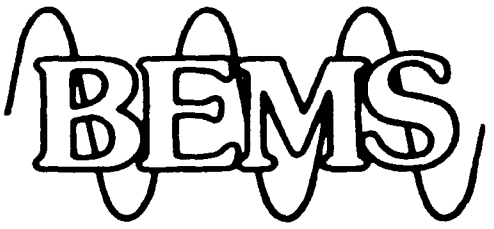

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THE BIOELECTROMAGNETICS SOCIETY

ELEVENTH ANNUAL MEETING 1989

ABSTRACTS

SESSION A-1:	SYMPOSIUM ON ELF FIELDS AND NEURO-ENDOCRINE FUNCTION
Moderator:	B. W. Wilson

A-1-1 NEUROENDOCRINE CONSEQUENCES OF PINEAL GLAND DYSFUNCTION.

Russel J. Reiter. Dept. of Cellular and Structural Biology, Univ. of Texas Health Science Center at San Antonio, 7703 Floyd Curl Drive, San Antonio, TX 78284-7762.

The pineal gland of animals and humans produces its chief hormonal product, melatonin, in a circadian manner with maximal production occurring during the dark phase of the daily light:dark cycle. The primary regulator of circadian melatonin production is the prevailing photoperiodic environment with the eyes perceiving the light which regulates the rhythm. The neural connections between the eyes and the pineal gland which mediate the effects of light on the pineal gland include the retinohypothalamic tract, suprachiasmatic nuclei (SCN), and pre- and postganglionic sympathetic neurons. In addition to light, exposure of rats to ELF influences circadian melatonin production within the pineal gland. Thus, the day:night rhythm of pineal melatonin is severely attenuated when animals are exposed to ELF fields; however, the rhythm is reestablished after the animals are removed from the ELF fields indicating there are no permanent deficits in the system induced by ELF exposure. The most likely receptor of the fields is the retina with the melatonin rhythm being attenuated because of altered communication between the nervous system and the pineal gland. Normally, the melatonin rhythm is very stable and its perturbation by ELF fields is, therefore, highly significant. The altered melatonin cycles may have a gamut of neuroendocrine consequences including changes in endocrine and especially reproductive physiology, alterations in circadian rhythms, and perhaps effects on immune responses and tumor incidence and growth. These changes may greatly change the ability of an organism to adapt to its environment. Supported by NSF grant # DCB 11241.

A-1-2 SEASONAL AFFECTIVE DISORDER: PINEAL FUNCTION AND DEPRESSION IN HUMANS.

A. J. Lewy. Departments of Psychiatry, Ophthalmology and Pharmacology, Oregon Health Sciences University, Portland, OR 97202.

Plasma melatonin levels are exclusively derived from the pineal gland. Unlike other markers for circadian phase, melatonin is relatively unaffected by masking effects due to acute changes in rest, activity and sleep. We have shown that bright light affects melatonin production and must be avoided around sampling time, therefore we use the dim light melatonin onset (DLMO) to mark circadian phase. Accordingly, following our discovery that bright light suppresses nighttime melatonin production in humans, we have shown that - holding the activity-rest cycle constant - bright light in the morning advances the human melatonin circadian rhythm and that bright light in the evening delays it. The DLMO is therefore a useful marker for determining the effects of appropriately bright light on phase-shifting human circadian rhythms. Certain types of patients may have abnormal circadian rhythms. We have proposed that, in addition to abnormally phase advanced circadian rhythms, some patients with sleep and mood disorders may be normally phase delayed. We further think that patients with chronobiologic mood disorders differ from patients with circadian rhythms that are more phase shifted than

sleep. Accordingly, we have found that most winter depressive patients have abnormally delayed DLMO's with respect to real time and to sleep, and that these patients' depressions respond best to bright light when it is scheduled in the morning, at which time it provides a corrective phase advance of the DLMO. Alternatively, these patients also respond to delaying their sleep, which also closes the phase angle between their sleep and their other circadian rhythms. The DLMO is particularly useful in these studies, because shifting sleep does not significantly affect the DLMO when the light-dark cycle is held constant.

A-1-3 **THE PINEAL GLAND AND CANCER.** David E. Blask. Department of Anatomy, University of Arizona, College of Medicine, Tucson, AZ 85724.

The pineal gland and its hormone melatonin have been implicated in the growth regulation of a variety of neoplasms including breast cancer, melanoma, sarcoma, leukemia and pituitary prolactinoma. In some cases, pinealectomy or exposure to constant light stimulates tumor growth presumably by eliminating the endogenous melatonin signal. On the other hand, either melatonin, or partially purified, melatonin-free pineal extracts have been shown to inhibit neoplastic growth. The relationship between pineal-melatonin and the growth of hormone-responsive breast cancer has shown great promise as a model system for elucidating some of the mechanisms mediating the pineal inhibition of oncogenesis. For example, melatonin administered as a series of daily, late afternoon injections inhibits the growth of carcinogen-induced mammary tumors in rats. This oncostatic effect of melatonin appears to be exerted during a "critical period" of tumor promotion rather than on tumor initiation. When the endogenous daily melatonin signal is removed by pinealectomy, the tumors become more sensitive to the cancer-inhibitory effects of melatonin. Melatonin's mechanism of action may involve an antagonism of the mitogenic effects of estrogen and prolactin at the level of the breast cancer cells themselves. Supported by NIH Grant CA-42424.

A-1-4 **ELF FIELD EFFECTS AND PINEAL FUNCTION IN HUMANS.** Bary W. Wilson. Battelle, Pacific Northwest Laboratories, Richland, WA 99352.

A number of reports in the literature now indicate that ELF electric or magnetic fields may affect nervous system or neuroendocrine function in animals and humans. In humans, such changes include observed changes in cardiac interbeat interval, and flicker fusion frequency perception. Recent experiments in our laboratory have indicated that human pineal gland function may also be affected by nightly exposure to ELF electric or magnetic fields. In these studies, urinary 6-hydroxy melatonin sulfate (6-OHMS) excretion was determined in 42 volunteers who used standard or modified electric blankets. Some of the subjects did demonstrate changes in 6-OHMS secretion in response to electric blanket use. This paper will present and discuss these latest findings and how they relate to results from animal studies that have shown analogous ELF field effects on pineal gland function. Possible consequences of putative ELF field-induced changes in human neuroendocrine function will also be explored. Supported by Electric Power Research Institute.

SESSION A-2: SYMPOSIUM ON ELECTROMAGNETIC THERAPY FOR CARDIAC ARRYTHMIA.

Moderator: J. C. Lin

A-2-1 **PHYSIOLOGICAL BASIS OF THE USE OF ELECTROMAGNETIC ENERGY IN THE TREATMENT OF CARDIAC ARRHYTHMIAS.** Robert J. Hariman and James C. Lin. Departments of Medicine and Bioengineering, University of Illinois, Chicago, IL 60680.

The occurrence of various types of tachyarrhythmias is dependent on certain electrophysiologic characteristics of cardiac structures. Modification or ablation of these structures by electromagnetic energy prevents and cures the arrhythmias. Therefore, ablation of the atrio-ventricular (AV) junction has been used to treat drug-refractory atrial fibrillation/flutter with rapid ventricular response, AV nodal reentry and in some cases of AV reentry, atrial tachycardia and other chronic supraventricular tachycardias. Ablation of the AV accessory pathway has been used to treat drug-refractory AV reentry and atrial fibrillation/flutter conducting through the AV accessory pathway. In some drug-refractory cases of atrial tachycardia due to enhanced automaticity of an atrial focus or due to a localized atrial reentry, ablation of atrial tissue responsible for the arrhythmia results in a good control. In cases of ventricular tachycardia occurring after myocardial infarction, the reentrant circuit responsible for the tachycardia is located at the endocardial site of tissue bordering the ventricular aneurysm. Ablation of this ventricular tissue results in cure or better response to antiarrhythmic drugs. The use of electromagnetic energy in the treatment of cardiac tachyarrhythmias requires careful analysis of the mechanism of the tachycardia and mapping of the site responsible for the arrhythmias.

A-2-2 **EFFECT OF SCATTERING IN MYOCARDIAL ABLATION WITH ND:YAG LASER IRRADIATION.** Daniel K. Bogen and Garrett J. Derbyshire. Department of Bioengineering, University of Pennsylvania, Philadelphia, PA 19104.

To test the hypothesis that tissue coagulation during high-power Nd:YAG (1.06 μm) laser-irradiation of heart muscle significantly alters tissue optical properties, absorption and scattering coefficients were measured in normal and coagulated samples of pig heart. Optical properties were derived from total transmittance and reflectance of laser light in thin slices of myocardium. In normal myocardium the scattering coefficient ($0.427 \pm 0.033\ mm^{-1}$) was found to be an order of magnitude greater than the absorption coefficient ($0.044 \pm 0.005\ mm^{-1}$). When the myocardium was coagulated, there was little change in the absorption coefficient ($0.051 \pm 0.009\ mm^{-1}$), but a four-fold increase in the scattering coefficient ($1.743 \pm 0.101\ mm^{-1}$). Further calculations indicate that coagulation-induced increase in the scattering coefficient during Nd:YAG ablation causes increased surface backscatter and reduced tissue penetration.

A-2-3 **RF ABLATION OF THE ATRIOVENTRICULAR JUNCTION IN HUMANS.** Jonathan Langberg. University of California, San Francisco, CA 94143-0214.

Catheter ablation of the atrioventricular (AV) junction using direct current defibrillator discharge requires general anesthesia and may have serious side effects. Twenty-one patients with drug-refractory supraventricular tachycardia underwent catheter ablation of the AV junction using radiofrequency energy. A standard 7Fr quadripolar catheter was used in the first 16 patients and a modified catheter with a larger electrode surface area in the subsequent five patients. The ablation catheter was positioned to record the largest unipolar His potential from the distal electrode. An electrocoagulator (Microvasive Bicap 4005) supplied continuous, unmodulated energy at 550 kHz. One to 14 applications of radiofrequency current were delivered between the distal electrode and a large diameter skin electrode. No patient had significant arrhythmias or blood pressure changes during radiofrequency ablation. Persistent complete AV block was produced in 14 to 21 patients and high-grade second degree AV block in one patient. Attenuated His bundle electrograms could still be recorded in the remaining six patients, four of whom underwent successful AV junction ablation using direct current shock during the same session. During 1 to 6 months of follow-up, none of the patients successfully treated with radiofrequency had recovery of conduction. We conclude that (1) catheter ablation of the AV junction using radiofrequency current appears to be safe and induced persistent AV block in 72% of patients and that (2) failure to achieve AV block with this technique does not appear to mitigate against successful application of direct current shock ablation.

A-2-4 **RADIOFREQUENCY ENERGY FOR CATHETER ABLATIVE PROCEDURES.** Frank I. Marcus, Leonard Blouin, and Kathy Gear. Department of Internal Medicine, University of Arizona, Tucson, AZ 85724.

Radiofrequency energy (RFE) for cardiac ablation ranges from 150 kHz to 1 MHz. RFE in this range can be readily transmitted through diagnostic electrophysiological catheters to ablate intracardiac structures including atrial and ventricular muscle, the A-V node or accessory bypass tracts. The major advantages of RFE for intracardiac ablation include the relatively low cost, small size and ease of operation of the RF generator, as well as the safety of this energy form since RFE does not induce ventricular fibrillation. The lesions produced are well circumscribed and their size can be well controlled. Also there is usually no need for general anesthesia since it does not induce painful tetanic muscle contraction. The major limitations are that blood coagulum can form on the catheter tip during the delivery of RFE causing increased impedance and inability to proceed with further ablation. Ablation with RFE causes well circumscribed injury and necessitates precise mapping techniques to localize the area required to ablate the arrhythmia. This sophistication is not yet available except for HIS bundle ablation. RFE is rapidly becoming the energy source of choice for ablation or modification of AV nodal function and for ablation of right sided accessory pathways. It should replace DC energy as soon as needed modifications of delivery and intracardiac mapping are forthcoming.

SESSION A-3:	SYMPOSIUM ON ELECTROMAGNETIC THERAPY FOR CARDIAC ARRYTHMIA (CONTINUED)
Moderator:	J. C. Lin

A-3-1 **MICROWAVE CATHETER ABLATION IN THE CANINE HEART.** James C. Lin[1], Karen J. Beckman[2], Yu-jin Wang[1] and Robert J. Hariman[2]. Department of Bioengineering[1] and Division of Cardiology[2], University of Illinois, Chicago, IL 60680.

Transvenous catheter induced complete atrioventricular block (AVB) has become an increasingly accepted method of treating selected patients with drug refractory, symptomatic supraventricular arrhythmias. The use of a microwave catheter with preferential power deposition at the tip for thermal ablation of cardiac conducting tissue has been demonstrated in both open heart and closed chest dogs. The catheter was constructed using flexible coaxial cables (1.78 mm OD or 6 French.) The entire catheter is insulated except for the tip which also serves as a bipolar recording electrode. In open-heart dogs, the tip of the microwave catheter was placed in the His bundle area localized by recording the His bundle electrograms (HBE) during cardiopulmonary bypass. In closed-chest dogs, the microwave catheter was inserted percutaneously through either the femoral vein or carotid artery, first to record a bipolar HBE and, then, to ablate the His bundle. Microwave energy was applied incrementally until temporary or permanent AVB occurred. The incident power varied from 50 to 100 W. With durations of application from 2 to 8 sec, the temperature at the catheter tip reached 80° C. Results indicate that transcatheter microwave energy can be used to cause temporary and permanent AVB. Permanent AVB was achieved in all dogs in which good HBE were obtained. Application of the microwave catheter technique in ablation of arrhythmogenic cardiac tissue may provide advantages over the currently existing techniques. As with other energy sources accurate localization of the HBE is necessary for successful ablation.

SESSION B-1:	RF AND MM WAVE EFFECTS ON NEURAL AND OCULAR SYSTEMS
Moderators:	H. Kues and H. Lai

B-1-1 **A COMPARISON OF THE EFFECTS OF LOW-LEVEL MICROWAVES AND WHITE NOISE ON NEUROLOGICAL FUNCTIONS IN THE RAT.** Henry Lai, Monserrat A. Carino, Akira Horita, and Arthur W. Guy. Departments of Pharmacology and Psychiatry & Behavioral Sciences, and the Center for Bioengineering, University of Washington School of Medicine, Seattle, WA 98195.

The effects of acute and repeated exposure to 2450-MHz, low-level, pulsed microwaves (1 mW/cm^2, average whole-body SAR 0.6 W/kg, 2-μsec pulses, 500 pps) and white noise (100 dB) on the actions of several psychoactive drugs and the activity of central cholinergic systems are compared. Similarities are found between the two stimuli. Furthermore, most effects elicited by microwaves and white-noise can be blocked by pretreatment with narcotic antagonist, suggesting the involvement of endogenous opioids. Since 100-dB white noise is a known "stressor" these data support the hypothesis that microwave irradiation elicits stress responses.

B-1-2 **NALTREXONE REVERSES THE EFFECT OF REPEATED LOW-LEVEL MICROWAVE EXPOSURE ON HIPPOCAMPAL MUSCARINIC CHOLINERGIC RECEPTORS.** Henry Lai, Monserrat A. Carino, Akira Horita, and Arthur W. Guy. Departments of Pharmacology and Psychiatry & Behavioral Sciences, and the Center for Bioengineering, University of Washington School of Medicine, Seattle, WA 98195.

