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Abstract: This contribution paper gives a reminder on exposure guideline of THz radiation by ICNIRP and call an attention to the biological effects of MMW-THz radiation.

Purpose: To call an attention to the possible biological effects of MMW-THz radiation.

Exposure Guideline and biological effects of THz radiation

1. Exposure Guidelines at THz frequencies by ICNIRP

   ICNIRP: International Commission on Non-Ionizing Radiation Protection

2. Biological Effects of MMW (30-300 GHz)
3. Results of THz-BRIDGE

   THz-BRIDGE: Tera-Hertz radiation in Biological Research, Investigation on Diagnostics and study of potential Genotoxic Effects

4. Fröhlich Hypothesis
5. Summary

http://www.icnirp.de/

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FOCUS AND NEWS

7th International NIR Workshop, 9-11 May 2012, Edinburgh, United Kingdom
180 delegates from 40 countries worldwide attended, 35 posters were displayed and 6 exhibitors participated in the Workshop. Additionally, the workshop was followed around the world online via a live stream.
----> More information

Open Consultation of ICNIRP Draft Guidelines - until 24 May 2012
ICNIRP Draft Guidelines for Limiting Exposure to Electric Fields Induced by Movement of the Human Body in a Static Magnetic Field and by Time-Varying Magnetic Fields Below 1 Hz were available for public consultation until 24 May. The comments will now be reviewed by the Commission.

Do you want to be informed regularly about ICNIRP activities ?
Send us an email indicating the field you are interested in. For specific local exposure appraisal, please contact the radiation protection agency of your country.

Order ICNIRP publications online ----> Go to the book list on EMF, optical radiation, ultrasound, general.

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Publications - EMF

----> New !! ICNIRP Statement on Health Issues Associated with Millimeter Wave Whole Body Imaging Technology

> Latest publications on radiofrequency

---> EMF guidelines - 1998
Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz). Health Physics 74 (4): 494-522; 1998.

The EMF guidelines published in 1998 are now being revised and replaced step by step. This process is explained in a statement.

---> Statement on EMF guidelines - 2009
Statement on the "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics 97(3):257-259; 2009.

Work on the RF range is ongoing and validated by the above mentioned statement on the EMF guidelines. In 2009 ICNIRP finalized a comprehensive review of health effects of radiofrequency by evaluating the research in the areas of biology, physics and dosimetry, and epidemiology. In this frequency range a statement on the results of the INTERPHONE paper has also been issued.

---> RF Review - 2009
Exposure to high frequency electromagnetic fields, biological effects and health

http://www.icnirp.de/documents/StatementEMF.pdf

Statement on the "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics 97(3):257-259; 2009.

Basic restrictions

Different scientific bases were used in the development of basic exposure restrictions for various frequency ranges:

Between 1 Hz and 10 MHz, basic restrictions are provided on current density to prevent effects on nervous system functions;

Between 100 kHz and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating; in the 100 kHz–10 MHz range, restrictions are provided on both current density and SAR; and

Between 10 and 300 GHz, basic restrictions are provided on power density to prevent excessive heating in tissue at or near the body surface.

Table 5. Basic restrictions for power density for frequencies between 10 and 300 GHz.[a]

Exposure characteristics	Power density ($W\ m^{-2}$)
Occupational exposure	50
General public	10

[a] Note:

1. Power densities are to be averaged over any 20 cm^2 of exposed area and any $68/f^{1.05}$-min period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases.
2. Spatial maximum power densities, averaged over 1 cm^2, should not exceed 20 times the values above.

Table 6. Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).[a] Note: For frequencies exceeding 10 GHz, *S*eq, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (*f* in GHz).

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

Table 7. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).[a] Note: For frequencies exceeding 10 GHz, *S*eq, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (*f* in GHz).

