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would rarely be encountered by members of the public. Therefore, this phenomenon should be of little concern to the general population. Furthermore, there is no evidence that it could be caused by telecommunications applications such as wireless or broadcast transmissions.

At relatively low levels of exposure to RF radiation, i.e., field intensities lower than those that would produce significant and measurable heating, the evidence for production of harmful biological effects is ambiguous and unproven. Such effects have sometimes been referred to as "non-thermal" effects. Several years ago publications began appearing in the scientific literature, largely overseas, reporting the observation of a wide range of low-level biological effects. However, in many of these cases further experimental research was unable to reproduce these effects. Furthermore, there has been no determination that such effects might indicate a human health hazard, particularly with regard to long-term exposure.

More recently, other scientific laboratories in North America, Europe and elsewhere have reported certain biological effects after exposure of animals ("*in vivo*") and animal tissue ("*in vitro*") to relatively low levels of RF radiation. These reported effects have included certain changes in the immune system, neurological effects, behavioral effects, evidence for a link between microwave exposure and the action of certain drugs and compounds, a "calcium efflux" effect in brain tissue (exposed under very specific conditions), and effects on DNA.

Some studies have also examined the possibility of a link between RF and microwave exposure and cancer. Results to date have been inconclusive. While some experimental data have suggested a possible link between exposure and tumor formation in animals exposed under certain specific conditions, the results have not been independently replicated. In fact, other studies have failed to find evidence for a causal link to cancer or any related condition. Further research is underway in several laboratories to help resolve this question.

In general, while the possibility of "non-thermal" biological effects may exist, whether or not such effects might indicate a human health hazard is not presently known. Further research is needed to determine the generality of such effects and their possible relevance, if any, to human health. In the meantime, standards-setting organizations and government agencies continue to monitor the latest experimental findings to confirm their validity and determine whether alterations in safety limits are needed in order to protect human health.

WHAT RESEARCH IS BEING DONE ON RF BIOLOGICAL EFFECTS?

For many years research into possible biological effects of RF energy has been carried out in government, academic and industrial laboratories all over the world, and such research is continuing. Past research has resulted in a very large number of scientific publications on this topic, some of which are listed in the reference section of this document. For many years the U.S. Government has sponsored research into the biological effects of RF energy. The majority of this work has been funded by the Department of Defense, due, in part, to the

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was more prevalent in the exposed group than in stock rats of the same strain maintained under similar specific-pathogen-free conditions. Taken as a whole, the results of this study cannot be interpreted as indicating a tumor-initiating effect of microwave fields.

Several studies have examined the effects of microwave exposure on the development of pre-initiated tumor cells. Szmigielski et al. (1982) noted an enhanced growth rate of transplanted lung sarcoma cells in rats exposed to microwaves at high power densities. It is possible that this resulted from a weakening of the host immune defense in response to thermal stress from the microwave exposure. Recent studies using athermal levels of microwave irradiation have found no effects on the development of melanoma in mice or of brain glioma in rats (Santini et al. 1988; Salford et al. 1993).

Repacholi et al. (1997) have reported that exposure of 100 female, *Eμ-pim1* transgenic mice to 900-MHz fields, pulsed at 217 Hz with pulse widths of 0.6 μs for up to 18 mo, produced a doubling in lymphoma incidence compared with 101 controls. Because the mice were free to roam in their cages, the variation in SAR was wide (0.01–4.2 W kg^{-1}). Given that the resting metabolic rate of these mice is 7–15 W kg^{-1}, only the upper end of the exposure range may have produced some slight heating. Thus, it appears that this study suggests a non-thermal mechanism may be acting, which needs to be investigated further. However, before any assumptions can be made about health risk, a number of questions need to be addressed. The study needs to be replicated, restraining the animals to decrease the SAR exposure variation and to determine whether there is a dose response. Further study is needed to determine whether the results can be found in other animal models in order to be able to generalize the results to humans. It is also essential to assess whether results found in transgenic animals are applicable to humans.

