6122 EFFECTS OF MAGNETIC FIELDS ON AVIAN ORIENTATION (MEETING ABSTRACT). *(Eng.)* Keeton, W. T. (Section Neurobiology and Behavior, Cornell Univ., Ithaca, NY 14853). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 11-13; 1978. (14 refs)

Studies on the effects of magnetic fields on avian and insect orientation are reviewed. Bar magnets were found capable of disrupting the orientation of mature birds under overcast skies, though not under the sun. The magnets were also observed to disorient first-flight birds even when the sun was visible. The orientation of pigeons was changed (not merely disrupted) under overcast skies by attaching Helmholtz coils around the birds' heads. A rotated orientation of migratory restlessness in birds exposed to turned magnetic fields in circular test cages has also been reported. The birds' sensitivity was limited to a narrow range of field strengths approximately equal to the geomagnetic field. The birds paid no attention to field polarity but read north as that direction where the magnetic and gravity vectors formed the most acute angle. Evidence that birds use the earth's magnetic field to calibrate the star compass has also been obtained. The dance of scout honeybees has been reported to be influenced by even minor natural fluctuations in the earth's magnetic field, suggesting a sensitivity to changes of less than 10^{-3} G and perhaps less than 10^{-5} G. Similar sensitivity has been reported for gull chicks and for free-flying migrants. Pigeons also are influenced by natural magnetic fluctuations and must have a similar sensitivity. Migrants have been found to be influenced by the weak low-frequency alternating fields produced by the test antenna for the Navy's proposed Project Seafarer. There is now abundant evidence that both birds and insects are very sensitive to magnetic stimuli when they are orienting. Whether they are responsive to such stimuli under other circumstances is not yet clear.

6123 EFFECTS OF 60 HZ ELECTROMAGNETIC FIELDS ON BEES AND SOIL ARTHROPODS (MEETING ABSTRACT). *(Eng.)* Greenberg, B. (Dept. Biological Sciences, Univ. Illinois at Chicago Circle, Chicago, IL 60680). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): p. 14; 1978. (1 ref)

Experiments on the effects of 60-Hz electromagnetic fields on soil arthropods and honeybees are reported. Population curves and predator-prey proportions of soil arthropods exposed to the Navy's Wisconsin test facility antenna fields (0.1-2.5 V/m; less than 0.9 G), which were monitored annually since 1969, did not show any significant departures from normal fluctuations observed in control populations. Also, no significant sustained differences in metabolic rate measurements were noted between several species of soil-dwelling animals (earthworm, slug, wood louse, and redbacked salamander) that were collected from sites near the antenna and control populations. A comparison of metabolic rates for the summer and fall months revealed no seasonally-linked change in sensitivity to the electromagnetic fields. Experiments with honeybees in conventional metal-containing hives under a 765-kV transmission line (7 kV/m; 10^{-3} G) showed the following effects not observed in shielded counterparts under the line or in a control area (10 V/m; 10^{-4} G): hives failed to increase in weight; individual bees weighed less; fewer pupae were produced; moisture content of honey was less; and propolization of hive entrances was extensive. Unshielded metal-free hives under the transmission line were normal except for some propolization of hive entrances, possibly higher hemocyte counts, and possibly higher overwintering mortality.

6124 TESTS IN THE PLANT *TRADESCANTIA* FOR MUTAGENIC EFFECTS OF STRONG MAGNETIC FIELDS (MEETING ABSTRACT). *(Eng.)* Baum, J. W. (Safety and Environmental Protection Div., Brookhaven Natl. Lab., Upton, NY 11973); Schairer, L. A.; Lindahl, K. L. *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 15-17; 1978. (4 refs)

Possible mutagenic effects of strong magnetic fields (20-37,000 G) on the plant *Tradescantia* were investigated. The endpoints for mutagenicity included pink stamen hair mutation, pollen abortion, and micronuclei formation in the tetrad stages of pollen production. Results were obtained in eight separate trials. For each of the three endpoints studied, no increase in mutation rate was observed for exposed compared to control plants over exposure periods varying from 0.9 to 6 days. The pooled data indicated that a small but not highly significant increase of $2.7 \pm 2.3 \times 10^{-4}$ pink mutations per hair resulted from these magnetic field exposures. These data were used to estimate a possible mutation increase of 8×10^{-5}% for exposures to 200 G for 8 hr (a conventional limit for whole-body exposure at several laboratories). In comparison, mutation increases of 0.015% would be produced in this system by a permissible daily dose of 20 milli roentgen equivalents (mrem) of ionizing radiation. Assuming that linear relations hold between field strength, exposure time, and the observed effect, then these results suggest that an 8 hr/day exposure to a 40-kG field would be necessary to produce the same (or probably lower) mutation frequency as a 20-mrem x-ray exposure.

6125 MAGNETIC FIELD INTERACTIONS IN MAN AND OTHER MAMMALS: AN OVERVIEW (MEETING ABSTRACT). *(Eng.)* Sheppard, A. R. (Jerry L. Pettis Memorial Veterans Hosp., Loma Linda, CA 92357). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 28-31; 1978. (29 refs)

Magnetic field interactions in man and other animals are reviewed. Reports of magnetic field effects

cluster about effects on blood composition, alterations in normal physiologic parameters of growth and activity, effects on the immune system, altered neural function, and altered animal behavior. Interest in possible effects on the central nervous system by weak fields is stimulated by evidence that birds possess a magnetic compass, by several findings concerning bird orientation in very weak electromagnetic fields, and by the extraordinary electric field sensitivity of certain fish. The effect of weak low frequency electric fields on calcium binding in neural tissue provides a possible neurochemical basis for these influences. It is clear that humans in a strong magnetic field (greater than 100 G) experience excitation of the visual pathway (magnetic phosphene) in the form of the sensation of flickering, shimmering light patterns. Swedish scientists have observed spike trains in retinal ganglion cells following exposure to a magnetic field, and they have characterized a frequency dependent threshold for phosphenes in humans. When phosphenes are produced under certain ambient light conditions, the threshold above 30 Hz differs in subjects with abnormal color vision, although the localization of phosphenes in the peripheral visual field suggests little involvement for the color-sensitive cone receptors of the foveal region.