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4,000/f$	$5,000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

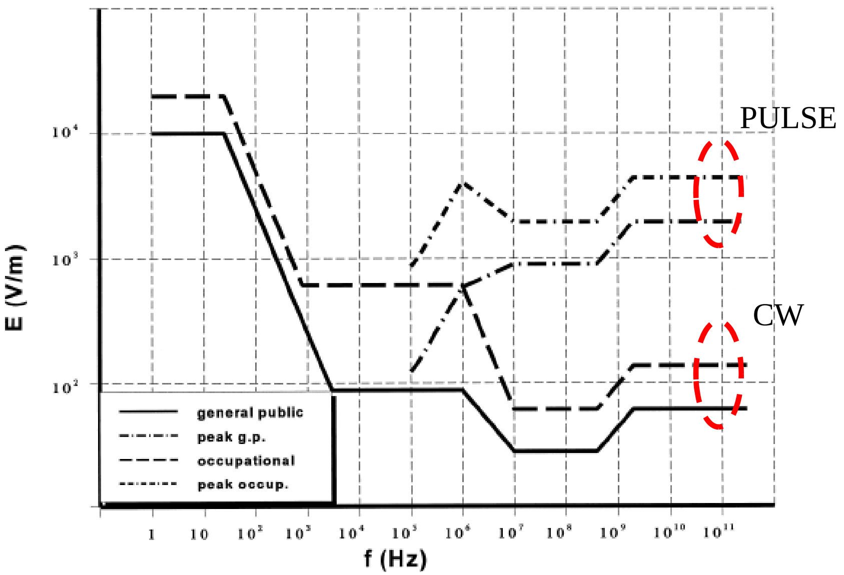

Fig. 1. Reference levels for exposure to time varying electric fields (compare Tables 6 and 7).

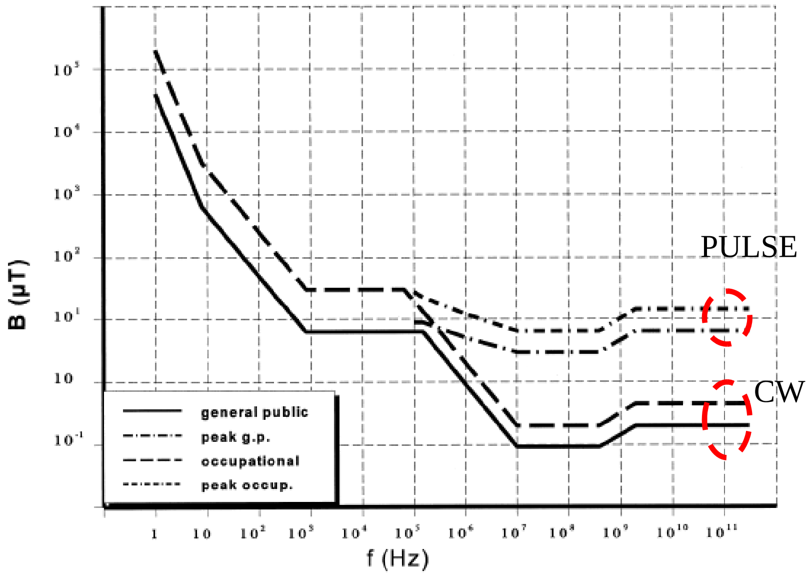

Fig. 2. Reference levels for exposure to time varying magnetic fields (compare Tables 6 and 7).

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> Guidelines

Guidelines on Limits of Exposure to Ultraviolet Radiation of Wavelengths Between 180 nm and 400 nm (Incoherent Optical Radiation). Health Physics 87 (2): 171-186; 2004.
Free download

Revision of the Guidelines on Limits of Exposure to Laser radiation of wavelengths between 400nm and 1.4µm. Health Physics 79 (4): 431-440; 2000.
Free download

Guidelines on Limits of Exposure to Broad-Band Incoherent Optical Radiation (0.38 to 3µm). Health Physics 73 (3): 539-554; 1997.
Free download

Guidelines on UV Radiation Exposure Limits. Health Physics 71 (6): 978; 1996.
Free download

Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180 nm and 1 mm. Health Physics 71 (5): 804-819; 1996.
Free download

Proposed Change to the IRPA 1985 Guidelines on Limits of Exposure to Ultraviolet Radiation. Health Physics 56 (6): 971-972; 1989.
Free download

Guidelines on Limits of Exposure to Ultraviolet Radiation of Wavelengths between 180 nm and 400nm (Incoherent Optical Radiation). Health Physics 49 (2): 331-340; 1985.
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Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180 nm and 1 mm. Health Physics 71 (5): 804-819; 1996.

Table 1. Divisions of the optical spectrum.

