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ULTRASOUND: BIOLOGICAL EFFECTS AND INDUSTRIAL HYGIENE CONCERNS

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ABSTRACT

Due to the increased use of high intensity ultrasonic devices, there is now a greater risk of worker exposure to ultrasonic radiation than there was in the past. Exposure to high power ultrasound may produce adverse biological effects. High power ultrasound, characterized by high intensity outputs at frequencies of 20-100 kHz, has a wide range of applications throughout industry. Future applications may involve equipment with higher energy outputs. Contact ultrasound, i.e., no airspace between the energy source and the biological tissue, is significantly more hazardous than exposure to airborne ultrasound because air transmits less than one percent of the energy. This paper discusses biological effects associated with overexposure to ultrasound, exposure standards proposed for airborne and contact ultrasound, industrial hygiene controls that can be employed to minimize exposure, and the instrumentation that is required for evaluating exposures.

INTRODUCTION

Ultrasound has been virtually ignored as a potential hazard by the industrial hygiene community. In the past this may have been due to the low power output of ultrasonic devices and the small number of workers with a potential for exposure. However, since the late 1960's there has been a sharp increase in the production and use of industrial ultrasonic equipment.[1] Industrial applications of ultrasound use frequencies ranging from 10 kHz to greater than 10 MHz, and intensities between 10^{-3} and 10^{5} W/cm^2. Ultrasound is generally divided into low power applications and high power applications. Applications of low power ultrasound in medicine, nondestructive testing, control applications, and delay lines make use of frequencies in the megahertz range and power intensities in the milliwatt range. High power ultrasound, characterized by lower frequencies and higher power outputs (Figure 1), has applications in cleaning, welding, impact grinding, drilling, atomization, sonar, and other processes.[1,3] Most high power applications occur at frequencies between 20 and 60 kHz.[4] Literature from the medical field, while often ambiguous, indicates that a variety of undesirable effects may be elicited by high power ultrasound.

The purpose of this paper is to summarize the state of knowledge concerning the biological effects of ultrasound. In so doing, an attempt was made to separate known verified effects from ungrounded speculation, in order to determine if any possible workplace hazards exist. Exposure standards, industrial hygiene controls available for minimizing the exposure potential and instrumentation for measuring ultrasound are discussed.

BIOPHYSICS

Ultrasound is defined as mechanical vibrations propagated at frequencies above the upper limit of human hearing.[5] The upper limits of useful ultrasound are 10^6 Hz in gases and 10^9 Hz in solids and liquids. Lower limits for ultrasound are not well defined for two reasons: first, upper limits for human hearing are quite variable; and second, the term ultrasound is occasionally used to designate frequencies within the range of human hearing.[5,6]

Ultrasound can be propagated as continuous or pulsed waves. Output is generally expressed as temporal average, but with pulsed waves, instantaneous peaks can be an order of magnitude or more greater than this average. Much of the early literature failed to differentiate between continuous or pulsed modes; therefore, all exposures are given as temporal averages. The majority of high-power industrial applications use the continuous wave mode.

The physical properties of ultrasound are basically those of audible sound. Ultrasonic wave interactions result in reinforcement, annihilation, or standing waves. Velocity is a function of density and elasticity of the medium as well as wave form. Ultrasound intensity is attenuated as the distance from the source increases. This is due both to geometrical factors (the inverse square law) and the scattering and absorption of energy. At the interface between two mediums, ultrasonic waves may be absorbed, transmitted, or reflected.[5]

Ultrasound of sufficient intensity interacts with biological tissues to produce lesions thermally, by mechanical disruption, or by cavitation.

1. Thermal Effects

Exposures of several seconds or more and intensities of greater than 100 mW/cm^2 produce lesions resulting from the absorption of acoustical energy and a concomitant rise in temperature. Experiments have demonstrated that identical lesions can be produced by direct heating by passing an electrical current through an implanted resistance wire. A threshold temperature must be exceeded before any irreversible damage will be seen. This threshold temperature is inversely related to the log of the exposure time, varying from 66.5°C for a 0.3-second exposure to 43°C for a 900-second exposure in the mammalian brain.[7,8,9]

2. Mechanical Disruption

When an ultrasonic field impinges on an object with a density different from the surrounding medium, a force called radiation torque will be exerted on the object.[11] An ultrasonic wave with a frequency of 1 MHz can produce tissue displacement ranging from 18-1,800A and acceleration ranging from 1,400-740,000 g's. Ultrasonically induced shearing stresses cause stretching, twisting, and rupturing of biological membranes. These shearing stresses have been implicated as a mechanism for inducing biological damage.[1] Mammalian brain lesions are characterized by an immediate loss of nerve electrical activity, a ten-minute development period before the lesion is histologically visible, and the appearance of lesions at the focus of the ultrasonic waves. White matter is more sensitive than gray matter.(7,10)

3. Cavitation

Alternating phases of rarefaction and compression result in dense zones of gas bubbles that grow and collapse. Bubbles grow during rarefaction and then collapse during compression to produce an expanding shock wave (3,7,8,12). The cavitation threshold for water is frequency-dependent ranging from 1 W/cm^2 at 10 kHz to 500 W/cm^2 at 1 MHz. Two forms of cavitation are recognized. Transient or collapse cavitation occurs at relatively high pressure amplitudes; in this case the gas bubble will collapse in a fraction of a single wave resulting in localized high pressure and temperature. Stable cavitation occurs at much lower pressure amplitudes, resulting in alternating compression and expansion of the bubbles. Cavitation can produce heating, mechanical stress, and ionization.(11) In the mammalian brain, cavitation lesions are characterized by instantaneous histological appearance, no discernable temperature rise, and lesions that do not always appear at the focus of the ultrasonic waves. Gray and white matter appear to be equally susceptible.(7,10)

