pest bird control

ENVIRONMENTAL & MEDICAL REPORT

for

PEST BIRD DEFENSE FACILITIES
BASED ON ULTRASONIC SOUND

Table of Content

based on the Environmental Health Expertise (Umweltmedizinisches Gutachten)

pest bird control

I. Scope & purpose

1.1.
<u>Introduction</u>

Electronic Innsbruck, Innrain 121, developed a pest bird control system based on ultrasonic waves, in order to keep pest birds, as pigeons in urban areas (health risks), away from target sites.
Guide lines and exposure values will be stated on the following pages.

1.2
<u>Task description</u>

Based on testing and expertise, continuous acoustic irradiation of specific target properties with ultrasonic beat frequencies shows effective long term pest bird control.
The basic principle of the systems above mentioned can be demonstrated as follows:
Two loudspeakers (A, B) positioned exactly opposite to each other in a distance of 4-7 m are emitting low freqency (f) aireborne ultra sonic waves, a technique based on the so-called piezoelectric effect.
In this way wave interference, so-called beat frequencies, occurs in the overlapping area.

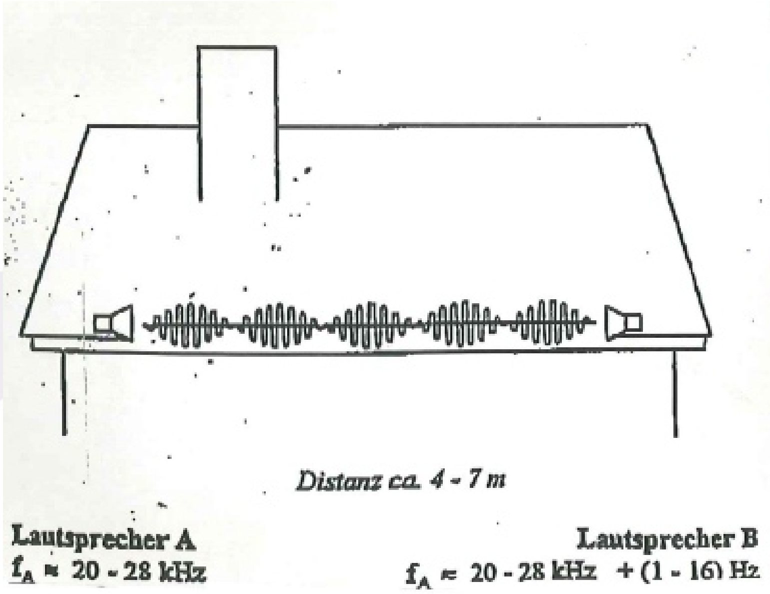


fig. 1

Maximum sound pressure: 96 dB
Primary frequency of both loudspeakers: 20-28 kHz
Additional emission shift: + (1-16) Hz
Mainly produced bird control beat frequency 1-16 Hz

fA = 20-28 kH
fB = 20-28 kHz + (1-16) Hz

II. Physical Characteristics

2.1
History of Ultrasound

Spallanzani published the first theory about sens-orientation of bats in 1794.
I. & P. Curie discovered the piezoelectric effect in 1880, the basis for all further technical application.
The invention of the echo sounder was the first technical application of ultra sonic waves in 1912, after the famous collision of the „Titanic“ with an iceberg.
Further developments for today universal use of ultrasonic waves were *Sokolov's* material testing devices, leading to the industrial production of tires by *Firestone* and *Dussik's* successful application in medical diagnostics, permanently improved up to real time treatment.
Today ultrasound wave application is common in various fields such as physics, technology biology and medicine.

2.2
Physical basics

Ultrasonic energy consists of mechanical vibrations occurring above the upper frequency limit of human audibility (generally accepted as about 16 kHz). Ultrasound consists of a propagating disturbance in a medium, which causes subunits (particles) of the medium to vibrate.
The vibratory motion of the particles characterizes ultrasonic (acoustic) energy propagation.
Unlike electromagnetic radiation, involving the superposition of electric and magnetic waves, acoustic energy cannot be transmitted through a vacuum.
The transmission through the medium depends to a great extent on the ultrasound frequency and the state of the medium, i.e., gas, liquid, or solid.
In any case waves can be considered as a periodic movement along time and position axis, basically expressed by the harmonic oscillation with a constant amplitude.

If a particle is forced out of it's equilibrium position there is always a restoring force, corresponding (proportional) to this particular shift.
A distinction between the harmonic oscillation and complex disturbances within a medium depends on this more or less complex relationship between restoring force and displacement.

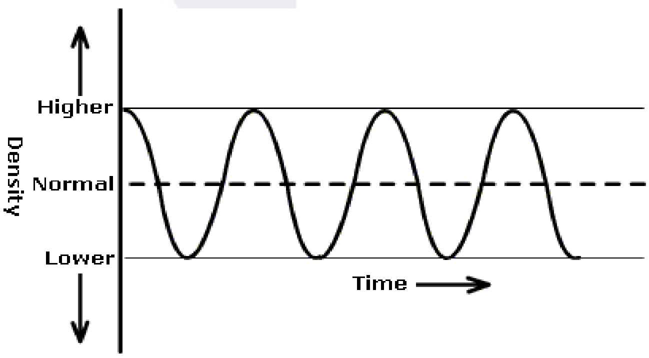


fig. 2

pest bird control

Wavelength (λ), is defined as the distance between the position of neighboring particles having an identical shifting amplitude. Hence, the oscillation period (T) is the time passing for the wave movement within the distance of a wavelength.
Frequency (f) is defined as the number of waves which are passing a fixed point in definite time.

$f = 1/T$

$c = f \cdot \lambda$

This equation is strictly defined for continuous waves with a constant amplitude.

The velocity (c) of the energy transfer through the medium depends on the deceleration between the movement of neighboring particles.
The type of medium, respectively the propagation velocity within the medium is characterized by the elasticity modulus (K) affecting the restoring force on the one hand, and by the density (ρ) affecting the displacement acceleration on the other hand.

$C = K / \rho$

In general, those velocities are very similar in human tissues, in bones (solid state body) they are rather higher and in pulmonic tissues lower.

Tab. 1:

Ultraschalleigenschaften bei verschiedenen Gewebsarten und bei einigen häufig vorkommenden Substanzen:

Medium	*Ausbreitungs-geschwindigkeit c* (m s^{-1})	*Schallimpedanz* $Z = \rho . c$ (10^6 kg $m^{-2}s^{-1}$)	*Schwächungskoeffizient α* bei 1 MHz (dB/cm)
Knochen	2700 - 4100	3,75 - 7,38	3 - 10
Muskel	1545 - 1630	1,65 - 1,74	1,5 - 2,5
Gewebsweichteile (außer Muskeln)	1460 - 1615	1,35 - 1,68	0,3 - 1,5
Lunge	650 - 1160	0,26 - 0,46	40
Luft	330	0,0004	10
Wasser	1480	1,52	0,002
Aluminium	6400	17	0,02
Plexiglas	2680	3,2	2

2.2.2
Effects on Interfacial Areas

A vertical impact of a sound wave on interfacial areas between 2 media results in a propagation in the same direction without change of direction, whereas an inclined impact leads to so called refraction:
one part of the wave is reflected (incident angle = emergent angle), the second part continues its way linearly after a characteristic change of direction.