6126 EFFECTS OF MAGNETIC FIELDS ON BEHAVIOR IN NONHUMAN PRIMATES (MEETING ABSTRACT). *(Eng.)* de Lorge, J. (Naval Aerospace Medical Res. Lab., Pensacola, FL 32508). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 32-33; 1978. (5 refs)

Studies of magnetic field effects on the behavior of nonhuman primates are reported. In one study three squirrel monkeys (*Saimiri sciureus*) were conditioned to respond on a visual vigilance task and were subsequently exposed to a direct current magnetic field in the core of a water-cooled Bitter magnet. Responding was greatly suppressed by fields of 70 kG or more, and a threshold seemed to exist between 46 and 70 kG. A second experiment in a superconducting magnet in which eight squirrel monkeys were trained on several operant tasks revealed similar suppressive effects at magnetic field strengths of up to 97 kG. In addition, two of the monkeys regurgitated when exposed to the higher fields. All of these effects were reproducible. Recent studies using rhesus (*Macaca mulatta*) and squirrel monkeys have revealed no behavioral effects of extremely low frequency electromagnetic fields. Magnetic fields ranging from 3-10 G and electric fields from 1-29 V/m (root mean square) at frequencies of 7, 10, 15, 45, 60, and 75 Hz were used. No consistent effects, other than one unreplicated effect on general activity, were observed. It is concluded that reported effects of low magnetic fields on behavior are probably related to other uncontrolled environmental variables.

6127 MAGNETIC FIELD EFFECTS ON RODENTS (MEETING ABSTRACT). *(Eng.)* Nahas, G. G. (Dept. Anesthesiology and Pathology, Coll. Physicians and Surgeons, Columbia Univ., New York, NY 10032). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 34-35; 1978. (1 ref)

Possible vascular or histopathologic effects in rats exposed to homogeneous magnetic fields produced by permanent magnets were investigated. Capillary circulation in the mesoappendix was observed by an in vivo microscopic technique after exposure to 500 G for 6, 12, and 30 days. Rats exposed to 200-1,200 G for 29-32 days were sacrificed for analysis of blood chemistry, body and organ weights, and histopathologic examination of vascular tissues and 10 selected organs. The in vivo capillary circulation study and histopathologic results indicated no hemodynamic alterations or intravascular thrombosis associated with magnetic field exposure. Hematology revealed no changes in hematocrit, white blood cell count, hemoglobin level, or coagulation time in exposed rats. Except for nonpathologic congestion of the spleen, no histopathologic effects were noted in any organs following magnetic field exposure. Body and organ weights of young rats exposed to magnetic fields were increased relative to matched controls; however, the number of animals studied was small, and further studies are required to determine the significance of this observation.

6128 STUDIES ON BIOMAGNETIC EFFECTS IN MICE (MEETING ABSTRACT). *(Eng.)* Biggs, M. W. (Dept. Industrial Medicine, Lawrence Livermore Lab., Livermore, CA 94550). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): p. 36; 1978. (3 refs)

The possible effects of magnetic fields ranging in strength from 8,800-14,400 G on murine growth rate and hematologic parameters and on in vivo tumor growth were investigated. In two separate experiments, the growth rate of young male mice weighing 12 g at the start of the experiment was unaffected by a continuous 15-day exposure to the magnetic field; no growth effects were observed following termination of the exposure. In adult mice, no alterations were observed relative to matched controls in body weight, white blood cell count, differential blood count, hematocrit, red blood cell count, or liver and spleen weights following magnetic field exposures for periods of 16-23 days. The effect of the magnetic field on the growth of Ehrlich ascites tumor was not statistically significant both in terms of tumor growth rate and mean survival time of tumor-bearing hosts.

6129 MECHANISMS OF MAGNETIC FIELD INTERACTIONS WITH RETINAL RODS (MEETING ABSTRACT). *(Eng.)* Hong, F. T. (Dept. Physiology, Wayne State Univ. Sch. Medicine, Detroit, MI 48201). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. Cali-

fornia, Berkeley, CA (LBL-7452): pp. 38-40; 1978. (11 refs)

Mechanisms of magnetic field interactions with retinal rods are discussed. It has been reported that isolated frog rod outer segments in aqueous suspension can be oriented by a homogeneous magnetic field of 10 kG. The equilibrium orientation is parallel to the applied field, and the two ends of a rod appear equivalent in a magnetic field. Among the possible mechanisms considered responsible for this orientation effect is magnetic anisotropy. Numeric estimation based on the mechanism of magnetic anisotropy indicates that it is impossible to orient individual molecules in a rod with a field strength of 10 kG. However, two major molecular constituents, visual pigment rhodopsin and phospholipid, are oriented along the axial direction in a rod. If either molecule possesses a small anisotropy, the anisotropy will be additively summed in a rod and increased by a factor of 3×10^9 (rhodopsin) or 10^{13} (phospholipid). The crucial parameter is the summed anisotropy, which is the sum of the anisotropy of all the individual oriented anisotropic molecules. An elementary calculation using classical magnetic theory leads to expressions that correctly describe the time course of orientation. Other investigators have confirmed the effect and have shown that the anisotropy is due mainly to the protein moiety of rhodopsin (possibly an alpha-helical region) rather than phospholipid or the chromophore retinal. The magneto-orientation effect is a manifestation of the extraordinary order in the rod membrane structure and has been utilized as an experimental tool in obtaining oriented biologic samples for x-ray crystallography and neutron diffraction studies in addition to fluorescence depolarization and linear dichroism studies. Similar magnetic orientation mechanisms might play a physiologic role in other systems. For example, accumulating evidence has shown that some birds use the terrestrial magnetic field as a cue in orientation and navigation. Experiments with European robins have suggested that the magnetic compass of the bird can only detect the axial direction of the magnetic field and cannot differentiate north from south. Thus, birds trained in the northern hemisphere will perhaps be confused in the southern hemisphere. If this turns out to be the case, then ordered biologic structures (such as *pecten oculi*) instead of ferromagnetic particles should be examined in the search for the biologic compass.

6130 ORIENTATION OF BIOLOGICAL MEMBRANES AND CELLS IN MAGNETIC FIELDS (MEETING ABSTRACT). *(Eng.)* Geacintov, N. E. (Chemistry Dept., New York Univ., New York, NY 10003). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 41-43; 1978. (3 refs)

A theoretic analysis of the orientation of biologic membranes and cells in magnetic fields is presented. The observation of magnetic orientation effects depends critically on the product of the volume of the domains of oriented molecules and the anisotropy; this product is found to be 10^{-20} cm^3 for whole *Chlorella* cells. The smaller the anisotropy, the larger the size of the domain containing the oriented molecules that is necessary to achieve an observable orientation. Using magnetic fields of 10-20 kG, it has been found that the minimum size of the biologic particles that can be oriented by magnetic fields is of the order of 1 μ. However, smaller particles, such as, small protein complexes can be readily oriented by electric fields. Also, while a magnetic field of 15 kG is necessary to completely orient spinach chloroplasts, these particles are easily oriented in the presence of weak alternating electric fields (60 Hz) as low as 20-30 V/cm. It is therefore evident that the orienting magnetic forces are much weaker for normally available magnetic fields than for commonly available electric fields. It is concluded that orientation forces in biologic systems must be considered when assessing possible biologic effects of magnetic fields.