Special considerations for pulsed and amplitude-modulated waveforms

Compared with continuous-wave (CW) radiation, pulsed microwave fields with the same average rate of energy deposition in tissues are generally more effective in producing a biological response, especially when there is a well-defined threshold that must be exceeded to elicit the effect (ICNIRP 1996). The "microwave hearing" effect is a well known example of this (Frey 1961; Frey and Messenger 1973; Lin 1978): people with normal hearing can perceive pulse-modulated fields with frequencies between about 200 MHz and 6.5 GHz. The auditory sensation has been variously described as a buzzing, clicking, or popping sound, depending on the modulation characteristics of the field. The microwave hearing effects have been attributed to a thermoelastic interaction in the auditory cortex of the brain, with a threshold for perception of about 100–400 mJ m^{-2} for pulses of duration less than 30 μs at 2.45 GHz (corresponding to an SA of 4–16 mJ kg^{-1}). Repeated or prolonged exposure to microwave auditory effects may be stressful and potentially harmful.

Some reports suggest that retina, iris, and corneal endothelium of the primate eye are sensitive to low levels of pulsed microwave radiation (Kues et al. 1985; UNEP/WHO/IRPA 1993). Degenerative changes in light-sensitive cells of the retina were reported for absorbed energy levels as low as 26 mJ kg^{-1}. After administration of timolol maleate, which is used in the treatment of glaucoma, the threshold for retinal damage by pulsed fields dropped to 2.6 mJ kg^{-1}. However, an attempt in an independent laboratory to partially replicate these findings for CW fields (i.e., not pulsed) was unsuccessful (Kamimura et al. 1994), and it is therefore impossible at present to assess the potential health implications of the initial findings of Kues et al. (1985).

Exposure to intense pulsed microwave fields has been reported to suppress the startle response in conscious mice and to evoke body movements (NRPB 1991; Sienkiewicz et al. 1993; UNEP/WHO/IRPA 1993). The threshold specific energy absorption level at midbrain that evoked body movements was 200 J kg^{-1} for 10 μs pulses. The mechanism for these effects of pulsed microwaves remains to be determined but is believed to be related to the microwave hearing phenomenon. The auditory thresholds for rodents are about an order of magnitude lower than for humans, that is 1–2 mJ kg^{-1} for pulses <30 μs in duration. Pulses of this magnitude have also been reported to affect neurotransmitter metabolism and the concentration of the neural receptors involved in stress and anxiety responses in different regions of the rat brain.

The issue of athermal interactions of high-frequency EMF has centered largely on reports of biological effects of amplitude modulated (AM) fields under *in-vitro* conditions at SAR values well below those that produce measurable tissue heating. Initial studies in two independent laboratories led to reports that VHF fields with amplitude modulation at extremely low frequencies (6–20 Hz) produced a small, but statistically significant, release of Ca^{++} from the surfaces of chick brain cells (Bawin et al. 1975; Blackman et al. 1979). A subsequent attempt to replicate these findings, using the same type of AM field, was unsuccessful (Albert et al. 1987). A number of other studies of the effects of AM fields on Ca^{++} homeostasis have produced both positive and negative results. For example, effects of AM fields on Ca^{++} binding to cell surfaces have been observed with neuroblastoma cells, pancreatic cells, cardiac tissue, and cat brain cells, but not with cultured rat nerve cells, chick skeletal muscle, or rat brain cells (Postow and Swicord 1996).

Amplitude-modulated fields have also been reported to alter brain electrical activity (Bawin et al. 1974), inhibit T-lymphocyte cytotoxic activity (Lyle et al. 1983), decrease the activities of non-cyclic-AMP-dependent kinase in lymphocytes (Byus et al. 1984), and cause a transient increase in the cytoplasmic activity of ornithine decarboxylase, an essential enzyme for cell proliferation (Byus et al. 1988; Litovitz et al. 1992). In contrast, no effects have been observed on a wide variety