Review of Current Recommendations for Airborne Ultrasound Exposure Limits

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ABSTRACT

The standards for airborne ultrasound exposure limits were derived from research conducted by three independent groups in the late 1960s. Recently, a regulatory body in the USA has proposed increasing the generally accepted exposure limits by 30dB. This paper contains a review of the literature concerning the effects of exposure to airborne ultrasound impinging on human ears and the suggested exposure limits that are used in several countries.

INTRODUCTION

Ultrasound is usually described as sound that has a frequency above 20kHz. Ultrasound is used in many devices such as motion detectors, cleaning baths, plastic welding equipment, fluid flow meters, and medical imaging equipment, among others. There has been a great deal of research undertaken to examine the effects of ultrasound on tissue to ensure that ultrasound medical imaging equipment, which is commonly used on pregnant women, does not harm either the patient or the foetus. However, the focus of the review presented here is the current recommended ultrasound noise exposure limits from standards organisations around the world, where the ultrasound noise is transmitted through the air and impinges on human ears.

Recently, devices have become commercially available from at least two companies, which indirectly generate audible sound by initially generating ultrasound. The details of the principle by which audible sound is generated from ultrasound can be found in Berktay (1965), Berktay and Leahy (1974), Yoneyama and Fujimoto (1983), and Kim and Sparrow (2002). These devices emit a highly directional beam of audible sound that could potentially be used as focussed sound sources in an active noise cancellation system. One of these devices was purchased by the authors and provided 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 exposure limits for ultrasound were developed in the late 1960s by three independent research groups who arrived at very similar findings (Gierke and Nixon 1992). The general consensus is embodied in a Health Canada (1991) report, which is based on the findings from the International Radiation Protection Association (IRPA) (1984), which provides recommendations to the World Health Organisation (WHO). 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 (1991) does not support this recommendation.

The following sections describe the potential effects of ultrasound and a review of current ultrasound exposure limits.

STANDARDS ON ULTRASOUND EXPOSURE

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 practitioners, patients or foetuses (Barnett and Kossoff 1998). This research is not relevant to the current discussion because 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 characterised by a frequency less than 50kHz, travels through air, and impinges on the ear.

There are no reports of hearing loss due to ultrasound exposure (Acton and Carson 1967, Knight 1968), although there is a report of temporary threshold shift in subjects exposed to frequencies of 18kHz at 150dB for about 5 minutes (Acton and Carson 1967). Research has shown that airborne ultrasound has the potential to cause nausea, fatigue, and headaches (NOHSC 2002, OSHA 2004, Gierke and Nixon 1992, Acton 1974, Damongeot and Andre 1988, and IRPA 1984).

Parrack and Perret (1962) found that slight heating of the skin could occur when exposed to sound pressure levels of 140-150dB at ultrasonic frequencies. Parrack (1966) has also calculated theoretically that a dose to the skin of more than 180dB would be lethal to humans.

Gierke and Nixon (1992) provided 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".

Schust (1996) 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 longterm ultrasound exposure".

The generation of ultrasound is often accompanied by high amplitude sound pressure levels of subharmonic frequencies in the audible frequency range. In addition, research has shown that the ear drum vibrates nonlinearly and can generate sub-harmonic vibration when exposed to sound pressure levels in the range from 110-130dB (Dallos and Linnel 1966). 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 often attributed to ultrasound are usually caused by 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 (NOHSC 2002). Criteria have been developed to limit the levels of ultrasound to control auditory and subjective effects. The criteria that have been developed in the past are discussed in the next section.

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 1, which was adapted from a table in a Health Canada (1991) report.

Table 1: Guidelines for the safe use of ultrasound.

	Exposure limit proposed by* (dB re 20μPa)						
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

Source: (Health Canada 1991)

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

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 nonionising radiation exposure. ICNIRP provides recommendations to the WHO for ultrasound exposure limits, which are listed in column 6 of Table 1.

