Letters

Comments on "Electric Current and Electric Field Induced in the Human Body When Exposed to an Incident Electric Field Near the Resonant Frequency" and "Electric Fields Induced in Cells in the Bodies of Amateur Radio Operators by Their Transmitting Antennas"

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King, using a cylindrical model of the human body, has performed a relatively accurate analysis of the electromagnetic fields within the adult human body due to incident radio frequency energy at 60 MHz in the above papers.[1] [2] The development of this model is well reasoned and produces results that are believable, though limited in accuracy and precision by the choice of method. However, the conclusions about biological effects due to this analysis are unsupported and flawed. King is perhaps unaware of the extensive work that has been done in this collateral field over the last two decades. His choice of five references from a field of over 1000 independent studies misrepresents the consensus of the scientific community with regard to the potential for RF energy to cause disease. Thus, the message imparted by the above papers can easily be misinterpreted to imply that an imminent danger exists, where one does not.

King relies on five papers to conclude that the absorbed energy in his calculations is synonymous with a potential for biological damage. The first is an epidemiological study of radio amateurs by Milham [1]. Milham has performed an epidemiological study of radio amateurs as a preliminary study to look for a suggestion of an association that would warrant further study. It is not possible to conclude that a statistical relationship exists between disease and a group based solely on the fact that the cohort held licenses from the Federal Communications Commission (FCC), Washington, DC. Failure to consider the occupations of the subjects, their extent of radio usage, their economic classes, their medical histories, their other exposures, and many other variables that can affect initiation of disease renders these results inconclusive. Such incomplete studies are commonly performed in the field of epidemiology with minimal resources to look for exposures that would benefit from the greater expenditure of time and money that a more complete study entails. The fact that a detailed follow-up study was not undertaken suggests that the results of the preliminary study were not convincing to the epidemiological community.

The study by Szmigielski *et al.* [2] used two types of mice, one strain bred to have a genetic predilection to breast cancer, and another treated with a known carcinogenic chemical in addition to RF exposure. Although they found an increase in tumor incidence when the mice were exposed to microwave energy at relatively high levels of absorption, a similar increase was seen in nonirradiated animals that were placed under chronic confinement stress conditions. The conclusion of this study was that the increase in cancer was due to the stressful experimental conditions and not the microwaves.

Prausnitz and Susskind [3] described studies on normal mice that were exposed to very high levels of RF energy for over a year. The RF absorption was high enough to raise the body temperatures of the mice by over 3 °C, an amount that a human would consider high fever. Even with an overexposure that resulted in burning of the testicles in some of the test animals, the conclusions of that study showed no other ill effects from the RF energy. Rather, the survival rate of the irradiated animals was higher than that of the nonirradiated animals.

Chou *et al.* [4] performed experiments with low-level exposure over the course of one year that showed no deleterious heath effects in rats. (Note that in [11] of the above paper[1], King referenced a different paper, which was published as a nonpeer-reviewed report for the U.S. Air Force. That report was later published together with seven other related reports in a peer-reviewed journal as [4].)

Reference [5] described a study with *in vitro* cells that had been irradiated with ionizing radiation (X-rays) and then exposed to RF energy at a level just above the current safety limit. A resulting increase in conversion of cells to cancerous form was seen. However, that result must be considered suspect due to the methods involved, particularly with the combination of ionizing radiation and nonionizing RF energy and the fact that the RF levels used potentially created some localized heating in the cell culture.

The mechanisms for cancer formation when there is an insult to tissue are well developed. Whether due to ionization of DNA from X-rays, repeated physical injury to the same area of tissue, or cell damage due to excessive heating, cancer can occur because of random mutations during the tissue repair process. Particularly in older studies, without accurate RF dosimetry, overexposure is common. Often, experiments have been performed with a given incident RF field that does not take into account resonance effects based on subject size, frequency, and polarization. These factors have been dealt with by the IEEE Standards Coordinating Committee 28 in formulating a standard for safe exposure to RF [6]. A uniform measure, i.e., specific absorption rate (SAR), has been adopted to take into account incident power density and the resonance and polarization effects based on frequency and subject size and orientation. Older studies have been reinterpreted with the computational tools that are available today, and an assessment of the amount of absorption that leads to tissue damage has been made. Uncertainties have been dealt with by the general population by incorporating a 50X-safety factor below the level of absorption that has been demonstrated to injure tissue.