Ultrasonic energy is absorbed by biological tissues. The lowest absorption coefficients are found in soft tissues such as liver, kidney, and brain. Fatty tissue coefficients are about 10% lower than for other soft tissues; the highest values are found in striated muscle. Some absorption coefficients are shown in Figure 1.(13,14) Higher absorption coefficients are found in skin, tendon, and bone;

these tissues will be heated at a faster rate than soft tissue. Bone in particular can produce very high local temperatures when subjected to ultrasound. In addition, bone produces a shadowing effect so that distal tissues remain cool.[13,14] Proteins are largely responsible for absorption of ultrasonic energy by biological tissues at the molecular level. Individual molecular constituents display a range of absorption coefficients dependent on pH and molecular integrity.[14] A proton-transfer mechanism has been postulated to explain the observation that absorption peaks occur at both high and low pH values. Blood circulation is an important factor in determining the heating effect of ultrasound; efficient circulation will minimize spot heating[15,16].

Ultrasonic exposure can occur from direct contact with a solid or liquid medium, or through the air. However, ultrasound is transmitted much more efficiently through a solid or liquid medium than through air (Table 2). The biological effects of contact and airborne ultrasound have been investigated and are summarized below. It must be emphasized that by definition, contact exposure to ultrasound indicates that there is absolutely no air space between the biological tissue and the ultrasound source.

BIOLOGICAL EFFECTS OF CONTACT ULTRASOUND

Nervous System

During the 1950's, investigators reported that ultrasound produced paraplegia in mice. Paraplegia and hindlimb dysfunctions were observed in cooled neonate mice exposed to beam intensities between 54 and 154 W/cm^2.[17,18] Paraplegia and hemorrhage into the spinal cord resulted when mice were exposed to a field of 25 or 50 W/cm^2 peak intensity for 300 seconds at 0.5-6 MHz; damage resulted at time average intensities as low as 2.5 W/cm^2. A 5.5-11.0°C temperature rise was recorded in damaged areas of the spinal cord.[(19)] Central nervous system lesions were produced in cat brains by cavitation (25 to 200 millisecond exposures to 5000 W/cm^2 at 1 and 3 MHz). The lesions were characterized by blood vessel destruction, disrupted neurons lacking cytoplasm glial cell detritus, and a dispersed or disarrayed matrix.[10] Focal lesions were produced in cat brains at intensities as low as 40 W/cm2 when ultrasound was applied to the exposed brain or spinal cord.[20]

Stolzenberg demonstrated evidence for autonomic nervous system damage as well as central nervous system damage.[(21)] Ultrasound, (at 2 MHz, 1 W/cm^2, and 80-200 seconds in duration), produced hind-limb dysfunction, a distended bladder syndrome, and intestinal paralysis in mice. Dose response damage thresholds were 140 and 120 seconds, respectively. Damage to the spinal cord and adjacent ganglia, bone marrow, and dorsal skeletal muscle were also noted. While mammalian brain lesions have been produced when a specific time-temperature threshold is exceeded, the specific mechanism by which morphological damage is produced is unknown. Damage thresholds range from 66.5°C (for a 0.3 second exposure) to 43.0°C (for a 900 second exposure). Lesion size is a function of peak intensity and exposure duration.[(8,12,22)]

Ear

Barnett determined that direct ultrasonic irradiation of the vestibule and cochlea of cats and guinea pigs via the sound window will produce histological and cellular damage. Test animals were subjected to intensities between 5-10 W/cm^2 for 20 minutes at 3.5 MHz. Histological damage, manifested as severe balance dysfunction, was seen throughout the vestibular labyrinth. The cochleas suffered cellular damage over an area greater than two cochlea turns. Inner hair cells appeared to be less sensitive to ultrasound than outer hair cells.[23]

Eye

Baum determined that all optical damage was reversible at a level of 0.25 W/cm^2 (1 MHz) for exposures up to five minutes.[24]. Other investigators demonstrated reversible changes for exposures of 0.2 W/cm^2 and no effect when 0.0337 W/cm^2 was applied for four hours.[25,26] The threshold for cataract formation in rabbit eyes has been reported to be in the range of 30-400 W/cm^2 at frequencies ranging from 1-9.8 MHz.[27,28]

Olson, et al., using an intensity of 3.4 mW/cm^2 and exposure times from 10 seconds to 5 minutes produced discrete lesions in the corneal endothelium of adult Dutch rabbit eyes when the ultrasonic probe was activated inside the anterior chamber. The theorized reaction sequence was: "(1) Cytoplasmic disruption near the basement membrane; (2) cellular condensation and contraction of apical membranes; (3) rupture of apical membranes and cytoplasmic loss; (4) increase in peripheral involvement and cell loss; (5) gross endothermal sloughing." The extent of the damage was related to the time of exposure.[29]

Testes

O'Brien, et al., exposed mice testicles to two levels of ultrasound at a frequency of 1 MHz; 25 W/cm^2 for 30 seconds and 10 W/cm^2 for 30 seconds. Both levels resulted in marked disruption of the testicular tissue affecting both spermatocytogenesis and spermiogenesis. The high exposure level produced detectable damage immediately, whereas the lower exposure level required several days for damage to appear. The lower intensity produced a 2°C rise in temperature, to 39°C, while the high intensity exposure produced intrascrotol temperatures of 47-50°C. In addition to thermal effects, cavitation could have produced damage at the higher intensity.(30)