Band	Wavelength	Other terminology
UVC	100 nm to 280 nm	Far ultraviolet
UVB	280 nm to 315 nm	Middle ultraviolet
UVA	315 nm to 400 nm	Near ultraviolet
Light	400 nm to 780 nm	Visible
IRA	780 nm to 1400 nm	Near infrared
IRB	1.4 μm to 3 μm	Middle infrared
IRC	3 μm to 10^3 μm	Far infrared

Note: These ranges are in accordance with those defined by the International Commission on Illumination (CIE). In addition, while there is no sharp boundary between the visible and UV wavelengths, the boundaries commonly used are given in this Table.

Effects of infrared (IRB and IRC) radiation

In the IRB and IRC regions of the spectrum (wavelengths greater than 1.4 μm), the ocular media are opaque because of absorption of the radiation by the water component. Thus, in these infrared regions, radiation causes damage primarily to the cornea, although lens damage has also been attributed to wavelengths below 3 μm (IRA and IRB). The IR damage mechanism appears to be thermal, at least for exposure durations greater than 1 μs; for pulses of shorter duration the mechanism may be thermomechanical. The CO_2 laser (10.6 μm), the Nd:YAG laser (1.06 μm), and the holmium laser (12.1 μm) that are now used in surgical applications are typical of IR radiation sources that cause thermal injury to tissue. In the IRC region, as in the UV, the exposure threshold for damage to the skin is comparable with that for damage to the cornea. However, damage to the cornea is likely to be of greater concern because of the adverse impact on vision.

Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180 nm and 1 mm. Health Physics 71 (5): 804-819; 1996.

http://www.icnirp.de/documents/laser180nm+.pdf

Table 2. Intrabeam laser ocular exposure limits.[a]

Wavelength, λ (nm)	Exposure duration, t	Exposure limit	Restrictions
⋮	⋮	⋮	
IRB and IRC			
1,401–1,500	1 ns to 1.0 ms	1,000 J m^{-2}	
1,401–1,500	1.0 ms to 10 s	5,600 $t^{1/4}$ J m^{-2}	
1,501–1,800	1 ns to 10 s	10^4 J m^{-2}	
1,801–2,600	1 ns to 1.0 ms	1,000 J m^{-2}	
1,801–2,600	1.0 ms to 10 s	5,600$t^{1/4}$ J m^{-2}	
2,601–10^6	1 ns to 100 ns	100 J m^{-2}	
2,601–10^6	100 ns to 10 s	5,600$t^{1/4}$ J m^{-2}	
1,401–10^6	10 s to 30 ks	1,000 W m^{-2}	

[a] See Table 5 for aperture sizes.

Note: 1 ks = 1,000 s; 30 ks = 8 h; $C_A = 1$ if λ = 400–700 nm; $C_A = 10^{[0.002(\lambda - 700)]}$ if λ = 700–1,050 nm; $C_A = 5$ if λ = 1,051–1,400 nm; $C_B = 1$ if λ < 550 nm; $C_B = 10^{[0.015(\lambda - 550)]}$ if λ = 550–700 nm;
$T_1 = 10 \times 10^{[0.02(\lambda - 550)]}$ s if λ = 550–700 nm; and
$C_c = 1$ if λ < 1,150; $C_c = 10^{0.0181(\lambda - 1150)}$ if 1,150 < λ < 1,200; $C_c = 8$ if 1,200 < λ < 1,400.

Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180 nm and 1 mm. Health Physics 71 (5): 804-819; 1996.

http://www.icnirp.de/documents/laser180nm+.pdf

Table 4. Laser radiation exposure limits for the skin.

Wavelength, λ (nm)	Exposure duration, t	Exposure limit	Restrictions
Ultraviolet			
180–400	1 ns to 30 ks	As for eye	
Visible and IRA			
400–1,400	1 ns to 100 ns	$0.2C_A$ kJ m^{-2}	See Table 5
400–1,400	100 ns to 10 s	$11\ C_A t^{1/4}$ kJ m^{-2}	for limiting
400–1,400	10 s to 30 ks	$2.0C_A$ kW m^{-2}	apertures
Far infrared			
$1,401–10^6$	1 ns to 30 ks	As for eye[a]	

[a] For exposed skin areas greater than 0.1 m^2, the exposure limit is reduced to 100 W m^{-2}. For exposed areas between 0.01 and 0.1 m^2, the exposure limit is inversely proportional to the exposed area.
Note: 1 ks = 1,000 s; 30 ks = 8 h; and
$C_A = 1$ if λ = 400–700 nm; $C_A = 10^{[0.002(\lambda - 700)]}$ if λ = 700–1,050 nm; $C_A = 5$ if λ = 1,051–1,400 nm.