In previous research, we showed that acute exposure (45-min) to pulsed (2 μsec, 500 pps) low-level 2450-MHz microwaves (1 mW/cm^2, average whole-body SAR 0.6 W/kg) caused a decrease in cholinergic activity in the hippocampus of the rat. This effect could be blocked by treatment with the narcotic antagonist naltrexone (Lai et al., J Neurochem 48:40-45, 1987). Repeated exposure (ten 45-min sessions) to the microwaves led to an increase in the concentration of muscarinic cholinergic receptors in the hippocampus (Lai et al., Pharm Biochem Behav, 1989, in press). In the present research, we found that the microwave-induced change in cholinergic receptors was blocked by pretreating the animals with naltrexone before microwave exposure sessions.

B-1-3 **NEUROGENESIS IN FETAL RAT CEREBRAL CORTEX AFTER EXPOSURE TO 2450 MHZ MICROWAVES.** Ernest N. Albert and Inder J. Jain. Department of Anatomy, The George Washington University Medical School, Washington, DC 20037.

Time pregnant Sprague Dawley rats at day 16 and 20 of gestation were exposed in the far field to 2450 MHz (CW) microwaves at 5 mW/cm^2 power density or sham exposed in the same anechoic chamber, with appropriate shielding, until day 21 of gestation. Average SAR was 0.46 W/kg with a range from 0.19-0.87 W/kg in the abdomen of 16 and 20 day pregnant rats. Pregnant dams were injected with a single dose of ^{3}H-thymidine (6 μCi/g body weight) intraperitoneally prior to starting irradiation. The observations reported below were gathered from 33 exposed and 33 sham exposed fetuses. Isotope labelled cells were counted in various layers of the cerebral cortex. Preliminary results indicate that there was a statistically significant decrease in the number of cells forming each layer of the developing isocortex of exposed fetal brains in contrast to sham exposed. This observation was more marked during early stages of cortical development. These results suggest that microwave exposure at the above parameters may affect neuronal proliferation and/or migration during early stages of brain development.

B-1-4 **SIMULTANEOUS INTRACELLULAR AND FLUORESCENCE MONITORING OF MINIATURE END PLATE POTENTIALS IN RAT NEUROMUSCULAR PREPARATIONS DURING MILLIMETER WAVE EXPOSURE.** Shirley Motzkin and Julie Feinstein. Department of Life Science/Chemistry, Polytechnic University, Brooklyn, NY 11201.

The effects of millimeter wave exposure on the transient membrane depolarizations caused by spontaneous neurotransmitter release at nerve-muscle junctions of the rat flexor digitorum brevis (RFDB) muscle were measured intracellularly with glass microelectrodes. Miniature end plate potentials collected from single fibers before, during and after continuous wave millimeter irradiation at 51.72 and 51.81 GHz and 5 mW/cm^2 were compared with respect to amplitude, duration, rise/fall time and frequency. Experiments were also performed on RFDB stained with the membrane potential sensitive dye, Merocyanine-540. In

our previously described system, a fiber optic interface with a fluorescence spectrophotometer allows the simultaneous excitation of fluorescence with emissions monitoring and intracellular electrical recording during microwave exposure. To date, significant treatment effects have not been observed. These experiments will be repeated with pulsed waves and tissue culture preparations.

B-1-5 **OCULAR CHANGES FOLLOWING EXPOSURE TO HIGH-PEAK PULSED 1.25 GHZ MICROWAVES.** H. A. Kues, D. S. McLeod, S. A. D'Anna[1], G. A. Lutty[1], C. Gambrill[2], and E. C. Elson[3]. The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20707; The Johns Hopkins Wilmer Ophthalmological Institute[1], Baltimore, MD 21205; ERCI Facilities Management Co.[2], Fairfax, VA; and Walter Reed Army Institute of Research[3], Washington, DC 20307-5100.

Previous studies have reported a number of ocular changes following exposure to low-level pulsed 2.45 GHz microwave radiation. This study is designed to investigate ocular changes that may be induced by high-peak power pulsed microwave exposures at 1.25 GHz. Anesthetized adult cynomolgus monkeys were exposed for four hours per day on two consecutive days to 1.25 GHz microwaves (10 μsec pulse width at 0.225 Hz). The peak power was 1 MW at an average *incident power density* of 12.5 mW/cm^2, producing an average SAR of 3.6 W/kg at the eye's center. Fluorescein iris angiography was performed following the last daily exposure. Wide field specular microscopy and standard slit-lamp examinations were conducted 24 hr later. Several animals were sacrificed for histopathologic examination after three 2-day exposure sessions spaced at 2-week intervals. Preliminary results indicate that ocular changes occur that are similar to those produced by 2.45 GHz radiation. Supported by the Walter Reed Army Institute of Research.

B-1-6 **PULSED MICROWAVE-INDUCED OCULAR PATHOLOGY IN NON-HUMAN PRIMATES.** H. A. Kues, D. S. McLeod, G. A. Lutty[1], S. A. D'Anna,[1] and J. C. Monahan[2]. The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20707; The Johns Hopkins Wilmer Ophthalmological Institute[1], Baltimore, MD 21205; and FDA Center for Devices and Radiological Health[2], Rockville, MD 20857.

We have demonstrated that exposure to pulsed microwave radiation damages the corneal endothelium and increases the permeability of the blood-aqueous barrier of non-human primates. Pretreatment with drugs used in glaucoma therapy significantly lowers the threshold for these effects. In an ongoing study, adult cynomolgus monkeys are exposed in repeated 3-day sessions (4 hr each day) to pulsed 2.45 GHz microwaves (10 μs, 100 pps) at power densities (PD) from 1 to 15 mW/cm^2 (SAR 0.26-3.9 W/kg) at the cornea surface. Sessions are $\geq$ 2 wk apart and sometimes involve drug pretreatment. Specular microscopy and iris angiography are performed after each session. Endothelial lesions and iris vascular leakage occur down to 1 mW/cm^2 (with drug pretreatment). Histology (after several sessions) shows pathological changes for PD $\geq$ 5 mW/cm^2. Changes include: formation of macro-melanosomes and melanosome complexes in the ciliary body pigment epithelium and choroidal melanocytes; vacuolation of the iris posterior pigment epithelium; and disruption of photoreceptor outer segments. One animal exposed up to 15 mW/cm^2 had retinal damage including a detachment in the macula and pigment epithelial pyknosis. Supported in part by the US Navy and the FDA Center for Devices and Radiological Health.

B-1-7 **MICROWAVE-MELANIN INTERACTION: A HYPOTHETICAL BASIS FOR OCULAR DAMAGE.** H. A. Kues, and J. C. Monahan[1]. The Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Road, Laurel, MD 20707; FDA Center for Devices and Radiological Health[1], Rockville, MD 20857.

Preliminary evidence from several studies strongly implicates melanin as an intermediary in the production of microwave-induced ocular damage. The physical properties of melanin and its ability to either produce or release free radicals lend credence to this hypothesis. Histological examination of various ocular structures following microwave exposure has demonstrated that the primary pathology is found in melanin-containing cells or in close physical proximity to these cells. Examination of ocular tissues following microwave exposure with electron spin resonance (ESR) has shown an increase in the inherent melanin signal. In addition, a preliminary in vitro study suggests that B-16 melanoma cells have a decreased survival following microwave exposure when compared to amelanotic controls. These experimental findings strongly implicate a melanin-microwave interaction. Under a variety of conditions (e.g., exposure to blue light, ultrasound) melanin can generate free radicals which are capable of producing tissue damage. On the basis of the above experimental evidence, we hypothesize that microwave absorption by melanin or melanin complexes results in the generation or release of free radicals, which in turn produce the cellular damage we have observed. Other reported microwave-induced biological effects could also be explained on the basis of such an interaction. Additional studies are currently underway to confirm this hypothesis. Supported in part by the US Navy and the FDA Center for Devices and Radiological Health.

SESSION B-2:	**PULSED AND ELF FIELD EFFECTS - *IN VITRO* STUDIES**
Moderators:	I. Nordenson and B. Greenebaum

B-2-1 **GENETIC EFFECTS ON HUMAN CELLS AFTER EXPOSURE TO WEAK LOW FREQUENCY MAGNETIC FIELDS.** Ingrid Nordenson, Kjell Hansson Mild, Monica Sandström and Mats-Olof Mattsson. National Institute of Occupational Health, Medical Division, S-900 06 Umeå, Sweden.

Human amniotic cells have been exposed to low-frequency magnetic fields during the exponential phase. The cells were exposed in petri dishes placed in a vertical field created by a pair of Helmholtz coils. Two different types of waveforms were used: (1) an ordinary 50-Hz sinusoidal signal with a flux density of 30 μT (rms) and (2) a 20-kHz sawtooth waveform with 45-μsec rise time and 5-μsec fall time, peak-to-peak amplitude 16 μT. The total exposure time was 72 hr after which the cells were analyzed for chromosome aberrations and effects on growth. The cultures exposed to the 50-Hz magnetic field showed an almost 3-fold increase in number of cells with chromosome aberrations when compared with the controls ($p < 0.001$). Also the exposure to the 20-kHz field showed an increase in number of cells with chromosome aberrations versus the controls, although not statistically significant ($p = 0.06$). Measurements of the DNA synthesis showed an inhibition after exposure to the sawtooth shaped signal whereas the exposure to the sinusoidal magnetic field

both showed inhibition and stimulation in the various experiments. Large interexperimental variation was at hand, which is interpreted to be due to the heterogeneity of the cell populations. Mitogen stimulated human lymphocytes have also been exposed to sinusoidal 50-Hz magnetic field with a flux density of 30 μT. The preliminary results show no increase in chromosome aberrations when compared with controls.

B-2-2 **EFFECT OF PULSED MAGNETIC FIELD EXPOSURE ON CELLULAR LEVELS OF *RAS* P21 IN A HUMAN LEUKEMIA CELL LINE.** Jerry L. Phillips and Linda McChesney. Cancer Therapy & Research Center, 4450 Medical Drive, San Antonio, TX 78229.

CCRF-CEM cells, originally derived from a patient with acute lymphoblastic leukemia, have been exposed to an asymmetric EM signal pulsed at 72 Hz for periods of time from 30 min to 28 hr. After cell lysis, the cells were extracted and the extract electrophoresed on SDS-polyacrylamide gels. Proteins were electroblotted onto nitrocellulose membranes and the product of the ras proto-oncogenes, p21, was identified and quantitated by successive treatment with pan ras p21 antibody, second antibody-alkaline phosphatase conjugate, and the enzyme substrate BCIP. No change in p21 levels were observed for the first 6 hr of EMF exposure as compared to unexposed control cells. However, between 6- and 16-hr exposure, p21 levels in exposed cells fell linearly to only 30% of control values. Between 16-27 hr, p21 levels in exposed cells increased linearly and returned to control cell levels. Northern analyses of total cellular RNA indicated that the effect of EMF exposure was, at least in part, on gene transcription. Also, EMF exposure for up to 24 hr produced no changes in cellular levels of cyclic AMP. Furthermore, exposure for either 24 or 48 hr did not induce cell differentiation as judged by flow cytometric analysis of cell surface markers. While the significance of the marked reduction in cellular p21 is unclear, the relationship between changes in p21 levels and membrane related events will be discussed. This work supported by a grant from the Morrison Trust.

B-2-3 **APPARENT REGULATION OF THE PEMF RESPONSE BY THE B-ADRENERGIC RECEPTOR.** J. T. Ryaby, S. Tannenbaum, and A. A. Pilla. Bioelectrochemistry Laboratory, Department of Orthopaedics, Mount Sinai School of Medicine, New York, NY 10029.

Pulsing electromagnetic field (PEMF) stimulation is capable of inducing differentiation in the murine melanoma cell line Cloudman S91. Analysis of the mechanism of action of PEMF at the receptor level has demonstrated involvement of adenylate cyclase and cAMP dependent protein kinase (PKA) in these effects. In this study, we demonstrate that the β-adrenergic receptor system regulates sensitivity to PEMF stimulation. Cloudman melanoma cells are grown in Hams F10 medium containing 15% Horse serum/2.5% Fetal Bovine serum and plated at a density of 20,000/cm^2. Partial synchronization and pharmacological sensitization are performed by incubating the cultures for 24 hr in F10 with 0.1% BSA. PEMF stimulation was applied with 10-cm coils in a 5% CO_2/20% O_2/75% N_2 atmosphere using a clinically active repetitive pulse burst signal (200 μsec main polarity, 20 μsec opposite polarity, 5 msec burst, overall frequency 15 Hz). dB/dt in the main polarity is 0.1 G/μsec corresponding to an induced electric field of 1 mV/cm. PKA activity was measured using the synthetic peptide, Kemptide. In short term experiments (5-30 minutes) PEMF stimulation of adenylate cyclase is enhanced from 2-5 fold when

the β-adrenergic response to isoproterenol (IPT, 10 μm) is maximal (>10 fold). In order to assess the role of desensitization in the PEMF response, pretreatment of cells with IPT for 48 and 72 hours was performed. Pretreatment with IPT decreased the short term stimulation of adenylate cyclase by 50% as opposed to control. The MSH response was not affected by this pretreatment. In accordance with the short term data, pretreatment with IPT decreased the PEMF induced tyrosinase stimulation by 40%. Since MSH response is not affected by pretreatment, the β-adrenergic receptor may be the regulator of sensitivity to PEMF stimulation.

B-2-4 **B-GALACTOSIDASE CONCENTRATION DECREASES IN *E. COLI* AFTER EXPOSURE TO TIME-VARYING MAGNETIC FIELDS.** E. M. Goodman, B. Greenebaum, and M. T. Marron[1]. Biomedical Research Institute and Division of Science, University of Wisconsin-Parkside, Kenosha WI 53141; and Office of Naval Research[1], Arlington, VA 22201.

Application of pulsed and sinusoidal magnetic fields has produced reproducible decreases in the level of β-galactosidase in E. coli. In our research program, we have been searching for clues to the biophysical mechanism of interaction between electromagnetic fields and biological organisms. We have previously seen changes in general physiological processes such as mitosis, respiration, and ATP levels that appeared only after weeks of exposure and in more specific membrane characteristics that required exposures of a day or more. Changes in this enzyme are detectable after exposures shorter than 1 hr. We suggest that shorter times before detectable changes may mean fewer intermediate steps between the interaction mechanism and the synthesis of this enzyme. The sinusoidal field frequencies were chosen to represent the various frequency ranges present in the Fourier decomposition of the pulsed field; certain of these are more effective than others in changing enzyme concentrations. (Supported in part by ONR.)

B-2-5 **EFFECT OF A TRANSIENT EXPOSURE TO A PULSED MAGNETIC FIELD UPON ORNITHINE DECARBOXYLASE ACTIVITY IN CULTURED CELLS.** Craig V. Byus, Jennifer L. Harrington, and W. Ross Adey[1]. Division of Biomedical Sciences and Department of Biochemistry, University of California, Riverside, CA 92521; and Jerry L. Pettis Memorial Veterans Hospital[1], Loma Linda, CA 92357.