Note that for the data listed in Table 1, some have exposure time limits and others do not. The amplitude limits prescribed by Health Canada (1991) in column 7 are independent of time, as the subjective effects of high amplitude ultrasound can occur immediately.

The exception to the general consensus are the guidelines from the US Occupational Health and Safety Administration (OSHA), which in 2004 voted to adopt the recommendations from The American Conference of Governmental Industrial Hygienists (ACGIH), which permit an increase in the exposure limits by 30dB under certain conditions (OSHA 2004). It is worthwhile highlighting the changes to the guidelines.

> These recommended limits (set at the middle frequencies of the onethird 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. (OSHA 2004).

Table 2: Ultrasound exposure limits adapted from OSHA (2004): Table III:5-4. TLV's for Ultrasound, Notice of Intended Change Ultrasound.

Mid Frequency of One-Third Octave Band (kHz)	Measured in Air Head in Air (dB re 20μPa)
10	105
12.5	105
16	105
20	105
25	110[1]
31.5	115[1]
40	115[1]
50	115[1]
63	115[1]
80	115[1]
100	115[1]

Notes: 1. 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.]

Table 2 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 ACGIH 1997, page 81. 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 listed in Table 1. This change in the permissible levels is significant and the authors have been unable to find a body of evidence to justify the reasons for the increase in the levels.

As a side issue, 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 (Sriwattanatamma and Breysse 2000, Petrick, Royster, Royster and Reist 1996, and Petrick 1997). The proposed OSHA levels are more than 15dB higher than the levels specified by other organisations.

CONCLUSIONS

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 for doing so is unclear.

Until more definitve data become available, it is recommended that the more conservative standard proposed by Health Canada (1991) and listed in Table 1 be adhered to. 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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REFERENCES

Acton, W. I. (1974), ‘The effects of industrial airborne ultrasound on humans’, *Ultrasonics*, vol 12, no. 3, pp. 124–128.

Acton, W. I. (1975), ‘Exposure criteria for industrial ultrasound’, *The Annals of Occupational Hygiene*, vol. 18, pp. 267–268.

Acton, W. I. and Carson, M. B. (1967), ‘Auditory and subjective effects of airborne noise from industrial ultrasonic sources’, *British Journal of Industrial Medicine*, vol. 24, pp. 297–304.

Barnett, S. and Kossoff, G. (1998), *Safety of diagnostic ultrasound*, The Parthenon Publishing Group, New York.

Berktay, H. (1965), ‘Possible exploitation of nonlinear acoustics in underwater transmitting applications’, *Journal of Sound and Vibration*, vol. 2, no. 4, pp. 435–461.

Berktay, H. and Leahy, D. (1974), ‘Farfield performance of parametric transmitters’, *Journal of the Acoustical Society of America*, vol. 55, no. 3, pp. 539–546.

Cordell, J. (1968), *Physiological effects of airborne ultrasound; a biography with abstracts*, Technical Report 4, Commonwealth Acoustic Laboratories, Department of Health, Commonwealth of Australia, Sydney, Australia. Report C.A.L. No. 4.

Dallos, P. J. and Linnel, C. O. (1966), ‘Evenorder subharmonics in the peripheral auditory system’, *Journal of the Acoustical Society of America*, vol. 40, no. 3, pp. 561–564.

Damongeot, A. and Andre, G. (1988), ‘Noise from ultrasonic welding machines: risks and prevention’, *Applied Acoustics*, vol. 25, no. 1, 49–66.

Gierke, H. E. V. and Nixon, C. W. (1992), *Noise and Vibration Control Engineering: Principles and Applications*, John Wiley and Sons New York, New York, USA, chapter 16: Damage Risk Criteria for Hearing and Human Body Vibration, pp. 598–600.