Table 5. Limiting apertures for applying the exposure limits.

Spectral region	Exposure duration, t (s)	Eye exposure (mm)	Skin exposure (mm)
180–400 nm	<10 s	1.0	3.5
	≥10 s	3.5	3.5
400–1,400 nm	1 ns to 30 ks	7.0	3.5
$1,401–10^5$ nm	1 ns to 0.3 s	1.0	3.5
	0.3 to 10 s	$1.5t^{3/8}$	3.5
	10 s to 30 ks	3.5	3.5
$10^5–10^6$ nm	1 ns to 30 ks	11.0	11.0

Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180 nm and 1 mm. Health Physics 71 (5): 804-819; 1996.

http://www.icnirp.de/documents/laser180nm+.pdf

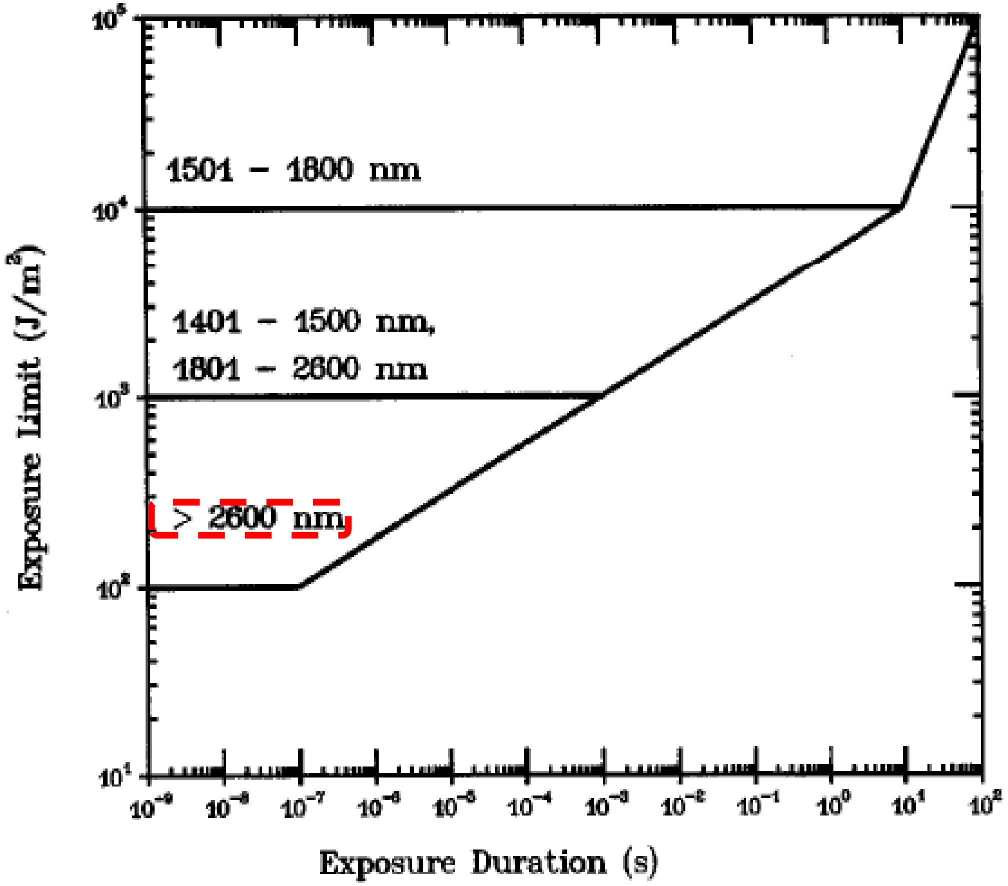


Fig. 8. Exposure limits for ocular exposure to middle and far-infrared laser radiation. For pulsed lasers only and for exposures up to 100 s, penetration depth into tissue results in a variation of exposure limit depending upon wavelength.