Ornithine decarboxylase (ODC) is the rate-limiting enzyme in polyamine biosynthesis. ODC activity has been reported to increase following treatment of tissues and cells with the phorbol ester tumor-promoting agents, and during certain preneoplastic states. We have shown previously that the enzyme ODC can be increased in activity inside of cells following exposure of these cells to low energy 60-Hz electric fields and that ELF microwave fields amplitude-modulated at 16 to 60-Hz lead to a rapid increase in the enzyme ODC via athermal mechanisms. In the study presented here we have investigated the ability of a 1-hr pulsed magnetic field to lead to an increase in ODC activity in cultured Reuber H35 hepatoma cells. Parallel helmholtz coils were used to deliver a 72-Hz, 325-msec pulsed magnetic field of peak intensity of 8 G, with an overshoot of opposite polarity lasting 5 msec and 20% of the amplitude of the main deflection. When this field was applied to the cultured hepatoma cells an increase in the activity of ODC was observed at 2, 3 and 4 hr following the 1-hr pulsed field. Sham-exposed cultures showed no alterations in ODC activity. ODC activity was observed to increase approximately 65%

greater than the sham-exposed cells. These studies indicate that increases in ODC activity in cells or animal tissues may serve as a very sensitive marker for exposure to either electric, microwave ELF, or magnetic fields. (These studies have been supported by DOE Contract DE-AI01-85CE76260).

B-2-6 EFFECT OF ELF PULSED MAGNETIC FIELDS ON KERATINOCYTE PROLIFERATION *IN VITRO*.

Neena Nirsimloo, Roy Smith[1], Mary Dyson, and Richard Dixey[1]. Department of Anatomy, United Medical and Dental Schools (Guy's Hospital), London, SE1 9RT, UK; and Department of Medical Electronics, St. Bartholomew's Hospital[1], London, EC1A 7BE, UK.

Transformed guinea pig keratinocytes (TK) were cultured in Dulbecco's Modified Eagle's Medium supplemented with 1% fetal calf serum (FCS), penicillin (25 units ml^{-1}) and streptomycin (25 μg ml^{-1}) for 4 wk, before a 30 min exposure to a pulsed magnetic field (PMF). The waveform was derived from a half-wave rectified sinusoid. The effects of frequency (10, 16.7, 50 Hz with an amplitude of 5.1 mT) and amplitude (0.6, 2.3, 4.2, 4.9, 5.1 mT at 16.7 Hz), on TK proliferation were investigated. Proliferation was assessed daily for 5 days using photometry. Exposed TK showed an increase in proliferation, with a peak at day 3. At 16.7 Hz this peak increase was significantly greater ($p < 0.05$) than the control level at all amplitudes: the largest effect was obtained at 5.1 mT, the smallest at 2.3 mT. All frequencies gave a significant ($p < 0.05$) increase over control at day 3; the most efficacious was 16.7 Hz, the least 10 Hz. By day 5 cell numbers had decreased to control levels. This may be due to the depletion of essential nutrients or to the accumulation of cytotoxic factors; replacing the original culture medium at day 3 maintained the initial increase in proliferation. Additionally, TK were exposed at 16.7 Hz, 5.1 mT PMF at FCS concentrations in the range 1-10%. At concentrations less than 5%, PMF had a stimulatory effect which was masked at higher concentrations. We conclude that PMF causes a frequency and amplitude dependent enhancement of TK proliferation, which is modified by factors in the culture medium.

B-2-7 CHANGES IN DOPAMINE PATTERN OF CLONAL NERVE CELL LINE EXPOSED TO 50 HZ ELECTRIC FIELD.

L. Zecca, A. Vescovi[2], P. Ferrario, G. Malanca[2], F. Bersani[1], and E. Parati[2]. CNR-ITBA, Milano, Italy; Physics Dept., University of Bologna[1], Bologna, Italy; and C. Besta Neurology Institute[2], Milano, Italy.

The purpose of this study was to determine whether exposure to ELF electric fields influences the dopamine synthesis release and metabolism in isolated PC12 nervous cells. Cultures were exposed for 3, 8, 12, or 24 hr in RPMI medium to 50-Hz electric field (0.1 and 1 kV/m). After 24 hr the field was turned off and cells monitored for 10 hr more. Dopamine and its main metabolite 3,4-dihydroxyphenylacetic acid (DOPAC) inside the cells and released in medium were measured and expressed relative to cellular proteins. In exposed cultures (1 kV/m) an increase was noted at 24 hours in DOPAC levels (21%, $p = 0.025$) released into the medium which disappeared after 10 hours of field-off conditions. The intracellular content of dopamine rose (29%, $p = 0.006$) the 12th hour in field-exposed cultures. No significant changes were observed in cells exposed to 0.1 kV/m. These data show that only in the presence of the higher field dopamine synthesis at first is stimulated then followed by an increase of its metabolism.

SESSION B-3:	CALCIUM EFFECTS AND ELF - *IN VITRO* STUDIES
Moderators:	C. F. Blackman and H. Bassen

B-3-1 **IMPROVED DOSIMETRY IS NEEDED FOR ELF *IN VITRO* RESEARCH.** H. Bassen, T. Litovitz[1], and R. Meister[1]. Walter Reed Army Institute of Research, Washington, DC 20307-5100; and The Catholic University of America[1], Washington, DC 20064.

Many experiments have been performed in vitro to study the biological effects of extremely low frequency (ELF) electromagnetic (EM) fields. While a uniform external magnetic field strength (B) is often used to expose biological materials, often no measurements or estimates are performed to quantify the magnitudes of the internal EM dosimetric parameters - current density (J) and electric field strength (E). Even when a highly uniform external B field is used to expose relatively homogeneous samples in a symmetric, dielectric sample holder, the spatial distribution of E and J in the sample are highly nonuniform. For the case of a petri dish containing a thin layer of cells in an aqueous buffer solution, the magnitudes of E and J increase from zero in the geometric center of the dish, to a maximum value at the periphery of the biological medium. This occurs for any orientation of the dish, in a plane that is perpendicular to the B field. Also, the magnitudes of E and J throughout the media can, in certain orientations, be proportional to the volume of the buffer solution in the sample holder, as well as the magnitude and frequency of the external exposure field. Therefore, if measured or calculated dosimetric data are not obtained and published along with observed biological effects, any attempts by others to replicate the experiment can easily produce contradictory results. This is due to the difficulty of reproducing the same internal EM environment, and the unavoidable nonuniformity of the internal EM parameters. We have developed an exposure system to produce relatively uniform J and E values throughout an in vitro sample. It consists of a special coil configuration and a unique sample holder - a modified petri dish with annular rings. Measured data confirms the uniform distribution of J and E throughout the biological medium being exposed.

B-3-2 **CALCIUM METABOLISM AND INTRACELLULAR PH IN THE LYMPHOCYTE DURING INTERACTION WITH TIME-VARYING MAGNETIC FIELDS.** R. P. Liburdy and B. Fingado. Bioelectromagnetics Research Facility, Research Medicine and Radiation Biophysics Division, Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720.

Fluorescent probes have been used to investigate the effects of oscillating and static magnetic fields on calcium metabolism and intracellular pH in the lymphocyte. We have previously demonstrated that the rat and the human lymphocyte exhibit a membrane structural transition at 37° C, as detected by calcium and sodium transport activity. Lymphocytes display enhanced transport activity in the presence of microwaves and static magnetic fields only at or near 37° C. Arrhenius analyses of calcium transport during exposure to 60 Hz and 38 Hz fields, under conditions of ion resonance, have revealed that at or near 37° C rat lymphocytes experienced an increase in net calcium transport. Fluorescence studies using FURA-2 to measure free intracellular calcium $[Ca^{++}]_i$, have shown that free intracellular calcium rises monotonically over a similar 2-hr exposure conducted at 37° C. This has been confirmed using a

second fluorescent probe INDO-1. Moreover, the fluorescent probe BCECF, which is sensitive to intracellular pH, detects a concomitant drop or acidification in intracellular pH. This is consistent with and supports the findings that Ca^{++} rises monotonically in response to ELF fields. These and other fluorescent probes are being used in in vitro studies to investigate the effects of varying field strength, frequency, and exposure duration. This work is supported by the Director, Office of Energy Research, Office of Energy Storage and Distribution, of the US Department of Energy under Contract DE-AC03-76SF00098.

B-3-3 ACTIVATION AND PROLIFERATION OF NORMAL AND LEUKEMIC T-LYMPHOCYTES EXPOSED TO MAGNETIC FIELDS UNDER CALCIUM CYCLOTRON RESONANCE CONDITIONS.

Daniel B. Lyle, Robert D. Ayotte, Zinghua Wang, Asher R. Sheppard, and W. Ross Adey. Jerry L. Pettis Memorial Veterans' Hospital, Loma Linda, CA 92357.

We have initiated experiments to evaluate the ability of a weak, alternating magnetic field meeting the conditions for calcium ion cyclotron resonance (20 μT; 13.6 Hz for ^{45}Ca, 15.3 Hz for ^{40}Ca) for the horizontal component (20 μT) of the local static magnetic field to influence lymphocyte activation and proliferation. The sinusoidal field was generated by a Helmholtz coil pair. Test cultures were compared to a sham culture located in the same incubator (37 ± 0.5° C) in a mu-metal box 120 cm from the Helmholtz coils, and also to a control culture located in a separate incubator at the same temperature. Cell proliferation was directly measured by double-blinded cell counts of EL4 cancer lymphocytes after a 3-day exposure to the fields in T25 culture flasks. EL4 proliferation was significantly increased (by 9%-125%) in 4 out of 4 experiments over sham and separate incubator cultures. These data suggest that the growth of cells in situ might be increased by the appropriate combination of an alternating magnetic field with the local geomagnetic field. Cell activation and proliferation of normal lymphocytes will be measured by ^{3}H-thymidine uptake at Day 4 of a murine mixed lymphocyte reaction conducted in microtiter well plates. (Supported by the US Dept. of Energy Office of Energy Storage and Distribution, the Dreyfus Medical Foundation, and the General Motors Medical Research Institute).

B-3-4 RESPONSE OF AN *IN VITRO* BRAIN-TISSUE PREPARATION TO EXTREMELY LOW-INTENSITY ELECTRIC AND MAGNETIC FIELDS.

C. F. Blackman, L. S. Kinney, D. E. House, S. G. Benane, and W. T. Joines. Health Effects Research Laboratory, US Environmental Protection Agency, Research Triangle Park, NC 27711.

Many aspects of the interaction of electric and magnetic (EM) fields with biological systems have been demonstrated by an assay using the release of calcium ions from in vitro preparations of chicken brain-tissue. These findings include: 1. the non-thermal nature of the response, 2. The primacy of the low frequency signal as the effective agent, 3. The influence of the local geomagnetic field (LGF) on the frequency effectivity, and 4. the multiple-windowed dose response using modulated radiofrequency radiation (RFR). In this report, we describe a multiple-windowed dose response to extremely low frequency (ELF) fields that is consistent with the modulated RFR results. Brain tissues labeled with trace amounts of radioactive calcium were exposed for 20 min at 37° C in a custom-built transmission line to sinusoidal EM fields between 1 and 60 Hz, at electric field intensities between 8 and 32

μV(rms)/m (in air) and magnetic-field flux densities between 36.0 and 144.2 fT (0.360 and 1.44 x 10^{-9} G). The results demonstrate that exposure to 16-Hz fields enhances the release of calcium ions only within two intensity windows. Further, at an effective 16-Hz dose rate, 15-Hz fields are effective while 1, 30, 35, and 60 Hz are not. The exquisite sensitivity of this brain tissue preparation to EM fields calls for a re-examination of the role for ephaptic transmission in the central nervous system, and a search for similar mechanisms involving magnetic fields, especially as they might be influenced by exogenous EM signals. This is the abstract of a proposed presentation and does not necessarily reflect EPA policy.

C-1, C-2, C-3: Joint Sessions with Bioelectric Repair and Growth Society and Bioelectrochemistry Society

SESSION C-1: SYMPOSIUM ON APPLICATION OF TIME-VARYING FIELDS FOR TISSUE HEALING

Moderators: R. K. Aaron and C. A. L. Bassett

C-1-1 DO PEMF'S HAVE A LEGITIMATE ROLE IN MEDICINE AND BIOLOGY.

C. A. L. Bassett. Columbia University, Bioelectric Research Center, Riverdale, NY 10463.

Pulsed electromagnetic fields (PEMFs), in clinical use for more than 15 years, were approved by the FDA 10 years ago, and have been used therapeutically in more than 100,000 patients. Yet contention still exists concerning efficacy. In fact, members of the FDA Orthopaedic Advisory Panel recently rejected a PMA of PEMFs on this basis. Fifteen years of clinical and laboratory data raise serious questions about this rationale. Several statistically significant double-blind studies confirm biological and clinical effects of selected PEMFs. Furthermore, carefully controlled experiments have defined mechanisms of action at the cellular and subcellular levels pertinent to control pathologic processes treated with PEMFs. The mechanisms include effects on cell migration and orientation, on angiogenesis, on synthesis and degradation of extracellular macromolecules (e.g. collagen and proteoglycans), on cellular calcium, and on mineralization patterns. Field energetics (e.g. amplitude and frequency "windows") and orientation and the type and state of cell function appear to determine responses. Since PEMF energetics were designed to be similar to electromagnetic events occurring, naturally, in skeletal tissues when they are dynamically deformed, it is not surprising that selected, inductively-coupled fields can affect the behavior of skeletal cells. Therapeutic use of PEMFs stands on a firmer foundation than many orthopaedic surgical procedures, the efficacy of which rarely is questioned, despite a paucity of mechanistic and double-blind data for surgical approaches.

C-1-2 **PULSED ELECTROMAGNETIC FIELD (PEMF) AND EXTRACELLULAR MATRIX-INDUCED CHANGES IN PULMONARY MICROVASCULAR ENDOTHELIAL CELLS (PMB) AND ONTOGENETICALLY-RELATED PERICARDIAL MESOTHELIAL CELLS (PMC).** G. P. A. Yen-Patton, W. F. Patton, N. Chung-Welch, and D. Shepro. Boston University, Boston, MA 02215.

Previously, we demonstrated that umbilical vein endothelial cells rapidly reorganized into vessel-like structures in the presence of a PEMF used clinically for the treatment of nonunion bone fractures (Yen-Patton et al., (1988) J Cell Phys 134:37-46). In this study we demonstrate that microvascular endothelial cells also form these structures after exposure to PEMFs but that ontogenetically related cell types do not. Mesothelial and endothelial cells are both mesodermally derived simple squamous epithelial cells derived from the splanchnic mesoderm. In vivo, endothelial cells form branching, tubular structures while mesothelial cells form sheets. Mesothelial cells form the single layer lining the pleura, pericardia, peritoneum, and the outer surfaces of the lungs, heart and viscera while endothelial cells line the blood vascular and lymphatic channels. Both cells were found to exhibit stringent contact inhibition and had microvilli on their apical plasma membrane surface. Both cells stained positively for Factor VIII, showed uptake of di-AC-LDL in 4 hours, and expressed low levels of angiotensin-converting enzyme when compared to macrovascular endothelial cells. Both had similar isoform profiles for vimentin, and actin. Both expressed the simple epithelial keratins, cytokeratins 8 and 19. PMC also expressed cytokeratin 18. PMC had 8 times as many 'stomata' as PMV. Only PMV could be induced to form branching tubes in vitro. Angiogenesis was induced by embedding cells in collagen 1 lattices, culturing them on reconstituted basement membrane protein gels or by applying a shaped-pulse electromagnetic field. Reorganization of PMV into vessel-like structures was more rapid and complete than PMC in all three angiogenic systems. PMV formed a branched network of anastomosing cells in 3 hours on Matrigel while PMC showed no structural organization though cells appeared polar and fibroblast-like. By 72 hours PMC formed simple coalescing structures while PMV formed thick, branched tubes. PMV in collagen 1 lattices formed simple, branched networks in 10 days while PMC only elongated in the gels. PMV exposed to pulsed fields formed long lamellipoidial extensions and unbranched linear tubes in 2-5 days. PMC formed lamellipoidial extensions, showed cell-cell alignment and coalesced into whorls in the presence of the pulsed field.