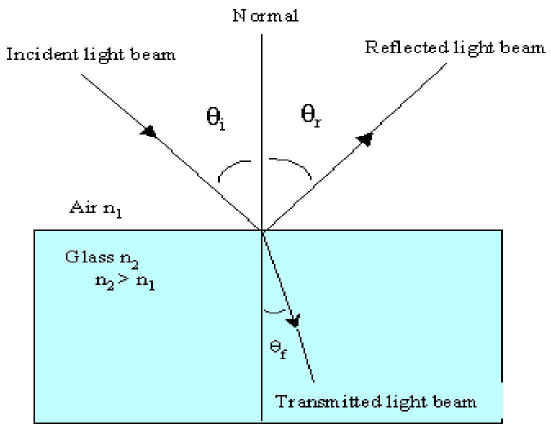


fig. 3

The ratio between the reflected and refracted sound energy depends not only on the incident angle but also on the characteristic resistance of the second medium against the invading wave, a parameter which is characterized by the difference of the acoustic impedances (Z) of both media.

$Z = \rho \, . \, c$

Therefore, differences between their acoustic impedances result in different propagation velocities as well as in a characteristic energy-distribution of the primal wave into their reflected and refracted part.
The reflection coefficient (R) for perpendicular incident is defined as follows:
perpendicularity assumed
R = [Z2-Z1) / (Z2+Z1)]2

Hence there is no reflection between 2 media with identical sound wave resistances, a perpendicular wave impact presumed.
This also means, that there is very low reflection between biological tissues having similar sound wave resistances, whereas airborne sound waves on biological tissues are almost totally reflected.

2.2.3
Dispersion

As for this approach a contact to planar interfacial areas is assumed yet, without considering possible surface structure, roughness or small surface bound obstacles.
Hereby the reflection of sound energy is replaced by the the phenomenon of dispersion.
Approaching a dimension of wavelength or lower, the influence of the surface geometry, grit size respectively increases dramatically up to the reciprocal power of 4.
This occurs, when ultrasonic sound waves in the MHz range are dispersed in blood.

As mathematics cannot describe the intermediate state between reflection and dispersion, entirely series of experiments will be made in order to compare the results with the theoretical consideration.

2.2.4
The Doppler effect

Moving reflecting surfaces in direction to the origin of waves cause a “compression” of the wavelength, moving in the opposite direction leads to a “dilatation” of the wavelength.
If the wave propagation velocity remains constant corresponding frequency changes occur.

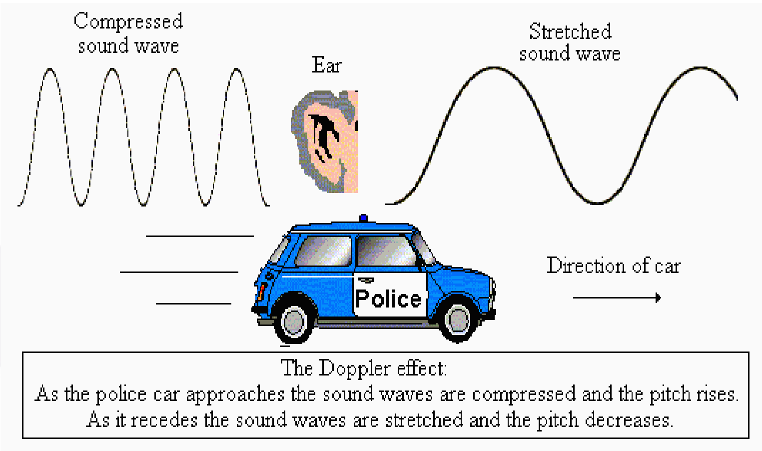


fig. 4

2.2.5
Beat frequency oscillation

Additive superposition of sinusoidal oscillation waves of equal frequency is called interference, the resulting oscillation is also sinusidal.
Superposition of different frequencies lead to non sinusidal oscillation.
Superposition of 2 oscillating waves with identical amplitude but different frequencies in different neighbouring frequencies (f1, f2), causes an alternating phase dependent swinging direction of both oscillators, resulting in an effective oscillation frequency (f3), described by their arithmetical mean and also characterized by oscillating amplitudes referred to the particular frequency difference.

$f3 = (f1 + f2) / 2$

$fS = f1 – f2$

This oscillating swinging of the amplitudes is called beat frequency (fS) and can be demonstrated as a sort of envelope curve.

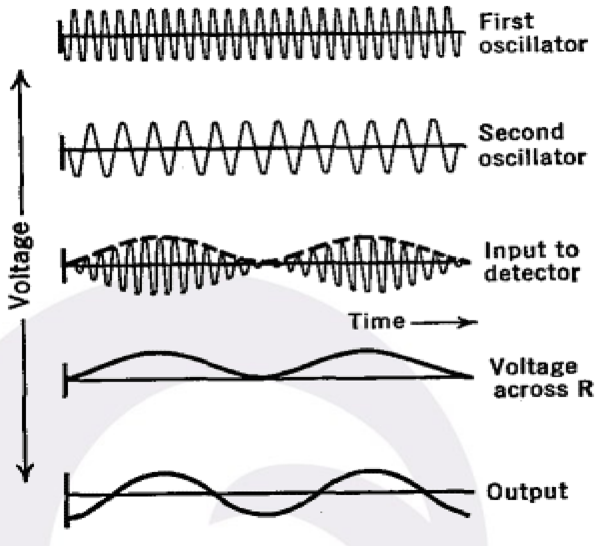


fig. 5

2.2.6
Capacity intensity & decibel unit

The powerfulness of sound waves can be expressed by the power unit “watt”.
One watt is the rate at which work is done when an object's velocity is held constant at one meter per second against constant opposing force of one newton.
1 W corresponds to an energy flow of 1 Joul per second.
Sound intensity is characterized as the amount of energy passing a definite area in a definite time. (Watt/m2).

In measuring practice the absolute sizes (amplitude, power) are replaced by comparing 2 different amplitudes or 2 different intensities (P1, P2 or A1, A2), particularly when a constant background level can be taken as a bench mark.
For simplicity regarding the mostly wide range scale of the expected values and for easy expression of the mean value, a logarithmic on the base 10 definition is made to characterize the physical unit, decibel (dB).

Mlg = 10 lg (P2/P1) dB = 20 lg (A2/A1) dB

So airborne sound intensities are usually referred to a bench mark, called sound pressure level (SPL = 2.10^{-5} Pa).

