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BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS ON VERTEBRATES. A REVIEW

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ABSTRACT

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Papers dealing with biological effects of electromagnetic fields are reviewed. The data indicate that certain biological changes are caused by exposure to electromagnetic fields. There is at present, however, no evidence of specific causal mechanisms.

INTRODUCTION

Questions have been raised as to whether animals exposed to ultra-high-voltage transmission lines are affected by the electromagnetic fields emitted from such power lines. This review has been carried out to make a comprehensive assessment of the present situation with regard to possible detrimental effects on animals of electric and magnetic fields.

Around a live wire there is an electric field which gets stronger with an increased voltage. The intensity also depends on the distance from a live or earthed wire. The electric field is known as the E-field and is stated in the unit V/m (1 kVm = 1 000 V/m).

Around a live wire there is a magnetic field increasing in strength with increased current intensity. The field diminishes with the distance from the wire. It is known as the B-field and is stated in the unit Tesla (T) or, formerly, Gauss (G) (10 000 T = 1 G).

Near high voltage installations, e.g. power lines, there are thus electric and magnetic fields oscillating with the frequency. On the ground under a 400 kV transmission line, the strongest B-field might be around 0.6 G and the E-field up to 20 kV/m.

The alternating current has a frequency of 50 Hz in Europe and of 60 Hz in the USA. This literature review covers field studies and experiments where the frequency does not exceed 100 Hz.

If a conductor (man and animal may in this connection be considered as good conductors) comes into an E-field, the original field near the conductor is affected. An amplification factor arises which, at the head of a person stand-

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ing upright, amounts to a factor of about ten times the original E-field.

REVIEW OF LITERATURE

1. Effects on the endocrine glands

Persons exposed to 10-12 kV/m (50 Hz) for 12 hours showed no changes in the cortisol content of the blood immediately after interruption of the field (Beyer et al, 1979).

An examination of line-men did not reveal any differences in the functioning of the thyroid gland (Altmann and Lang, 1974).

Rats exposed to 100 kV/m (50 Hz) have been shown to have increased catecholamine contents in blood and urine (Groza et al, 1978b). After six hours' exposure the adrenalin content was predominant, and after 12 days' exposure noradrenalin prevailed.

In another investigation where exposure of rats to 15 kV/m (60 Hz) for 30 days resulted in depressed levels of serum corticoids (Marino et al, 1977). Repeated experiments resulted in decreased body weight, enlarged hypophysis and adrenal glands and a decreased water absorption. The capacity of the rats to respond to cold stress was, however, unchanged. In another experiment with rats an exposure of 100 kV/m (50 Hz) for six hours or 15 minutes resulted in a great increase of antidiuretic hormones from the hypophysis with an accompanying reduction of urine secretion by 30 % (Carmaciu et al, 1977).

Mice exposed to an E-field of 60 Hz showed an immediate and very short-term increase in serum corticosterone level at 25 kV/m (Bridges, 1978).

2. Effects on the reproductive organs

An investigation of switch-yard worker has shown that they have fewer children and among their children there are a few more cases of malformation compared to a control group. These men also had an increased frequency of chromosomal aberrations (Nordström, 1979). Reduced sexual potency has been reported in male switch-yard workers (Korobkova et al, 1972). Studies of sperm from line-men did not show significant differences from a control population (Kouwenhoven et al, 1967).

Studies of dairy cows exposed to 400 kV-lines for an average of one week per grazing season, and in no case for more than 16 days, did not show reduced fertility in terms of insemination statistics, compared to a control group (Algers et al, 1981). On the other hand , a connection in time has been shown in two herds between severe fertility disturbances during the grazing period and the putting into operation of a 400 kV-line over the pasture to which the animals were exposed for more than 25 days per grazing season (Algers et al, 1981).

The rearing of three generations of mice under constant influence of 10 kV/m, 60 Hz, showed no difference in the pregnancy frequency of the females or the size of the litters. The mortality of the young increased after the first generation. This increased mortality remained but started at an earlier age when the experiment was repeated (Marino et al, 1979).

Male mice exposed 6.5 hours daily to 60 Hz 160 V/m for 10 months were each mated with 20 different females in the course of the experiment. No decrease in the frequency of female reproduction was noted. Male progenies of these animals did not grow to be quite as heavy as progenies of control animals (Marino et al, 1979).

