhile highlighting the changes.

> "The American Conference of Governmental Industrial Hygienists (ACGIH) has established permissible ultrasound exposure levels (Table III:5-4). The latest edition of the ACGIH publication, 1998 Threshold Limit Values (TLV's) and Biological Exposure Indices (BEI's), adopted TLV's that had been proposed in the 1997 publication as a "nature of intended changes." Therefore, Table III:5-4 represents the newly adopted TLV's for ultrasound. These recommended limits (set at the middle frequencies of the one-third octave bands from 10kHz to 50kHz) are designed to prevent possible hearing loss caused by the subharmonics of the set frequencies rather than the ultrasonic sound itself." [4].

Table 3 lists the ultrasound exposure limits that were described in Table III:5-4 from the above quote. The 1997 reference in the quote refers to a publication of the American Conference of Governmental Industrial Hygienists 1997, page 81.

The accompanying Note 2 is confusing as the title of the column describes the ultrasound exposure limit when the noise is "Measured in Air" and "Head in Air". However Note 2 says that "These values assume that human coupling with water or other substrate exists." It is unclear how the effects of ultrasound are modified when a person with their head in the air has contact with water or not.

The second statement implies that the values may be raised by 30dB, and hence the limits are 145dB, which is 30dB greater than the limits proposed by other countries

Table 3: Ultrasound exposure limits from OSHA [4]: Table III:5-4. TLV's for Ultrasound, Notice of Intended Change - Ultrasound.

	Measured in Air in dB re 20μPa Head in Air		Measured in Water in dB re 1μPa Head in Water
Mid-Frequency of Third-Octave Band (kHz)	Ceiling Values	8-Hour TWA	Ceiling Values
10	105[1]	88	167
12.5	105[1]	89	167
16	105[1]	92	167
20	105[1]	94	167
25	110[2]	–	172
31.5	115[2]	–	177
40	115[2]	–	177
50	115[2]	–	177
63	115[2]	–	177
80	115[2]	–	177
100	115[2]	–	177

Notes:

1. Subjective annoyance and discomfort may occur in some individuals at levels between 75 and 105 dB for the frequencies from 10 kHz to 20 kHz, especially if they are tonal in nature. Hearing protection or engineering controls may be needed to prevent subjective effects. Tonal sounds in frequencies below 10 kHz might also need to be reduced to 80 dB.

2. These values assume that human coupling with water or other substrate exists. These thresholds may be raised by 30 dB when there is no possibility that the ultrasound can couple with the body by touching water or some other medium. [When the ultrasound source directly contacts the body, the values in the table do not apply. The vibration level at the mastoid bone must be used.] Acceleration Values 15 dB above the reference of 1g RMS should be avoided by reduction of exposure or isolation of the body from the coupling source. (g = acceleration due to the force of gravity, 9.80665 meters/second; RMS = root-mean-square.)

as listed in Table 2. One would have expected that the exposure limits are based on measurements at the listener's ear when their head was in air, and that the limit values would be unmodified if the person was in contact with water or a substrate. Further clarification of this table is necessary to determine if the clauses are relevant to the application where the ultrasound travels through air and the listener is not in contact with water.

The changes made to OSHA's exposure limits have also caused concern amongst hearing conservationists who predict that the changes made to acceptable levels in the audible frequency range ($<$ 20kHz) are likely to cause a substantial increase in the number of workers in hearing conservation programs [22–24].

Results of tests conducted on two devices which emit ultrasound to generate highly directional audible sound has found that the ultrasonic noise levels are about 130-140dB at 1 metre, which exceeds the recommendations described in Table 2. One manufacturer has published data to show that their product generates ultrasonic sound pressure levels around 130dB [25]. Another manufacturer of the ultrasonic devices writes in a whitepaper [26] that the ultrasound "... thresholds may be raised by 30dB when there is no possibility that the ultrasound can couple with the body by touching water or some other medium," to claim that their device is safe for humans.

3 Conclusion

The United States of America's OSHA recommendations appear to be inconsistent with the ultrasound exposure limits proposed by other countries. In 2004 OHSA have increased the permissible levels, under certain conditions, and their justification is unclear.

Until more definitve data become available, it is recommended that the more conservative standard proposed by the Health Canada [13] and listed in Table 1 be adhered. This means that sound pressure levels should be less than 110dB above 25kHz, regardless of the exposure duration, to prevent the undesirable subjective effects of ultrasound.

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