Furthermore the so-called half-value layer is defined as the thickness of any given medium, where 50 % of the incident energy has been attenuated, and this can be also expressed as the thickness for reduction of the sound power by 3 dB.
The *American Institue of Ultrasound in Medicine (AIUM)* introduced special definitions and units for practical use.
Ultrasonic power is hereby defined as a "sonar field", according to the sonic power, which is transported normal to the acoustic beam.

2.2.7
Attenuation

During propagation the intensity of ultrasound waves can be diminished by different occurrences.
Sound waves can be spread (diverged) after emission from the source; dispersion on small particles representing different sound impedances has the same effect.
In both cases ultra sound power or intensity is transmitted through larger areas.
On the other hand absorption leads to a transformation from sound energy into heat.

Using decibel units, the logarithmic scale leads to linear proportionality between attenuation and thickness of the medium.
E.g. if 10 cm media thickness reduces the wave energy about 10 dB, attenuation after the passage of 20 cm is 20 dB, and the so called attenuation coefficient is defined then as 1 dB/cm.

The extent of attenuation depends on the property of the medium, where sound waves are propagated.
In gases or non biological liquids sound attenuation is proportional to the square of emitted frequency, and absorption is basically the consequence of the viscosity, a phenomenon based on the friction between the particles.

In non biological solid matter thermal conductivity is the main reason for sound absorption.
Sound waves lead to reversible compression within the lattice structure, resulting in transformation into heat energy, which is dissipated into the surroundings.
In this case then the sound attenuation is rather direct proportional to the frequency.

Attenuation in biological tissues, which can be regarded more or less aqueous, is also proportional to the frequency, considering specific frequency ranges.
Mediated by protein clusters sound wave energy is transformed into rotation and vibration energy of neighboring molecules.
Interaction between incident sound waves and hereby induced random temporal orientation of the molecules leads to a so called relaxation phenomenon and therefor to the degradation of the energy.

Very low sound frequency waves are hardly absorbed, but increasing frequency lead to a maximum absorbency, where the orientation of transformed energy can be considered as inversely phased.

Above this frequency absorbency is decreasing once again, because there is no more time for energy transformation between the different forms of energy.
Heterogeneity in complex biological structures e.g., gas filled cavities in pulmonary tissue or the "substantia spongiosa" in bones pose a special challenge in the research of sound influence in biology and environmental health criteria.

2.2.8
Generation of ultra sound waves

Basically, ultra sound waves are generated in the same way as audible sound.
Solid bodies (boards and bars) as well as gas filled tubes (pipes) can be activated to vibration by mechanic, thermic or electric means.
For technical purpose ultra sound is produced in a so called transducer, crystal lattices as quartz or tourmaline, where electric energy is transformed into vibration energy, based in the "reciprocal piezoelectric effect".
Today frequencies up to 1 GHz as well as energies up to 500 W/cm2 can be generated.

2.2.9
Propagation of ultra sound intensity

Propagation of ultra sound intensity and its biological effect can be simplified using 2 oppositional approaches: the free 3-dimensional propagation and the effect of standing waves, where the sound waves are propagating into a defined space, but then reflected in opposite directions.

For the free wave propagation following parameters are defined:

p	sound pressure	unit	Pa, N/m2
ξ	particle shift	unit	m, µm
v	particle velocity	unit	m/s, cm/s
a	particle acceleration	unit	m/s2

pest bird control

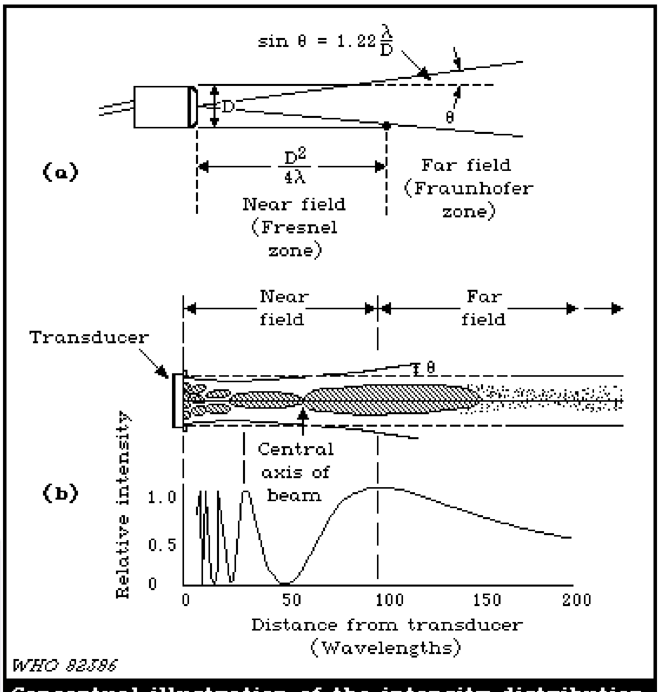
Free 3-dimensional propagation assumed, intensity corresponding to the sound beam axis in direction to the source is increasing up to a maximum in a specific distance (Xmax) from the oscillating sound producer

X`max = r2/4 λ ….the most distant maximum of intensity

(r.. radius of oscillator, r>>λ2)

The area between the sound source and the last maximum is called "Fresnel zone" (near field), here the beam is still circular.
Reaching long distances in the so called far field area the beam is diverging, characterized by the angle (Θ) and the diameter (D) of the swinging transducer.

sin Θ = 1,22 l/D



Conceptual illustration of the intensity distribution of cw ultrasound: (a) the near- and far-field regions in relation to the transducer, (b) the field distribution of an ideal piston source generating a continuous wave (Adapted from: Wells, 1977).

fig. 6

III. Bio-effects & possible harms caused by ultrasonic sound

3.1.
Historical Background

For the first time *Lengevin* used the piezo effect on a quartz crystal in order to generate ultra sound waves in solid matter and liquids, in 1917.
By inventing the echo sounder for safety in navigation it could be observed, that sonar waves can kill small fish.
Wood and *Loomis* confirmed this possible bio hazard investigating the effect on fish, mice, blood cells and protozoa.
After World War II, when investigation continued, improving radar and sonar technology, basic principles for quantification of biologic affects were established.

3.2
Biophysics

The effect of ultra sound waves on biologic tissues is characterized by the complex procedures and interactions concerning the absorption of ultra sound energy in liquids and tissues.

3.2.1
Ultra sound absorption

Attenuation of an ultra sonic beam passing through a biological medium can be seen as the result of the between absorption, dispersion and (fluid) cavitation.

The so-called real absorption is stated as the irreversible transfer of coherent mechanical energy on an intra- and intermolecular level resulting in heat production.
The simplest approach to this complex and not yet entirely investigated phenomenon is the influence of ultra sound on monoatomic liquids (fused metal), which is characterized by the extent of viscosity, which can be pointed out as a resistance to mechanical movements of the atoms.

