Bioeffects Research for Emerging RF Technologies

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Introduction: New technologies employing radio frequency (RF) emissions are constantly emerging. Some of them employ frequencies and pulse characteristics that have not been well studied for their effects on biological material. Bioeffects research is required to determine the hazard thresholds and interaction mechanisms of such emissions and address the appropriateness of current health and safety standards. Additional data may indicate that current standards are lax and permissible exposure limits (PEL) need to be reduced; or they may indicated that current standards are unnecessarily restrictive and the PEL can be safely raised. This paper concerns recent bioeffects research on two types of emissions: (a) High Peak-Power Low Average-Power Pulses, including Ultrawideband Pulses (UWB) (1); and (b) millimeter Waves (MMW). This paper will focus primarily on the research studies conducted by the U.S. Air Force, Army, and Navy at the Tri-Service Directed Energy Bioeffects Complex at Brooks AFB, Texas, United States.

High Peak-Power, Low Average-Power Pulses: Occupational exposure standards in the United States and Europe limit exposure to such pulses based on Specific Absorption Rate (SAR), peak electric field (e.g., IEEE C95.1-1999 limits peak E-field to 100 kV/m), or to Specific Absorption (SA) (e.g., ICNIRP-1998 limits the SA of such pulses to 10mJ per kg). The bioeffects of such pulses have been considered in two recent reviews (2,3). Research at Brooks AFB on this topic has addressed a wide range of pulse parameters, including ultrawideband exposures up to 250 kV/m and narrowband exposures up to 1500 kV/m. The studies have been conducted on whole animals (monkeys, rats, mice) in free field conditions and on isolated cells, tissues, and other in vitro preparations.

Results: Exposures of 950 kV/m pulses to the frog heart (4) and of 1500kV/m to the rat hippocampal slice (5) revealed no special effects of pulses; observed effects were due to SAR heating. In one study, no acute effects of UWB pulses of 250 kV/m were found in monkeys or rats on several measured parameters (6-7). Several studies on the acute cardiovascular effects of UWB pulses found no effect during exposures up to 100 kV/m (8-9). However, other studies have reported a delayed decrease in blood pressure in rats following 6 minutes exposure to such pulses (10). Three significant and apparently unrelated effects, out of dozens of measures taken, have been found in the offspring of female rats exposed to UWB pulses during pregnancy (11). No effects were seen on cancer promotion, life expectancy, or morbidity in mice receiving multiple exposures to UWB pulses (12), on genetic factors in yeast (13-14), or on the induction of micronuclei in mice (15). Drug-induced convulsions in rats were not affected by UWB exposure (16).

Conclusion: Data on the biological effects of high peak power, low average power pulses are sparse due to limited exposure equipment and the still rare opportunity for human exposure. None of the data to date indicate an acute hazard to a few pulses or short pulse bursts of UWB or other high peak power pulses in the absence of heating.

However, some delayed effects have been observed after thousands of pulses presented for a longer time period (e.g., 6 minutes). Research is continuing.

Millimeter Waves: The biological effects of low-intensity millimeter waves (MMW), 30-300 GHz, have been studied for decades, especially in the countries of the Former Soviet Union, where MMW are utilized extensively as a therapeutic modality (17-19). MMW have been considered for military applications (radar & communications) since the early 1980's (20-21) and are currently being developed for civilian applications in communications and traffic radar. Recent reports indicate that the U. S. Military is considering the use of 95 GHz MMW in a unique, non-lethal force protection application. In this concept, the energy would be beamed onto humans at a distance in a controlled manner, so as to raise the skin temperature to a level that is painful but not damaging (22). Because of the increased use of MMW and the consequent increased potential for human exposure, it has become more important to investigate the biological effects of higher intensity MMW. Because MMW are absorbed superficially on the exposed body surfaces, research has focused on the skin and the cornea (23).

Effects on the Skin: In 1997, Blick et al., (24) reported that the human threshold for the detection of 94 GHz MMW is 4.5 mW/cm^2, based on a 10 s exposure. Later modeling (25) suggested that this detection threshold was based on a less than 0.1 °C temperature rise, assuming a baseline temperature of 34 °C. In 2000, Walters et al. (26) reported that the human threshold for pain perception to 94 GHz MMW is 1250 mW/cm^2, corresponding to a temperature rise of about 9.9 °C. Although damage thresholds have not been reported for MMW, other literature (see 23, 26) suggests that thermal damage occurs after a temperature rise of about 34 °C.

Ocular Effects: Beuerman & Tanelian (27) indicate that human corneal sensitivity to thermal pain occurs at about 38-39 °C, using a water bath technique. Using 94 GHz, D'Andrea et al. (unpublished) have found that, for short exposures, the threshold for ocular avoidance responses in moneys occur at an estimated corneal fluence of less than 0.3 J/cm^2 and the threshold for damage is about 5 J/cm^2 (28). Kues et al. (29), have reported that "repeated exposure to 60 GHz CW radiation at 10 mW/cm does not result in any detectable ocular damage."

The Question of Cancer: A recently completed study (30) tested the cancer promotion and co-promotion potential of 94 GHz MMW under acute (10 s exposure, 1000 mW/cm^2) or repeated (10 s exposure twice weekly for 12 weeks, 333 mW/cm^2) conditions. A SENCAR mouse model of skin cancer was used and DMBA was used as a cancer initiator and TPA as a co-promoter. There were no effects of the MMW exposure.

Conclusion**:** High intensity MMWs act on human skin and cornea in an orderly, dose-dependent manner; detection occurs at very low power densities, followed by pain at higher exposures, followed by physical damage at even higher levels. Because the effective stimulus is joule heating, exposure duration is a critical factor.

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