Biological Effects of Radio- and Low-Frequency Electromagnetic Radiation

PRELIMINARY DRAFT
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by

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FOREWORD

The Bureau of Radiological Health conducts a national program to limit man's exposure to ungainful ionizing and nonionizing radiations. To this end, the Bureau (1) develops criteria and recommends standards for safe limits of radiation exposure, (2) develops methods and techniques for controlling radiation exposures, (3) plans and conducts research to determine health effects of radiation exposure, (4) provides technical assistance to agencies having radiological health programs, and (5) conducts an electronic product radiation control program to protect the public health and safety.

The Bureau publishes its findings monthly in Radiological Health Data and Reports, and in the Environmental Health Series, Public Health Service numbered publications, appropriate scientific journals, and from time to time in Division-sponsored technical reports.

The technical reports published by the Division of Biological Effects contain information generated by the Division staff which is timely and useful to the radiological health program. Subjects covered by these reports are varied, for the Division is charged with developing--through animal investigations and population studies--knowledge of the biological effects of radiation delivered to man from his environment and from his use of substances and devices that emit radiation. The reports are distributed to persons and repositories that have expressed an interest in the biological effects of radiation; in addition, the reports are available from the Clearinghouse for Federal Scientific and Technical Information.

Readers are encouraged to report omissions or errors to the Bureau. Additional comments or requests for further information are also solicited.

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PREFACE

This paper is one of several developed by the Division of Biological Effects to summarize the existing literature concerning the effects of various electromagnetic irradiations on biological specimens. Until enactment of the Radiation Control for Health and Safety Act of 1968 (Public Law 90-602) the Division was concerned primarily with the biological effects resulting from exposure to particulate radiation and electromagnetic radiation in the X- and gamma-ray regions of the spectrum which are of sufficiently high energy to cause ionization in tissues.

The Division has responded to the Act, in part, by developing a series of papers summarizing what is known of the biological effects of non-ionizing radiations. The proposed series will include the biological effects of microwaves, lasers, ultraviolet, visible and infrared, radiofrequency and very low frequency, magnetic fields, ultrasonic, and sonic and infrasonic radiations. The papers presently available are listed on the back of the front cover. The others are in various stages of publication.

These staff papers will provide some of the basic information required to establish programs aimed at evaluating and controlling potential health hazards associated with electromagnetic radiations, magnetic fields, and sonic vibrations.

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BIOLOGICAL EFFECTS OF RADIO- AND LOW-FREQUENCY ELECTROMAGNETIC RADIATION

The electromagnetic spectrum includes radiation over a continuous range of energies. It is arbitrarily divided into a number of categories that differ only in frequency or wavelength. The portion of the spectrum that will be reviewed here will be that part which falls below 30 MHz. Up to date the radio frequency (RF) range receiving the most intensive attention with respect to biological hazards has been almost exclusively confined to 100 to 3000 MHz. Within this high frequency range, thermal effects appear to predominate in biological effects, although non-thermal effects may also be induced. These very high oscillation frequencies cause resonant heating of some organs, primarily affected are the eyes and testes. Below 30 MHz, however, no resonant heating occurs and the RF energy completely penetrates the body, exposing all organs (11).

Artificially produced electromagnetic waves may be either continuous (communication systems) or pulsed (industrial and medical equipment). Pulsed waves are of special interest in studying nonthermal biological effects (changes not associated with generalized heating of the system) inasmuch as any heat developed has a greater possibility of dissipation than under continuous wave (CW) irradiation (14, 25). It is possible to separate the pulses with respect to time, allowing the temperature of the biological target to remain below the level at which heating effects occur.

An area of investigation which is related to and often spoken of in the same context as electromagnetic waves and electromagnetic fields is high-frequency electric current. Its ability to heat tissue simulates the effect of electromagnetic waves. Consequently high frequency alternating currents have their medical application in diathermy (deep tissue heating), and have been erroneously given the name of "ultra-short wave" therapy (U.S.W.).

Unlike microwave (M.W.) therapy also used in medical diathermy, "ultra-short wave" therapy has nothing to do with short waves, but utilizes ultra-high frequency electrical currents. The commonly used and approved frequency is 27 MHz (20). One of the two techniques employed is called the condenser field technique in which the target (patient) is a part of the total circuit which conducts the electrical current from the current generator through a capacitor. The second or the inductive field technique involves an alternating current passing through a coil. The subsequent alternating magnetic field in turn causes electrical currents (20) in the conducting body tissues. The extent of the heating of biological material in high frequency condenser fields is related both to the dielectric constant and to the conductivity of the material. The conductivity at which the maximum effect occurs is proportional to the frequency for a given concentration of the electrolyte. This heating of electrolytes in high-frequency fields has an important bearing upon the extent to which biological specimens are heated when placed in such fields (19, 12). Biological effects of high-frequency alternating currents have been observed for bacteria and viruses (14), which were totally inactivated when an alternating current was passed through the liquid medium below the temperature at which heating effects may occur.