Leaving the atomic and reaching the molecular scale, inter- and intramolecular interaction is additionally involved.
In biological tissues, proteins play the main role in the absorption of ultra sound, so time consuming realignments and reorganization within the macromolecular structures occur as a result of the oscillation pressure.
The question about the reversibility of the change of protein or other macromolecules as a fact of the relaxation process or simply due to the heat as a product of wave absorption is not answered.

3.2.2
Dispersion

Local differences in densities or inhomogeneity in general, typical for biological cells and tissues, result in different swinging directions and amplitudes, causing a complex relative movement of waves and particles, reflected from an to each other.

Viscosity power seems to play a considerable part concerning the absorbed part of the ultra sonic wave energy.

3.2.3
Cavitation

Cavitation can be regarded as one special form of dispersion, in this particular case the dispersed particles (gas vesicles or bubbles) are the product of the ultra sound waves themselves.
All kinds of liquids contain an amount of submicroscopic gas bubbles, which are growing under the influence of mechanic vibration, due to the mechanism of “rectified diffusion”.
Reaching a specific vesicle size, related to the ultra sound wavelength their state can be seen as a kind of oscillator circuit (cavity resonator), the size of oscillation amplitude of this cavitation now can also reach a multiple of the invading ultra sound wave.
The latter can be the reason of alteration in biologic structures in two different ways.
First a constant current pattern is induced in the ambient liquid layers in a high velocity gradient, leading to shearing stress on larger molecules and cell membranes.
Then also inside the vesicles phenomenons are occurring,which remind on the effect of ionizing radiation, creating free radicals delivered into the surroundings.
The latter is also called “stable cavitation”.
In-vitro experiments (cell suspensions) involving large ultra sound intensities lead to the so called “transient cavitation” bringing about a break down of the liquid structure, again characterized by temporary forming of cavitation structures.
Hitherto, there are only ambiguous experimental references for both principles, stable and transient cavitation, in biological tissues, except micro vesicles in plant cells.

3.3.
Biology of ultrasound

An overview about results given by biophysical and biological is given in following sections, ordered by increasing complexity.

3.3.1
Chemical systems

Ultrasonic effects on simple aqueous solutions lead to typical forming of radicals (H., OH.), the extent is dependent on the gas concentration and on the viscosity of the gases involved.
Also, chemical reactions can be accelerated.

3.3.2
Macromolecules and bio-polymers

Special attention was drawn on ultrasonic influences on macromolecules, especially when interacting with genetic materials.
The primary effect is expressed as the division of the DNA double helix, starting in the middle of the macromolecule and caused by shearing forces within the surrounding liquid.
Change in UV absorption and in melting temperatures, which can be observed after sonar treatment, give evidence that also a generation of free radicals is involved, which could lead to DNA mutations.

These observations were made, based on experiments in the range of 10 kHz, but also ranges between 0,25 – 4 MHz showed effects on the tested suspensions.
In general cavitation forming, followed by chemical degassing, which can be experimentally stopped by increasing ambient pressure, seems to be responsible for DNA rupture.

3.3.3
Cells

First experiments on ultra sound influence an cells were conducted in aqueous suspension of microorganism and protozoa, the consequence of increasing sound intensity was always a rupture of the treated cell membranes, caused by cavitation, which can be influenced by choosing different surrounding media.
Non lethal reversible damages in cell membranes under certain intensity levels are regarded as the consequence of constricted electrophoretic mobility in mammalian cells, due to reduced superficial charge.
But also non reversible changes in membrane transport performance have been shown after ultra sound treatment.
Carrying out in vivo-like experiments it is necessary to inhibit cavitation, therefor cells and tissues were fixed on special needles activated to ultrasonic oscillation (20 kHz).
The results were acoustic streamings within the nucleo- and cytoplasm followed by movement, deformation and rupture of inter-cellular particles (organelle).
Visco-elastic changes in plant cytoplasms were observed below an ultrasound intensity of 40W/cm with a constant frequency of 1 MHz.

3.3.4
Tissue

Interpreting the experimental data concerning ultra sound effects poses a great challenge.
Biological tissues are always characterized by a rather low heat transfer, due to also low heat conductance and missing convection but a high ultra sound absorbency.
The latter could be the reason of the successful ultra sound applications in physical medicine, e.g. focused ultra sonic waves for destroying of small soft part abscesses.

A special situation can be observed, when sonar waves meet interfacial areas between soft part tissue and bones, hereby ultra sound is propagating mostly mediated by transversal waves, especially in solid materials, instead of common propagation mediated by longitudinal waves, in gases and partially in liquids.
Absorption followed by heat production is caused by transversal waves is always higher, compared to the influence of longitudinal waves.

A cumulative effect of ultra sound application was observed when mice extremities were ultrasound treated twice resulted in a paralysis, whereas single treatment had no visible effect.
Therefore a special threshold for ultrasound effect accumulation is obvious.
An increase of DNA- and probably protein synthetization as well as accelerated lesion healing can be interpreted as positive sound influences, rupture of lysosomal membranes followed by enzyme release could be here the reason for.

Also synergistic application of ultra sound together with X-ray treatment in oncology medicine has been demonstrated.

3.4
Biologic effects of ultrasound – Literature survey

Tab.2: *Ultrastrukturelle Veränderungen als Folge von in vitro Exposition mit Ultraschall*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
800	cw	5	Zunahme der Thrombocytenaggregation; (menschliches Blut)	Chater & Williams (1977)
900	cw	0.3 - 2	Beschädigung von Plasma- u. Kernmembran, Zunahme an Zellzertrümmerung; (HeLa Zellen)	Watmough et al. (1977)
2000	cw	2	Riß von Myofibrillen; (Hühnermuskel)	Samosudova & El' piner (1966)
2600	cw	40	Erythrocytendeformierung; (menschliches Blut)	Koh (1981)

Tab.3: *Ultrastrukturelle Veränderungen als Folge von in vivo Exposition mit Ultraschall*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
100	cw	15	Plasmamembranschäden, Zellzertrümmerung; (Hühner Embryo)	Dyson et al. (1974)
1000	—	10	Membranveränderungen, geschwollene Mitochondrien, Zellzertrümmerung; (Ratte - Hoden)	Dumontier et al. (1977)
1000	cw	9.1	Veränderungen an Mitochondrien; (Mäuseleber, Pankreas, Niere)	Stephens et al. (1978)
1000	cw	10	Membranveränderungen, Veränderungen an Mitochondrien	Hrazdira & Havelkova (1966)
1000	cw	20	Schwellung von Basallabyrinth, Mikrovilli u. Mitochondrien; (Hund - Niere)	Pincuk et al. (1971)
2000	cw	1	Nekrose, Hämorrhagie; (Mäuseleber)	Valtonen (1967)
2500	cw	5	Vakuolenbildung, Nekrose, Desquamation und murale Thrombose; (Kaninchenarterien)	Fallon et al. (1973)
3000	cw	5 (mehrfach)	Zunahme an Lysosomenzerstörung; (Rattenleber)	Majewski et al. (1966)
3000	cw	5	Zunahme an Lysosomenzerstörung; (Kaninchenleber)	Jankowiak & Majewski (1966)
3500	cw	3	Nekrose, Intracytoplasmatische Vakuolenbildung, zerstörte Mitochondrien; (Kaninchenlarynx)	Karduck & Wehmer (1974)