C-1-3 **PROSPECTIVE DOUBLE-BLIND STUDY OF PEMF'S IN INTERBODY LUMBAR FUSION.** Casey K. Lee. University of Medicine & Dentistry of New Jersey, Newark, NJ 07103-2757.

Seventy-six adult patients undergoing initial attempts at lumbar fusion were enrolled into a multicenter randomized double-blind clinical study to test the effectiveness of PEMFs in increasing fusion rates. Anterior or posterior interbody surgical technique was mandatory, though type of graft material was used as a stratifying variable. Independent, blinded radiographic view confirmed that 90.2% of active patients achieved solid fusion vs. 65.7% of placebo patients (significant at $p = .008$, Fisher's exact test). The treatment effect differential was observed consistently across all three categories of graft: autograft, allograft, and mixed. Among the categories, there did not appear to be any significant differences in outcome. This held true regardless of fusion level or number of levels but smoking had a profoundly negative effect only in cadaver graft placebo patients. This study

indicates a significantly increased rate of successful spinal fusion in the group with PEMF compared to the group with autograft alone and compared to the group with allograft alone.

SESSION C-2:	SYMPOSIUM ON APPLICATIONS OF TIME-VARYING FIELDS FOR TISSUE HEALING (CONTINUED)
Moderators:	R. K. Aaron and C. A. L. Bassett

C-2-1 **THE EFFECT OF PEMF'S ON CONNECTIVE TISSUE REPAIR.** Sylvia Fitton-Jackson and Sharyn Bord. Biophysics Section, Strangeways Research Laboratory, Cambridge CB1 4RN, UK.

Studies of connective and skeletal tissues grown in vitro and subjected to various pulsed electromagnetic fields, similar to those used in the clinic, will be reviewed. A characteristic feature of these results showed that a number of different biological processes, essential to the repair of connective tissues, were influenced to different degrees during their application. The suggestion was made that the response must lie within the levels of the inherent control systems to be effective; if not, they would be deleterious. An extensive program of experiment has now been undertaken to test the effects of precisely controlled sine waves on the same biological processes in similar systems in vitro. The results obtained to date indicate guidelines within which the physical parameters of the sine wave signal must conform to achieve a specific level of effect on one process. This information, by implication, provides some understanding of the way certain parameters of the clinical signals may influence repair processes.

C-2-2 **COMPARISON OF LOW-INTENSITY ULTRASOUND AND LOW-INTENSITY ELECTROMAGNETIC FIELDS FOR *IN VIVO* BONE REPAIR.** Arthur A. Pilla. Mount Sinai School of Medicine, 1 Levy Place, New York, NY 10029.

Low-intensity ultrasound (US) and low-intensity electromagnetic fields (EMF) have been proposed for in vivo bone repair. EMF serves currently as clinical treatment for nonunion and delayed union bone fractures. US is presently being investigated for accelerating the rate of fresh fracture repair. This paper will review the current status of EMF and US for treating fresh fractures, as well as delayed and nonunions. A comparison of US and EMF will be given with respect to daily treatment time, treatment period, and methods of application. A discussion and comparison of possible mechanisms of action of each modality will also be presented.

C-2-3 **DOSIMETRY OF ELECTRICAL STIMULATION IN BONE REPAIR.** Sol Pollack. University of Pennsylvania, Philadelphia, PA 19104.

Electrical and electromagnetic stimulation for the treatment of specific orthopaedic problems occurs each day around the world. In addition, clinical investigators are studying the application of these devices to a variety of other bone disorders. Doubt exists, however, as to the biological significance of the extremely low amplitude electric and electromagnetic fields involved. There is a lack of understanding of the underlying mechanism(s) of action combined with a limited number of publications on rigorous field dosimetry in combination with carefully controlled cell, tissue or animal models. Ideally, dosimetry defines the field amplitude, spatial variation, frequency characteristics and duty cycle at the cell level for the responding cells involved. This is possible for some in-vitro cell models. Methods exist for determining dosimetry at the tissue level however, and considerable progress has been made for comparing cell culture, animal studies and human investigations with regard to dosimetry and biological response. For example, specific instrument settings on external devices used in stimulation experiments define device voltage and currents. The device voltage and current together with specific electrode or coil orientation, shape, anatomical configuration of animal or limb, signal frequency, etc., all affect the actual value of the fields at the tissue site. This problem has been solved for some cases and field values producing biological responses are found in the range of 10 mV/cm to 500 mV/cm. These values agree well with cell studies in which fields as low as 10 mV/cm to 20 mV/cm have resulted in statistically significant increases in ^{3}H-thymidine per μg DNA.

SESSIONS C-3: SYMPOSIUM ON APPLICATIONS OF TIME VARYING FIELDS FOR TISSUE HEALING (CONTINUED)

Moderators: R. K. Aaron and C. A. L. Bassett

C-3-1 **WOUND HEALING: ENHANCEMENT OF MACROPHAGIC ACTIVITY USING SINUSOIDAL ELECTROMAGNETIC FIELDS.** B. F. Sisken and E. Herbst[1]. Center for Biomedical Engineering and Dept. of Anatomy and Neurobiology, University of Kentucky, Lexington, KY 40506; and Biomedical Engineering Dept., Tulane University[1], New Orleans, LA 70118.

The role of macrophages in wound healing is well recognized; they have been shown to contribute to the repair of skin wounds both as phagocyte cells and as a source of trophic factors for angiogenesis and fibroblast activity. When an inflammatory reaction occurs macrophages are "activated" to phagocytose, producing superoxide and hydrogen peroxide. Previous results from our laboratories demonstrated the stimulatory influence of sinusoidal electromagnetic fields (SEMF) on healing of rat skin flaps (Herbst et al. 1986, 1987): the best response observed at 72 Hz (1.1 mT). In the present study we used a line of macrophage-like mouse cells (PD388) to determine the degree of activation induced by this 72-Hz signal. Macrophagic cells were plated (≈50,000/ml) and exposed to SEMF immediately for 2 hr (fresh) or continuously (2, 4 or 7 days). Each experiment was repeated on three different days.

Peroxide formation was determined using the method of Pick and Mizel (1981). SEMF increased peroxide formation relative to controls by 130% ± 3.1 for fresh cells and 141% ± 3.3 in cultured cells. Addition of phorbol ester (PMA, 20-200 nM) did not augment the SEMF response. This "activation" of macrophages may be involved in the mechanism by which SEMF enhances healing of skin flaps. Office of Naval Research #N00014-86-K0221.

C-3-2 **MEASUREMENT OF THE POTENTIAL GENERATED BY WOUNDS IN THE GUINEA PIG.** *Neena Nirsimloo*, Roy Smith[1], Mary Dyson, Steve Young, Stefan Scicinski[1], and Richard Dixey[1]. Department of Anatomy, UMDS (Guy's Hospital), London SE1 9RT, UK; and Department of Medical Electronics, St. Bartholomew's Hospital[1], London EC1A 7BE, UK.

The potential difference (PD) between a full thickness skin excision (wound), located on the dorsal midline between the scapulae, and a subdermal reference electrode (RE) in the right flank has been continuously recorded, for seven days, in the guinea pig (GP). The PD was measured using a telemetry unit (TU) comprising two electrodes and biopotential radiotelemetry pill (Remote Control Systems, London, UK) operating at 400 kHz. The sensing electrode, 8 mm diameter Ag/AgCl, was mounted on the base of the TU. The RE consisted of a porous wick leading from another Ag/AgCl electrode in the TU. Except for the wick's exposed end it was surrounded by a silicone rubber tube (2.5-mm diameter, 45-mm long) packed with KCl. Female, Dorset-Henley GPs weighing 200-300 g were anesthetized with halothane/oxygen and a 8-mm diameter wound was produced on shaven skin. The TU was affixed to the area surrounding the wound with Histoacryl blue skin glue (Geistlich, Chester, UK); electrical contact between the wound and the sensing electrode was obtained with an agar/salt bridge. The tip of the RE was then inserted under the skin, the remainder secured to the skin surface with Histoacryl blue and the point of entry covered with Opsite (Smith and Nephew). Aerials mounted outside the animal's cage detected the radio signal from the TU. We found that the PDs obtained varied between +50 mV and -100 mV; this variation appears to be associated with progress through the different stages of wound healing.

C-3-3 **EXPLOITING THE BODY'S IMMUNE AND ANTI-INFLAMMATORY DEFENSE SYSTEM: ENTRAINMENT POSSIBILITIES OF HIGH FREQUENCY FIELDS IN RELATION TO TUMOR NECROSIS FACTOR (TNF) IN TUMOR THERAPIES.** Victor M. Fellus, Frederic P. Baumgarten, and Sebastiano P. Rizzo. Meudon 92190, France; France; and Italy[1].

Twenty European studies show that very-high-frequency fields reduce inflammation, repair tissue injury, reduce infection, stimulate angiogenesis and intracellular enzyme function, increase blood flow, plus confer resistance to high-dose X rays. Recently, an identical range of effects has been described from a similar immunological perspective, but relating explicitly to tumors. A review article (Scientific American, May 88) describes the discovery of tumor necrosis factor (TNF), a polypeptide cytokine. High frequency currents initiate the same range of effects as those in which TNF is implicated and has been shown to be therapeutic with tumors. High frequency fields may operate by stimulating the production of TNF and the entire group of cytokines to activate the general immune response. It is thus proposed that high frequency fields provide a rational and very important

adjunctive treatment. No alteration to existing treatments is required. No side effects have been reported; and it appears to be a very safe treatment in this context suitable for wide experimentation. We are undertaking trials in large groups of patients mainly in hospitals situated in northern Italy, in Algeria and in France with very encouraging results; such as a total relief of pain in more than 318 cases in 327 patients.

C-3-4 **USE OF AC MAGNETIC FIELDS TO ALLEVIATE DISUSE OSTEOPOROSIS IN MICE.** S. J. Simske, H. Wachtel, M. Luttges, and L. Stodieck. Bioserve Space Technologies Center, University of Colorado, Boulder, CO 80309.

Tail-suspended mice develop a form of disuse osteoporosis in their long bones similar to that studied extensively in tail-suspended rats (Holten, et al.). We have previously reported that pulsed magnetic fields, applied selectively to the suspended rear legs of mice, could markedly alleviate such an effect. (Simske, et al., 1988). We can now report that similar alleviation is achieved using sinusoidal (AC) fields applied to the whole body. The AC field chosen for these studies was 383 Hz at 5 G which, along with a DC magnetic field of 5 G is purported to produce "cyclotron resonance" for calcium ions. Four-month-old mice were separated into three groups: tail-suspended mice exposed to magnetic fields, tail-suspended controls (no field) and normals (not suspended). The tibiae, femurs and humeri of all mice were assayed for wet and dry weight, strength, and stiffness. Of the 12 assays (four each for the three long bones) six showed osteoporetic effects in the controls compared to normals ($p < .05$). The magnetic-field-exposed mice showed significantly less effects in five out of these six assays. The AC-field strengths used in these experiments are similar to those of the pulsed fields found to be effective in earlier experiments which indicates that phenomenon other than "cyclotron resonance" may be operative.

C-3-5 **INTERACTION OF TISSUE AGE AND CALCIUM CONCENTRATION WITH ELF MODULATION OF TENDON FIBROPLASIA *IN VITRO*.** Stephen F. Cleary, Li-Ming Liu, Ronald Graham, and Robert Diegelmann[1]. Departments of Physiology and Biophysics, and [1]Departments of Biochemistry and Molecular Biophysics and Plastic Surgery, Medical College of Virginia, Virginia Commonwealth University, Richmond, VA 23298.

A chicken tendon explant model system was developed to investigate the effects of extremely-low-frequency (ELF), low-amplitude, unipolar, square wave pulsed electric fields on fibroplasia and collagen synthesis in vitro. Fibroplasia exhibited a biphasic response depending upon current density of 1-Hz ELF electric fields with a pulse duration of 1 msec. The response was dependent upon polarity of the electric field with respect to the explant axis. Fibroplasia and relative collagen synthesis were inversely proportional to age of the explant donor. Donor age also determined the effect of extracellular Ca++ concentration on fibroplasia and on interaction of ELF electric fields with fibroplasia and collagen synthesis. The implications of these findings will be discussed with respect to tissue regeneration by ELF fields.

SESSION C-4:	ELF AND STATIC MAGNETIC FIELDS - *IN VIVO* STUDIES
Moderators:	C. T. Gaffey and H. Wachtel

C-4-1 EXPERIMENTAL DESIGN AND STATISTICAL CONSIDERATIONS.

R. L. Buschbom. Battelle, Pacific Northwest Laboratories, Richland, WA 99352.

Steps in the design of laboratory animal toxicity studies are briefly reviewed. These steps include stating the problem, formulating the null and alternative hypotheses, determining the statistical analysis procedure and design, re-evaluating the design to see if the experiment adequately provides required information, considering possible results of statistical procedures to ensure that experimental conditions are valid, applying statistical analysis procedures to the experimental results, determining conclusions from the experimental results accounting for prior knowledge, and evaluating the whole process. Other statistical issues discussed are sample size and multiple comparison considerations. A sufficient number of animals should be included in the experimental design to insure reasonable power for detecting effects. However, in most animal experiments the ideal number of animals has to be reduced because of logistic or cost factors. Nevertheless, one should always consider the power of the design before the experiment is begun. Another important interpretative issue in toxicity testing concerns multiple comparisons. Normally, a large number of variables are examined per animal or per litter and a battery of statistical tests are employed. The potential exists for finding false positives, i.e., statistically significant differences that are due to chance variation alone. One possible strategy to deal with this problem is to use a Bonferonni-type multiple comparisons adjustment. Another strategy is to use the p-value as one piece of information in the process of determining conclusions. Support was from the Electric Power Research Institute.

C-4-2 DEVELOPMENTAL TOXICOLOGY STUDY IN RATS EXPOSED TO 60-HZ HORIZONTAL MAGNETIC FIELDS.

Larry E. Anderson, Donald N. Rommereim, Ray L. Buschbom, and Melvin R. Sikov. Battelle, Pacific Northwest Laboratories, Richland, WA 99325

A study has been designed to determine if exposure of rats to 60-Hz magnetic fields results in alterations of embryonic and fetal development. The experiment involves a detailed evaluation of rat fetuses from dams exposed for the first 20 days of gestation to 60-Hz sinusoidal, horizontal, magnetic fields. Magnetic field exposure for 20 hr/day is provided on a modified parallel plate electrode system, the characteristics of which are described in a poster session abstract (Miller, Miller, and Anderson). One group of rats was exposed to a uniform 10-G magnetic field. A second group, located in the same room received an exposure as a result of field leakage from the 10-G exposed group estimated to be about 0.01 G. A third group of animals was housed in an "unexposed" condition in another room (Richland ambient magnetic fields, less than or equal to 0.001 G). The study was conducted in two successive replicates (80 litters per group per replicate) with analysis of representative maternal and fetal indices of effects. Statistical analyses consisted of summary statistics with accompanying multivariate and univariate

ANOVA based on multiple comparisons where appropriate. Research was supported by the Electric Power Research Institute under contract 2596-10.