Teratology

Female mice were exposed to 2.0 or 2.5 W/cm^2 of ultrasound (at 1 MHz) for a period of three minutes on the eighth day of gestation. Exenchalies, an anomaly not found in normal or control animals, were produced in irradiated fetuses.(31) Fry, et al., determined that there was a significant reduction in litter size for female mice irradiated with a 2 mm diameter beam at an intensity of greater than 45 W/cm^2.(32) In addition, a significant rise in abnormalites concomitant with a reduction in average pup weight was seen when pregnant mice were irradiated with a beam intensity of 50 W/cm^2 or greater. Lele(31) states that a 2.5°C temperature increase can be produced in anesthetized mouse fetuses _in situ_ when using an ultrasound beam of 2.7 MHz and 200 mW/cm^2 and exposure times of 30 minutes or more. It is further stated that such hyperthermia, produced during fetal organogenesis, would be sufficient to produce an excess of abnormalities. Systemic hyperthermia, 2.5-5.0°C, for one hour or longer during fetal organogenesis (rat, guinea-pig, sheep) produced a number of teratological effects including fetal resorption, growth retardation, exencephaly, tail defects, limb defects, and palate defects (see Table-III).(33) Abnormalities were reported when 9-day-old rat fetuses were exposed above a threshold beam intensity of 3.0 W/cm^2 for 5 or 15 minutes at frequencies of 0.71 or 3.2 MHz continuous wave or 2.5 MHz pulsed wave. Gross and microscopic heart abnormalities were observed.(34) A recent review of medical ultrasound indicated that with pulsed ultrasound exposures it may be the peak power which is the determining factor in the reported effects.(34)

Genetic and Cellular

In 1970 Macintosh and Davey reported that ultrasound from an ultrasonic fetal heart detector produced an increased frequency of chromosome and chromatid irregularities in human blood cultures.(36) The author concluded that ultrasound was potentially mutagenic to humans. Several later studies have refuted the claims of Macintosh and Davey; some investigators have claimed that a toxin, given off from the polythene culture bags upon exposure to ultrasound, was the cause of increased chromosome irregularities.(37-41) Galperin-Lemaitre, et al., reported that ultrasonic intensities utilized for therapy (200 2, mW/cm^2, 1 W/cm^2 and 1.5 W/cm^2) broke down all of the DNA molecules exposed. However, DNA was not damaged by a 20 mW/cm^2 beam.(42) In contrast, Prasad, et al., reported that DNA synthesis was reduced in cultures of hela cells irradiated by an ultrasonic beam of only 4 mW/cm^2.[43] Cellular inactivation by ultrasound, measured by plating efficiency, was reported by Li, et al.[44] The mechanism inactivating mammalian cells is apparently non-thermal. Two recent papers by Liebeskin, et al., investigated the effects of ultrasound (15 mW/cm^2 temporal average intensity) on cell cultures. Hela cells demonstrated increased immunoreactivity to antinucleoside antibodies in G1 cells, indicating single strand breaks or unwinding of the helix. C3H mouse cells demonstrated a loss of contact inhibition, while surface membranes of cultured babl/c 3T3, clone 1-13 cells showed increased densities of microvilli.[45,46]

BIOLOGICAL EFFECTS OF AIRBORNE ULTRASOUND

Machines or processes employing ultrasound sources may emit high-level, random, and audible noise, possibly as subharmonics of the fundamental frequency. This noise can lead to temporary hearing threshold shifts, permanent hearing loss, and subjective effects such as fatigue, nausea, and headaches. High-frequency audible sound in the upper region of human hearing has been reported to produce tinnitus, ringing in the head, and a sensation of pressure in the ears. Parrack reported that subharmonics of frequencies between 9.2 and 37 kHz at levels of 148-154 dB produced temporary threshold shifts.[47] Hearing loss has been documented at frequencies up to 14 kHz.[48] The biological effects of noise are well documented and will not be considered further here. It is assumed that exposure to pure ultrasound at levels less than 140 dB will not produce even temporary threshold shifts.[47,49,50]

Acton[50] reviewed the physiological effects of airborne ultrasound in animals and man. These effects are summarized in Figure 2. Fatal body temperature rises occured between 144 and 165 dB at 1-30 kHz for mice, rats, guinea pigs and rabbits. The calculated lethal whole-body exposure dose for man is at least 180 dB at 20 kHz.[48] Documented human responses include mild warming of the body surface at 159 dB and loss of equilibrum and dizziness at 160-165 dB (20 kHz).[51,52] Acton stated: "In the case of air-borne ultrasound, the acoustic mismatch between the air and tissue leads to a very poor transfer of energy. The effects on small fur-covered animals are more dramatic because the fur acts as an impedance matching device; they have a greater surface area to mass ratio; and they have a much lower total body mass to dissipate the heat generated than man. Furthermore, the lower ultrasonic frequencies may well be audible to these animals, and the exposures have been to high sound pressure levels. Therefore, the effects on small laboratory animals cannot be extrapolated directly to the human species."