Tab.4: *Effekte auf zellulärer und molekulärer Ebene*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
10	cw	30 und 90	Keine Veränderung in der Geschwister-chromatidaustauschrate; (Chinesischer Hamster - Ovarialzellen)	Wegner et al. (1980)
20	cw	10	Zunahme an Chromosomenabweichungen präexpositionell vor zusätzlicher Röntgen-betrahlung;	Kunze-Muhl (1981)

40	cw	3	veränderte viskoelastische Eigenschaften; (Elodea Zellen)	Johnson & Lindvall (1969)
200	cw	15	DNA - Schädigung; (Kalb - Thymus)	Galperin - Lemaitre et al. (1975)
200	cw	5	Steigerung der Proteinsynthese; (Leber-, Nieren- und Herzmuskelgewebe)	Belewa-Staikowa & Kraschowa (1967)
250	cw	0.5	topographische Veränderungen an der Zelloberfläche; (m3-1 Zellen)	Martins (1971)
400	cw	3	Entartung der DNA; (Kalbsthymus und Lachssperma)	Hill et al. (1969)
500	cw	10	Veränderungen im Eiweißstoffwechsel;	Bernat et al. (1966a)
500	cw	5	ultrastrukturelle Veränderungen; (menschliche Fibroblasten)	Harvey et al. (1975)
500	cw	5	Zunahme der Permeabilität an der menschlichen Erythrocytenmembran für K^+	Lota & Darling (1955)
600	cw	30	Abnahme von Leucintransport in Geflügel-erythrocyten;	Bundy et al. (1978)
800	cw	60	Unterdrückung des Zellwachstums;	Maeda & Murao (1977)
1000	cw	5	verzögerte Eiweißsynthese	Belewa-Staikowa & Kraschowa (1967)
3000	cw	10	Zunahme an Chromosomenabweichungen postexpositionell nach zusätzlicher Röntgen-betrahlung;	Kunze-Muhl (1981)
36 000	cw	10	kein Geschwisterchromatidaustausch	Morris et al. (1978)

Tab.5: *Gewichtsreduktion bei Mäusen*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
75	cw	2	reduziertes fetales Organgewicht	Stratmeyer et al. (1979,1981)
80	cw	8	reduziertes Fetalgewicht	Tschibana et al. (1977)
500-1000	cw	1-3	reduziertes Fetalgewicht	Stolzenberg et al. (1980b)
500-5000	cw	0.16-5	reduziertes Fetalgewicht	O' Brien (1976)
1000	cw, (p)	8.8	reduziertes Fetalgewicht	Stolzenberg et al. (1980a)
2000	cw	5	reduziertes Muttergewicht	Hara et al. (1977, 1980)

Tab.6: *Übersicht über berichtete Abnormalitäten bei Nagetieren*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
125	cw	3	postpartale Mortalität; (Mäuse)	Curto (1975)
1400	cw	5	fetale Abnormitäten; (Mäuse)	Shimizu (1971)
1400	cw	5	fetale Abnormitäten; (Mäuse)	Tachibana et al. (1977)

2000	cw	5	Zunahme an fetalen Mißbildungen; (Mäuse)	Hara et al. (1977, 1980)
3000	cw	5	fetale Abnormitäten und Schwelle für pränatalen Tod; (Ratten)	Sikov & Hildebrand (1977)

Tab.7: *Auswirkungen des Ultraschall auf das Blut*

Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
4 W/cm²	cw	10	Abnahme des Glutathionspiegels und Zunahme des Ascorbinsäurespiegels; (Meerschweinchen - in vivo)	Straburzynski et al. (1965)
65	cw	5	Abnahme der Gerinnungszeit; (menschliches Blut - in vitro)	Williams et al. (1976a, 1976b)
32 - 64 SPTP	cw	1 & 10	Verklumpung in thrombozytenangereichertem Plasma; (menschliches Blut - in vitro)	Miller et al. (1978)
6.4 -12.5 SPTA	(p)	1 & 10	Verklumpung in thrombozytenangereichertem Plasma; (menschliches Blut - in vitro)	Miller et al. (1978)
1 W/cm²	cw	200 s	biochemische und hämatologische Veränderungen; (Maus - in vivo)	Glick et al. (1981)
2	(p)	30	funktionelle Änderungen in Erythrozyten; (menschliches Blut - in vitro)	Pinamonti et al. (1982)

Tab.8: *Verhaltensveränderungen bei Ratten und Mäusen*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
20	cw	300	Verzögerung der neuromotorischen Reflexausbreitung; (Ratte)	Murai et al. (1975)
20	cw	300	Veränderungen im emotionellen Verhalten; (Ratte)	Murai et al. (1975)
50-500	cw	2 - 3	unterschiedliche Ergebnisse; (Maus)	Brown et al. (1979, 1981)

Tab.9: *Berichtete Auswirkungen auf das zentrale Nervensystem (ZNS), auf das Skelettsystem und auf Gewebeweichteile*

SATA-Intensität [mW/cm²]	Wellenmodus cw - (p)	Expositionszeit gesamt (min)	beobachtete Effekte	Referenz
10	cw	Tage	Störungen in der Mikrozirkulation; (Kaninchen und Frösche)	Yaroniene (1978)
40	cw	300	Zunnahme an Abnormitäten im Skelettsystem; (Mäuse)	Shoji et al. (1971)
80	cw	5	stabile Blasenbildung; (Meerschweinchen)	ter Haar & Daniels (1981)
100	cw	5 (wiederholte Exposition)	Wundheilung; (Kaninchen)	Dyson et al. (1968)
400	cw	10 (wiederholte Exposition)	Heilung von Cornealulcera; (Kaninchen)	Goralcuk & Kosik (1976)