6131 ENZYME-SUBSTRATE REACTIONS IN HIGH MAGNETIC FIELDS (MEETING ABSTRACT). *(Eng.)* Weissbluth, M. (Stanford Univ., Stanford, CA 94305). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 44-45; 1978. (4 refs)

Three sets of experiments investigating the possible effects of high-strength magnetic fields on enzyme-substrate reaction rates are reported. The experiments were performed at a temperature close to 25 C, with temperature variation generally being limited to within 0.5 C. In the first series, the systems ribonucleic acid (RNA)-ribonuclease and succinate-cytochrome c reductase were investigated in magnetic fields of up to 48 kG over exposure periods of 5-6 min. The second series of experiments consisted of exposing the following systems to 85 to 170 kG magnetic fields over periods of 2-20 min: RNA-ribonuclease, horseradish peroxidase (which catalyzes the oxidation of o-dianisidine by hydrogen peroxide), tyrosinase-L-tyrosine, and aldolase-fructose 1,6-diphosphate. The peroxidase was additionally placed in the fringe field at 85 kG to provide a field gradient with a variation of about 30% over the sample volume. In the final series of experiments, trypsin-BAPA was exposed to 220 kG for 9 min; finally, the enzyme alone was pretreated for 65-220 min at 208 kG. In all cases the reaction rates were independent of the magnetic field. A survey of the literature indicated that positive results have been obtained in some instances, e.g., a magnetic field of 3,200 G resulted in a 30% increase in the reaction rate of deoxyribonuclease.

6132 EFFECTS ON CELL FUNCTION RESULTING FROM EXPOSURE TO STRONG MAGNETIC FIELDS AT 4°K (MEETING ABSTRACT). *(Eng.)* Malinin, G. I. (Physics Dept., Georgetown Univ., Washington, DC 20057); Gregory, W. D.; Morelli, L.; Ebert, P. S. *In: Proceedings of the Biomagnetic Effects Workshop,*

April 6-7, 1978. Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 46-47; 1978. (1 ref)

Various cell types were exposed to magnetic fields at a temperature of 4 Kelvin (K), thus transforming a fluid cellular target into a solid state system, in an effort to overcome the ambiguous quantitative results of magnetic field effects on cellular functions observed at ambient temperature. In all experiments, target cells were frozen to 4 K in the presence of an appropriate cryoprotective agent, exposed to a given magnetic field for a predetermined time, thawed rapidly, and allowed to resume metabolism under optimal growth conditions. Murine heteroploid L-929 and human diploid WI-38 fibroblasts exposed to a 5-kG magnetic field at 4 K subsequently developed morphologically distinct cell types that could be propagated from generation to generation. Deoxyribonucleic acid synthesis in spleen-derived murine lymphocytes was measured by tritiated thymidine (^{3}H-TdR); ^{3}H-TdR incorporation in concanavalin A-stimulated lymphocytes previously exposed to a 40-kG field at 4 K was drastically reduced compared to controls. Hemoglobin synthesis in murine erythroleukemia cells could not be induced with butyrate following exposure of the cells to a 40-kG field at 4 K. In this series of experiments, control cultures showed a normal response to butyrate induction as measured with the benzidine assay. These data seem to indicate that the exposure of target cells to strong magnetic fields at 4 K results in reproducible and measurable alterations of cellular metabolic indicators. Preliminary measurements of this magnetization of cells with a superconducting SQUID magnetometer indicated a possible difference in cell magnetization between control and target cells.

6133 EFFECTS OF A TRANSVERSE MAGNETIC FIELD ON THE DOSE DISTRIBUTION OF HIGH ENERGY ELECTRONS AND ON THE RESPONSES OF MAMMALIAN CELLS IN VITRO TO X-RAYS (MEETING ABSTRACT). *(Eng.)* Nath, R. (Dept. Therapeutic Radiology, Yale Univ. Sch. Medicine, New Haven, CT 06510); Rockwell, S.; Bongiorni, P.; Schulz, R. J. *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978*. Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 48-49; 1978. (2 refs)

Possible changes in the viability of radiation responses of mammalian cells in vitro exposed to high magnetic fields were investigated in connection with potential complications of using transverse magnetic fields for enhancing the dose of high-energy electron beams in clinical radiotherapy. The exposure of unirradiated EMT6 mouse mammary tumor cells to an almost uniform magnetic field of 1,400 G for up to 48 hr did not alter the proliferation or viability of the cells. Exposure of the cells to this magnetic field during irradiation with 120-kV x-rays did not alter the repair of sublethal damage. Exposure of plateau phase cultures to the magnetic field after irradiation for times up to 24 hr did not alter the repair of potentially lethal damage. An almost uniform magnetic field of 5,700 G did not alter the repair of sublethal or potentially lethal damage of x-irradiated EMT6 cells and did not alter the viability of unirradiated cells during exposures of up to 6 hr. More recent experiments with DON Chinese hamster cells and higher field strengths have indicated that the exposure of these cells to an almost uniform field of 20.5 kG or to a nonuniform field of 17.4 kG with a gradient of 2,300 G/cm for 2 hr did not alter their viability. The survival curves for cells exposed to 30-MV x-rays delivered in a single treatment or in two treatments separated by an incubation period of 2 hr outside the magnetic field were not affected by the almost uniform 20.5-kG magnetic field. Thus far, no significant changes in the viability of radiation responses of mammalian cells in vitro have been observed in cells exposed to high magnetic fields.

6134 EFFECT OF MAGNETIC FIELDS ON THE DRUG-INDUCED CONTRACTILITY OF THE CILIATE SPIROSTOMUM (MEETING ABSTRACT). *(Eng.)* Ettienne, E. (Univ. Massachusetts Medical Sch., Worcester, MA 01065); Ripamonti, A.; Frankel, R. B. *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978*. Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 50-52; 1978. (4 refs)

The effect of a homogeneous magnetic field on drug-induced contractility of the ciliate *Spirostomum ambiguum* was investigated. Ciliate contraction was induced by the addition of 10 µmol of 2,2'-dipyridyldisulfide (PDS). *Spirostomum* were exposed to a 9,200-G magnetic field, and the number of PDS-induced contractions per minute was monitored over a 20-min interval in populations of cells exhibiting synchronous contractions. At 7, 10, 13, and 16 min following incubation in PDS, the values for peak contraction frequencies were depressed in the exposed samples relative to controls by 50, 37, 33, and 33%, respectively; all of these differences were significant ($p<0.001$). The duration of the relaxation phase in the magnetic field was observed to be extended over that of controls. A significant decrease in cell survival over the entire incubation period for cells exposed to magnetic fields of either 5,000 or 9,200 G also was observed. Based on the known physiology of *Spirostomum*, the above observations suggest that the presence of a magnetic field serves to decrease the enzymatic transport of calcium ion out of the cytoplasm following contraction.