EXPOSURE STANDARDS

Three frequency dependent exposure standards for airborne ultrasound were proposed in the 1960's. These are summarized in Figure 3. Grigor'eva experimented with both audible sound and airborne ultrasound. She suggested acceptable limits for airborne ultrasound and also for one-third octave bands in the audible sound spectrum. Exposure time limits were not specified. Grigor'eva concluded, in 1966, that: "The experiments lead one to believe that airborne ultrasound is considerably less hazardous to man by comparison with audible sound. Also bearing in mind the data available in the literature, 120 dB may be adopted as an acceptable limit for the acoustic pressure for airborne ultrasound. The possibility of raising this level should be tested experimentally".[52] In 1968 Acton proposed a level of 110 dB in the one-third octave bands centered on 20, 25, and 31.5 kHz to prevent both auditory and subjective effects, i.e., fatigue, loss of equilibrium, nausea, etc., in the majority of the population exposed over a single work day.[47,49] In 1969 a subgroup of ANSI Standards Working Group S3-W40 chaired by Parrack made recommendations based on biological effects at sound frequencies just below and in the ultrasonic range. The proposed criteria, which were never published, were designed to prevent subjective and audible sound effects over an eight-hour work day for five or five and one-half days per week.[52]

More recently, two additional exposure standards have been proposed for airborne ultrasound. In 1980 Benwell and Rapacholi of the Radiation Protection Bureau, Department of National Health and Welfare, Canada recommended a maximum permissible exposure level which is shown in Figure 4. A TLV® (the time-weighted average limit for a normal eight-hour day and a 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effects) for airborne upper sonic and ultrasonic acoustic radiation has been proposed by the ACGIH (Figure 5).[53]

These standards are consistent in that they present exposure limits to prevent subjective effects at one-third octave bands centered at or below 20 kHz and exposure limits for one-third octave bands at 20 kHz and above to prevent thermal effects and hearing loss from possible subharmonics.

The only exposure standard available for contact ultrasound was proposed by Nyborg in 1978 and recommended by Benwell and Repacholi in 1980.[53,54] The recommended standard shown in Figure 7 was set to prevent reported biological effects that are considered hazardous. One hundred mW/cm^2 is considered a threshold below which no adverse biological effects are seen. Exposures to intensities greater than 10 W/cm^2 should not be allowed.

MEASUREMENT OF AIRBORNE ULTRASOUND

Equipment used in measuring ultrasound must be capable of measuring accurately the frequencies of interest. Measurements should be made in one-third-octave-bands. The microphone used should have a flat response over the frequency range. Commercial equipment is available from Bruel & Kjaer, General Radio, and other manufacturers to meet the needs for obtaining accurate and reliable measurements.

The audible sound alone should be measured by adding to the existing A-weighting response of the sound level meter a low-pass filter (with a relatively sharp cutoff) to reject the ultrasonic frequencies at 20 kHz and above. Commercial equipment is available to measure ultrasound in the frequency range of 20 kHz to at least 50 kHz.

Complete calibration should be performed by a qualified laboratory or the equipment manufacturer when needed. Frequency of calibration depends on the extent of use in certification and routine field use conditions. Although the field calibrator check (calibrated couplers operate at about 2000 Hz) does not test the high frequency measuring system, it nevertheless is highly recommended. Usually the instrumentation either performs correctly at all frequencies or malfunctions at all frequencies.

High frequency sound waves are highly directional and therefore are easily attenuated by barriers. The existing radiation field may be very complex. Constructive or destructive interferences between waves may occur over short distances so that experimentation is required for placement of the microphone. Conduct preliminary measurements to assess the noise field; then select the location and orientation of the microcphone. Use of a rotating microphone boom will facilitate this test.[52]

MEASUREMENT OF LIQUIDBORNE ULTRASOUND

Acoustic power and intensity are the parameters that have been specified in most equipment performance standards.[55,56] Basically there are two types of measuring instruments available: those that measure total power, and those that measure "point" quantities, i.e., intensities over areas small compared to the dimensions of the ultrasound field.[57]

Total power is generally measured by the radiation force method. It is relatively simple, accurate, frequency independent, and an absolute method for determining total power. Momentum is transported in a traveling plane wave ultrasonic field. If momentum is transfered at a constant rate to a reflecting or absorbing target, the target will respond as if acted on by a steady force, which is the radiation force.[58] This method can be used when the entire ultrasonic field is intercepted or when only a portion is intercepted. Absolute calibration can be done by weight substitution. The literature contains descriptions of several systems for measuring radiation force; however, this equipment is not readily available for workplace measurements.[57]

"Point" quantities are generally measured using miniature piezoelectric hydrophones. There are some drawbacks: not all commercially available units are frequency independent and most units have resonance in the relevent frequency range distorting ultrasonic pulses. The piezoelectric polymer, polyvinylidene fluoride shows promise as a broadband acoustically transparent receiver. Calibration techniques have been described.[57] Ultrasound dosimetry is not available at the present time.

INDUSTRIAL HYGIENE CONTROLS[52]

1. Since high power ultrasound can cause a temporary or permanent physical change in a system, the following control measures are recommended.
    - Avoid direct contact at all times.
    - Equipment should be operated only by qualified personnel, knowledgeable about potential harmful effects.
    - Warning signs should be placed at the entrance to any area which contains high power ultrasound equipment or applied to each such device with appropriate precautionary statements for safe use.

- Ultrasonic cleaning tanks should have precautionary labels cautioning operators from immersing hands or parts of the body into the tank while it is operating.
  - turn off ultrasonic generators when loading/unloading parts
  - if not possible to turn off, place parts in sieves having non rigidly fastened handles coated with elastic covering. Sieve handles should not come in contact with liquid or sides of bath.

2. Low power ultrasound is used for non-destructive testing without inducing temporary or permanent changes in the system.
   - There is little or no chance of harm from contact; however, direct contact should be avoided as a matter of good practice (biological data inconclusive, some effects may occur).
   - Equipment should be operated by qualified personnel.
   - Precautionary signs on or near equipment to indicate presence of device and to caution workers to take appropriate action.