500	cw	2	Knochenmarkshämorrhagien; (Hund)	Bender et al. (1976)
500	cw	10	Veränderung der Schilddrüsenfunktion; (Meerschweinchen)	Slawinski (1966)
500	cw	--	Blutstockung; (Huhn)	Dyson & Pond (1973)
500	cw	10	Abnahme an SH - Gruppen; (Epidermis Maus)	Chorazak & Konecki (1966)
500-1000	cw	--	Knochenverdickung und Verlust des Periosts; (Hund)	Barth & Wachsmann (1949)
1000	cw	1.3	Fehlfunktion der Hinterbeine; (Maus)	Stolzenberg et al. (1980c)
1000	cw	1.3	Blasenausdehnung; (Maus)	Stolzenberg et al. (1980c)
1500	cw	--	Gewebeschäden bei stationärem Wandler; (Hund)	Hug & Pape (1954)
1000-2000	cw	--	Gewebeschäden bei stationärem Wandler; (Hund)	Lehmann (1954b)
2000	cw	5	fetale Skelett Variationen; (Mäuse)	Hara et al. (1977, 1980)
2400	cw	10	Veränderungen in der Herzmuskelruhe-spannung; (Ratte)	Mortimer et al. (1978)
2500	cw	10 (wiederholte Exposition)	Knochenmarksschäden; (Hund)	Payton et al. (1975)
3000	cw	5	Knochenschäden bei bewegtem Schallfeld; (Hund)	Kolar et al. (1965)
4000	cw	--	Gewebeschäden bei bewegtem Wandler; (Hund)	Lehmann (1965b)

3.5
Effects caused by airborne ultra sound on biological systems

Nowadays airborne ultrasonic devices are used on a large application scale, emitting so-called working frequencies, which are accompanied by harmonic oscillating frequencies and mostly audible sound as a byproduct.

Several symptoms as nausea, emesis, headache, fatigue and apraxia under the exposure of ultra sound waves were summarized as “ultrasound-sickness” in 1948.
Further investigation on ultra sound influence on human population shows, that the expected effects can be devided into the following groups:

. effects on the auditory system
. physiological effect
. heating skin and tissues
. other symptoms

3.5.1
Effects on auditory system

The effects of airborne ultra sound mediated by the auditory systems is 2-3 times higher compered to surface or bone mediation.
Ultra sound experiments undertaken on the so called “octave band” (SPL) concerning industrial devices showed higher dB values in audible frequency ranges than in ultrasonic bands.
Only ultra sonic frequencies are able to produce subharmonic vibrations in the ear and are therefor regarded as the reason for auditory effects.
On the one hand there are still no standardized exposure limits, on the other hand diverging or opinions based on also diverging experimental results are expressed in technical literature.
Reversible reduction in hearing was observed, as well as the harmful influence of frequencies close to the upper auditory threshold.
Sound intensity about 120 dB in the lower frequency range of ultra sound led to reversible or even total hearing-loss in industry.
Reversible changes in the audibility threshold were observed, when workers were exposed to subharmonic sound waves between 17 and 37 kHz after an exposure time of 150 dB for 5 minutes.
Thus it is supposed, that remaining changes in the auditory threshold can be expected after a long period of exposure.

3.5.2.
Physiological changes

Investigation on human being led to contradictory changes of the blood sugar level after an ultra sound exposure about 110 dB, also a electrolyte dis-balance in nerval tissue and in the adrenalin level was observed.
10 kHz exposure caused physiological non auditory effects, whereas no effects were observed, when workers were exposed to 110-115 dB and 20 kH over a period of 1 hour.

3.5.3.
Temperature rise in skin tissue

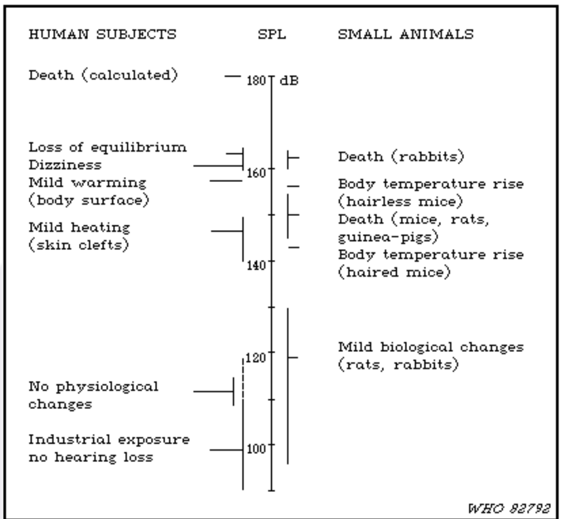
Excessive heating is observed, when rodents are exposed to 150 dB after a period of 40 minutes, after a period of 10 minutes exposure to 155-108 dB they die.
Human beings suffer from hair vibration as well as heating and vibrations in the auditory canal and in the nostrils, caused by 140-250 dB.
Mild skin heating is observed on human skin up to an intensity of 159 dB, death occurs on an exposure of about 180 dB.

3.5.4.
Symptomatic effects

According to Acton & Carson (1967) and Acton (1973, 1974, 1975) labourers exposed to industrial ultrasonic sources complained of fatigue, headache, nausea, tinnitus and vomiting. After an exposure to a sound pressure level of 110dB at 17.6-20 kHz, labourers working in the close vicinity of ultrasonic sources showed severe troubles with the sense of hearing and complained of subjective effects such as plugged ears or an unpleasant feeling of pressure in their ears (Crabtree & Forshaw, 1977). Changes in vestibular function as stated in Knight (1968) and Dobroserdov (1967) may explain the above mentioned nausea. Many of the reported subjective effects occurred at frequencies below 20 kHz and presumably only few individual workers to whom these frequencies were still audible showed these symptoms. Nausea, dizziness, and fatigue may involve an interaction of high-frequency inaudible sound with cochlear or other inner ear functions. Moreover, cases are reported that exposure to airborne ultrasound resulted in problems with the neuromuscular coordination, the loss of ability to perform mathematical tasks, or even the complete loss of capacity to perform voluntary acts (Brown, 1967).

3.5.5.
Summary

The physiological effects of exposure to increasing airborne acoustic energy can be stated as follows:



Reported physiological effects in human beings and animals from exposure to airborne ultrasound (From: Acton, 1974).

fig 7.

pest bird control

No undesirable physiological or auditory effects seem to occur in human subjects exposed to sound pressure levels up to about 120 dB. At 140 dB, mild heating may be felt in the skin clefts. With increasing sound pressure levels, the human body becomes warmer until death from hypothermia has been estimated to occur at levels greater than 180 dB.

Subjective or symptomatic complaints such as nausea, dizziness, vomiting, headache and an unpleasant sensation of fullness or pressure in the ears have been reported by persons exposed to industrial ultrasonic energy. It is difficult to state if these observed effects were caused by airborne ultrasound and not by audible noises, because many sources of exposure contain acoustic frequencies in both the audible and ultrasonic range.

There is some evidence that any hazard to the hearing is probably due to the high-frequency audible sound or to sub-harmonious ultrasonic frequencies. However, it has been reported that temporary threshold shifts in hearing might occur after short-term exposures to airborne ultrasound at 150 dB.

IV. Overview of existing standards and safe-use guidelines

4.1.
Protective limits

The multitude of ultrasonic devices and systems on the market, their ever faster development and the numerous reports about potential health hazards for people exposed to them ask for an implementation of standards which limits the exposure and provides voluntary safe-use guidelines as well as a frame of reference for the industry.