6135 ANALYSIS OF STATIONARY MAGNETIC FIELD EFFECTS ON IONIC DIFFUSION AND NERVE ACTION POTENTIALS (MEETING ABSTRACT). *(Eng.)* Liboff, R. L. (Sch. Applied Physics and Electrical Engineering, Cornell Univ., Ithaca, NY 14853). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978*. Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 80-81; 1978. (6 refs)

Studies of magnetic field effects on ionic diffusion

and nerve action potentials are reported. Magnetically-induced changes in ion diffusion rates were studied by measuring the conductivity of cesium chloride solutions in the presence and absence of a magnetic field. An alternating current bridge circuit was employed in which the frequency was about 10^3 times lower than the Larmor frequency (about 10^7 Hz at 1 kG). A null-point conductivity measurement was made to detect any imbalance of the bridge circuit resulting from the application of the magnetic field, thus signifying an influence of the field on the ionic diffusion coefficient. No imbalance of the bridge circuit was observed following the application of fields of up to 1 kG. A possible inductive interaction between a steady magnetic field and a nerve action potential was also analyzed. An action potential propagating along a squid axon with a velocity of about 10^3 cm/sec was assumed to enter a region with a steady magnetic field directed transverse to the axis of the axon. The analysis indicated that magnetic field effects tend to be nullified because of the rotational symmetry of the current loops in the action potential. Previous experimental studies indicated that no magnetic effects on the action potential of the frog sciatic nerve occurred at fields of up to 100 kG distributed over 0.5 cm. The possibility of current distortion of the action potential due to a magnetic field was also investigated; the extent of such distortion was evaluated by comparing the Hall electric field (E_H) to the electric field associated with the current flow of the action potential (E_a). For parameters appropriate to the squid axon, the ratio of E_H/E_a remained less than unity for magnetic fields less than about 1 kG.

6136 MECHANISMS OF BIOMAGNETIC EFFECTS (MEETING ABSTRACT). *(Eng.)* Mahlum, D. D. (Biology Dept., Pacific Northwest Lab., Richland, WA 99352). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 82-83; 1978. (0 refs)

Studies conducted by the Pacific Northwest Laboratories on the mechanisms of biomagnetic effects in both warm- and cold-blooded animals are described. Studies with mice are being performed using a replicate experimental design that permits prolonged exposures of mice in different stages of gestation to static homogeneous (10,000 G), static gradient (260 G/cm), or cyclic gradient (250 G/cm, approximately 0.6 cycles/min) magnetic fields. Some animals are examined prenatally for morphologic effects, while others are evaluated postnatally for functional changes. In other studies with trout, eggs are fertilized and permitted to develop in the magnetic field for 21 days (approximately 7 days before hatching). The eggs are then removed from the field and allowed to hatch in a flow-through incubator. Several endpoints including morphologic alterations, hatching efficiency, and survival are used to assess the effects of exposure. These studies should provide an integrated assessment of biomagnetic effects that is independent of the level at which the effect occurs and that is independent of the mechanism. In addition, a number of simpler in vitro systems are being investigated. These include changes in permeability characteristics of artificial and natural membranes, changes in gelation temperatures of macromolecules, effects on growth and morphologic and functional characteristics of cells in tissue culture, and the effects on neuromuscular function. Studies of possible genetic effects using microbial and animal systems are also in progress. Current speculation suggests that alterations in macromolecular or membrane conformation could result in biochemical and physiologic changes that would serve to amplify small effects produced by the interaction of magnetic fields with biologic material. Singer's fluid mosaic model of membrane structure may provide a tool for exploring the validity of these speculations if reproducible effects can be identified.

6137 MAGNETIC FIELD COUPLING WITH LIQUID CRYSTALLINE STRUCTURES (MEETING ABSTRACT). *(Eng.)* Labes, M. M. (Dept. Chemistry, Temple Univ., Philadelphia, PA 19122). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 84-85; 1978. (4 refs)

A model for magnetic field coupling with liquid crystalline structures is proposed. In a magnetic field, arrays of diamagnetic rods adopt a position that minimizes their free energy. If the diamagnetic anisotropy (X_a) is greater than 0, then the long molecular axis aligns in the field. The free energy perturbation $(F_m) = -1/2\ X_a\ (nH)^2$, where n is the director of the liquid crystal and H is the magnetic field strength. The critical magnetic field to produce reorientation of the director in a thin sample (about 0.1 mm in depth) is typically 10^3-10^4 Oe, depending on the magnitude of X_a. Subcritical fields perturb cholesteric liquid crystals by changing the pitch of the cholesteric helix. Transport processes are known to be anisotropic in liquid crystals; e.g., diffusion coefficients are typically twice as large parallel to the long axis as compared to the perpendicular direction. The proposed model for biomagnetic effects consists therefore of the perturbation of a transport process through a liquid crystalline membrane. The perturbation can be expected to influence the rate of transport by a factor of 2 for magnetic fields of 10^3-10^4 Oe. Measurements of magnetic field effects on diffusion in liquid crystals and on the anisotropy of diffusion confirm several aspects of the above model of biomagnetic effects.

6138 SUPERCONDUCTIVE JOSEPHSON JUNCTIONS--A POSSIBLE MECHANISM FOR DETECTION OF WEAK MAGNETIC FIELDS AND OF MICROWAVES BY LIVING ORGANISMS (MEETING ABSTRACT). *(Eng.)* Cope, F. W. (Biochemistry Lab., Naval Air Development Center, Warminster, PA 18974). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 86-87; 1978. (7 refs)

The phenomenon of superconductive Josephson junctions is considered as a possible mechanism for the detection of very weak magnetic fields (0.1-5 G) and microwaves by living organisms. Although no direct evidence for this phenomenon has been obtained in vivo, various model chemical systems have been examined for the presence of superconductive transitions and Josephson junctions at temperatures in the physiologic range. For example, experimental evidence indicates probable superconductive transitions in the cholates at near room temperature. Also, weak magnetic field effects on probable Josephson junctions have been observed in carbon films at 25 C. Electron tunneling through these junctions responds to very small magnetic fields as evidenced by the fact that superconducting Josephson junctions have been fabricated that exhibit sensitivity to fields as small as 10^{-11} G. Josephson junctions between superconductive microregions in living systems may therefore provide a possible physical mechanism with more than enough sensitivity to explain the observed responses of organisms to weak magnetic fields. Microwave effects observed on probable room temperature Josephson junctions in carbon films suggest that nonthermal effects of microwaves in biologic systems may occur with high sensitivity by the same mechanism.