3. Airborne Ultrasound
   - Adhere to proposed exposure guidelines.
   - Use total or partial enclosures, baffles, and absorbers to reduce sound levels.
   - Use hearing protection.

CONCLUSIONS

The majority of research concerning biological effects of ultrasound deals with diagnostic or low power ultrasound. Several thorough reviews concluded that low power ultrasound is relatively harmless when applied with discretion.[32,34,59,60] The American Institute of Ultrasound in Medicine (August 1976; revised October 1978) has endorsed the following statement: "In the low megahertz frequency range there have been (as of this date) no independently confirmed significant biological effects in mammalian tissues exposed to intensities below 100 mW/cm^2. Furthermore, for ultrasonic exposure times less than 500 seconds and greater than one second, such effects have not been demonstrated even at higher intensities, when the product of intensity and exposure times is less than 50 $joules/cm^2$."[61] Epidemeological studies have shown no adverse effect due to obstetric or clinical ultrasound.[61]

The picture for high power ultrasound is less clear. Actually, the biological effects of true high power ultrasound, characterized by high intensity outputs at frequencies of 20-60 kHz, have not been investigated with regard to contact ultrasound. In the case of airborne ultrasound, the majority of investigations were done in the 1940's, 50's and 60's when industrial sources of ultrasound were generally much less powerful than those employed today. Until data are collected on true high power ultrasound, it must be assumed that the biological effects of high-frequency, high-intensity ultrasound can be extrapolated to the lower frequencies used in industrial applications.

However, frequency may be related to ultrasonic penetration of biological tissues and this may significantly change the type and extent of effects. Direct contact between ultrasonic sources and solid or liquid transmitting mediums and biological tissues produce a significant hazard because there is an efficient transfer of energy. In industrial settings the major concern would be with exposure of the hands and arms. Direct contact between ultrasound and the eyes, ears, testes, etc. appears very unlikely. Airborne ultrasound appears less hazardous because of its inefficient transfer through air (see Table 2).(62) However, powerful industrial ultrasonic equipment may be able to produce relatively high ultrasound intensities for short distances around equipment. For example, an aircraft take-off from an aircraft carrier can produce nearly 150 dB around flight deck personnel.(64) Equipment capable of generating 160 dB would expose people to 10 W/cm^2, an energy level capable of producing biological effects on contact. Early investigators of the biological effects of airborne ultrasound did not consider many of the effects now being investigated with low intensity contact ultrasound. Some hazards generally associated with airborne ultrasound may be the result of audible subharmonic frequencies.

The literature reviewed here documents a number of effects resulting from exposure to high intensity (contact and airborne) ultrasound; however, there is insufficient data to quantify dose-response relationships.(32) In addition, there are problems associated with extrapolating animal effects to humans. No epidemiological studies have been conducted on workers exposed to high power ultrasound. Until the hazards associated with high power ultrasound are more completely understood, a cautious approach should be taken in its use. This is particularly true with pregnant women because fetal effects have been documented at relatively low intensities. The relevence of *in vitro* genetic effects to workplace exposures is unknown. Phantom dosimetry is a tool that may help in elucidating the mechanism and effects of exposure to high power ultrasound (both contact and airborne).

Industrial hygienists should be aware of the potential hazards of ultrasound, just as we are aware of the hazards associated with microwaves, infrared, and other forms of nonionizing radiation. Exposure standards available for airborne and contact ultrasound can be used to determine which employees may be overexposed. Many workplaces lack the equipment to measure contact ultrasound; therefore, administrative controls and employee education are extremely important in minimizing worker exposure.

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TABLE I

Percentage of Ultrasound Energy Reflected at Various Interfaces (Reference 52)

Reflecting Interface	Energy Reflected (%)
Fat-Muscle	01.08
Muscle-Blood	00.07
Bone-Fat	48.91
Soft Tissue-Water	00.23
Soft Tissue-Castor Oil	00.43
Soft Tissue-Air	99.90

TABLE II

Teratological Effects of Systemic Hyperthermia, 2.5 - 5.0°C for 1 Hr. or Longer at the Stage of Organogenesis in the Fetus (Guinea Pig, Sheep, Rat). For Details, see Lele, 1975 (Reference 29)

General	Central Nervous System	Musculo-Skeletal System
Fetal Resorption/ Abortion	Reduction in Brain Weight	Talipes-Like Conditions
Growth Retardation	Microencephaly	Arthrogryposis Multiplex
Microphthalmia	Anencephaly	Amyophasia
Cataract	Defects in the Spinal Cord	Hypoplasia of Forefeet
Defects of the Abdominal Wall		Absence, Defects or Deformations of Tibia, Fibula
Renal Agenesis		
Defects of the Palate		Failure of Incisor Teeth to Erupt, Abnormal Amelogenesis

TABLE III

Some Industrial Applications of High Power Ultrasound Showing the Range of Frequencies and Intensities Used (Reference 1)

Application	Description of Process	Frequency (KHz)	Intensity Range (W/cm^2)
Cleaning & Degreasing	Cavitation Cleaning, Solution Scrubs Parts Immersed in Solution	20-50	Generally Less Than 6
Soldering & Braising	Displacement of Oxide Film to Accomplish Bonding without Flux	-	3 - 32
Plastic Welding	Welding Soft and Rigid Plastics	About 20	Below 1,000
Metal Welding	Welding Similar & Dissimilar Metals	10-60	About 10,000
Machining	Rotary Machining, Impact Grinding Using Abrasive Slurry, Vibration Assisted Drilling	Usually 20	Variable
Extraction	Extracting Perfume, Juices, Chemicals from Flowers, Fruits, Plants	About 10	About 500
Atomization	Fuel Atomization to Improve Combustion Efficiency and Reduce Pollution; also, Dispersion of Molten Metals	20-300	Variable