C-4-3 **EFFECT OF A PULSED ELECTROMAGNETIC FIELD ON INCUBATION TIME OF TURTLE EGGS AND SIZE OF HATCHLING TURTLES.** Christopher H. Dodge, Barbara J. B. Dodge, Marie T. Dimond[1], and Arthur Pilla[2]. 112 16TH St. N.E., Washington, DC 20002; Department of Biology, Trinity College[1], Washington, DC 20017; and Mt. Sinai School of Medicine[2], New York, NY 10029.

Some previous studies have reported adverse effects of low-level pulsed electro-magnetic fields (PEMF's) on incubation outcomes of chicken eggs. Turtle eggs, with longer incubation times and fixed blastodiscs have never been exposed experimentally to such fields. A total of 51 eggs representing four local turtle species were exposed for nearly the whole term of their incubation (about 60 days) at 26-28° C to a constant 50 msec burst of bipolar pulses (250 μsec positive, 5 μsec negative) repeated at a rate of 2 Hz. A total of 26 experimental and 25 control eggs were litter paired and maintained under identical thermal conditions. No differences between experimental and control incubation time were found and fertility in both cohorts was essentially identical. There was no difference between experimental and control hatchling size measured in carapace length, width, height, and body weight. The experiment is continuing to determine if hatchling growth is influenced by the same PEMF parameters, as reported by the authors in 1985 (7th Annual BEMS poster session).

C-4-4 **ELECTRICAL ACTIVITY OF THE CNS VISUAL PATHWAYS AS A FUNCTION OF STATIC MAGNETIC FIELD EXPOSURE.** C. T. Gaffey. Research Medicine and Radiation Biophysics Division, Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720.

When a bioelectric signal travels along the central visual pathway, ionic currents flow in local currents across neural membranes. Mathematical models predict that static magnetic fields (SMF) can distort these biocurrents via a Lorentz force. The electrophysiological characteristics of the lateral geniculate nucleus (LGN) and the visual cortex (VC) were measured as a function of SMF in cats stereotaxically implanted with bipolar electrodes. Each animal was placed between the horizontal poles of a large DC electromagnet. When the magnet was energized, the SMF was approximately perpendicular to the movement of signals along the central nervous system visual pathway. Before, during, and after SMF exposures to 0.5, 1.0, and 1.5 T, the LGN and VC activities were recorded as: (1) an electroencephalogram (EEG) from cats in the alert and anesthetized state; (2) an EEG in cats presented with photic stimuli; (3) an oscillogram of evoked responses to single flashes; (4) an oscillogram of a computer averaged evoked response to 100 flashes; (5) a driving response to light flashes delivered at 5, 10, and 15 Hz; and (6) the conduction time required for a photic stimulus to reach a visual station. An analysis of the data will determine if SMF strengths up to 1.5 T have a biomagnetic effect on LGN and VC activity. This work was supported by the Director, Office of Energy Research, Office of Health and Environmental Research, US Department of Energy, under Contract DE-AC0376SF00098, and the National Institutes of Health Grant RO1 NS524997-02.

SESSION D-1:	RF DOSIMETRY AND INSTRUMENTATION
Moderators:	O. P. Gandhi and R. A. Tell

D-1-1

USE OF THE IMPEDANCE METHOD TO CALCULATE 3-D POWER DEPOSITION PATTERNS FOR HYPERTHERMIA WITH CAPACITIVE PLATE ELECTRODES. Niel Orcutt and Om P. Gandhi. Department of Electrical Engineering, University of Utah, Salt Lake City, Utah 84112.

We have used the three-dimensional impedance method together with an anatomically realistic model of the human body to calculate the power deposition in the human pelvic region due to a radiofrequency current at 13.56 MHz applied through systems of two or three round or oval capacitive-plate applicators. The model consists of about 40,000 cubic cells in the body, each 1.31 cm per side, and about 100,000 air cells. We compare the energy deposited in several tumor sites when energy is applied using a variety of applicator sizes, locations, and saline boluses of various conductivities. We show detailed maps of the power deposition in these cases for selected regions of the body and suggest useful configurations of applicators for heating tumors in several locations in the body. We conclude that higher salinity boluses are more efficient that those of low salinity and do not greatly increase the power deposition at the edges of the applicator. We conclude that the conventional idea that large plates are superior for heating deep-seated tumors, because of their lower deposition near the body's surface, is valid for tumors at or near the center of the body but not as useful for tumors elsewhere. For those situations, placing a small plate on the side nearer the tumor increases the percentage of power deposited in the tumor, at the expense of a somewhat higher deposition at the body surface.

D-1-2

CURRENT METERS FOR ASSESSMENT OF RF HAZARDS TO 100 MHZ. Jin-Yuan Chen and Om P. Gandhi. Department of Electrical Engineering, University of Utah, Salt Lake City, Utah 84112.

In response to the reports of RF induced currents in the human body, limits on the body to ground current have been proposed by IRPA, in Canada, and are also being considered by ANSI C 95.4. Restrictions on the contact currents have similarly been proposed to eliminate the potential for RF shock and burns. To assess these currents in the RF environment, we have fabricated the following prototype instruments: (1) A body current meter capable of measuring RF currents passing through the human feet. This meter has a frequency range of 3 kHz - 100 MHz and current ranges of 0-2, 2-200 and 200-2,000 mA. The two versions of this meter utilize either a two-feet bilayer sensor on which a person can stand or a shoe-insertable single-foot sensor. (2) A contact current meter with internal impedance equivalent to that of the human body for a variety of contact conditions. These include smaller area finger contact, larger area grasping contact, and use of safety gloves and shoes by the subject. We will report on the fabrication, frequency, response and RF testing of these instruments.

D-1-3 FIELD STRENGTH METERS FOR USE IN THE NEAR-FIELD OF A TRANSMITTING ANTENNA.

S. Wakeling. BBC Research Department, Kingswood Warren, Tadworth, Surrey, UK.

The increasing evidence of the biological effects of non-ionizing electromagnetic radiation has led standards authorities all over the world to introduce new, more restrictive levels for the exposure of people to RF radiation. These exposure levels present significant problems to the broadcaster in relation to both public and occupational exposure. These problems are exacerbated by the difficulty of measuring the fields on a mast or in the vicinity of a HF array where the meter is often in the near-field region of the transmitting antenna. As most commercial meters measure one component of the field only and apply the free-space plane-wave conversion to power density, large errors in the readings result. Ideally, broadcasters would like a meter which would give a true reading of the power available in the field and would not alter the field in any way by its presence. Two novel meters have been considered by the BBC along these lines. One uses a piece of RF absorber to convert the field energy to heat and the resulting temperature rise is measured. This can then be calibrated to read the power available in the field but has the severe practical disadvantage that it has to cool down in a zero-field environment between readings. The second design uses an arrangement of 6 optical crystals to measure the E and H components of the field and derives the Poynting vector to give a reading for the power density. The crystals induce a rotation in the polarization of the light passing through them when the field component is applied. However, this effect is only just measurable, just a few seconds of arc, so further development work is required to make this a viable proposition.

D-1-4 MEASUREMENTS OF CONTACT CURRENTS IN RADIO-FREQUENCY FIELDS.

Maria A. Stuchly and David W. Lecuyer. Bureau of Radiation and Medical Devices, Tunney's Pasture, Ottawa, Ontario, K1A 0L2.

Radiofrequency (RF) electromagnetic fields can affect human health not only by direct interactions but also indirectly through induction of charges on isolated or poorly grounded conductive (metallic) objects located in these fields. In the recent Canadian recommendations on RF exposure, contact-current limits are specified to achieve protection against perception or pain by a person touching the object, for the general population and workers, respectively. Threshold currents for perception and pain have been previously measured (Chatterjee et al., IEEE Trans., BME 33:486-494, 1986). Since testing with human volunteers is not acceptable, we have used previously proposed (Kanai et al., IEEE Trans., BME 32:763-771, 1984, Richman, Proc. IEEE-EMC, 1985) equivalent circuits for the human body impedance to derive proper test conditions. The selected test conditions correspond to finger contact with a charged object, for a person without shoes and having a wet finger. These test conditions simulate the worst case practical conditions. A printed board, RC circuit designed to operate at high frequencies was built and tested in the field. The method and circuit developed provide viable means for measurements of contact currents to prevent perception or pain by a person due to touching objects in RF fields.

D-1-5 **A DOSIMETRIC ASSESSMENT OF THE SIGNIFICANCE OF HIGH INTENSITY RF FIELD EXPOSURE RESULTING FROM RERADIATING STRUCTURES.** Niels Kuster and Richard A. Tell[1]. Swiss Federal Institute of Technology, 8092 Zurich, Switzerland; and Richard Tell Associates, Inc.[1], Las Vegas, NV.

The issue of human exposure to radiofrequency (RF) fields has, in the last several years, taken on a more significant level of importance in the context of determining compliance with RF exposure standards. This has been especially evident in the case of near-field exposure to the relatively intense fields that can be observed near passive, reradiating objects. While ambient RF field intensities may be substantially less than that allowed by various exposure guidelines, the local fields, typically witnin 20 cm of certain types of conductive objects, can often be found to exceed these same standards. The present study examines the SAR in a 3-D human model made of soft muscle and brain tissue which results from the near-field exposure to a passive, resonant reradiating metallic rod illuminated with a plane-wave RF field (100 MHz). The simulations are computed with the 3-D MMP Program Package. The EMF interaction between plane-wave, rod and human is explained by the field vector plots for different positions of the rod and human model. The resulting SAR's are compared to those permitted by the ANSI RF radiation protection guide (RPG) and practical implications for assessing compliance with the ANSI RPG in the vicinity of very-high-frequency (VHF) broadcast stations is discussed.

SESSION D-2: DOSIMETRY OF PULSED RF FIELDS

Moderators: A. W. Guy and S. S. Stuchly

D-2-1 **MAGNETIC FIELD SENSOR FOR TRANSIENT AND PULSED RADIOFREQUENCY FIELDS.** Herve Le Pocher, David Gibbons, Art Thansandote, and Maria A. Stuchly. Department of Electrical Engineering, University of Ottawa, Ottawa, Ontario, K1N 6N5 Canada.

Measurements of transient and pulsed electromagnetic fields are of importance in characterization of these fields to evaluate whether they may interact with biological systems, and in evaluation of electromagnetic interference and compatibility. The main challenge presented by these measurements is due to a very wide frequency range required for operation and the requirement to measure both the magnitude and phase of the field. For magnetic fields, a circuitry which was selected to satisfy these requirements comprises an electrically small loop, a current transformer and a broadband amplifier with a current follower as its first stage for low frequencies. We have modelled the system performance using a computer simulation program, SPICE. As an example we describe the design and performance of a single axis magnetic field sensor operating from 10 kHz to 100 MHz with a sensitivity of 0.05 A/m. The sensor loop has a diameter of 6 cm, and the current transformer consists of a high μ-toroidal core and about 50 turns. The most important feature of the sensor is that its output voltage to a 50-Ω impedance has a constant amplitude (within $\pm$ 1 dB) and linear phase within the whole frequency range. Furthermore, the sensor practically does not respond to the electric field.

D-2-2 **A TIME-DOMAIN SYSTEM FOR MEASURING DIELECTRIC PROPERTIES OF BIOMATERIALS IN HIGH-INTENSITY PULSED RADIOFREQUENCY FIELDS.** Artnarong Thansandote, Stanislaw S. Stuchly, Mariusz Barrski, and Nai Yu Zeng. Department of Electrical Engineering, University of Ottawa, Ottawa, Ontario, K1N 6N5 Canada.

A system for measurements of the dielectric properties of biological materials exposed to high-intensity pulsed radiofrequency fields was developed. The system consists of a capacitive sample holder, a bidirectional coupler, a high-speed digitizing oscilloscope and a microcomputer. The test material is placed in the sample holder (38 mm^3) terminating a coaxial line section. High intensity electric field across the sample is produced by a pulsed RF source followed by a high power amplifier. The system is designed to operate in the frequency range 1-100 MHz with the RF electric field intensities 1-10 kV/cm and the pulse width 1-20 μsec The measurements of incident and reflected waves are performed in the time domain using the bidirectional coupler and the digitizing oscilloscope (HP 54200A). The outputs are fed to the microcomputer (Compaq Deskpro 386/20) for processing and calculations of the reflection coefficient and sample permittivity. Permittivities of various standard liquids (water, saline, methanol, etc.) are measured and compared with those obtained from theoretical calculations and measurements using a frequency domain automatic network analyzer (HP 3577A). The results of the three methods for saline (conductivity 0.0103 S/m) agree within 2% in the dielectric constant and 5% in the loss factor. This system may find wide range applications in measurements of nonlinear properties of biomaterials and as a diagnostic tool in studies of electroporation of cells.

D-2-3 **A VERY HIGH POWER, PULSED MICROWAVE EXPOSURE FACILITY OPTIMIZED FOR BIOLOGICAL EFFECTS RESEARCH.** F. Bates and H. Bassen[1]. ERC BioServices Corp., Rockville, MD; and Walter Reed Army Institute of Research[1] (WRAIR), Washington, DC 20307-5100.

A unique "High Power Microwave" (HPM) exposure facility has been developed for the study of the biological effects of exposure to emissions from electronic jamming and other HPM transmitting systems. This facility is unique in that it generates true HPM exposure fields in a standard biological laboratory environment. An experimental virtual cathode oscillator, developed by Sandia National Laboratories, has been extensively modified and optimized as a biological effects research tool by ERC engineers. The resulting system consistently produces 20-40 nsec pulses in excess of 800 megawatts peak at 3000 MHz. A circular waveguide slot antenna in an anechoic chamber provides a uniform (±1.5 dB) exposure area 50 x 50 x 100 cm, with peak power densities of 50-80 kW/cm^2. Corner-reflector exposure devices allow for simultaneous irradiation of two rat-size subjects to enhanced intensity fields of over 500 kW/cm^2 equivalent power density. In vivo experiments, with exposure series consisting of up to 1000 pulses per day, at 10 to 60 pulses per minute have been performed to study the effects of HPM radiation on behavior, physiology and neuropathology. Microwave dosimetric measurements are made in conjunction with each experiment. Additionally, measurements of acoustic levels and ionizing radiation have been performed and these confounding variables have been minimized and accounted for during sham exposure experiments.

D-2-4 **MEASUREMENT OF BODY CURRENTS IN HUMANS EXPOSED TO EMP.** P. C. Gailey and C. E. Easterly[1]. The EC Corporation, Knoxville, TN 37932; and Health and Safety Research Division, [1]Oak Ridge National Laboratory, Oak Ridge, TN 37831.

The total energy absorbed by humans exposed to EMP fields is far too small to cause significant whole body heating. If any biological effects occur as a result of EMP exposure, the pertinent exposure parameter may be internal current density or internal field strength. These parameters can be used to infer membrane potentials, charge transfer, or other potentially significant biological quantities. The experimental system described here will be used to attempt measurement of body currents induced in humans exposed to EMP fields. The exposure system consists of large parallel plates driven by a pulse generator and is capable of producing 50-kV/m fields. Electric and magnetic field distributions inside the exposure area will be characterized. Body currents will be measured using current probes and transmitted over a fiber optic link to a shielded instrumentation room. Methods for characterizing the pulse response of the current probes and preliminary body current measurement results will be presented.

D-2-5 **ANALYSIS OF MAXIMUM TIME DOMAIN INDUCED CURRENT AND ABSORBED ENERGY DENSITY LEVELS IN PERSONS EXPOSED TO EMP SIMULATORS.** Arthur W. Guy. Bioelectromagnetics Research Laboratory, Center for Bioengineering, University of Washington School of Medicine, Seattle, 98195.