In female rats exposed eight hours per day for three months to 50 kV/m the genital cycle was investigated through vaginal smears. The length of the cycle did not change compared to that of the same rats before exposure. These females were mated during exposure, exposed throughout the whole gestation and an autopsy was performed on them. No significant differences in number of foetuses or number of undeveloped uterine implantations per female rat could be found compared to controls (Le Bars and Andre, 1976).

3. Effects on the nervous system

Investigations of switch-yard workers (Gamberale et al, 1978) and line-men (Kouwenhoven et al, 1967) showed no abnormal EEG. Persons exposed to 20 kV/m, 0.3 mT in an experiment for three hours (Hauf, 1976) showed no changes in EEG. However, EEG-changes have been reported for switch-yard workers (Korobkova et al, 1972). Also, in an experiment, EEG-changes were registered in persons exposed to 10 - 20 kV/m for 12 hours (Beyer et al, 1979).

Persons exposed in an experiment to a 50 Hz alternating field of up to 20 kV/m for two hours showed no deviations in EEG compared to a control group (Hauf, 1974). Other persons, exposed to 6.0 kV/m for three minutes (interrupted by nine minutes with field off) showed alterations in EEG when the field was turned on. The persons did not know when this happened (Richter, 1977).

Rabbits housed in a 400-kV switch-yard until eight weeks of age showed biochemical changes in the sciatic nerve (acetylcholine-esterase content) (Hansson, personal communication 1980).

Isolated frog nerve tissue exposed to electric fields of up to 4 kV/m showed an immediate, pronounced and sustained increase in the amplitude of the action potentials in all of the nerves tested (Lott and Lin, 1975).

An investigation of the state of the central nervous system with the help of psychological performance tests has been used in several studies. An examination of switch-yard workers showed that those exposed within 14 days of the examination (Gamberale et al, 1978) had a lower performance in all tests than non-exposed workers with the exception of simple reaction time. Experimental exposure of persons to 10 to 20 kV/m for 12 hours did not result in a slower reaction time (Beyer et al, 1979). Another experiment with 20 kV/hour, 0.3 mT for three hours gave a significantly faster reaction time (Hauf, 1976). When using electromagnetic fields with lower frequency, 2 to 12 Hz of weak strength, 4 V/m, a slower reaction time resulted (Hamer, 1968).

Large and statistically significant reductions in inter-response time have been shown for skinner-trained monkeys (Macaca nemestrina) exposed to up to 56 V/m (B-field is not indicated) with 7-75 Hz (Gavalas-Medici, 1976). Higher strength gave a 24-hour carry-over effect. A dose-dependet relationship is suggested for 7 Hz fields. In a similar investigation using the same frequency range, but 1-29 V/m and 0.3-1.0 mT, these results could not be confirmed (de Lorge and Grisett, 1977).

Changes in nucleus supraopticus and nucleus paraventricularis have been noted in rats exposed to 100 kV/m for 120 minutes. The changes consisted in a marked decrease of the content of neurosecretory material (Groza et al, 1978a).

The norepinephrine content of brain tissue has been examined in rats exposed to 5.3 kV/m for 21 days (Fisher et al, 1978). After 15 minutes' exposure the content rose rapidly from 0.358 g/g tissue to 0.415 g/g tissue ($p < 0.05$) but sank significantly ($p < 0.01$) below that of a control group to 0.268 g/g tissue after an exposure of 10 days and more.

Cat brain subjected to pulsed electromagnetic fields, 0.2 to 0.6 mV/m, 200 puls/s has been shown to react with increased efflux of Ca^{2+}ions (Adey, 1973).

Important histological changes in the form of an increased number of myelin bodies, multivesicular bodies and lysosomes in Purkinje's cells as well as degeneration changes in single cells have been noted in rabbits (Hansson, personal communication 1980), which indicates moderate functional damage to the central nervous system.

4. Effects on the circulatory system

An examination of the circulatory system did not show any effects of electric or magnetic fields in line-men (Kouwenhoven et al, 1967) or workers (Gamberale et al, 1978). Effects on the circulatory system in switch-yard workers have been reported (Nordström, 1979).

Exposure of mice to 5.3 kV/m showed a decreased pulse frequency after 15 minutes which then slowly increased to the initial value during the 21 days the experiment lasted. Pulsating field, 3.5 kV/m, 10 puls/s, has been shown to lower the hematocrit in mice after 14 days but the effect faded away within 56 days (Lang, 1972).