After completing the description of his modeling results, King makes the following statement: "These values are significant and provide a quantitative basis for the statistically observed increases in malignancies in amateur radio operators." As previously noted, there is no basis for the second part of this statement. The subjective nature of the first part of the statement does not agree with established standards of significant biological absorption of electromagnetic energy. Reference [6] sets a safe maximum permissible exposure (MPE) limit of SAR at 1.6 W/kg in any 1-g cube of tissue. The product of current density $|J|$ and electrical field strength $|E|$ with units of W/m^3 is converted to SAR in watts per kilogram by approximating the density of tissue to be 1 g/cm^3 and assuming that all of the energy is absorbed. King calculates a peak

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[1]R. W. P. King, *IEEE Trans. Microwave Theory and Tech.*, vol. 48, no. 9, pp. 1537–1543, Sept. 2000.

[2]R. W. P. King, *IEEE Trans. Microwave Theory and Tech.*, vol. 48, no. 11, pp. 2155–2159, Nov. 2000.

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field at the skin of 96 W/m^3, or an SAR of 0.096 W/kg, and his peak in the center of his model is 14 W/m^3, or an SAR of 0.014 W/kg. Thus, the worst-case absorption in King's analysis is 17 times lower than the MPE.

Three other factors further decrease the actual SAR levels that would be likely to affect amateur radio operators. The calculations do not take into account the duty cycle of typical amateur radio operation that would further divide these values by at least four times. The typical modulation methods on the 6-m band, i.e., continuous wave (CW) and single sideband (SSB), produce average power levels that are maximally 50% lower than peak power. Amateur operators tend to listen at least as much as they transmit, and this further reduces the SAR by at least 50%. Thus, it is reasonable to estimate SAR for typical amateur radio operation based on 25% of the peak-transmitted power. King's calculations are also based on possible, but very unusual power levels. He models the transmitter power as 1 kW at the antenna. Not only is it relatively rare for a radio amateur to transmit the full legal limit of power on the 6-m band, typical feed-line losses would make that amount of power at the antenna feed point a highly unlikely occurrence. Yet, even without taking these practical exposure reductions into account, the results of King's analysis are very far below the exposures that are considered to be harmful.

Refinement of the model yields detail that further decreases the likelihood of overexposure. When SAR for a real human model is calculated for 60 MHz with the finite-difference time-domain (FDTD) method, taking into account actual human geometry and magnetic field coupling, it is found that more of the power deposition occurs at the knees and ankles than in the sensitive tissues in the body core [7]. Even though the overall SAR agrees with King's calculations, the distribution of the electromagnetic absorption is concentrated in less sensitive tissues. Reference [6] deals with the difference in sensitivity for different types of tissue by designating two different classes. The sensitive organs in the core of the body have an MPE limit of localized SAR described above, i.e., 1.6 W/kg in any 1-g cube of tissue. With the FDTD method, the maximum SAR calculated for these tissues is 0.07 W/kg, which is 23 times less than the MPE. The more robust tissues of the extremities have an MPE limit of 4 W/kg in any 10-g cube of tissue. With the FDTD method, the highest SAR calculated for the tissues in the extremities is 0.09 W/kg, which is 44 times less than the MPE.

In the above paper[2], King refers to a document by the FCC [8] that "establishes general guidelines and information concerning recommended limits of exposure at all frequencies." In fact, this document is the first "Report and Order" of the FCC to amend their rules to require exposure limits for all services that they regulate. After being modified by five other memoranda and orders and errata [9]–[13], FCC "Rules and Regulations" [14] were updated and the changes went into effect on January 1, 1998. The current and most comprehensive set of documents from the FCC that describes the exposure limits was published by their Office of Engineering and Technology [15]–[18]. The existence of these changes to the regulations further refutes King's hypothesis. The regulations governing the Amateur Radio Service require that every operator be aware of his or her safe exposure limits and further require that amateur operations be modified to ensure that safe limits are not exceeded. The FCC obtained the values for safe exposure limits mainly from [6]. A review of the documents from the FCC indicates that safety limits have been carefully considered and the regulatory exposure limits represent the best consensus of the scientific community for maintaining the health and safety of humans who are exposed to electromagnetic fields. Thus, King has modeled an improbable situation since his results indicate that amateur radio operators are exposed to electric fields that exceed these limits. There is no way that conditions in this model can occur for an amateur radio operator who is operating legally.

The model employed by King yields a reasonably accurate general estimate of electromagnetic energy absorption in the human. Coupling realistic operating and exposure conditions with the results of the model decreases exposure levels by an order of magnitude. Even without these considerations, the absorption levels that the model estimates are far below the safety limits that have been set in a safety standard developed by hundreds of experts who have considered over 1000 research studies in the field of biological effects of electromagnetic energy. There is absolutely no basis for the conclusion that amateur radio operators are at any health risk under these conditions.

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