As a result of renewed concern about potential health effects in workers exposed to simulators, an analysis was made of the maximum possible induced current and absorbed energy density associated with such exposures. The analysis was done by representing the human body by conducting cylindrical sections with distributed impedance obtained by measurements on human volunteers at frequencies of 0.01-3 MHz. Values of impedance up to 200 MHz was obtained by extrapolation based on the known frequency dependence of the dielectric properties of human tissue. The Lawrence Livermore Numerical Code 3 (NEC3) Method of Moments was used to determine the frequency dependence of the induced current in the model, which was verified by experimental measurements. Standard Fast Fourier Transforms (FFT) were then used to convert the EMP source field into the frequency domain in order to calculate the frequency domain induced current, which in turn, was converted by the inverse FFT to the time domain. Maximum time domain levels of 10-A induced current, 6.23 kA/m^2 current density and 48.4 kW/kg SAR were calculated for an exposure field of 1 kV/m. The maximum specific absorption was found to be 0.354 mJ/kg per pulse for this exposure level.

SESSION E-1:	SYMPOSIUM ON BIOPHYSICS OF RESONANCE PHENOMENA IN ELECTROMAGNETIC FIELD INTERACTIONS WITH BIOMOLECULAR SYSTEMS
Moderator:	W. R. Adey

E-1-1 **OVERVIEW OF PROPOSED MECHANISMS OF BIOLOGICAL INTERACTIONS WITH LOW-LEVEL ELECTRIC AND MAGNETIC FIELDS.** Yngve Hamnerius. Department of Applied Electron Physics, Chalmers University of Technology, S-412 96 Goteborg, Sweden.

Intense electric and magnetic fields have long been known to cause biological effects. The mechanisms are well known, e.g., heat production or triggering of nerve cells. Research results from the last decade give evidence in numerous experiments that there are biological effects of low-level electric and magnetic fields. The mechanisms of these interactions are, however, not well known. Against the background of an eventual link between low-level magnetic fields and the incidence of cancer, understanding of their interaction mechanisms is the ultimate challenge for the bioeffect research community. Several mechanisms have been proposed, usually building on some amplification process. Some of the experimental data indicate that this amplification has to do with resonant phenomena. Most proposed mechanisms are on the biomolecular level. The interest is focused on the cell membrane and the transport of signals, electric or chemical, across the membranes. The understanding of the mechanism or mechanisms will probably have an impact beyond the field of bioeffect research.

E-1-2 **BIOLOGICAL AMPLIFICATION IN NONLINEAR MOLECULAR SYSTEMS.** Albert F. Lawrence. Hughes Aircraft Company, Long Beach, CA.

A starting point for modeling the quantum mechanics of charge and transport in biological systems is the behavior of a particle in a multiple well potential. The potential may represent the potential seen by a charged particle as it moves from site to site, or alternatively it may represent the energy of a molecular configuration as it changes from one relatively stable state to another. Numerous molecular systems in the cell membrane exhibit the transmission and control of signals through modulation of an effective potential. Often, the fundamental mechanics include (i) a conformation switch from one metastable state to another along a dynamically changing potential, (ii) the motion of a charged particle via a combination of tunneling and escape processes along a periodic potential and (iii) the coupling of a conformational switch to a transport process. Any or all of these steps can provide amplification of initially weak disturbances. Furthermore, the primary event in many of the transport processes involves a change in the shape of the conformational potential energy surface (due to the excitation of the electrons) followed by a conformational change and a nonradiative decay to the ground state of the electrons. A minor change in the potential for the excited state may act to change the relative probabilities of decay to the original conformational state and decay to the new conformational state. This affords a further mechanism for the amplification of the effects of weak fields in biological systems.

E-1-3 **COHERENCE AND WEAK EFFECTS IN LIVING MATTER.** Giuseppe Vitiello, Physics Department, University of Salerno, 84100 Salerno, Italy.

The dynamical origin of coherent structures in biological systems is studied in the framework of quantum field theory. Stability of coherence and weak dynamical effects are analyzed. Efficient energy transfer on protein chains and molecular membranes is shown to be realized by nonlinear solitary waves.

SESSION E-2: SYMPOSIUM ON BIOPHYSICS OF RESONANCE PHENOMENA IN ELECTROMAGNETIC FIELD INTERACTIONS WITH BIMOLECULAR SYSTEMS (CONTINUED)

Moderator: W. R. Adey

E-2-1 **SOME THOUGHTS ON THE ROLE OF CELL MEMBRANE IN LIVING SYSTEMS.** Gerald C. Huth. Institute of Physics, University of Southern California, and Xsirius Scientific, Inc., Scottsdale, AZ 85260

The possible connection between solitary wave generation in a unique, self-organized monomolecular optical dye layer (the Scheibe of "J" aggregates) and Frohlich's ideas regarding high frequency oscillatory behavior in living cell membrane is discussed.

E-2-2 **ION CYCLOTRON RESONANCE IN LIVING SYSTEMS: EXPERIMENTAL EVIDENCE AND THEORETICAL CONSTRAINTS.** A. R. Liboff, Physics Department, Oakland University, Rochester, MI 48309.

There is now considerable evidence that short-term exposure of living systems to weak ELF fields in the presence of magnetostatic fields can alter normal biological response. These changes appear to be greatest when the ratio of EM frequency to DC field intensity equals the charge-to-mass ratio of non-hydrated ions Ca^{++}, Mg^{++}, Li^{+}, K^{+}. This signature is remarkably similar to the cyclotron resonance (CR) effect observed for electrons in metals and semiconductors. Of all the experimental models designed to test this CR possibility (rat, lymphocyte, red blood cell, chick femur), none of the results are more striking than from diatoms exposed to combinations of AC and DC magnetic fields at different calcium concentrations. The motility undergoes sharp changes following such exposures; it is maximized by tuning to the CR frequency for Ca^{++} and minimized by tuning to K^{+}. Both extrema occur for the same set of harmonic frequencies, (1, 3, 5, 15). Finally, what is most remarkable is that the motility as a function of frequency follows a typical resonance curve. Even before these results, we argued that an ion CR effect might explain earlier calcium-efflux experiments, and further that an excellent candidate for such an interaction site would be the membrane ion channel, considering the helical periodicity often associated with this class of proteins. With one critical exception, the theoretical problems attached to this hypothesis are as troublesome today as they were in 1984. Although there is presently less concern about the hydration state of transiting ions, the

transit time of a typical channel ion is hardly reconcilable with estimated CR transit times. Further, the actual mode of energy transfer to the ion remains unclear, and, as a result, we simply have no handle on fundamental questions relating to scattering times and losses.

E-2-3 VARIABILITY IN BRAIN FUNCTION: PARAMETRIC CONTROL OF NOISE AND CHAOS IN MOTOR PATTERNS.

George J. Mpitsos and Robert M. Burton. Mark O. Hatfield Marine Science Center, Oregon State University, Newport, OR 97365.

The brain may be viewed as a Darwinian engine following the dynamical principles of diversification and selection. Although much evidence indicates that behaviors and the functional role of neurons arise predictably from hardwired circuitry, we also find that the underlying circuitry represents the potential expression of many different and changeable behaviors. The function of a given neuron arises contextually through differing patterns of activity of that neuron with other neurons. Variability may arise from the effect of sensory inputs and also from a natural tendency of the brain itself, presumably for better matching with unpredictable environments. Such response diversification makes biological systems error-prone. Here, the dialectic between animal and environment rather than wiring determines the appropriateness of a response. Some variability may be high-dimensional "thermal" noise. Other forms may involve chaos by being deterministic and low-dimensional yet having only short-term predictability. In our computer simulations of simple neural networks, either time- or event-dependent control of noise may aid in response optimization. Importantly, variability in biological systems may be nonstationary. We propose that nonstationarity may arise when bifurcation parameters that switch a system between different forms of periodic or chaotic activity are time- or activity-dependent. Such parameters may be a distributed property representing the state of the coactive neural system as a whole. Thus, by affecting the level of noise or the bifurcation state, it is conceivable that small or subtle environmental stimuli, particularly when amplified by nonlinear dynamics, may alter the ability of a biological system to optimize its responses or may determine the type of response it produces. (Supported by AFOSR-0262).

SESSION E-3: MEMBRANE AND MECHANISMS - ELF INTERACTIONS

Moderators: A. R. Sheppard and M. Blank

E-3-1 RELATIONSHIP OF TRANSCRIPT QUANTITY TO SIGNAL AMPLITUDES.

Reba Goodman, Lin-Xiang Wei, Jing-Chu Xu, and Ann Henderson. Department of Pathology, Columbia University, New York, NY 10032; and Department of Biological Sciences, Hunter College-CUNY, New York, NY 10021.

The quantity of RNA transcripts can be altered in cells exposed for short time periods to signals generating ELF EM fields. The present experiments addressed the role of amplitude in quantitative changes. DNA, homologous to the coding regions of human c-myc, histone 2B and actin genes, was used in dot blot hybridizations to determine the relative quantity of corresponding RNA

in human cultured cells resulting from increasing amplitude EM fields. Multiple experiments were done at 10, 20 and 40 minute exposures, each testing the effect of amplitudes at 1 μV, 10 μV, 100 μV and 1 mV in two sinusoidal signals (60 and 72 Hz). The measured level of these transcripts in exposed cells in any experiment was greater than in unexposed cells. The increase in all transcripts was both time and amplitude dependent; no significant differences were observed related to frequency. Highest augmentation of transcripts was at 1 mV in 10 minute exposures and 10 μV at 20 minutes; at 40 minutes, the results were approximately equivalent within the 10-μV to 1-mV range. (Supported by ONR, EPRI, and Electro-Biology, Inc.)

E-3-2 TWO PATHWAYS IN THE ELECTROMAGNETIC STIMULATION OF BIOSYNTHESIS.

M. Blank and R. Goodman[1]. Dept. of Physiology and Cellular Biophysics and [1]Dept. of Pathology, Columbia University, New York, NY 10032.

Weak electromagnetic (EM) signals turn on transcription and translation in the cells of several species. We have analyzed RNA and polypeptide biosynthesis and find that the distributions of molecular weights change with EM stimulation and depend upon the frequency of the applied field. The changes in the molecular weight distribution of the proteins, also seen in heat shock and in experiments where cell membranes have been damaged, appear to be a general response to stress. The characteristic "signature" of this response is an augmented synthesis of 20- to 50-kD molecular weight polypeptides, and a reduced synthesis in the molecular weight ranges below 20 and above 50 kD (Blank and Goodman, Bioelectrochem Bioenerg 19:569, 1988). In addition there appear to be modality related responses that reflect the properties of the stimulus. An analysis of the specific responses to EM, based on an electrochemical model that has successfully described the opening/closing reactions of voltage gated channels and the ion flows during nerve excitation (Blank, BBA 906:227, 1987), predicts that the charged surfaces involved in biosynthesis should experience frequency dependent interference in alternating EM fields. The new proteins synthesized during EM or thermal stress have properties that would be expected if they arose from interference of the electric fields with biosynthesis. They tend to have lower molecular weights and are more highly charged. The number of new proteins divided by the amount synthesized increases with the frequency. (We thank the ONR and EPRI for support).

E-3-3 INFLUENCE OF TIME-PERIODIC ELECTROMAGNETIC FIELDS ON ION MOTIONS NEAR MACROMOLECULES.

Alessandro Chiabrera and Bruno Bianco. Department of Biophysical and Electronic Engineering, Via all'Opera Pia 11A, 16145 Genova, Italy.

The motion of a single ion under the action of a time-periodic electromagnetic field in a viscous medium is considered. The ion is modelled as a nonstructured particle endowed with mass and charge. Such situation is a picture of the actual behavior of ions more or less strictly bound to biological macromolecules, in cells exposed to exogenous electromagnetic fields. In order to model concrete experimental situations, the exogenous field is assumed time-periodic, either sinusoidal or sawtooth-like in its shape (as regards the magnetic induction) also the presence of a steady magnetic induction is considered. The endogenous field reduces to an electrostatic one due to the macromolecules. The motion equations for the ion have been solved

in closed form in an important case, when the total magnetic induction vector has a fixed spatial direction. It has been found that the time-periodic part of the magnetic field is very effective on the trajectory amplitude, hence on the processes of ion transport and absorption, and eventually on the time rate of many bioelectrochemical processes. Such phenomena occur at intensities of the d.c. magnetic induction related to multiple values of the ion cyclotron frequency. The theoretically predicted maximal field effectiveness offers a consistent explanation of experimental results on paramecia.

E-3-4 NUCLEAR PRECESSIONAL MAGNETIC RESONANCE AS A CAUSE FOR BIOLOGICAL EFFECTS OF TIME VARYING ELECTRIC OR MAGNETIC FIELDS IN THE PRESENCE OF AN EARTH STRENGTH STATIC MAGNETIC FIELD.

C. Polk. Department of Electrical Engineering, University of Rhode Island, Kingston, RI 02881.

Reports in recent years have shown that the effects on tissue and cells of low frequency, low intensity electric and magnetic fields can critically depend upon the magnitude and direction of a simultaneously present static magnetic field. It has previously been pointed out that in the earth's magnetic field the Cyclotron Resonance Frequency (CRF) of many nonhydrated ions of biological importance lies in the extremely low frequency range. However it is very difficult to see how the circular or spiral orbits required by cyclotron motion could be maintained in an aqueous environment where the ion-neutral and ion-ion collision frequencies are orders of magnitude above the CRF. Nuclear magnetic resonance (NMR) in the earth's magnetic field was first proposed by Jafary-Asl et al. in 1983 as an explanation of the results of some dielectric measurements at audio frequencies and more recently Blackman (in BEMS, 1988) pointed out that experiments on Ca efflux from neural tissue between 15 Hz and 510 Hz suggest an NMR or an electron paramagnetic resonance mechanism. NMR is attractive as an explanation of observed synergistic DC/AC magnetic field effects, because unlike the CRF mechanism, it does not require the virtual absence of ion-ion or ion-neutral collisions. For a relatively weak static magnetic field to be effective, it is necessary that the magnetic field of the electronic shells vanish at the nucleus. This is the case for biologically important substances such as C, S, H_2, NH_3 and H_2O. On the other hand the nuclear magnetic moment must be non-zero, which would exclude NMR effects in $^{12}_{6}C$, $^{16}_{8}O$, $^{40}_{20}Ca$ and several other elements. Characteristic spin resonance frequencies of several elements at specified static magnetic field levels have been evaluated and the role of electric and magnetic field orientation has been analyzed. The manner in which NMR might affect enzymatic processes or DNA/RNA transcription, as in the Goodman Henderson experiments, is discussed and critical experiments are suggested.

E-3-5 THE EFFECT OF ELF ELECTRIC FIELDS ON MEMBRANE RESISTANCE AND POTENTIAL IN *APLYSIA* NEURONS.

A. R. Sheppard, R. G. Villanueva, M. R. Wacker, and W. R. Adey. J. L. Pettis Memorial Veterans Hospital; and Loma Linda University, Loma Linda, CA.