Guinea-pigs exposed to 100 kV/m for 30 minutes have been shown to experience a 10-minute sinusal arrhythmia beginning 10 - 20 minutes after the end of the exposure (Blanchi et al, 1973). Rats exposed to 80 kV/m alternating with rest periods showed at the beginning of the exposure a considerable increase of pulse- and respiratory frequency which later resumed normal values (Schaefer and Silny, 1977).

5. Effects on metabolism

Blood chemical studies including Urea-N, uric acid, glucose, cholesterol and protein-bound iodine in line-men (Kouwenhoven et al, 1967) showed no influence of the working conditions. Neither did this study indicate any influence on the kidney- or liver functions. Experiments with persons exposed to 20 kV/m, 0.3 mT for three hours showed no differences with regard to cholesterin and triglycerides in the blood (Hauf, 1976). However, no relevant hypotheses for possible effects have been expressed.

In an experiment made to study the influence of natural electromagnetic fields, keeping female mice in Faraday cages for 56 days resulted in a reduction of urine secretion by 30 %. O_2-consumption also decreased. These effects were cancelled by exposing the animals to a pulsating field of 3.5 kV/m, 10 puls/s (Lang, 1972).

Body temperature was shown to drop in an experiment with rats or mice exposed to 15 kV/m for 21 days (Richter, 1977). The greatest drop occurred after 15 minutes; further reduction was more gradual. When rats were exposed to 80 kV/m for four hours the body temperature, especially of the skin and heart muscle, rose and some rats died in heat-stroke symptoms (Lang, 1972).

Waibel (1975) compared metabolism in mice exposed to an E-field of 4.8 kV/m, 50 Hz with that of mice kept in Faraday cages. After one hour of exposure the oxygen consumption of the liver had risen and during the first 24 hours the body temperature had gone up.

Altmann et al (1976) report that exposure to an E-field of 10 Hz, 200 V/m, for one week affects the blood content of protein and the proportions of albumins and globulins in rats compared to rats kept in Faraday cages.

6. Effects on the immunity defence

An increased number of neutrophilic leukocytes has been shown in switch-yard workers exposed within 14 days of testing (Gamberale et al, 1978), in experimental exposure of humans to 20 kV/m, 0.3 mT for three hours (Hauf, 1976) and in mice exposed to 100 kV/m in nine-hour periods twice every 24 hours (Blanchi et al, 1973). Rats exposed to 100 kV/m for one year exhibited a decreased number of leukocytes (Bayer et al, 1978).

In persons exposed experimentally to 10 - 20 kV/m for 12 hours, no qualitative differences were noted with regard to white blood corpuscles (Beyer et al, 1979). In a study of rats exposed to 100 kV/m for one year, the total amount of white blood corpuscles diminished while the distribution of the various types remained unchanged (Bayer et al, 1978; Brinkman, 1976). Other rats exposed to 15 kV/m for 30 days showed a lowered albumin/globulin quotient in the blood (Marino et al, 1977).

Experiments with rabbits have revealed an increased number of white blood corpuscles and a tendency to a relative lymphopenia when exposed to 40 kV/m for eight hours daily for three months (Le Bars and Andre, 1976).

7. Effects on behaviour

Weak electromagnetic fields (2.5 V/m) of low frequency (10 Hz) have been shown to influence the circadian rhythm of man (Wever, 1973). The influence of similar fields (4 V/m, 8 and 12 Hz) on human judgement of time was studied and 12 Hz was found to shorten judgement of time relative to 8 Hz (Hamer, 1969).

Switch-yard workers have been reported to suffer from headache, disturbances in the central nervous system and reduced sexual potency (Korobkova et al, 1972). According to a review by Knickerbocker (1975), these nervous disturbances consisted of fatigue, irritability, sleep difficulties, shaky hands, perspiration, heart trouble and changes in the excitability of the nervous system.

Various animal species have been shown to be able to perceive electromagnetic fields. Thus it was possible to train pigeons and miniature swine with an E-field of about 30 kV/m as a signal, rats with 5 - 7 kV/m (Hilmer and Tembrock, 1970; Kaune et al, 1978; Poznaniak et al, 1979). Anaesthetized rats exposed to 10 kV/m directly above the head have shown EEG-changes, interpreted as perception (Lott and McCain, 1973). Schua (1953) showed that hamsters avoided electric fields of 0.9 kV/m of low frequency. Similar investigations have shown that mice avoid pulsating E-field of 3.5 kV/m, 10 puls/s (Altmann and Lang, 1974) and rats 10 kV/m, 50 Hz (Bayer et al, 1978). However, Schua's experiment has been repeated without any noted escape reactions (Zahner, 1964).