4.2.
Types of standards for ultrasound

Other than emission or performance standards which primarily refer to medical equipment specifying emission limits, minimum distance, maximum output intensity, etc. there exist also exposure standards referring to the occupational exposure due to the industrial use of ultrasound.

4.2.1.
Exposure standards

The following two tables illustrate exposure standards for airborne ultrasound focusing on exposure limits for human subjects.

Tab. 10: Exposure limits (dB) for airborne acoustic energy at the workplace[a]

	Sound pressure level within one-third octave band (dB relative to 20 µPa)							
Mid-frequency of one-third octave band (kHz)	Jpn. Min. Lab. (1971)	Acton (1975)	USSR St. (1975)	USAF (1976)	Dept H&W Canada (1980b)	Sweden (1978)	ACGIH (1981)	IRPA draft (1981)
8	90	75			80		80	80
10	90	75			80		80	80
12.5	90	75	75	85	80		80	80
16	90	75	85	85	80		80	80
20	110	75	110	85	80	105	105	80
25	110	110	110	85	110	110	110	110
31.5	110	110	110	85	110	115	115	110
40	110	110	110	85	110	115	115	110
50	110		110		110	115	115	110

[a] For total ultrasound exposure exceeding 4 h/day.

Tab. 11: Permitted increase in sound pressure levels (SPLs) at workplaces in the vicinity of ultrasound sources

	Total ultrasound exposure time (per day)	Permitted rise in SPL	Total ultrasound exposure time (per day)	Permitted rise in SPL
USSR St. (1975)	1 - 4 h 1/4 - 1 h	+6 +12	5 - 15 min 1 - 5 min	+18 +24
Sweden (1978)	1 - 4 h 0 - 1 h	+3 +9		
IRPA (draft) (1981)	1 - 4 h 0 - 1 h	+3 +9		

Grigor'eva, (1966a, b) argued in her test series that airborne ultrasound is considerably less hazardous to man than audible sound and that 120 dB may be adopted as an acceptable limit for the acoustic pressure for airborne ultrasound. Moreover, the possibility of raising this level should depend on further test results. However, she did not propose any exposure-time limits for her suggested values for acceptable limits of acoustic pressure.

Acton (1968) proposed a criterion below which auditory damage and/or subjective effects were unlikely to occur as a result of human exposure to airborne noise from industrial ultrasonic sources over a working day. He subdivided his results into different levels of frequency ranges; a maximum level of 75dB at a narrow band analysis up to 22.5 kHz and 110 dB for narrow bands above this range. In his further studies (1974) he gained additional data which confirmed that the levels set in the proposed criterion were at approximately the right level and therefore he did not modify and adjust his first assumptions and proposed limits.

Parrack (personal communication, 1969) experimental findings of temporary threshold shifts (TTS) in hearing levels at subharmonic frequencies were used by the American Conference of Governmental Industrial Hygienist (ACGIH, 1981) for their ultrasound exposure levels.

4.2.2.
National Standards

The USSR introduced maximum sound pressure levels to limit exposure of workers in the vicinity of ultrasound sources (USSR State Committee for Standards, 1975). These levels were divided into three frequency ranges by one-third octave bands.

pest bird control

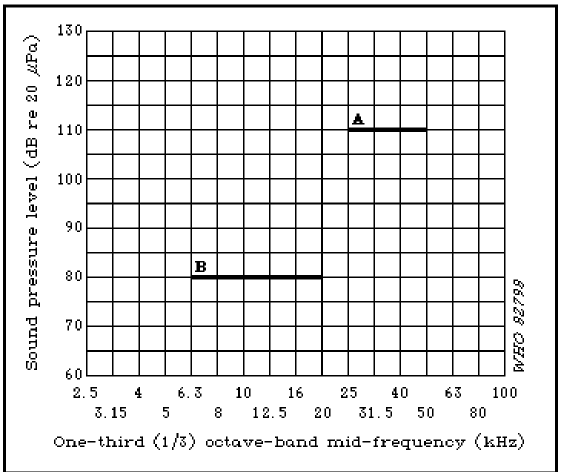
In Poland, there is a regulation that states that the effective sound pressure at a working environment with ultrasonic equipment must not exceed the following limits:

10 kHz – 75dB	16 kHz – 85 dB
12.5 kHz – 77 dB	20 kHz – 110 dB

In Japan, the limits have been regulated by the Japanese Ministry of Labour (1971) as shown in table 10 .

Noise caused by ultrasound is limited to 85 dB per one-third octave by the US Air Force (US AF, 1976) for frequencies in the range of 12.5-40 kHz.

In Canada, the Department of National Health and Welfare (1980b) introduced the following recommended exposure limits for airborne ultrasound that are frequency-depended:



Recommended exposure limits for airborne ultrasound (From: Canada, Department of National Health and Welfare, 1980b).
A=line representing the maximum sound pressure level for frequencies 25 kHz and above.
B=line representing the maximum sound pressure for frequencies 20 kHz and below.
NOTE: The nominal centre frequency of 20 kHz has a one-third octave passband from 17.8-22.4 kHz, and the nominal centre frequency of 25 kHz has a one-third octave passband of 22.4-28.2 kHz.

fig. 8

The Swedish limits refer to > 4 h / per day as illustrated in table 10 and to < 4h / per day as illustrated in table 11.

As for Norway, regulations state that a level above 120 dB is not permitted for frequencies of the octaves of 31.5 – 125 kHz.

The Swiss Unfallversicherungsanstalt introduced a limit of 100 dB for all ultrasonic systems in order to minimize health hazards.

As for Austria, the ÖAL Richtlinien Nr. 3, Blatt 2 of the Österreichischen Arbeitsringes für Lärmbekämpfung (dating 12/12/1989) regulate the noise control of devices of an average range of 12.5 – 40 kHz with regard to industrial safety (AU-Bewertung according to IEC 1012). The maximum exposure is limited to a maximum of 85 dB for 8h / per day.

The International Radiation Protection Association (IRPA, 1981), referring to Acton, drafted the first international limits for human exposure to airborne acoustic energy having one-third octave bands with mid frequencies from 8 to 50 kHz in 1981. These limits were proposed for industrial workers and their occupational exposure. They were adjusted to 110 dB at 100 kHz (third-octave bands) in 1984. The proposal is similar to the standards existing in a number of countries.
Furthermore, the IRPA (1981) has also proposed a set of exposure limits for exposure of the general population to airborne acoustic energy.

Tab. 12: Limits of continuous exposure of the general population to airborne acoustic energy[a]

Mid-frequency of one-third octave band (kHz)	SPL within one-third octave (dB re: 20 µPa) Day	Night
8	41	31
10	42	32
12.5	44	34
16	46	36
20	49	39
25	110	110
31.5	110	110
40	110	110
50	110	110

[a] From: IRPA (1981).