6139 THEORETICAL REMARKS ON LOW MAGNETIC FIELD INTERACTIONS WITH BIOLOGICAL SYSTEMS (MEETING ABSTRACT). *(Eng.)* Swenberg, C. E. (Dept. Physics, Univ. Puerto Rico, Rio Piedras, PR 00931). *In: Proceedings of the Biomagnetic Effects Workshop, April 6-7, 1978.* Lawrence Berkeley Lab., Univ. California, Berkeley, CA (LBL-7452): pp. 88-90; 1978. (8 refs)

The theory of low magnetic field interactions with biologic systems is discussed, with particular emphasis on examples of biomagnetic hyperfine interactions. One such example is provided by the photochemical properties of the bacterium *Rhodopseudomonas sphaeroides*. In this system, if the photochemical electron transfer to the iron-ubiquinone complex is blocked by chemical reduction, the lifetime of the radical pair intermediate ($P870^{+}I^{-}$) formed by a flash excitation will increase from 0.2 to 10 nsec. Under this condition, a magnetic field effect on the spin state of the intermediate can be observed as a change in the absorption spectrum of the carotenoid receptor. The saturation field is approximately 100 G, and the maximum magnetic field effect on the absorption is about 30%. Other examples of biomagnetic hyperfine interactions may arise in systems where a photoisomerization is coupled to an exothermic transfer reaction. It has been proposed that the sensitivity of certain migratory birds to the geomagnetic field may originate from an anisotropic hyperfine tunneling mechanism that serves as an internal compass. In cases where light is necessary for the detection of both the presence and direction of the earth's field, small fluctuations are predicted to occur in the plasma membrane current of retinal photoreceptor cells when they have different spatial orientations relative to the field.

6140 THE APPLICATION OF TRANSMISSION MICROWAVE TECHNOLOGY TO LUNG WATER MEASUREMENTS (MEETING ABSTRACT). *(Eng.)* Bragg, D. G. (Dept. Radiology, Coll. Medicine, Univ. Utah, Salt Lake City, UT); Durney, C. H.; Iskander, M. F. *Invest Radiol* 13(5): 373; 1978. (1 ref)

A pulmonary edema animal model was developed to test the transmission microwave monitoring method. The method employs a transmission microwave applicator and detector system and appears to have good power coupling to the tissue, with minimal external radiation. The open strip transmission line has been tested in animal models and appears to satisfy the requirements of small size and the ability to be conveniently attached to the chest wall. In the present study, the amplitude and phase of the transmitted microwave signal was constantly monitored during the induction and reversal of pulmonary edema. The animals were simultaneously evaluated with serial chest radiographs, together with a constant monitoring of systemic arterial pressures, mean pulmonary arterial and venous pressure, and cardiac output. The microwave transmission technique appears to be the most sensitive and specific method available to detect changes in total lung water content. Future research will be directed toward improvements in system design to eliminate problems of maintaining the opposing applicator reference position and reducing the sensitivity of the technique in response to geometric and motion artifacts.

6141 LOCALIZED RADIOFREQUENCY HYPERTHERMIA (LRFHT) OF THYROID GLAND (WORK IN PROGRESS) (MEETING ABSTRACT). *(Eng.)* Kotlyarov, E. V. (Univ. Nebraska Medical Center, Omaha, NB 68105); Washburn, J. H.; Baltaxe, H. A. *Invest Radiol* 13(5): 425; 1978. (0 refs)

The possibility of utilizing localized radio frequency hyperthermia (LRFHT) (alone or with radioactive iodine) in the treatment of euthyroid goiter and possibly in primary or secondary thyroid cancer was investigated. Initial studies of the effect of LRFHT on the uptake of ^{131}I and ^{99m}Tc-pertechnetate and the pathologic effects of LRFHT on the thyroid gland are presented. The initial parameter of localized hyperthermia was determined by direct implantation of a thermoprobe into one of the thyroid lobes of six rabbits (1.5-2 kg) (both sexes). A triport 222 three-channel radio frequency generator transmitting at 13.56 MHz was utilized to induce localized hyperthermia. Eliptical copper electrodes measuring 6 cm^2 were used, and a mean power of 10-12 W was applied to the electrodes to produce localized hyperthermia with an average applied power of 1.8-2.2 W/cm^2. Power was pulsed through the electrodes and an intrathyroid temperature of 41.5 ± 0.5 C was maintained for 60 min. In a second study, the effect of LRFHT on 2-hr ^{99m}Tc-pertechnetate and 2, 24, 48, and 72-hr ^{131}I thyroid uptake was investigated. The discharge of incorporated ^{131}I from the thyroid due to different time (30-60 min) of hyperthermia during 1 wk daily was studied. The thyroid (neck) uptake was obtained in vivo after intravenous injection of 20 µCi of ^{99m}Tc-pertechnetate and 3 µCi of ^{131}I. Radiometry was performed by

scintillation detection placed on the skin in front of maximal radioactivity on the neck. The results indicate a significant decreased thyroid function (trapping and organification) as well as a significant discharge of organified iodine compounds from the thyroid gland.

6142 UNIFORM THAWING OF CANINE KIDNEYS USING SINGLE-FREQUENCY ELECTROMAGNETIC ENERGY (MEETING ABSTRACT). *(Eng.)* Burdette, E. C. (Engineering Experiment Station, Georgia Inst. Technology, Atlanta, GA 30332); Karow, A. M., Jr. *Cryobiology* 15(6): 725; 1978. (0 refs)

Uniform thawing of canine kidneys was investigated using kidneys from dogs perfused with a K^+,Mg^{++}-rich perfusate containing one of several dimethylsulfoxide (Me_2SO) concentrations, frozen to -80 C, and thawed using 918-MHz electromagnetic (EM) energy. A special dielectric-loaded horn illuminator was designed to accomodate the kidney geometry and provide a uniform field incident upon the kidney. The thawed kidneys were evaluated by anatomic (macroscopic and microscopic) and physiologic observations. Temperature and thawing uniformity were measured by monitoring the power reflected back to the EM source during thermal phase change and by using high-resistivity thermistors during and immediately following thawing. Temperature uniformity was maintained to within 4 C throughout the entire kidney with thawing rates of 30 to 45 C/min. Histologic evaluation revealed little difference between frozen-EM-thawed renal tissue and controls.