Review of Biological Effects of MMW (30-300 GHz)

Bioelectromagnetics 19:393–413 (1998)

The studies reviewed demonstrate effects of low intensity MMW (10 mW/cm^2 and less) on cell growth and proliferation, activity of enzymes, state of cell genetic apparatus, function of excitable membranes, peripheral receptors, and other biological systems. In animals and humans, local MMW exposure stimulated tissue repair and regeneration, alleviated stress reactions, and facilitated recovery in a wide range of diseases (MMW therapy)

> 1 mW/cm^2 = 10 W/m^2 (ICNIRP Guideline for General Public)

Physicochemical Effects

Influence at the Subcellular, Cellular and Tissue Levels

- Effects on Human Erythrocytes
- Effects on Growth Rate
- Effects on Proteins, Chromosomes and Genes
- Effects on Membranes .

Influence at the Organism Level

- Effects on Receptors
- Animal Studies
- Influence on SurfaceWounds
- Influence on Organism Self-Repair
- Influence on Tumor Growth
- Clinical Studies

Mainly, f < 100 GHz

Thermal v.s. Non-thermal

http://www.frascati.enea.it/THz-BRIDGE/

THz- BRIDGE

"Tera-Hertz radiation in Biological Research, Investigation on Diagnostics and study of potential Genotoxic Effects"

A RTD Project in the framework of the EU "Quality of Life" programme

In this project TeraHertz (THz) radiation is used to study structural and functional properties of biological systems, following a streamline of increasing complexity: from bio-molecules to cell membranes, cell nuclei and tissues. Aim of THz-BRIDGE is also to investigate the potential damage of electromagnetic radiation on biological systems in the above spectral ranges, and to guide the development of biomedical imaging at THz frequencies. The reseaarch activity of the project has covered the period from Feb. 1, 2001 to Jan 31, 2004. The final report and related documents, as well as a spectroscopic database are now available to the public.
For further information please contact the project coordinator: Dr. Gian Piero Gallerano

The dissemination activity of the THz-BRIDGE results and its perspectives is being performed within the EMF-NET Coordination Action of the EU.

NEW!!! EMF-NET Survey form on Exposure to THz Radiation

DOCUMENTS		
THz-BRIDGE Project Summary	THz-BRIDGE Final Report	THz Spectroscopic Database
additional documents		
THz related Conferences	THz-BRIDGE mid term Brochure (PDF)	Project History

What the Terahertz Bridge had done

Evaluation of genotoxic effects on human peripheral blood leukocytes following in vitro exposure to THz radiation.

Overall, the findings of present investigations have demonstrated that, 20 min THz exposures of whole blood samples, at 120 and 130 GHz, in different exposure conditions, do not induce neither direct DNA damage in human leukocytes, nor long lived damage in human lymphocytes. These results suggest that THz exposure, in our experimental conditions, cannot produce genotoxic effects by directly causing DNA damage.

Evaluation of genotoxic effects on lymphocyte cultures following in vitro exposure to THz radiation

Both genotoxic and epigenetic effects are induced in lymphocytes following exposure to CW 100 GHz radiation of 0.05 mW/cm^2 intensity when the exposure period exceeds one hour. The induced effects seem to saturate already for short exposures. Although the reported effects have been observed on cells directly exposed to THz radiation, without the shielding effect of the human body, they occurred at a relatively low intensity when compared to the exposure limits set by the ICNIRP guidelines (1mW/cm^2 for general public exposure and 5mW/cm^2 for occupational exposure). More experiments are needed to establish accurate doseresponse relationships.

Effects on membrane model systems

Our results indicate that terahertz fields can affect lipid bilayer permeability; we observed an increase in substrate permeation rate across the liposome bilayer (DPPC:Chol:SA = 5:3:2) over two minutes of exposure to 130 GHz radiation with a pulse repetition rate of 7Hz and an incident intensity of about 7.8 mW/cm^2.

To verify the specific role of carrier frequency and pulse repetition rate in eliciting the THz-induced effect, additional experiments have been conducted changing the carrier frequency from 130 GHz to 3 GHz. Continuous wave (CW) irradiation was also performed at a carrier frequency of 150 GHz. No effects were observed in the two latter cases.