Although some investigators still question the interpretation of so-called non-thermal effects, numerous claims strongly supporting non-thermal interactions between electric and magnetic fields exist in the literature at low frequency.

One of the most significant and consistent athermal effects is "pearl-chain" formation which is observed within a frequency range of 1-100 MHz. Pearl-chain formation refers to the tendency of microscopic particles to rearrange under the influence of electrical fields, to form chains of particles in the field direction. Particles suspended in a liquid of a different dielectric constant, become electrically polarized when they are subjected to a high frequency alternating field. Electrical charges appear on the boundaries of the particle which in essence create an electrical dipole, aligning itself with the electrical field. Particles in close proximity will tend to attract each other forming the characteristic pearl-chains (9, 20, 22) (see figure 1).

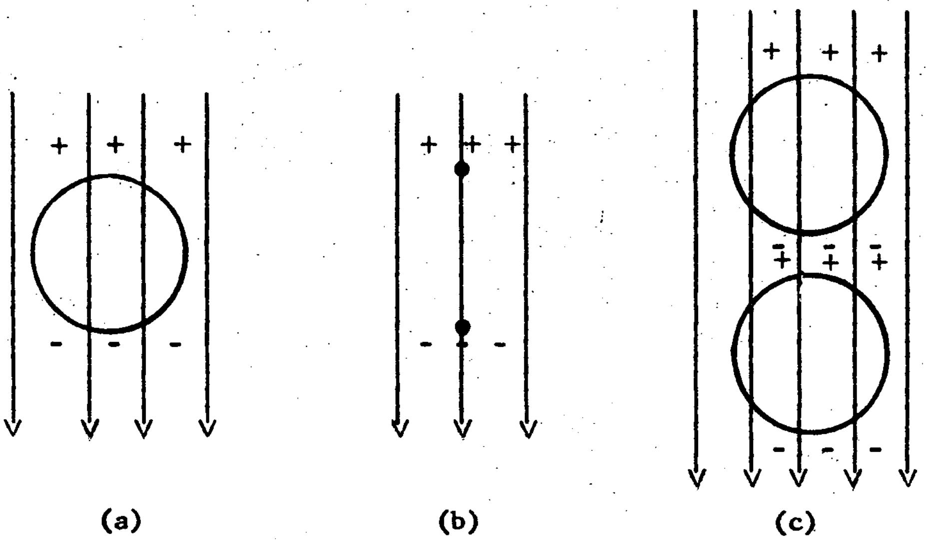

Fig. 1. (a) Induced charges on boundary of particle
(b) Equivalent dipole
(c) Attraction of particles to form "pearl-chain".

The ability of the particle to rotate its dipole in the field direction is more restricted the higher the frequency (21).

Takashima (25) in exposing alcohol dehydrogenase and DNA to very low and radio-frequency fields found no observable structural changes (as determined by changes in enzyme activity and hypochromicity and viscosity, respectively) even though absorption of electromagnetic energy was observable through measurement of dielectric loss. Maximum absorption was shown to exist around the frequency of 1 MHz for alcohol dehydrogenase and in the kHz region for DNA. Nonthermal chemical changes in macromolecules were reported by Bach (1) who observed that irradiation at 13 MHz produced a component in gamma globulin that has a different electrophoretic mobility as well as different immunochemical properties from unirradiated gamma-globulin. Bach and his co-workers also found a decrease of enzymatic activity of α-amylase even after relatively short exposures to a low-intensity radio wave. Even more startling are the observations of Heller (7) who reports chromosomal aberrations - linear shortening of chromosomes, pseudochiasma, amitotic division, bridging, irregularities in the chromosomal envelope - in garlic root tips growing in water. The root tips had been placed between two insulated electrodes for five minutes with a pulsed frequency of 27 MHz with no observable change in water temperature.

Possibly related to "pearl-chain" formation of particles is the strange behavior of unicellular and microorganisms when exposed to radio-frequency fields. Non-motile organisms align parallel to the lines of force at frequencies in the lower megahertz range, and some of them lie at right angles to the lines of force at higher frequencies. Similarly, motile microorganisms travel only parallel to the field at lower frequency (8.5 MHz) and at right angles to the lines of force at higher frequencies (26). Snails and planaria, too, seem to have the ability to detect the presence and direction of a relatively weak electromagnetic field (2, 3).