6143 RECENT DEVELOPMENTS IN MICROWAVE HEATING (MEETING ABSTRACT). *(Eng.)* Hand, J. W. (Medical Res. Council Cyclotron Unit, Hammersmith Hosp., Du Cane Rd., London W12 OHS, England). *Br J Radiol* 51(611): 934; 1978. (0 refs)

Recent developments in microwave heating are discussed with emphasis on microwave applicators that are likely to be useful for hyperthermia application. In particular, a waveguide applicator partially loaded with dielectric slabs in order to produce a uniform microwave field across part of the aperture is described. Heating patterns produced by such an applicator are of greater uniformity than those produced by direct contact microwave applicators operated in the TE_{10} mode. This new type of applicator could be used in treating patients with superficial lesions. Microwave applicators made from micro-miniature coaxial waveguide also are reviewed. These applicators may be inserted into tissue via a catheter or as interstitial implants and are capable of producing localized hyperthermia deep in tissue. Small applicators of coaxial geometry could prove useful in the treatment of areas, such as, bladder, rectum, esophagus, and cervix. An experimental technique for inducing hyperthermia in a loop of exteriorized mouse intestine is described. The organ is immersed in a liquid that is both biologically compatible with and dielectrically similar to this tissue. This technique improves the efficiency of coupling the microwaves into the tissue and avoids the effects of shape and size on the absorption characteristics of the irregularly shaped mouse jejunum. A multi-sensor thermistor probe produced by thick film technology for temperature measurements in the presence of electromagnetic fields also is discussed.

6144 A TECHNIQUE FOR PRODUCING LOCALIZED MEASURABLE HYPERTHERMIA IN SUPERFICIAL RAT TUMOURS USING RADIO-FREQUENCY CURRENTS (MEETING ABSTRACT). *(Eng.)* Dunscombe, P. B. (Dept. Medical Physics and Radiotherapy, Charing Cross Hosp., London W6 8RF, England); Backhouse, B. M. *Br J Radiol* 51(611): 934; 1978. (0 refs)

Currents at 433 MHz were passed through superficial tumors of rats by means of a waveguide and aerial system to produce localized hyperthermia. It was demonstrated that this hyperthermia technique resulted in higher rates of heat production in fat and in the regions near the electrodes. Both the tumor and rectal temperatures were monitored during heating using thermocouple probes. The tumor probe was housed in a steel needle to facilitate insertion into the tissue. By maintaining the metallic components of the probes normal to the electric vector of the field it was possible to reduce pick up of the electromagnetic field to an acceptably low level. Thermographic studies performed on tissue-equivalent gels indicated a high degree of localization of heat production (full width at half maximum height of the temperature distribution was 1.5 cm) and surface heating. Similar studies failed to show any perturbation of the temperature distribution due to the presence of a thermocouple probe. A series of anesthetized rats carrying tumors on the flank was subjected to the heating system. The mean rate of rise of temperature in the tumors was 3.3 ± 2.2 C/min at 37 C corresponding to a power absorption of 270 ± 190 W/kg.

6145 MEASUREMENT OF THE ELECTRICAL PROPERTIES OF MATERIALS OF BIOLOGICAL INTEREST (MEETING ABSTRACT). *(Eng.)* Sheppard, R. J. (Dept. Physics, Queen Elizabeth Coll., London, England). *Br J Radiol* 51(611): 934; 1978. (0 refs)

Complex permittivity and conductivity is briefly defined and explained with particular reference to biologic materials. The reasons why such parameters and in particular their variation with frequency need to be known are discussed and apparatus required for such measurements is described. Frequency domain techniques are outlined, and alternating current bridges (10 kHz-100 MHz), coaxial lines (50 MHz-12 GHz), and waveguides that can operate over narrow frequency bands up to about 100 GHz are discussed. In addition, the new method of time domain spectroscopy (TDS), which enables data to be taken in the time domain, is explained. These data are Fourier transformed to give permittivity as a function of frequency. The advantages of TDS are that it has a wide frequency response and can

measure small (less than 1 ml) conductive samples. The technique is also ideally suited to measure tissue as well as solutions. Recent data on the lens of rabbit's eyes also are presented.

6146 HEAT TRANSFER AND CONDUCTION IN RADIO-FREQUENCY HEATING (MEETING ABSTRACT). *(Eng.)* Strang, R. (West of Scotland Health Boards, Dept. Clinical Physics and Bioengineering, 11 W. Graham St., Glasgow G4 9LF, Scotland); Patterson, J. *Br J Radiol* 51(611): 934; 1978. (0 refs)

Radio frequency hyperthermia is discussed with respect to heat transfer and conduction. In this heating modality the tissue to be heated is placed between two electrodes and a high-frequency alternating current is passed between them. The main advantage of this type of heating over other techniques is that it is possible to achieve heating at depth. Several factors affect the distribution of temperature produced by this technique, including differences in electrical impedance and specific heat, conduction of heat out of the heated volume and the transfer of heat by blood flow. Differences in electrical impedance and specific heat give rise to preferential heating in some tissues. In particular, if the tissues are in series, the relative temperature rise in fat and bone is much greater than in muscle (18:1 fat, 27:1 bone). After heat is deposited in a tissue there are processes that modify the resulting temperature distribution. One such process is the flow of blood through the tissue. Blood flow has two main effects: (1) for a given rate of production of heat in a tissue the temperature produced is limited to a certain value dependent on the blood flow; and (2) the temperature subsequently produced in normal tissues varies widely due to the large range of blood flows encountered.

6147 ATHERMAL EFFECTS OF MICROWAVES AT THE CELLULAR LEVEL (MEETING ABSTRACT). *(Eng.)* Ramsey, N. W. (Medical Physics Dept., Charing Cross Hosp., London W6 8RF, England). *Br J Radiol* 51(611): 935; 1978. (5 refs)

Investigations concerning the athermal effects of microwaves at the cellular level are reviewed. Cataract formation was induced in the lens of rabbit eyes by exposure to 12.2 cm wavelength radiation. A roughly reciprocal relationship was found between incident power and exposure time required, but at less than 40 mW/cm^2 incident power, virtually unlimited exposure could be tolerated. Using 1.25 cm wavelength it was found that an exposure of 5 min duration was sufficient to impair production of testosterone in the rat testes even though histologic examination revealed no obvious damage. This treatment produced a slight temperature rise but a comparable temperature rise induced by exposure to infrared radiation did not impair testosterone production. The absorbed power was less than 250 mW/cm^2. Embryonic chick hearts exposed to 1.25 cm wavelength radiation at an incident power of 74 mW/cm^2 and for durations up to 3 min showed gross changes in the electrocardiographic pattern. Evoked potentials were recorded from an electrode in the brain stem of a cat exposed to pulsed radiation at 20 cm to 25 cm wavelength, and peak power level of 60 mW/cm^2. The effect of 12.2 cm radiation on the intercellular reaction between mouse macrophages and a suspension of human erythrocytes was to depress phagocytosis. The effect was found to be transient, recovery taking place when the irradiation ceased. The incident power level was 50 mW/cm^2 with exposures lasting up to 30 min. Erythrocytes from rabbit venous blood and granulocytes isolated from the peritoneal cavity of the rabbit, following exposure to 10 cm wavelength radiation in vitro showed evidence of damage. An incident power of less than 10 mW/cm^2 for a period of 1 hr was sufficient to produce a loss of potassium from erythrocytes, indicating interference with the sodium-potassium pump. Hemoglobin loss from the erythrocytes occurred at an incident power of less than 10 mW/cm^2, and the osmotic resistance of the lymphocytes indicated some degree of cell damage for a similar exposure. Incident powers as low as 5 mW/cm^2 for periods of less than 1 hr were sufficient to kill a proportion of granulocytes, as demonstrated by nigrosin staining. If cells in the blood are readily damaged by such low power levels, the implications could be far reaching in that however radiation may be applied to the body, some fraction of the blood will always be irradiated. It is concluded that carefully quantitated data on the athermal effects of ultra high frequency (UHF) radiation on intact animals is an essential prerequisite to the use of UHF heating for the production of hyperthermia in humans.