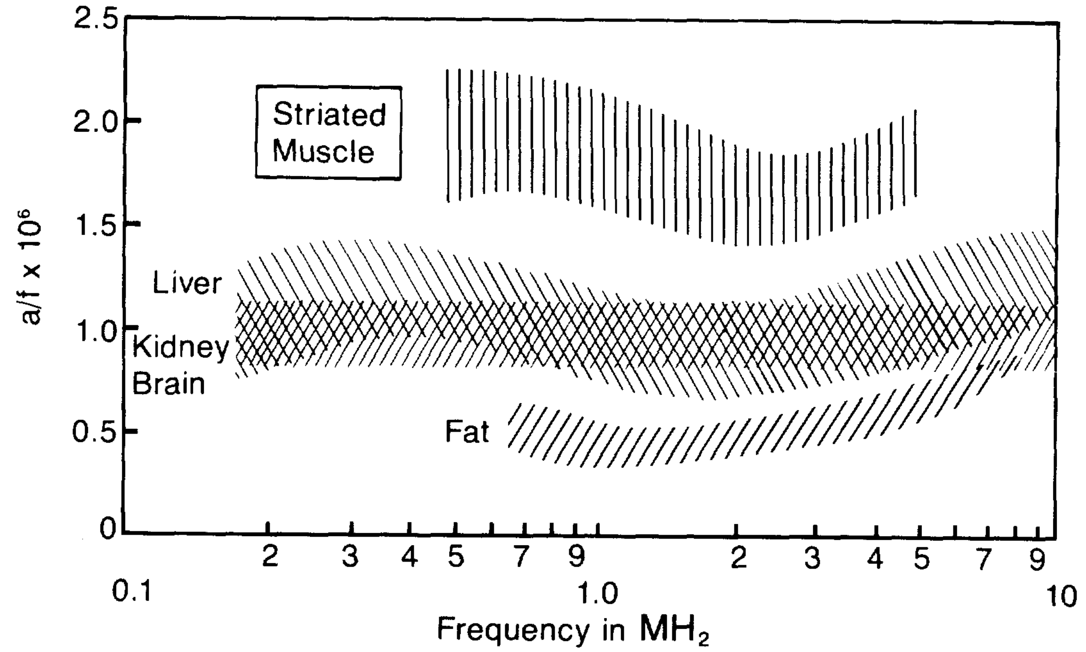


Figure 1 - Acoustic amplitude absorption coefficient (in dB/cm) per wavelength versus frequency for several mammalian tissues (Reference 14)