Previous evidence for disrupted firing patterns among Aplysia pacemaker cells exposed to electric (E) fields at 60-Hz indicated latencies of several minutes. Also, field polarity changed too rapidly (8.7 msec) to significantly charge cell membranes (time constants of about 200 msec). Therefore, those data suggested effects on membrane channels. In this study, we measure membrane resistance (R_m) and potential (V_m) of Aplysia ganglion neurons in

vitro to look for changes attributable to field effects on membrane ion channels. Measurements of R_m (by hyperpolarizing current clamps) and V_m were taken every 30 sec for 4 hr, including two 30-min exposures to a 10-Hz, 10-mV/cm rms E-field. R_m was reduced during field exposure in about 50% of tests, increased in about 25%, and unaffected in the remaining tests. Changes took several minutes to develop fully and had a latency from field onset of about 6 min. V_m changed concurrently with resistance changes, but did not track R_m. We conclude that 10 mV/cm E-fields alter membrane properties which regulate net channel conductivity, thereby affecting the number of functional ion channels or their individual conductances. [Research support by Department of Energy, Office of Storage Systems and Distribution DE-AI01-85CE76260, and General Motors Medical Research Institute].

SESSION E-4: MEMBRANES AND MECHANISMS - ELF INTERACTIONS (CONTINUED)

Moderators: R. Goodman and J. C. Weaver

E-4-1 APPROACHES TO THEORIES OF ELECTROPORATION.

James C. Weaver, Alan Barnett, and Kevin T. Powell. Harvard-MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, MA 02139.

Electroporation is the occurrence of aqueous membrane openings ("pores") as the result of elevated transmembrane potentials, U(t), caused by applied electric fields. A number of dramatic phenomena are believed to result from a population of transient pores which have a wide range of sizes, including ionic and molecular transport, membrane recovery and stressed cell behavior. These are generally of considerable practical and theoretical interest. Strikingly, electroporation phenomena have been observed over twelve orders of magnitude in time (from about 10^{-8} to about 10^{4} seconds), but have not yet been fully explained. At very short times (e.g. 10^{-8} to about 10^{-4} seconds) and $500 < U(t) < 1,500$ mV, reversible electrical breakdown (REB) can quickly discharge the membrane, without damage. At longer times (e.g. 10^{-5} to about 10^{-1} seconds), however, a smaller elevated potential can result in rupture of planar membranes, whereas cell membranes are apparently unaffected. At still longer times a high permeability state, believed to be created coincident with reversible electrical breakdown, can persist, and can contribute to molecular and ionic uptake/release, and then to cellular stress. Recently there has been a rapidly growing interest in the use of electroporation to insert DNA and other macromolecules into cells. However, in contrast to these many empirical studies, development of theory has lagged. Here we identify several candidate theoretical mechanisms, and show how present, partially successful theories might be extended to account fully for electroporation. Our emphasis is on mechanisms which may provide a unified, quantitative description of both electrical and molecular transport behavior over the full twelve orders of time, and which can yield results which can be compared directly with experiments.

E-4-2 EFFECTS OF LOW-FREQUENCY WEAK AC-DC MAGNETIC FIELDS ON BILAYER PHOSPHOLIPID MEMBRANES.

Carl H. Durney, Mark Kaminski, Cynthia Bruckner-Lea, Jiri Janata, and Catherine Rappaport. Electrical Engineering, Bioengineering, and Materials Science and Engineering, University of Utah, Salt Lake City, UT 84112.

In an attempt to determine whether the cyclotron-like resonance response observed in organisms by others would also occur in artificial membranes, we have measured the effects of combined weak ac-dc magnetic fields on dc current through planar phospholipid membranes containing no channels. Mixed phospholipid bilayer membranes were painted across a 1-mm hole located in a partition separating two chambers filled with electrolyte and exposed to combined low-level dc and ac magnetic fields with frequencies of 100 Hz or lower. The dc and ac magnetic fields were parallel to each other. We measured the dc current through the membranes as a function of magnetic field strengths with each of the following electrolytes: $CaCl_2$, NaCl, KCl, LiCl, and $MgCl_2$. In each case, other ions were not present in the electrolyte. We found that for each electrolyte the dc current in some of the membranes was increased over that of controls for some combination of magnetic field strengths and frequencies. There was no consistent resonant frequency of response, however, in contrast to the organism response reported in the literature at the cyclotron frequency of unhydrated ions. The dc currents measured in the control membranes was not consistently stable from one membrane to the next, nor in one membrane as a function of time. The results of our experiments indicate that the magnetic fields have some effect on dc currents through phospholipid membranes containing no channels, but not at a characteristic resonant frequency, and not in a repeatable and consistent way.

E-4-3 A THEORETICAL MODEL THAT PREDICTS FREQUENCY, AMPLITUDE, AND HARMONIC RESONANCES IN CELL CHANNELS.

Bruce R. McLeod, Abraham Liboff[1], and Stephen D. Smith[2]. Dept. of Electrical Engineering, Montana State University, Bozeman, MT 59717; Dept. of Physics, Oakland Univ.[1], Rochester, MI 48063, Rochester, MI; and Dept. of Anatomy and Neurobiology, Univ. of Kentucky[2], College of Medicine, Lexington, KY 40536-0084.

We have reported in previous work that the diatom, Amphora coffeaeformis, can be used as a model biosystem to demonstrate frequency and to some extent amplitude resonance effects when the correct dc and ac magnetic fields are applied to the diatoms. The ac frequency was chosen using the cyclotron resonance expression of the frequency being equal to the charge to mass ratio of the target ion times the dc magnetic field divided by 2π. The data exhibited not only a frequency resonance, but also a curious response pattern to the higher order harmonics (1, 3, 5, and 15). We have now developed a model based on the solution of the Lorentz force equation in cylindrical coordinates that exhibits these results. The solution is fitted to a channel model, the latter being developed from current literature on channels in cells, and the solution follows the radial motion of the center of mass of an ion as it passes through the channel. Because of the shape of the inside of the channel, only a narrow region of frequencies will be allowed and only an ac amplitude below a certain level will correctly pump the ion. In addition, only harmonics 1, 3, 5, and possibly 15 will fit, with some indication that even higher harmonics may also fit.

E-4-4 **REGULATION OF CELL-CELL COMMUNICATION BY PHOSPHORYLATION: A POSSIBLE DISTURBANCE OF THESE EVENTS BY A MODULATED MICROWAVE FIELD.** William H. Fletcher, Anna-Marie Martinez, Angela J. Godwin, and W. Ross Adey. J. L. Pettis Memorial Veterans Hospital, Loma Linda, CA 92357.

In previous studies it was found that exposure to the tumor promoter TPA and a modulated microwave field rendered some clonal cells deficient in their capacity for cell-cell communication relative to controls exposed to TPA and carrier wave only. Subsequent studies have shown that gap junctional communication can be regulated by protein kinase A (pkA) and protein kinase C (pkC). Thus altered phosphorylation by one or more of these could be a mechanism by which field exposure interacts with TPA. To test this the subunits of pkA were purified to homogeneity as was the protein kinase inhibitor protein (pkI). pkC and its specific inhibitor ckI were generous gifts. When a cell was injected with the fluorescent dye Lucifer Yellow (LY; M_r 476) dye moved to all contacting cells and beyond them to cells in 3rd and 4th order contact within 2 min. If a cell was given pkI first, then 5 min later LY, dye did not transfer to any cells. This effect could be reversed by injecting similarly treated cells with active pkA 5-10 min after injection of LY. Further, cells were exposed for 60 min to 100 nM TPA which activates pkC then injected with LY. Dye seldom moved to neighbors. Administration of ckI 5 min after LY reversed the effect of TPA. It appears that phosphorylation mechanisms involving pkA and pkC have a rapid positive effect on junctional communication. Over longer periods of time pkA remains a positive modulator of communication while pkC has a negative effect on this process. With these basic data in hand, we have begun to examine the effect, if any, of field exposure on regulation of cell-cell communication by protein phosphorylation. Supported by DOE and General Motors Research Corporation.

E-4-5 **ELECTRICAL CONDUCTIVITY OF PLASMA MEMBRANE CELLS AFTER HYPERTHERMIC TREATMENTS.** Adalberto Bonincontro and Gianni Mariutti[1]. Dipartimento di Fisica and CNSM-CISM, Università "La Sapienza," Rome, Italy; and [1]Laboratorio di Fisica and INFN, Sezione Sanità, Istituto Superiore di Sanità, Viale Regina Elena, 299, 00161 Rome, Italy.

Experimental data obtained from studies on mammalian cells show that hyperthermic treatments can induce structural and functional alterations on plasma membrane. Heat damage changes the membrane transport capabilities for ions (N^+, K^+, Cu^{++}), amino acids and other essential metabolites. In order to better evaluate these phenomena, conductivity measurements in the frequency range 10 kHz - 100 MHz have been performed on samples of Chinese hamster fibroblasts V79 exposed to hyperthermia in different experimental conditions. With our experimental set up such a measurement can be rapidly done without perturbing cell samples. Therefore this physical approach seems appropriate to investigate the biological effects of any treatment which is expected to alter the electrical properties of cells, particularly cell membrane conductivity and permittivity. The dielectric dispersion curves obtained from cell suspensions have been analyzed in terms of the Maxwell-Wagner theory of interfacial polarization. Our results demonstrate that hyperthermic treatments generally decrease the conductivity of plasma membrane. The observed effect strongly depends on temperature value and time duration of hyperthermic treatment. At constant experimental conditions the decrease of membrane conductivity may he enhanced by lowering the pH of the culture medium during heat administration.

SESSION F-1:	EFFECTS OF RF AND ULTRASOUND - *IN VITRO* STUDIES
Moderators:	G. H. Harrison and S. F. Cleary

F-1-1 **MODULATION OF MAMMALIAN CELL PROLIFERATION BY IN VITRO ISOTHERMAL RADIO-FREQUENCY RADIATION EXPOSURE.** Stephen F. Cleary, Li-Ming Liu, Guanghui Cao, and Randall E. Merchant[1]. Department of Physiology and Department of Anatomy[1], Medical College of Virginia, Virginia Commonwealth University, Richmond, VA 23298.

Human peripheral mononuclear cells (MNC) and glioma (LN71) were exposed to 27- or 2450-MHz CW or pulse-modulated radiofrequency radiation (RF). Cells were exposed or sham-exposed once for 2 hr or for 1 hr followed by a second 1 hr exposure 24 hr later. Cells were exposed isothermally at 37 ± 0.2°C in vitro. RF effects on mitogenesis were assayed 1-, 3-, or 5 days after exposure by determining relative incorporation rate of tritiated thymidine (^{3}H-TdR) or tritiated uridine (^{3}H-UdR). The mitogen phytohemagglutinin (PHA) was used to determine RF effects on human lymphocyte transformation in vitro. RF exposure, at either frequency, for either cell type caused highly statistically significant dose-and time-dependent modulation of cell mitogenesis in the specific absorption rate (SAR) range of 5 to 400 W/kg. Implications of these findings will be discussed.

F-1-2 **IN VITRO INHIBITION OF SMALL CELL CARCINOMA OF THE LUNG CELLS BY PULSED RF.** Darragh Foley-Nolan, Patrick Johnston, Amanda McCann, Desmond Carney. Department of Oncology, Mater Misericordiae Hospital, Dublin 7, Ireland.

Small cell carcinoma of the lung is a rapidly proliferating malignancy with a poor prognosis. Current treatment by chemotherapy is unsatisfactory. We report an inhibition of growth of between 32% and 40% in a series of three experimental groups - each comprising of five separate experiments - thus totalling 15 individual observations altogether. The 146 lung small cell line was continually exposed to a 27.12 MHz pulsed radiofrequency field, maximum power 3 mW/cm^2. Controls and treated cells were incubated for 96 hours in separate identical incubators. An inhibition of between 11.3% and 28.6% was achieved in 15 experiments conducted in an identical fashion on a H23 lung adenocarcinoma line. A previous report by Philips (1) describes increased cell turnover in cells exposed to 60-Hz electric/magnetic/electromagnetic fields. In conclusion this study shows in contradistinction an inhibitory effect of a particular type of A/C electromagnetic field on cell growth of types of small cell and adenocarcinoma of the lung, which may have future clinical significance.

REFERENCE

1. Transferrin binding to two human colon carcinoma cell lines characterization and effect of 60 Hz electromagnetic fields. L. Philips, L. Rutledge, W. D. Winters, Cancer Research 46:239-44.

F-1-3 **EFFECT OF METABOLIC FACTORS ON COMPLEX DIELECTRIC CONSTANT OF MAMMALIAN CELLS AND VIRUSES IN THE FREQUENCY RANGE 100 MHZ TO 24 GHZ.** Li-Ming Liu, Stephen F. Cleary, Guanghui Cao, Kee W. Rhee[1], Ewa Czerska[1], Christopher Davis[1]. Department of Physiology and Biophysics, Medical College of Virginia, Richmond, VA 23298; and Department of Electrical Engineering. University of Maryland[1], College Park, MD 20742.

The effect of metabolic factors on the real and imaginary dielectric constant and the absorption coefficient of mammalian cells and viruses was investigated over the frequency range of 100 MHz - 24 GHz. Dielectric spectra were determined with an open coaxial probe antenna and a HP8510 network analyzer system. Effects of metabolic inhibitors (e.g. sodium azide, sodium fluoride, ouabain), fixatives, ionophores (A23187), anesthetic agents, and temperature were determined. Dielectric properties of cellular genomic DNA and RNA were investigated using normal or mitotically stimulated asynchronous log phase cells. The dielectric properties of cell monolayers were also studied. Results will be compared to previously reported results and to results predicted by classical Debye theory.

F-1-4 **SEARCH FOR NEOPLASTIC TRANSFORMATION *IN VITRO* FOLLOWING PULSED ULTRASOUND.** George H. Harrison and Elizabeth K. Balcer-Kubiczek. Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, MD 21201.

Neoplastic transformation of actively growing C3H 10T1/2 cells was assayed following insonation with beams simulating diagnostic or Doppler ultrasound (US). Uniform ultrasonic beam profiles were produced by using high-power unfocussed fields so that all cells experienced negative peak pressures between 0.8 and 1.2 MPa. The two pulse configurations were: 1 pulse (2 or 3.5 MHz center frequency) every msec, or 8 pulses (2 MHz center frequency) in a burst every 0.2 msec. Attached cells were insonated in medium with 10% fetal bovine serum in a transmission chamber for 30 min. US was delivered alone or in combination with 2 Gy of X rays delivered in the middle of US, with or without the tumor promoter tetradecanoyl-phorbol-13-acetate (TPA) at 0.1 μg/ml in culture medium following exposure to US or X rays. The average number of transformants per dish for cells exposed to a given treatment with US was compared with that of similarly treated sham-exposed controls, using a chi-square test. With 1960 dishes evaluated, none of the group comparisons were significant at $p = 0.95$; the excess of transformants following US compared to untreated controls was significant at $p = 0.93$.
(This work was supported by USPKS/NCI Grant CA 40233.)

F-1-5 **MODIFICATION OF SCIATIC NERVE ELECTRICAL EXCITABILITY BY SINGLE LOW LEVEL ULTRASOUND PULSES.** Richard Mihran, Howard Wachtel, Frank Barnes. Department of Electrical & Computer Engineering, University of Colorado, Boulder, CO 80309-0475.

Single pulses of focused ultrasound have been found to induce transient modifications of the excitability of myelinated fibers in frog sciatic nerve at specific, temporal windows in the milliseconds following an acoustic prestimulus. These modifications include both enhancement and suppression of relative excitability and are distributed differently in the two major classes

of myelinated fibers found in the sciatic bundle. The acoustic pre-stimuli were of submillisecond duration, and of intensities such that specific absorbed energies were typically less than 20 mJ/g, which strongly precludes bulk thermal mechanisms as the basis of these observations. On the other hand, no significant frequency dependence of the excitability modifications were observed over the range of 1 to 8 Mhz studied, which argues against a resonance phenomenon. These effects could not be elicited using either a subthreshold DC or RF electrical pre-stimulus, suggesting that the mechanisms involved are uniquely sensitive to acoustic perturbation. Low frequency sound pulses were, however, as effective as ultrasound which suggests a broad spectrum of mechanical sensitivity. Since the levels of ultrasound used in these studies is comparable to those commonly used in medical diagnosis questions regarding safety as well as therapeutic uses of ultrasound may arise.