6148 EVALUATION OF THE PERTH EXPERIENCE IN TREATING WITH IONIZING RADIATIONS AND VHF (434 MHz) RADIATIONS (MEETING ABSTRACT). *(Eng.)* Caldwell, W. L. (Div. Radiation Oncology, Dept. Human Oncology, Univ. Wisconsin Center for Health Sciences, Madison, WI 53706). *Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 120-121; 1978. (1 ref)

The results of a series of 52 patients with advanced head and neck cancer treated with ionizing radiation in combination with 434 MHz very high frequency (VHF) radiation are reported. Included were cancers of the tonsil (8), pharynx (5), anterior tongue (5), floor of the mouth (4), soft palate (4), supraglottic larynx (4), larynx (4), maxilla (3), and other sites (15). The patients were administered doses of irradiation that were consistently lower than those used conventionally. The doses for the 18 patients with extensive disease who survived ranged from 4,000 rad/6 wk to 6,300 rad/7 wk (one patient was administered 2,500 rad/4 wk) with three patients having gold grain implant boosts; only six patients had doses in excess of 5,500 rad/6 to 7 wk. The doses in the 19 patients who died within 2 or more yr of completion of treatment were slightly lower, with only two patients being irradiated above 5,500 rad/6 to 7 wk. The treatment approach was not consistent; the site and extent of disease at the time of treatment varied sufficiently that individualization of treatment was felt unnecessary. Most of the pa-

tients were exposed to 434 MHz radiation in a Tronado unit (three rings of 434 MHz diathermy units, each ring composed of four units) for 20 to 30 min before treatment with ionizing radiation. Six to 18 exposures to VHF radiation were used, but generally these were expected to be between 39 C and 40.5 C. At this temperature for 20 min there is no cell kill from the heat, but there is sensitization to ionizing radiation. Normal tissue tolerance was excellent.

6149 THERMAL DISTRIBUTIONS FOR CLINICAL MICROWAVE HYPERTHERMIA (MEETING ABSTRACT). *(Eng.)* Kopecky, W. J. (Div. Radiation Oncology, Mallinckrodt Inst. Radiology, Washington Univ. Sch. Medicine, 510 S. Kingshighway, St. Louis, MO 63110); Perez, C. A. *Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 119; 1978. (0 refs)

A saline-filled bath was used to determine the thermal distribution for several clinically useful waveguide applicators used in microwave hyperthermia. The system utilized a saline-filled compartment placed within a temperature-controlled water bath set to 37.5 C. Thermal distributions were taken with a hypodermic thermistor probe placed perpendicular to the electric field. In this way longitudinal and transverse cross sections of the heat deposition due to microwave interaction with the saline bath could be elicited. A similar arrangement was carried out to determine the thermal distribution from these waveguides in a tissue phantom. Results using these techniques are compared with thermographic camera data on central axis, and cross sectional distributions. Additionally, the clinical significance of these results are discussed.

6150 CLINICAL HYPERTHERMIA AND RADIATION (MEETING ABSTRACT). *(Eng.)* Johnson, R. J. R. (Dept. Radiation Medicine, Roswell Park Memorial Inst., 666 Elm St., Buffalo, NY 14263); Bicher, H. I.; Clubb, B. S.; Sandhu, T. S.; Hetzel, F. W.; Kowal, H. S.; *et al.* *Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 119-120; 1978. (0 refs)

The potential application of hyperthermia in combination with x-irradiation was investigated using 2,450, 915, and 434 MHz microwaves for local tumor heating and whole-body hyperthermia for deep tumors. Local hyperthermia to 42.5 C will only produce tumor differential heating when the normal tissue perfusion rate exceeds that of the tumor. Hyperthermia at 42.5 C, applied immediately after x-irradiation, will cause a thermal enhancement ratio of 1.3:1.6 for both normal and tumor tissue. An improvement in the therapeutic ratio will result if the normal tissue can be maintained below 41 C. A pilot program using whole-body hyperthermia induced and controlled by a NASA environmental suit was used to assess the clinical feasibility of whole-body hyperthermia and x-irradiation and also to determine changes in distribution of regional and tumor blood flow, tumor PO_2 and pH. The relevance of these findings in relation to the potential use of whole-body hyperthermia and radiotherapy are discussed.

6151 MICROWAVE-INDUCED LOCAL HYPERTHERMIA IN COMBINATION WITH RADIOTHERAPY OF HUMAN MALIGNANT TUMORS (MEETING ABSTRACT). *(Eng.)* U, R. (Dept. Radiology, Duke Univ. Medical Center, Durham, NC 27710); Noell, K. T.; Woodward, K. T.; Worde, B. T.; Fishburn, R. I.; Miller, L. S. *Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 122; 1978. (0 refs)

A pilot study using microwave hyperthermia immediately following administration of ionizing radiation was undertaken to evaluate the response of normal tissues, the regression of cutaneous or subcutaneous tumors, and the practical feasibility of such combined modalities in therapeutic radiology. Ionizing radiation in individual fractions of 200-700 rad was used 2-5 times per week to total doses of 1,400-6,000 rad in 5-30 fractions. Microwave hyperthermia (42-43.5 C) was applied 2-3 times per week, maximum 14 sessions in 5 wk. The 20 patients treated had squamous cell carcinoma, adenocarcinoma, malignant melanoma, plasmacytoma, epithelioid sarcoma, and undifferentiated carcinoma. After over 150 microwave hyperthermia sessions, it was found that: (1) local hyperthermia with microwave alone or in combination with ionizing radiation can be used with excellent normal tissue tolerance provided local tissue temperatures are carefully monitored and controlled; (2) a significantly higher level of preferential heat induction into tumor tissue occurs as compared to surrounding normal tissues; and (3) repeated microwave hyperthermia at 42-43.5 C for 45 min/session immediately following photon irradiation yields a favorable therapeutic ratio, often with dramatic results. It is concluded that microwave hyperthermia in combination with radiotherapy has significant potential in clinical cancer therapy, whether of curative or palliative intent.

