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Risk Perception and Safety Issues

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1. Introduction

This session on 'Risk perception and safety issues' was a companion to the session 'Biological effects'. Where the latter was concerned with studies designed to determine any genotoxic effects from exposure of human cells to terahertz frequency radiation, here the topic of safety was considered in somewhat broader terms. International guidelines in relation to the heating effects of electromagnetic radiation were of interest, together with the methods for the assessment of risk and a consideration of the perception of risk, especially among non-scientists.

A number of bodies have an interest in this field, but because the terahertz band has not until recently been widely used, the expertise tends to lie in adjacent wavelengths. The most relevant body is the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which has its website at `www.icnirp.org`. It has published guidelines covering the terahertz band over both its optical and electromagnetic field regions [1, 2], which meet at 1 mm (300 GHz), and copies are available for download from the website.

Other relevant organisations include the World Health Organisation [3], which offers a summary on the public perception of risk [4] and the two US organisations whose standards documents provide the basis for the international guidelines. The Institute of Electrical and Electronics Engineers publishes the IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [5] and the Laser Institute of America is responsible for the American National Standard for the Safe Use of Lasers [6]. The websites for these organisations are respectively `www.ieee.org` and `www.laserinstitute.org`. Further resources are the International EMF Project's database of standards [7] and the list of national organisations for non-ionizing radiation protection [8].

URLs quoted in the text were all last accessed 23 November 2002.

Table I. Hazards and regulations associated with some established medical imaging techniques

Medical imaging modality	Limit on	Associated hazard	Reference
X-ray imaging and other techniques using ionizing radiation	Absorbed dose	Ionization leading to molecular changes, subcellular and cellular damage or death	ICRP73 [16]
Magnetic Resonance Imaging	(i) Magnitude of static magnetic field (ii) Rate of switching of the gradient magnetic fields (iii) Specific absorption rate of radiofrequency radiation	(i) Induced voltages (ii) Induced currents leading to nerve stimulation, for example in cardiac tissue (iii) Heating, leading to thermoregulatory problems	IEC 2–33 [17]
Ultrasound	Time averaged intensity Total sound energy	Local heating, acoustic streaming, cavitation, mechanical damage	IEC 2–37 [18]

2. Medical Imaging Safety Guidelines

In vitro results from freshly excised tissue [9, 10] have encouraged development towards human *in vivo* medical imaging using coherent terahertz radiation. Advocates of terahertz pulsed imaging have been quick to point out that this wavelength band is non-ionizing, which gives it an advantage over nuclear medicine and x-ray based techniques. However, hazards in medical imaging can arise from numerous mechanisms other than ionization. The widely used modalities of ultrasound and magnetic resonance imaging, which do not involve ionizing radiation, are also subject to exposure limits to protect individuals. These are summarized in Table I.

It is important to recognise that the limits mentioned in Table I are for diagnostic technologies that have well-established roles in a number of areas. In such cases it is possible to determine the size of the risk to the individual if the investigation were not performed, and balance this against any risk from the diagnostic technique. In early work with terahertz radiation, researchers must be aware that there is no possibility of benefit to patient or volunteer from a purely research technique thus exclusion clauses for medical applications are inapplicable, and conservative limits must be applied.

3. Application of International Guidelines to Terahertz Pulsed Imaging

The international guidelines for exposure to electromagnetic radiation in the terahertz band appear in two documents [1, 2]. In each case the limits for the terahertz band were drawn from US standards [11, 12], for the bands 2.6 μm to 1 mm (0.3

to 115 THz) and 1 mm to 20 mm (0.015 THz to 0.3 THz). The most recent editions of these standards are [5, 6].

A hazard analysis has been performed for a typical terahertz pulsed imaging system that uses optical rectification or a photoconductive antenna to generate the terahertz pulses. The analysis [13], followed the methods recommended by Thomas et al. [14] for optical wavelengths 2.6 μm to 1 mm, with the limits selected from the standards [5, 6] for the full range of wavelengths 2.6 μm to 20 mm, so that the most conservative were applied. The reason for applying the hazard analysis methods used for optical wavelengths rather than those for electromagnetic fields was because the document [5] covering wavelengths 1 to 20 mm states that exposures above 6 GHz (wavelengths below 50 mm) are quasi-optical, so an optical analysis was believed to be most appropriate across the full range of wavelengths considered.

This analysis showed that the maximum permissible exposure, for an area of skin under 0.01 m^2 for up to eight hours, was 4.69×10^{-11} J. For a focused beam under 3.5 mm in diameter this translated to a limiting average beam power of 3.85 mW. In a particular terahertz pulsed imaging system the average power, measured for a stream of pulses using a Golay cell was of the order of 3 nW, showing the system to comply with the guidelines.

4. Discussion

However there remain some gaps in knowledge that should be investigated before terahertz pulsed imaging moves from being a research tool to more general human applications. The published guidelines are based solely on damage thresholds established for heating effects, and in a spectral region and for exposure durations differing from those used in terahertz pulsed imaging [15]. Investigation of damage mechanisms other than heating were reported in other sessions at the conference, but knowledge is limited at present, and there are no data on long term effects of exposure to the radiation. The guidelines were set using damage threshold data acquired using wavelengths under 10.6 μm and pulse durations over 1.4 ns. It is thought [1] that additional thermomechanical damage may occur for pulses of under 1 μs duration, and those used in terahertz pulsed imaging are of picosecond duration.

Overall the message from this session was one of cautious encouragement for the development of *in vivo* terahertz pulsed imaging. There is clearly a need for further basic research to be performed on the effects of the radiation, and scientists and engineers must be aware of the possibility of the development of a distorted perception of the risks involved.

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