Much of the literature on biological effects of radio-frequency and low-frequency waves has come out of Russia, primarily dealing with functional changes in the nervous and cardiovascular systems. Some of the documented effects which have been categorized as nonthermal must be viewed with some criticism and suspicion (13, 24). Gordon (6) observed an alteration in conditioned-reflex activity of the brain of animals (rabbits), evidenced by an increased amplitude of biopotentials. Sazonova (17) showed that a high field intensity (238 W/m^2 to 2,655 W/m^2) at a frequency as low as 50 Hz produced deleterious effects on motor functions. In a subsequent study Sazonova (18), using stimulatory and inhibitory neurotropic drugs, explicitly demonstrated an electromagnetic field (EMF) effect on the central nervous system relative to its participation in motor functions. Human subjects studied by Plekhanov (16) when exposed to 735 kHz EMF exhibited a conditioned reflex to cold.

In studying subjects working in the environment of an electromagnetic field of radio and low frequency (0.5 kHz to 30 MHz), along with the more common symptoms of headaches, insomnia, irritability, and fatigue, Russian observers have found: changes in the EEG, glycemic curve, increase in gamma globulin (23), deviations of the brain nerves, pyramidal symptoms (10), slight enlargement of the thyroid gland, increases in leukocyte count, and slight shifts in the protein composition of the blood (5).

The biological effects of electromagnetic radiation described above have been termed nonthermal since no appreciable change in temperature of the system could be detected. However, the separation of thermal and nonthermal effects in biological systems might very well rest in our inability to detect highly localized or microthermal centers (15).

Before discussing specific thermal effects of electromagnetic radiation it might serve well to review some general physiologic effects of heat. "Severe high body temperatures may cause denaturation of protein, irreversible coagulation of protein, increased permeability of cell membranes, liberation of toxins, and decrease in enzyme activity as well as many other changes. Chemical reactions in the body, just as in the test tube, are speeded up by temperature increases. The rate of chemical reactions may be doubled by a rise of 10°C. The neuron (the basic functional unit in the nervous system) is seriously impaired at high temperatures. At a temperature of about 41°C (normal temperature is 37°C) the central nervous system cannot function normally. Conditions such as prostration, coma, and even death may occur (8)".

The effectiveness of an EMF in producing tissue temperature elevation will depend upon the rate at which energy is absorbed (i.e. dependent on the frequency of radiation, intensity of the beam, and conductivity and dielectric constant of tissue), the thermal conductivity of the tissue, the thermal capacity of the tissues absorbing the energy, and the efficiency of the circulating blood in dissipating the heat generated.

A study of two groups of mice irradiated with an EMF operating at 27.2 MHz at room temperature (26°C) and in the cold (3°C) respectively demonstrated that the same field strength of electromagnetic waves which killed the mice at room temperature had little effect on the mice in the cold environment. As might be expected, mice irradiated in the cold environment seemed perfectly content. In contrast mice not irradiated exhibited a behavior of misery, shivering, failing respiration, and indifference to other physical stimuli (4).

One of the most recent and exhaustive studies concerning the biological effects of high-frequency (3-30 MHz) radiation is the work of Kall et al. (11). Rats were exposed to frequencies of 6, 14, and 21 MHz at three levels of radiation exposure (arbitrarily termed low, medium, and high) measured in watt-seconds per gram. Biological effects were classified at two levels: physiological and pathological. The physiological parameters that were studied consisted of water consumption, fecal count, weight change, and intestinal motility. Although there were differences between the various groups and their controls, changes were not consistent and precise. More conclusive were the results of the pathological effects derived from observations during irradiation and post-irradiation analysis of autopsies. The pathological effects were based on studies of the cardiovascular, respiratory, hematopoietic, gastro-intestinal, genitourinary, and endocrine systems. All but the endocrine system showed significant effects of the irradiation over the control.

<u>Summary</u>

There is sufficient evidence in the literature indicating that electromagnetic radiation in the radio-frequency and very low-frequency range is capable of producing thermal effects which are, therefore, absorbed dosage dependent as well as non-thermal effects which are field dependent and not necessarily related to heating. These effects are primarily concerned with pearl-chain formation, changes in the central nervous system and peripheral nervous system.

The current radiation protection guideline in this country for normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100,000 MHz has been set at 10 mW/cm^2 as averaged over any possible 0.1 hour period. More work is needed in the radio and very low frequency range to determine if the value of 10 mW/cm^2 is extendable to frequencies below 10 MHz.

In view of the continuously increasing number of Radar, TV, AM, and FM transmitters and multitude of communication channels in our environment, a coordinated and systematic effort would seem worthwhile to investigate the long-range effects of these artificial electromagnetic radiations on the public. Regional surveillance with respect to frequencies and respective field intensities might serve as guidelines for subsequent thorough investigations of physiological and psychological effects.

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