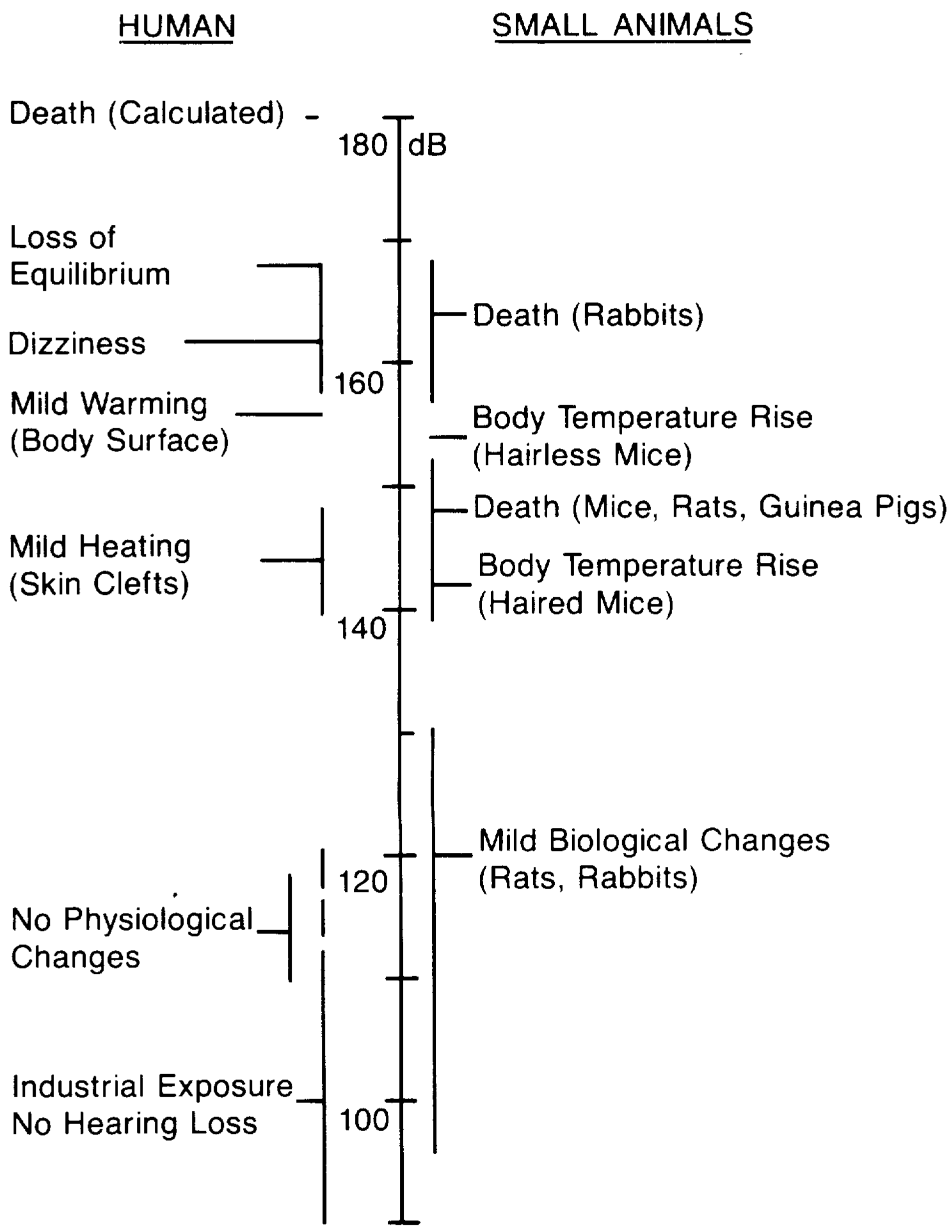
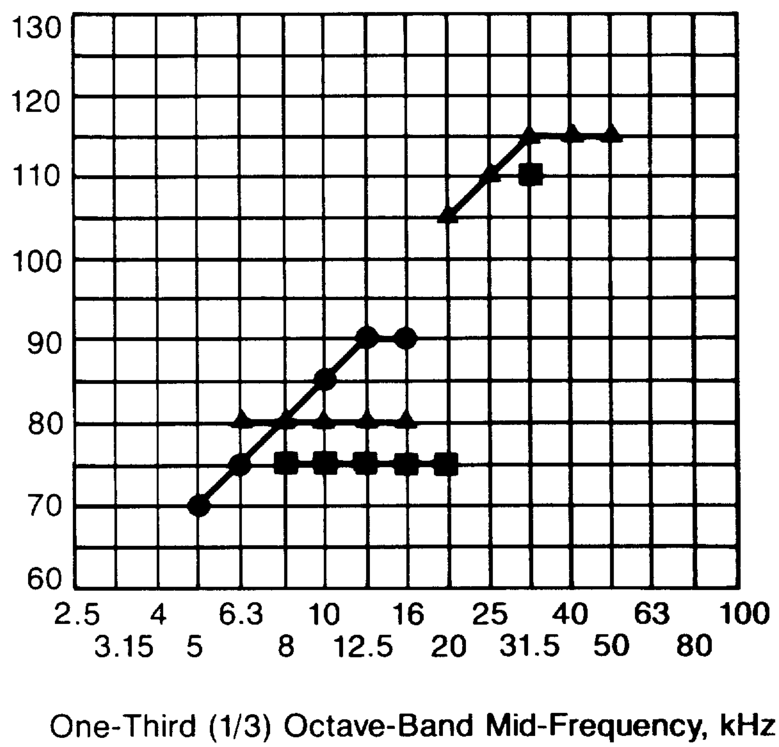
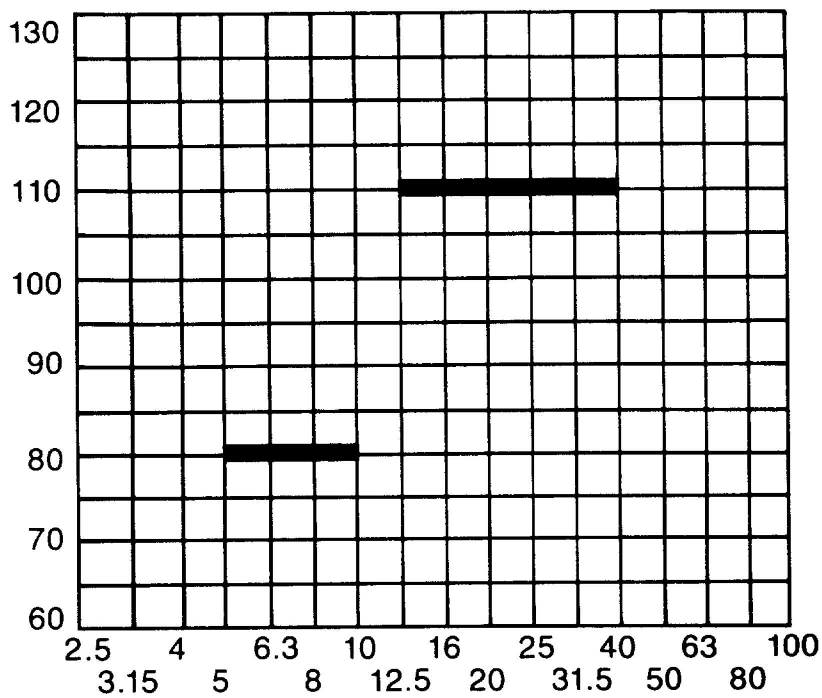


Figure 2 - Physiological effects of airborne ultrasound (Reference 47)



Proposed exposure limits for airborne upper sonic and ultrasonic acoustic radiation: (a) Grigor'eva, U.S.S.R., one-third octave-band levels (●) and overall sound pressure level for ultrasonic noise (dashed-line curve) – no specified time of exposure duration; (b) Acton, England, one-third octave-band levels (■) for noise from ultrasonic sources over a working day; and (c) Parrack, U.S.A., one-third octave-band levels (▲) for high frequency airborne sound – 8 hours per day (nominally) for 5 or 5-1/2 days each week.