V. Conclusion

Final evaluation of the environmental medical parameter –
Setting up guidelines for a non-hazardous operation of the developed bird control system

Biologically significant effects were known ever since the industrial use of ultrasound. Early basic research on ultrasound and its effects were related to military interests. Later on, research was conducted in order to test ultrasound in medicine. The ongoing research studies of possible applications of ultrasound in the fields of clinical diagnostics and therapy contributed a lot to the current publications in various fields of science.

First, in order to assure transferable results and information about this particular bird control system, physical properties of ultrasound were dealt with at the outset, also with regard to better understand the general effects on and of biological matter.
Second, the biophysical interactive effects such as dispersion, attenuation etc., were identified as causing purely biological effects and explained in greater detail.
The most significant consequences as for instance absorption (heat generation), dispersion and cavity, as well as their particular impact on hierarchically organised biological systems, like molecules, single cells, tissue particles, organs up to living laboratory animals were highlighted.
Furthermore, the characteristics of ultrasound have been outlined with reference to the relevant subject literature. Special focus was given to the effects of continuous waves caused by airborne ultrasound. (The great majority of subject literature referring to the medical uses of ultrasound, describe the effects of pulsed, focused ultrasound primarily transmitted by media (gels) reducing impedance.
Moreover, the discrepancy between *in vitro* and *in vivo* effects has been pointed out. A direct extrapolation of in vitro results on in vivo outcomes is not possible. The same is true for the transfer of test results for lower organisms, as for instance molecules (DNA), onto higher organisms, like experimental animals. The absorption of airborne ultrasound at 20 kHz is for instance 200 times higher for fury animals. Temperature regulating mechanisms and compensation mechanisms are far less effective for small mammals than for bigger ones. Besides, lower frequencies of ultrasound are more likely to still be in the audible level for smaller mammals than they are for bigger ones.

In addition, on overview of the most significant symptoms of the biological effect of ultrasound on the human body has been given. Possible simple subjective effects are a shift of the auditory threshold or the hearing ability. Other symptoms might be fatigue, headache, nausea, tinnitus, a feeling of pressure in the ear or vomiting. On rare occasions more complex physiological and neurological dysfunction might occur. Ultrasound at highest intensity generates a raised body temperature and may theoretically lead to death from hyperthermia. Additionally, cumulative and synergetic effects have been described.
Furthermore, international safe-use guidelines and protective limits were pointed out in this report. These guidelines and limits are based on research studies conducted by Acton, Grigoreva, Parrack etc. and were introduced by various nations and organisations, first and foremost by the IRPA.

Nevertheless, wildly accepted safety limits such as Acton´s criteria which form the basis of the IRPA guidelines are not without controversy (cf. K. Körpert: *Geräuschmessungen an industriellen Anlagen und Vergleich mit Beurteilungskriterien zur Vermeidung gesundheitlicher Auswirkungen;* 1985). However, although there are no internationally standardised limits, recommended figures shall be highlighted once more:

Tab. 13: Relevant limits for an exposure of 8h/per day

Frequency (one-third octave band/kHz)	**Acton** (dB re: 20 µPa)	**IRPA** (dB re: 20 µPa)	**ÖAL RL.3. Bl.2** (dB re: 20 µPa)
20	75	80	85
25	110	110	85
31.5	110	110	85

These figures refer to an exposure of 8h/per day (`Arbeitnehmerschutz´/industrial safety) to continuous airborne emitted ultrasound.

IRPA (1981) states the only available data referring to an exposure of 24h/per day (`Anrainerschutz´/local residents´ protection). Yet, they can be regarded as the most significant criteria of protection.

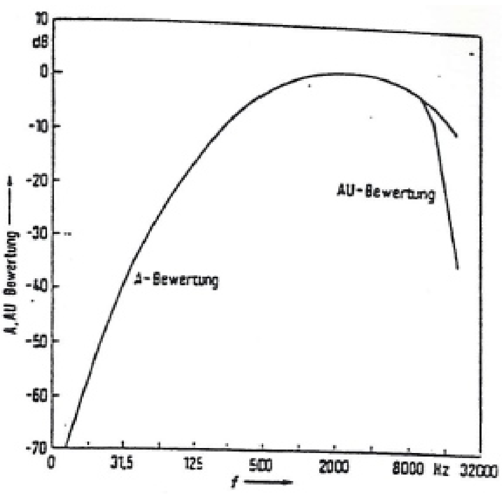
Tab. 14: Relevant limits for local residents´ protection (24h/per day)

Frequency	**dB SPL**	
	day	**night**
20	49	39
25	110	110
31.5	110	110

Hence, operating frequencies between 25-28 kHz are the most favourable from a medical point of view.

Beat characteristics of the relevant ultrasonic field are not dealt with separately. On the one hand, no specific indications could be found in the relevant references (with the exception that for audible acoustic fields the human threshold of perception is approximately at ≤ 16 beats/per second). On the other hand, beat characteristics have probably no major influence on the energy equivalent of the intensity (peaks counterbalance nodes).

Tab. 15: A- and AU-valuation curve according to IEC 651 & Herbertz



The A-valuation curve was deduced from the vertical curves of the same volume. The latter are not standardised above 15 kHz. The extension of the A-curve up to 20 kHz is extrapolative. Herbertz (1981) demonstrated that a correlation with the hearing ability was not intended as it is not given. Therefore, he suggested to complete the A-valuation via a deep bass filter Herbertz; 1982).

Successful positioning of ultrasonic devices depends on the knowledge of the impedance values of construction materials.
But also attention should be payed on the characteristics of sound level propagation, which is similar to audible sound waves.
At least also meteorological criteria and the way of ultrasound production, concerning the material of the transducer (quartz, tourmaline, e.g) should be considered.

Ing. Dr. Hans-Peter Rammer
Sadarchstraße 30/22
Tel.: 0512-295175
A-6020 Innsbruck

EXPERT REPORT

The examined bird control system operates, compared to other current industrial ultrasonic devices, at the lower end of the frequency range.
An operation in compliance with the recommended exposure limits for 24h or under (IRPA; 1981), as for instance 8h/ per day (possible reduction of operating time by use of timer, light barrier, motion sensor etc.) and an emission level of 75 dB can be regarded as non-hazardous for the general population.
Higher limit values are also tolerable for shorter exposure. The recommended IRPA-limits are listed in table 11 of this report.
The predetermination of operating frequencies between 25-28 kHz increases the biological tolerance considerably and thus also the safety of the exposed persons.
Especially children who have not yet completed their skeleton growth as well as pregnant women should not be exposed to ultrasonic fields. Special limit values for adolescents are unknown to the author of this report.
Calibration and dimensioning as well as local adjustments and distance computing should be AU evaluated.
Ultrasound specific physical conditions and acoustical boundary conditions should always be taken into consideration.
Furthermore, the general guidelines and precautions as stated on the system should be observed.

Innsbruck, 15th of December 1995

Signature: Ing. Dr. Hans-Peter Rammer