6152 MICROWAVE HEATING AND THERMAL SENSITIVITY OF MICROWAVE HEATED MOUSE MAMMARY TUMORS (MEETING ABSTRACT). *(Eng.)* Robinson, J. E. (Div. Radiation Res., Univ. Maryland Sch. Medicine, Baltimore, MD 21201); Cheung, A. Y.; Harrison, G. H.; Samaras, G. *Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 122; 1978. (0 refs)

Microwave heating techniques designed to heat tumors uniformly in mice are described. The technique employed tissue equivalent bolusing to minimize size and shape dependence of microwave absorption, and parallel opposed microwave beams to improve uniformity of energy deposition within the tumor. The techniques were used to quantitate the effects of microwave heating on mammary carcinomas in C3H mice under three conditions: tumors implanted on the flank and immersed in semi-solid gel, and flank tumors and leg tumors immersed in liquid bolus. All microwave irradiation was at a frequency of 2.45 GHz, and treatment temperatures ranged from 37.5 C to 44.0 C. Data from tumors heated in the semi-solid bolus yielded plots of tumor-volume-redoubling time versus treatment time that were shallower and had larger intercepts than data from tumors heated in water baths, which implied thermal non-uniformity of the microwave

heated tumors. Plots of thermal sensitivity versus treatment temperature were parallel to, but displaced upward from those obtained with water bath heating. The displacement suggested that at least some part of the microwave-heated tumors was about 1 C lower in temperature than the target temperature. To obviate thermal gradients, tumors were microwave heated in a well-stirred liquid bolus (20% ethanol in saline) maintained 0.1 C below the target temperature. Tumor regrowth curves determined with this heating technique were consistent with uniform tumor temperature. Plots of thermal sensitivity versus target temperature indicated that all parts of the tumor were at or slightly above those heated with water baths at the same target temperature. Prior to microwave heating, the thermal uniformity of leg tumors immersed in the liquid bolus but not microwave heated was studied. Temperatures in the interior of the tumor and adjacent to large blood vessels were 1 C or more below water bath temperature. Microwave heating markedly improved the temperature uniformity. Tumor regrowth curves were consistent with good thermal uniformity. Because of the marked thermal heterogeneity of these leg tumors without microwave heating, it was not useful to do regrowth studies by water bath heating. Therefore, it was not possible to directly compare the effects of microwave and water bath heating with the leg tumors. However, plots of thermal sensitivity of the microwave-heated leg tumors suggested a lower inherent thermal sensitivity or lower temperatures than with the waterbath heated flank tumors with the same target temperature.

6153 REOXYGENATION INDUCED BY LOCALIZED MICROWAVE HYPERTHERMIA AS AN ADJUVANT TO RADIATION THERAPY (MEETING ABSTRACT). *(Eng.)* Bicher, H. I. (Dept. Radiation Medicine, Roswell Park Memorial Inst., 666 Elm St., Buffalo, NY 14263); Hetzel, F. W.; Johnson, R. J.; Mitagvaria, N.; O'Hara, M. *Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 145; 1978. (0 refs)

Tissue oxygen levels (TPO_2) and local blood flow were determined on subcutaneous tumors in patients and in implanted leg tumors in mice, using a 100 μ tip floating oxygen microelectrode and a local hydrogen generation method. TPO_2 and response to 100% O_2 breathing were recorded on a Grass Model 7 polygraph, as well as temperature changes both on tissue surface and in-depth, as measured with needle thermocouples. Hyperthermia was induced with microwave irradiation at the frequency of 2,450 MHz. Tumor temperature was maintained below 40 C for 2 hr. There was an increase in TPO_2 that paralleled the rise in tumor temperature, which was sustained throughout the test period. The elevation in TPO_2 may also have been potentiated in some locations by the hyperthermia-induced increased local blood flow. In a separate group of mice, the temperature was elevated to 46 C in tissue and it was found that the TPO_2 decreased. These findings suggest an increased tumor blood flow, depending on the temperature changes up to 40 C, with a decrease in tumor blood flow above that temperature. The results in human tumors paralleled those obtained in animals. The possible influence of concomitant metabolic changes remains to be investigated. The influence of microwave-induced tumor oxygenation on the TCD_{50} and regrowth times of mouse leg tumors treated with x-irradiation was tested on four groups of 120 mice at 10 different dose levels. One control group received x-irradiation alone. The second, x-irradiation and hyperthermia (40 C), the third, x-irradiation with hyperthermia and O_2 breathing, and the fourth, x-irradiation and O_2 breathing alone. Preliminary results suggested that moderate hyperthermia may cause tumor reoxygenation.

6154 RADIOFREQUENCY INDUCED HYPERTHERMIA IN AFTERLOADING IRIDIUM 192 IMPLANTATION (MEETING ABSTRACT). *(Eng.)* Mantik, D. (Univ. Southern California Sch. Medicine, Dept. Radiation Medicine, Los Angeles, CA 90033); Puffer, H. W.; Astrahan, M. A.; Norman, A.; Roseboro, J. A.; Syed, A. M. N.; *et al. Int J Radiat Oncol Biol Phys* 4(Suppl. 2): 225; 1978. (0 refs)

A system for radio frequency current induced hyperthermic fields using afterloading needle guides as electrodes was developed for use in afterloading ^{192}Iridium therapy to achieve hyperthermic radiosensitization. Radio frequency current patterns and isothermal distributions were mapped. In vivo oxygen levels were measured using teflon-encased hydron-coated gold tissue electrodes, and point by point temperature mapping was performed. Initial results confirmed a rapid decline in temperature with distance from the electrodes, but the predicted rapid diffusion of heat from the implanted area was not encountered, and consistent maintenance of desired thermal levels was accomplished with a temperature regulation system using an implanted thermistor at the geographic center of the volume defined by the needle electrodes. This technique is effective in producing and monitoring homogeneous hyperthermic fields at depth without overheating more superficial tissues. In addition, monitoring of oxygen values is facilitated. The invasive nature of the technique is not an adverse consideration when used with afterloading ^{192}Iridium implantation. Extending the system to external radiotherapy applications, however, requires special indications. The technique and methods, phantom, animal, and human pilot studies are described.

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This quarterly digest presents current awareness information on the biological effects of nonionizing electromagnetic radiation (microwave and radio frequency) in the range of 0 Hz to 100 GHz. The effects of magnetic and electric fields (static and alternating) are also covered. Each issue contains abstracts of English and foreign current literature, summaries of ongoing research investigations, news items, and a directory of meetings and conferences.

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