Rabbits exposed to E-fields in a 400-kV switch-yard have shown serious behavioural disturbances such as the absence of flight reactions and cleaning behaviour (Hansson, personal communication, 1980).

An investigation of the influence of an E-field on memorized behaviours in rats (Spittka et al, 1969) showed that an exposure to 50-70 kV/m (50 Hz) for two minutes impaired the performance of a conditioned behaviour. The authors have also noted tendencies to lasting effects.

Reindeer are said to be frightened by and to avoid 400-kV lines. However, the effect apparently disappears after some years (Ellis et al, 1978; Klein, 1971). Investigations (Algers et al, 1981) of dairy cows in pasture under

400-kV lines led to the conclusion that other factors than a possible influence of the lines determined where in the pasture the cows preferred to stay.

The orientation ability of migrating birds has been shown to be disturbed by electromagnetic fields as low as 0.07 V/m, 0.1-0.5 microtesla (less than 1 % of the magnetic field of the earth) 72 - 80 Hz (Larkin and Sutherland, 1977).

8. Other effects

Mice exposed to an electric field of 50 Hz (field strength not given) (Mamontov and Ivanova, 1971) showed an increased number of mitoses in the corneal epithelium and liver cells. However, in the proximal convoluted tubules of the kidney no differences were found between the mitotic indicec of the control and experimental groups.

Kidney- and liver tissue from mice exposed to 55-60 Gauss, 60 Hz for 11 days and tested in a biological system showed a change in the Na^+-pump activity of the cell membrane compared to a control group. The same change was found after 17 days' exposure as after 11 days (Batkin et al, 1978).

Due to the piezoelectric qualities of bone tissue, bone growth can be stimulated by an E-field applied on the outside (Norton, 1974). The author describes the E-field used as "strong" and states that 163 V, 327 V and 890 V were applied at a distance of 0.6 cm between the electrodes.

PREVIOUS REVIEWS

In 1973 Persinger and Ossenkopp made an extensive summary of natural E-fields and their influence, including effects on the nervous and the circulatory systems. They established that the frequency range (< 100 Hz) corresponds to that of the electric activity in the mammal organism, e.g. the activity of the brain. Effects on the brain have been shown, such as changes in reaction time, the circadian rhythm and conception of time, as well as on the oxygen uptake. The authors point out that close but different frequencies can vary in effect and also that unnaturally high frequencies can have a stronger or opposite effect. They discuss possible mechanisms for these effects such as the paramagnetic qualities of oxygen and iron in hemaglobin; the quality of liquid cristal of the phospholipids in the nerve-cell membrane, the change of which influences ion-permeability above all for Ca^2+.

König (1974) summarizes evidence that electromagnetic fields of low frequensy change man's reaction time. The field strength 1 mV/m is reported as threshold value for the E-fields; König also points out that the frequency-dependence is remarkable in that frequencies around 3 Hz slow down the reaction time and frequencies above 10 Hz speed it up. The author's choise of references concerns investigations where measurements have been carried out simultaneously with or very shortly after exposure.

In 1977 Atoian summarized the current situation with regard to research and debate. He criticizes large parts of the literature for lack of an interdisciplinary approach, inconclusive and some contradicting statements, lack of appreciation of electromagnetic field theory by many medical researchers, and lack of consideration of enhancement of electric field effect. However, the author comes to the conclusion that no experimental results support the hypothesis of a long-term biological and psychological influence of high voltage installations.

In 1977 Gavalas-Medici summarized the effects of weak E-field within the frequency range < 50 Hz on behaviour and on EEG. Positive results, e.g. a disturbance of conditioned reflexes, were seldom reproduced. The author discusses possible reasons for this such as differences in the experiments with regard to frequency, E-field, exposure time and type of behaviour tests.

In a work published in 1977, Marino and Becker reviewed 122 references and stated that several biological effects are reported to be due to exposure associated with changes in behaviour, whereas chronic exposure often leads to slower than normal or retarded development and growth. At the same time, they point out that there is a strong indication that long-term exposure is a "biological" stressor". As an explanation of these effects the authors put forward the possibility of an electromagnetic field acting as a trigger which causes the biological system to change from one stage to another.