Figure 3 - Exposure limits proposed in the 1960's by Grigor'eva, (1966), Acton (1968) and Parrack (1969) for Airborne Ultrasound (Reference 53)



One-Third (1/3) Octave-Band Mid-Frequency, kHz

A = Line representing maximum permissible exposure level 25 kHz 1/3 octave band mid frequency and above

B = Line representing maximum permissible exposure level 20 kHz 1/3 octave band mid frequency and below

Figure 4 - Recommended maximum permissible exposure levels for airborne ultrasound (Reference 53)

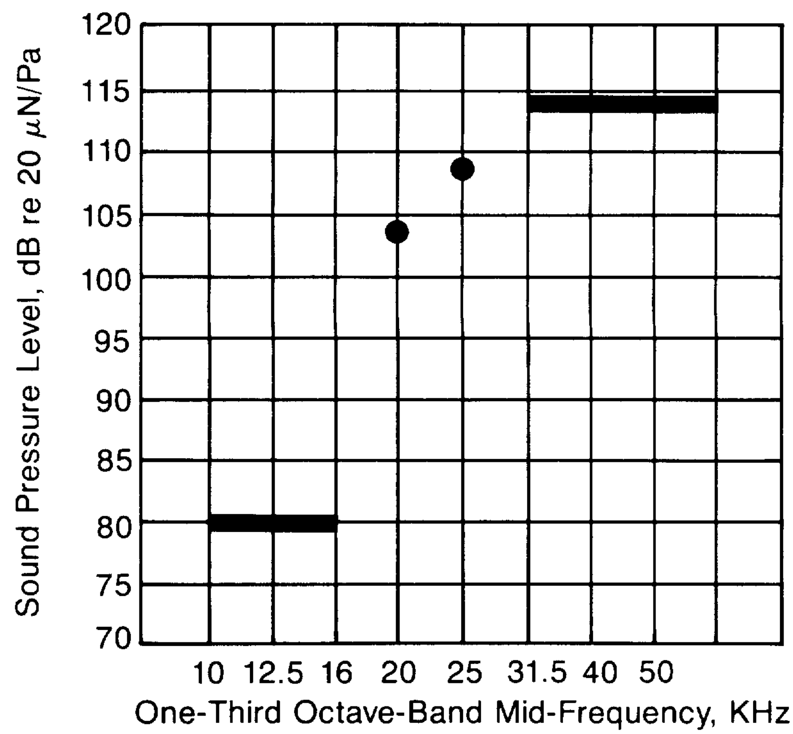


Figure 5 - The ACGIH proposed TLV® for airborne upper sonic and ultrasonic acoustic radiation (Reference 54)

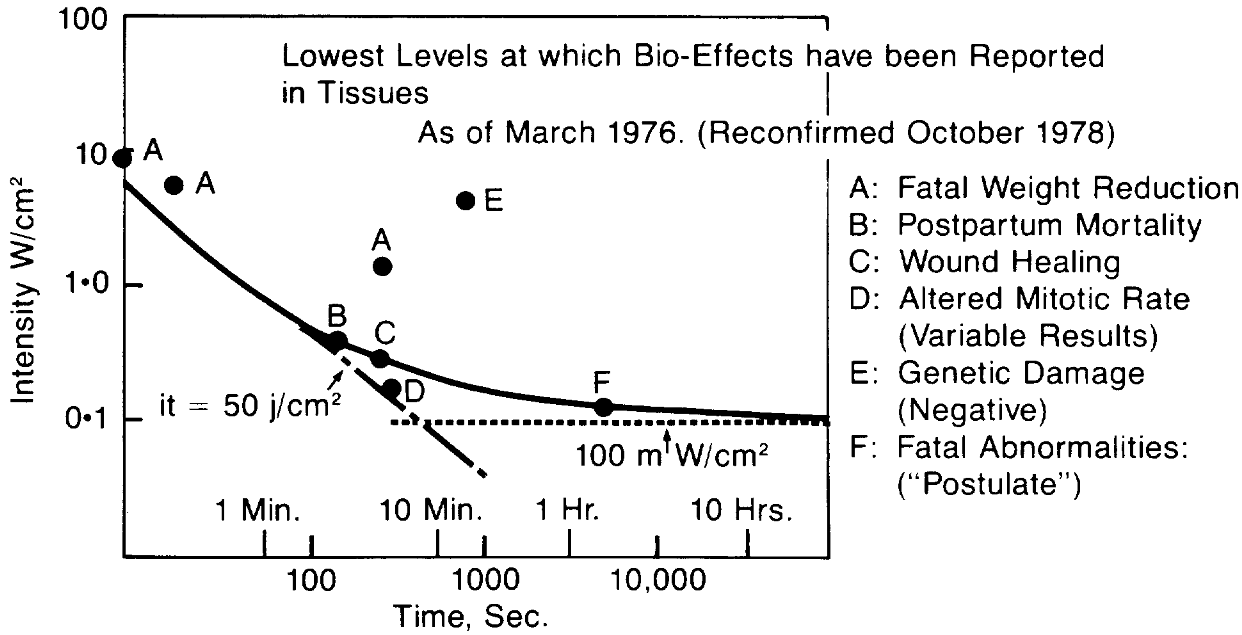


Figure 6 - Recommended maximum permissible contact exposure levels for ultrasound (for water and not air) (Reference 52)

Safety

CC: E. L. Bowser, DOE-SR
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TO DISTRIBUTION

Attached is a copy of the following:

DP-MS-84-36, "ULTRASOUND: BIOLOGICAL EFFECTS AND INDUSTRIAL HYGIENE CONCERNS", by Christopher Wiernicki and William J. Karoly.

A paper proposed for publication in the American Industrial Hygiene Journal.

If any technical clarification is needed please call C. J. Banick.

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