Health Canada, Environmental Health Directorate, Health Protection Branch (1991), *Guidelines for the safe use of ultrasound: Part II Industrial and commercial applications safety code 24*, Technical report, Published by authority of the Minister of National Health and Welfare. EHDTR158, Catalogue No. H462/90158E, ISBN 0660137410 See Table 4, page 25. URL: http://www.hcsc.gc.ca/hecssesc/ccrpb/pdf/safetycode24.pdf

National Occupational Health and Safety Commission (2002), *Noise annual situation report 2002*, Technical report, Commonwealth of Australia. URL: http://www.nohsc.gov.au/PDF/Standards/ASR/Noise2002ASR.pdf

Kim, W. and Sparrow, V. (2002), *Audio application of the parametric array implementation through a numerical model*, in ‘Proceedings of the 113th Convention of the Audio Engineering Society’, Audio Engineering Society, Los Angeles, California, USA. Convention Paper 5652.

Knight, J. J. (1968), ‘Effects of airborne ultrasound on man’, *Ultrasonics*, vol. 6, no. 1, pp. 39–41.

Department of Defense (2004), *Department of defense instruction number 6055.12: DoD Hearing Conservation Program (HCP)*, Technical report, United States of America Department of Defense. See Section 6.3.11. URL: http://www.dtic.mil/whs/directives/corres/pdf/i605512_030504/i05512p.pdf

American Conference of Governmental Industrial Hygienists (1989), *Threshold limit values and biological exposure indices for 1988-1989*, Technical report, American Conference of Governmental Industrial Hygienists, available from American Conference of Governmental Industrial Hygienists, 6500 Glenway Ave, Building D7, Cincinnati, Ohio, USA 45211-4438.

International Non-Ionizing Radiation Committee of the International Radiation Protection Association (1984), ‘Interim guidelines on the limits of human exposure to airborne ultrasound’, *Health Physics*, vol. 46, no. 4, pp. 969–974.URL: http://www.icnirp.de/documents/ultrasound.pdf

Parrack, H. O. (1966), ‘Effects of airborne ultrasound on humans’, *International Audiology*, vol. 5, no. 3, pp. 294–308. from (Knight 1968).

Parrack, H. O. and Perret (1962), *Effects on man of low frequency ultrasonics produced by aircraft*, in ‘Report presented at meeting of group of experts on the struggle against noise caused by aircraft’, Organisation de Cooperation et de development economiques, Paris. from (Cordell 1968).

Petrick, M. E. (1997), ‘Comparison of daily noise exposures in one workplace based on noise criteria recommended by ACGIH and OSHA’, *Noise and Vibration Worldwide*, vol. 28, no. 8, p. 19. Note that this reference only contains the abstract.

Petrick, M., Royster, L., Royster, J. and Reist, P. (1996), ‘Comparison of daily noise exposures in one workplace based on noise criteria recommended by ACGIH and by OSHA’, *American Industrial Hygiene Association Journal*, vol. 57, no. 10, pp. 924–928.

Schust, M. (1996), *Biological effects of airborne ultrasound* (in german “Biologische wirkung von luftgeleitetem ultraschall”), Technical report, Federal Institute for Occupational Safety and Health. ISBN 3894297360. URL: http://www.baua.de/english/info/ld/ld04e.htm

Sriwattanatamma, P. and Breysse, P. (2000), ‘Comparison of NIOSH noise criteria and OSHA hearing conservation criteria’, *American Journal of Industrial Medicine*, vol. 37, no. 4, pp. 334–338.

Occupational Safety and Health Administration (2004), *OSHA Technical Manual, Section III: Chapter 5 Noise Measurement.* URL: http://www.osha.gov/dts/osta/otm/omiii/otmiii5.html5

Yoneyama, M. and Fujimoto, J. (1983), ‘The audio spotlight: An application of nonlinear interaction of sound waves to a new type of loudspeaker design’, *Journal of the Acoustical Society of America*, vol. 73, no. 5, pp. 1532–1536.