Sheppard and Eisenbud review 75 references and state that relatively weak electric or magnetic fields may induce neurophysioligical or behavioural effects. Great importance is attached to effect on the calcium efflux in brain tussue, to epidemiological studies on the effects of worker exposure to electric fields, and to investigations of effects on steroid hormones in animals. Adey's theory about catalytic effects on biochemical reactions, which in turn can free sufficient energy to influence synaptic processes and the possible release of a general stress reaction, is discussed. According to the authors, there is no evidence for the assumption that strong electric fields would influence fertility or cause teratogenic effects. It is finally pointed out that a large number of the reviewed work are of low scientific quality.

Marino and Becker (1977) made a comprehensive study of the biological risks involved in high voltage installations. The authors state a number of effects of low frequency electric field, effectc of which the causal mechanisms are unknown. After a review of the literature until the beginning of the 1970's, the authors describe the organization of current American research in this field and point out that in a large part of the research in question (mainly where no effects of electromagnetic fields have been shown) irrelevant parameters have been chosen for study.

.Through theoretical calculations Bernhardt in 1979 tried to determine the limits for E- or B-fields above which biological influence is possible according to known mechanisms such as excitation, radiation heat, release of action potentials and electrically or magnetically induced current. As an example it is stated that for frequencies around 50-60 Hz an E-field of more than 10^3 kV/m and/or a B-field of more than 0.1 mT are necessary to induce a current of 1 uA/cm^2. For release of action potentials in the central nervous system, frequencies between 50 and 100 Hz are stated be effective, with an optimum at 75 Hz, and the threshold value for E-field strength would be 10^4 kV/m according to present knowledge of possible mechanisms and under the assumption that the external E-field penetrates the organism homogenousy. Thus the author points out that biological effects of E- or B-fields under these threshold values are not impossible but that "other mechanisms should be responsible for demonstrated biological effects".

DISCUSSION

The contents of catecholamins in brain, blood and urine, corticoids in serum, as well as antidiuretic hormones in the hypophysis, have been shown to change after exposure to electric fields (Carmaciu et al, 1977; Groza et al, 1978b; Marino et al, 1977).

The capacity for reproduction after exposure to E-fields has been only very incompletely studied. The investigations indicating an influence on human male reproduction made so far (Korobkova et al, 1972), are not contradicted by the study by Kouwenhoven et al (1967). Measured parameters are not the same and the exposed populations have not been similarly exposed. The study of Kouwenhoven et al comprises too few subjects (11 in all) for a parameter with such a large normal variation (sperm quality). An epidemiological study by Algers et al (1981) in which the average exposure time of cows was short but where a couple of herds were extremely exposed, showed a correlation in time between the appearance of severe female fertility disturbances and the putting into operation of high voltage lines.

When examining the electrical activity of the brain (EEG) it has in some cases been considered impossible to show any influence of electromagnetic fields (Gamberale et al, 1967). In these experiments the measurements were carried out later than the exposures. When, on the other hand, measurements have been made during exposure (Beyer et al, 1979; Lott and McCain, 1973; Richter, 1977; Waibel, 1975), changes have usually been found. It is obvious that many of the studied effects occur at definite times in relation to the exposure. Choise of measuring time is therefore of utmost importance in order to capture passing or delayed effects. An example pointed out by Blanchi et al (1973) is the disturbance in a normal EEG starting 10-20 minutes after the end of the exposure. Studies of EEG carried out so far seem thus to show that changes influencing EEG appear in the nervous system as a consequence of exposure to electromagnetic fields.

Biochemical investigations have been less difficult to interpret. Changes with regard to catecholamines or acetylcholine esterase in nerve tissue have been noted after an exposure comparable to exposure under high voltage lines (Hansson, personal communication, 1980; Fisher et al, 1978). Regardless of the strength and extention of electric activity in the organism caused by external electromagnetic fields, field strengths of about 5 kV/m have been shown to have a measurable effect on the organism (Fisher et al, 1978).

The changes found by Adey (1973) in the central nervous system of monkeys after exposure to field strengths < 1 mV/m are extremely noteworthy, as, according to earlier theories for the release of action potentials, these field strengths are said to be without biological effects. Adey, calculating theoretically necessary potential gradients according to classical theories, established that weak fields probably cannot directly influence the synaptic transmission mechanism. Instead he points out a possibility of a catalytic function as an explanation of the influence of a weak extracellular electromagnetic field on the excitability of the neurons.

Lott and Lin (1975) suggest two theories with regard to the process for the effect on the action potential in isolated nerves: (a) the fields produce a physical change in the cell membrane which changes the flow of ions, and (b) the fields influence the metabolic mechanisms which control the flow of ions through the membrane.