Effects on epithelial models

No changes compared with the unexposed controls, in terms of cell activity (Resazurin assay) or differentiation (Fluorescein Cadaverine assay), or barrier function in terms of the air liquid interface models (sodium fluorescein assay), were observed with any of the exposure conditions. It was also found that no damage in terms of cell activity, measured via oxidative stress, or differentiation was caused to ND7/23 cells or human keratinocytes. This was also true even if the cells were stressed by the surfactant, sodium lauryl sulphate, which could form a residue on the skin of patients, prior to GHz exposure. Hence we are reasonably confident that the THz/GHz exposure rendered to potential patients by the Teraview imaging system is not potentially harmful at least upon one exposure and probably a few exposures.

Evaluation of biological effects on DNA bases

From the analysis of the mass spectra, and the number of photons, which were required to break one CN bond, it was found than the damage on the DNA bases under high irradiation conditions is only thermal, with no indication of any photochemical damage.

CONCLUSIONS

The results indicate that under various exposure conditions no biological effects could be detected. However, under some specific conditions of exposure, change in membrane permeability of liposomes was detected and an induction of genetoxicity was observed to occur in lymphocytes. These studies suggest that medical imaging employing appropriate exposure parameters is probably unharmful at least for single exposures. Moreover, since some effects were observed to be induced by the THz radiation at a relatively low intensity when compared to the limits set by the ICNIRP for exposure, these studies should be extended to establish more accurate dose-response relationships. This is expected to provide in future improved guidelines of exposure.

Different THz sources have been employed for irradiation studies, including
a Backward-wave oscillator operating at 100 GHz,
a Compact Free Electron Laser operating in the frequency range between 90 and 150 GHz,
a solid state IMPATT diode operating at 150 GHz and
a laser driven solid state source operating in the range between 0.3 and 3 THz.

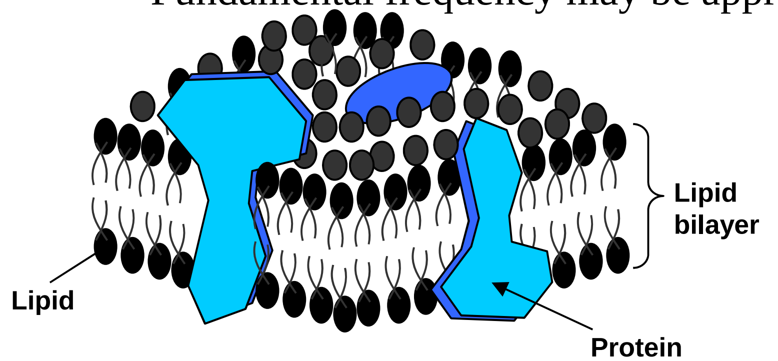
Fröhlich Hypothesis

(Electric Resonant Longitudinal Vibration of Cell Membrane)

Metastable states in membranes suggest that the space and time dependent oscillations due to the polarisation properties of the molecules in the membrane are coupled nonlinearly to the electric field and this results in chaotic oscillatory behaviour. The transition from a non-polar to a highly polar metastable state becomes established when a system is forced into large amplitude electrical vibrations through supply of energy.

Excitations of coherent modes of large molecules, the supply of energy to these modes leads to coherent excitation of a single mode provided the energy supply is larger than a critical value.

Fundamental frequency may be approximately 75 GHz using d=10 nm, and v=1500 m/s (d: membrane thickness v: acoustic velocity of water)



$$f = \frac{v}{2d} = \frac{1500}{2\times10\times10^{9}} = 75GHz$$

But water molecules or proteins around the cell membrane may cause the vibrational frequency become lower…

However, the mechanisms have been insufficiently studied because of the lack of widely tunable MMW&THz source.

*1 H. Fröhlich, "The extraordinary dielectric properties of biological materials and the action of enzymes," Proc. Natl. Acad. Sci. USA, 1975, 72, p. 4211.

Summary

1. Exposure Guidelines at THz frequencies by ICNIRP

There is a gap at 300 GHz

2. Biological Effects of MMW (30-300 GHz)

Lots of biological effects has been reported

Exposed powers were sometimes larger than ICNIRP guideline

Difficult to distinguish thermal or non-thermal effects

3. Results of THz-BRIDGE

No biological effects could be detected.

4. Fröhlich Hypothesis

Electric Resonant Longitudinal Vibration of Cell Membrane

→ This might cause biological effects

Lots of researcher will try to this issue.