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BIOLOGICAL INTERACTIONS AND HUMAN HEALTH EFFECTS OF STATIC MAGNETIC FIELDS

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Mechanisms through which static magnetic fields interact with living systems will be described and illustrated by selected experimental observations. These mechanisms include electrodynamic interactions with moving ionic charges (blood flow and nerve impulse conduction), magnetomechanical interactions (orientation and translation of molecular structures and magnetic particles), and interactions with electronic spin states in charge transfer reactions (photo-induced electron transfer in photosynthesis).

A general summary will also be presented of the biological effects of static magnetic fields studied in the laboratory and in natural settings. There is convincing evidence for magnetoreception mechanisms in several classes of lower organisms. The elasmobranch fish, which include sharks, skates and rays, possess ampullary canals in the head region that are filled with an electrically conductive jelly. The strength and polarity of the weak voltages that are induced in these ampullary canals as the animal swims through the geomagnetic field provide sensory information on the compass direction along which the fish is headed. Several species of animals, including bees, avians, and various types of fish, have been shown to possess localized deposits of magnetite (Fe_3O_4) that are believed to be magnetoreceptors for fields as weak as the geomagnetic field. The existence of single-domain crystals of magnetite in a living cell was first demonstrated in the 1970s for iron-rich bacteria, which were appropriately named "magnetotactic bacteria" because of the effect of the geomagnetic field on their direction of movement. Recent studies have shown that magnetite crystals are present in human brain tissue. Humans, however, do not appear to possess a magnetoreception mechanism, and the possible biological role of magnetite in the brain is not understood at this time.

Based on laboratory studies with several species of mammals and on controlled human experiments, there is no evidence that the interactions of static magnetic fields with flux densities up to 2 Tesla (20,000 gauss) produce either behavioral or physiological abnormalities. Although significant electrical potentials are induced in the central circulatory system of animals exposed to strong static magnetic fields, there is no indication from extensive laboratory studies with rodents, dogs, and subhuman primates that these electrical stimuli produce alterations in cardiovascular functions. Similarly, the available experimental evidence indicates that magnetic fields with flux densities up to 2 Tesla do not perturb visual and nervous system functions, the hematologic and immunologic systems, reproduction and development, or physiological regulatory mechanisms. These conclusions are supported by the results of several epidemiological surveys on the health profiles of human populations exposed occupationally to static magnetic fields.

One aspect of magnetic field effects that merits special concern is their influence on implanted medical electronic devices such as cardiac pacemakers. Several extensive studies have demonstrated closure of the reed switch in pacemakers exposed to relatively weak static magnetic fields, thereby causing them to revert to an asynchronous mode of operation that is potentially hazardous because of competition with the heart's intrinsic pacing rate. A small percentage of the commercially available pacemaker models exhibit reed switch closure at field levels as low as 0.5 mT.

Several guidelines have been proposed to limit occupational and public exposure to static magnetic fields. Based on limiting the magnetically-induced voltage in the human aorta and other major blood vessels to less than 1 mV, the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended that whole-body exposure of workers should be limited to a time-weighted-average value of 60 mT. This limit is relaxed to 600 mT for the body extremities. A ceiling value of 2 T is recommended for brief whole-body exposures. ACGIH also recommends that persons wearing cardiac pacemakers or other medical implants should be excluded from fields exceeding 0.5 mT.

A limit of 200 mT for the time-weighted-average daily exposure of workers has recently been recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) of the International Radiation Protection Association. This limit is based on the maximum induced current density of 10 to 100 mA/m^2 induced in body tissues as a result of low-frequency movements within a static magnetic field of this magnitude. The ceiling value of 2 T recommended by ACGIH has also been adopted by ICNIRP for acute whole-body exposures of workers, and this value is raised to 5 T for acute exposures of the arms and legs. ICNIRP also recommends that workers with cardiac pacemakers or other electrically-activated medical devices should not enter fields greater than 0.5 mT. For the general public, a whole-body continuous exposure limit of 40 mT is recommended. This limit introduces a safety factor of 5 relative to occupational exposures, and is consistent with the difference in the maximum possible exposure duration in a public versus an occupational setting when averaged over a one-week interval.