Via the autonomous nervous system, pulse frequencies can be influenced in both directions. During registration the subject may become calmed or disquieted according to circumstances, which can mask possible effects of E-fields. An experiment by Richter (1977) in which rats were anaesthetized for an EEG examination immediately after exposure, is therefore very interesting. After exposure to 5.3 kV/m as well as to 50 kV/m, a decrease in the pulse frequency was obtained.

Those investigations (Bayer et al, 1978; Beyer et al, 1979; Gamberale et al, 1978; Hauf, 1976; Kouwenhoven et al, 1967; Schaefer and Silny, 1977) which seem to contradict the above findings by not showing changes in the activity of the heart, have been differently designed with respect to the relation in time between exposure and measurement.

An increased metabolism (Lang, 1972; Richter, 1977; Waibel, 1975) is indicated by the findings of an increased liver O_2 consumption and a body temperature rise.

A great number of independet studies have shown an influence on the white blood corpuscles such as reduced number and/or larger proportion of neutrophil leucocytes. No thorough investigations of the function of the immunity defence, for instance concentrated on bone marrow or tolerance towards infection, seem to have been made, and so it is difficult to assess the importance of the findings regarding white blood corpuscles. The relative proportions of albumin and globulin in the blood had changed in the only investigation where this parameter seems to have been studied.

It is clear that the organism can perceive electric fields. There is a big variation in threshold values from 1 mV/m in certain electro-sensitive fish species to 30 kV/m in pigs (Kaune et al, 1978). In humans the sensation consists of vibrations of the hair appearing when the E-field exceeds about 10 kV/m (Beyer et al, 1979). Therefore if humans are not to know whether they are being exposed or not, experiments cannot be carried out with field strengths above this level. There are, however, individual variations. Of practical importance is, for example, the question whether a possible perception causes animals to stay away from areas under power lines, thus avoiding exposure.

No avoidance of areas under ultra-high-voltage transmission lines by cattle has been established. This has led to the assumption that other qualities, such as supply of pasture, are more important for domestic cattle (Algers et al, 1981). Wild ruminants may be supposed to have physiology similar in this respect to domestic cattle. The few investigations that have been published on this subject have shown contradictory results.

Electromagnetic fields with frequencies varying from 5 to 15 and with varying strengths < 1 kV/m occur naturally. In spite of their low strength, such fields have been shown to be of decisive importance for the notion of time and the circadian rhythm. Electromagnetic fields from ultra-high-voltage transmission lines have a somewhat higher frequency and a considerably higher strength. An assumption that the natural fields may get disturbed by signals produced by ultra-high-voltage transmission lines could explain the effect on, for instance, circadian rhythm. However, this has not been studied.

An examination of switch-yard workers by means of mental tests showed significant deterioration for acutely exposed workers. Several different tests were used and, with the exception of simple reaction time, reduced performance was found in all tests (Gamberale et al, 1978). Simple reaction time was also the only test investigated by Beyer et al (1979).

The study of changed mitotic activity (Mamontov and Ivanova, 1971) leads the authors to conclude that electric fields accelerate the speed of a certain phase in cell-division for certain types of tissue but not for others, due to differences in tissue sensitivity to the frequency uses.

In the reported work it has, as a rule, not been of primary interest to study the effect of the magnetic fields, and the field strength has generally not been noted. However, it can not be excluded that the results obtained are due to magnetic fields. Single studies of the influence of magnetic fields have shown effects on, for example, the transport mechamism in the cell membrane (Batkin et al, 1978).

Choice of exposure time, period of measurement and number of experimental objects have not always been adapted to individual parameters with regard to sensitivity and latency. This and technical fallacies apply to a great number of investigations presented in the literature, most of which have, therefore, not been cited here. These difficulties have often been unavoidable as many individual investigations have comprised a great number of and very different parameters. When chosing parameters, definite questions at issue have very often been overlooked, which inevitably makes the results impossible to interpret, especially where no effects have been noted.

CONCLUSIONS

Many experiments and investigations have been carried out on the influence on human beings and animals of electric and magnetic fields. Exposure to electromagnetic fields has been demonstrated to induce biological effects.

Some results indicate certain specific effects of electric fields on the organism (e.g. chromosomal aberrations, structural and functional changes in the central nervous system, changes in the immune defence system).

The exact process for the influence of electric and magnetic fields on the organism is not known.

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