SESSION F-2: BEHAVIORAL EFFECTS OF EM FIELDS

Moderators: J. A. D'Andrea and R. H. Lovely

F-2-1 MILD HYPERTHERMIA ACCOMPANIES BEHAVIORAL THERMOREGULATION DURING PROLONGED EXPOSURE AT RESONANCE.

Eleanor R. Adair, Barbara W. Adams, and Holly M. Jager. John B. Pierce Foundation Laboratory, New Haven, CT 06519.

During 90-min exposures to 2450-MHz microwaves (SAR = 3.0 W/kg), trained squirrel monkeys select a preferred ambient temperature (T_a) such that skin and deep body temperatures are regulated at normal (sham exposure) levels. Current experiments were designed to determine the thermoregulatory efficiency of this behavioral response during comparable exposures at the resonant frequency. Following a 2-hr baseline period of T_a selection, individual monkeys were exposed for 90 min in the far field of a dipole antenna (E-polarization) to 450 MHz CW microwaves at a power density of 5 mW/cm^2 (SAR = 3.0 W/kg) or sham exposed. Five microwave and five sham exposure sessions were conducted on each of four monkeys. T_a selected, colonic and four representative skin temperatures were monitored continuously. As long as the microwave field was present, each animal selected a T_a about 2.5° C cooler than normal, a selection similar to that stimulated by exposure to 2450 MHz microwaves. Although this T_a yielded normal skin temperatures, the associated colonic temperature was regulated about 0.8° C above normal. These results provide additional evidence that thermoregulatory behavior is less effective during exposure at resonance because peripheral thermodetectors are inefficiently stimulated and deep tissues are heated more efficiently. [Supported by US Air Force Contract F33615-87-C-0607]

F-2-2 AGE-RELATED DIFFERENCES IN THERMOREGULATORY RESPONSE DURING ACUTE EXPOSURE TO 2450 MHZ MICROWAVES.

Donald E. Spiers, Eleanor R. Adair, and Laura E. Fusco. John B. Pierce Foundation Laboratory, New Haven, CT 06519.

Metabolic and thermal responses to CW microwave irradiation (2450 MHz, k-polarization) at cold ambient temperature (T_a) may change during postnatal development when there is significant reduction in whole-body SAR. Rats were partially restrained in cylindrical holders at 2-3, 6-7, 10-11 and 15 days of

age and individually exposed to cold T_a (31.5-25.0° C) capable of elevating metabolic heat production (M) 100% above resting level. Each animal was exposed to microwaves at a power density of either 0, 5, 10 or 20 mW/cm^2. Tests consisted of a 1 hr thermal equilibration period, followed by 1 hr microwave exposure and 1 hr reequilibration periods. Colonic (T_{co}) and skin temperatures were measured in the absence of microwaves using 40 g thermocouples and M determined from measurements of oxygen consumption. T_{co} increase during irradiation (ΔT_{co}) was greater at 2-3 days (2.2° C maximum) than at 10-11 days (0.6° C maximum) of age. By 15 days, however, ΔT_{co} response at 20 mW/cm^2 had increased to 1.2° C. M was reduced by 28% in 2-3 day old rats exposed to 5 mW/cm^2 and remained at this level at higher power densities. In contrast, older animals exhibited a proportional reduction in M with increasing power density, averaging 40% at 20 mW/cm^2. A nonlinear change in thermoregulatory responsiveness to microwave irradiation occurs during the first 2 weeks of postnatal growth and is attributed to a reduction in SAR with simultaneous improvement in homeothermic ability. (Supported by NIH Grant HD 18002-06).

F-2-3 **POSSIBLE BASES FOR THE SUPPRESSION OF STARTLE RESPONSES BY SINGLE MICROWAVE PULSES.** H. Wachtel, D. Beblo[1], C. Vargas[1], H. Bassen[2], D. Brown[1]. University of Colorado, Boulder, Co, 80309-0425; and ERC Bioservices Corp.[1], Rockville, MD 20850-1452; Walter Reed AIR[2], Washington, DC 20307-5100.

We have recently reported that single microwave pulses (1250 MHz, durations as short as 1 μsec with a peak SAR of 0.2 MW/kg) can markedly suppress the startle response normally produced in mice by a loud acoustic stimulus (typically a 10 msec, 20 kHz tone at 90 db or greater intensity). The suppressive effect is seen consistently when the microwave pulse is delivered anywhere from 0.5 seconds to .005 seconds prior to the onset of the acoustic stimulus. On occasion suppression can be demonstrated with even shorter latencies - down to essentially zero msec. The specific energy absorbed per microwave pulse (0.2 J/kg) predicts a temperature rise of only 0.00005° C which rules out a "bulk thermal" basis for the suppression. However, thermoelastic explanations are plausible; including the possibility of microwave hearing. Our recent experiments show that, contrary to results reported by others, an acoustic prestimulus can be delivered very shortly (5 or 10 msec) before a startling sound and still have some suppressive effect on the response. It can, however, also be argued that microwave induced thermoelastic, or microthermal, effects could lead to direct modification of neural activity - which would explain the shortest latency microwave pulse results. It is also conceivable that a "microwave hearing" effect and direct neural intervention could be occurring together.

F-2-4 **BEHAVIOR IN RHESUS MONKEYS EXPOSED TO VERY HIGH PEAK POWER 3.0 MICROWAVE PULSES.** John A. D'Andrea, Brenda L. Cobb, James Knepton, and Frank Bates[1]. Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700; and ERC Bioservices Corp.[1], Washington, DC 20307-5100.

To investigate behavioral effects of very high peak power 3.0-GHz microwaves, four male rhesus monkeys (Macaca mulatta) were trained on a operant task for food pellet reward. The behavioral task was twofold. In the first component, the task required the monkeys to press one lever during a variable interval of 20 sec (VI-20). During the second component, they were required to press

another lever within 1 sec of the onset of a visual signal. The monkeys discriminated between one of three colors displayed by a fiber-optic cable. A red signal was displayed during the VI-20 component. If the monkeys responded on the other lever during the second component when a green signal light was on, they received a food pellet. If they responded to the white signal, they received a 10-sec timeout. During the behavioral task, the monkeys were exposed to 20-60 nsec microwave pulses (7.5 sec interpulse interval) produced by the Walter Reed Army Institute of Research TEMPO vircator. Peak field power densities averaged 46 kW/cm^2, which produced peak whole-body SARs of approximately 400 kW/kg. Behavioral performance was not altered significantly.

F-2-5 **EXPOSURE OF PREGNANT RATS TO A 10 TESLA STATIC MAGNETIC FIELD: OPERANT BEHAVIOR CONSEQUENCES IN OFFSPRING.** Michael Bornhausen. Institute of Toxicology, Gesellschaft für Strahlen- und Umweltforschung (GSF), D-8042 München-Neuherberg, Federal Republic of Germany.

To detect an eventual risk of magnetic resonance imaging (RI) techniques - especially during pregnancy - pregnant Wistar rats were exposed (group A: days 12 through 16 p.c., 8 hr/day; group B: day 16 p.c., 1 hr) to a 10-T static magnetic field at the CNCI/CNRS facility, Grenoble, France. Two additional groups served as controls. Both were kept in identical containers, one at Grenoble, the other at München to assess eventual travel stress during car transport. Male offspring (randomly selected 1 pup/litter) of the four groups were coded and tested at an age of 14 weeks in a battery of 10 computer-controlled Skinner Boxes by the schedules Differential Reinforcement of High (DRH) and Low (DR) Rate with incrementally increased contingencies of food reward. Variability of data (six nocturnal 15-hr sessions) within groups was low. A comparison between group means (N=10) of DBRH- and DRL-performance provided evidence that acute or prolonged exposure to static magnetic fields 2-3 times the strength of actual MRI-procedures during major organogenesis does not induce overt functional changes in the central nervous system of rats. This conclusion was validated by measurements of developmental landmarks, Rotarod-performance, brain histopathology, and equally negative results in female siblings (Residential Maze, ETH-Zürich, Switzerland). (Part of this work was done in fulfillment of the requirements of a veterinary thesis by A. Lax, K. Blab, and G. Serra).

SESSION F-3:	PHYSIOLOGICAL EFFECTS OF RF FIELDS.
Moderators:	M. A. Stuchly and J. C. Toler

F-3-1 **LONG-TERM, LOW-LEVEL RADIOFREQUENCY RADIATION BIOEFFECTS ON MAMMALIAN CELL GROWTH AND DIFFERENTIATION: ENGINEERING CONSIDERATIONS AND STANDARD OPERATING PROCEDURES.** J. C. Toler, E. Sjoberg, D. Banks, S. Bonasera, M. Stetham[1], and J. Hickman[1]. Bioengineering Center, Georgia Institute of Technology, Atlanta, GA 30332; and Pathology Associates Inc.[1], Ijamsville, MD 21754.

There have been conflicting reports concerning the possible effects of low level, athermal radiofrequency radiation (RFR) exposure on mammalian cell growth and differentiation. An ongoing study is now testing the null hypothesis that chronic exposure to low level RFR fields results in no effects on mammalian cell growth and differentiation. In this study, 200 mammary-tumor-prone mice (strain C3H/hej) are being exposed to a low-level (1.0 mW/cm^2) pulsed-wave (1.0 kHz pulse rate, 1.0 sec pulse width) 435 MHz RFR environment. Exposure group animals are irradiated for 20 hours daily, 7 days a week, for a period of 18 months. The RFR environment is generated between the tiers of a stacked, parallel-plate waveguide fed by slotted cylinder antennas. A sham-exposure group of 200 C3H/hej mice is maintained under identical conditions, but is not radiated. An additional 50 mice (25 exposure, 25 sham-exposure) are sentinel animals for murine mycoplasma determinations. At the conclusion of the exposure duration, all animals will be necropsied, and the harvested tissue samples examined by a pathologist for evidence of neoplastic or other alteration. All engineering, animal husbandry, histology, and analysis protocols are described in standard operating procedures (SOPs), and the SOPs themselves are subject to rigorous examination and quality control. The facility and all animals are briefly inspected twice each day, additionally, each animal receives a detailed physical examination (including tumor palpation) once a week. Animal growth curves, survival curves, and in-life results covering the first 5 months of exposure will be presented.

F-3-2 **EFFECTS OF CHRONIC, LOW-LEVEL 435-MHZ RFR ON BLOOD-BORNE HORMONES IN CANNULATED RATS: HEMATOLOGY.** V. Popovic, J. Toler[1], S. Bonasera[1], P. Popovic, C. Honeycutt, and D. Sgoutas. Departments of Physiology and Pathology, Emory University School of Medicine, Atlanta, GA 30322; and Bioengineering Center, Georgia Institute of Technology[1], Atlanta, GA 30332.

Two hundred adult male white rats (Sprague-Dawley) with chronically implanted aortic cannulas were randomly divided into two groups. Animals in the first group were exposed to low-level (1.0 mW/cm^2 pulsed-wave 435-MHz RFR for approximately 22 hours daily, seven days each week, for six months. Depending upon animal orientation within the home cage (all animals caged singly), estimated whole body specific absorption rate (SAR) ranged from 0.04 to 0.4 W/kg. Animals in the second group were maintained under identical conditions but were not radiated. Microsamples of blood (0.2 ml), withdrawn from 126 (63 irradiated and 63 control) unanesthetized and unrestrained rats through the cannulas, were used to determine hematocrit ratio, complete red blood cell

count, complete white blood cell count, and a differential count of neutrophils, eosinophils, and monocytes. Polynomial regression techniques modeled these hematological parameters as functions of time, and additionally tested for RFR-induced effects on various model terms. The models detected no significant difference in these hematological parameters when the RFR-exposed group was compared to the sham-exposed group. Eosinophil and monocyte counts Increased linearly in both RFR-exposure and sham-exposure groups for the duration of the experiment. This increase was attributed solely to the effects of animal aging, and not to RFR exposure. Chronic exposure to the low-level pulsed RFR field resulted in no adverse effects on animal health, as measured by the hematological evaluations. Supported by USAF contract F33615-83-K-0600.

F-3-3 **EFFECTS OF PULSED AND AMPLITUDE-MODULATED LOW POWER MICROWAVES ON THE ANTIBODY RESPONSE IN VIVO.** R. de Seze, A. Caristan, C. Bouthet, P. Deschaux, M. Geffard, J. Joussot-Dubien, M. Le Diraison, J.-M. Moreau, and B. Veyret. Groupe de Bioélectromagnétisme, ENSCPB, Université de Bordeaux I, 33405 Talence, France.

A study of the effects of low power (30 $\mu W/cm^2$) pulsed microwaves (9.4 GHz, 1 μsec pulse, 1000 pps), amplitude modulated at frequencies between 14 and 41 MHz (100% modulation) on the immune system of mice was carried out. Balb/C mice (6 wk old males in all experiments) were exposed 10 hr/day for 5 days. In a first set of experiments, 10 mice were immunized with Bovine Serum Albumin conjugated with glutaric anhydride (BSA-GA) and then exposed. They were immunized again 3 days after the end of exposure. Blood samples were taken every 2 days and ELISA assays were performed to obtain the IgG and IgM titers. The yields of both antibodies were reduced in the presence of the modulated microwaves except at 21 and 32 MHz where they were increased. In a second set of experiments, 14 mice were immunized once with Sheep Red Blood Cells (SRBC) and then exposed. The spleen lymphocytes were counted on the 6th day and the number of plaque forming cells (PFC) was then measured. The dependence of the number of PFC on the modulation frequency was similar to that found for the antibodies in the BSA-GA experiments. More experiments are being done to learn about the effect on B-T cell cooperation and other experiments are being carried out using a cytofluorimeter in order to determine the early effects of the microwaves on the immune cell populations. Preliminary results show that at short times (a few hours), immune cell subpopulations are strongly modified by the field, depending on the modulation frequency.

F-3-4 **STUDY OF TERATOGENIC EFFECTS OF MICROWAVE AND RADIATION ON RATS.** Liu Wenkui and Zheng Hexin. Shanxi Medical College, Taiyaun Shanxi, PRC.

Pregnant Wistar rats that are healthy and mature are divided into six groups randomly, that is 100, 80, 60, 40 mw/cm^2 groups, a negative group, and a positive group. The former four groups are radiated by 2450 Mc consecutive microwave on the sixth, eighth, tenth, twelfth, fourteenth, and sixteenth days of rat's pregnancy. The positive group is radiated by 150R gamma-ray. No radiation is done on the negative group. All rats are killed on the twentieth day of their pregnancy, taken out fetus by laparotomy and observed teratogenic changes. The changes include weight gain of maternal rats, early embryonic development, fetus' growth level, appearance, nerve systems, internal organs

and skeletons. The results indicate that microwave radiation has significant teratogenic effects on the maternal weight gain, fetal developmental level, appearance, nerve systems and skeletons, and even induces absorption of embryos and death of fetus. The highest dose group (100 mW/cm^2) is the most significant. Simultaneously, there are dose-response relationships in the indicators of nerve systems, skeletons, embryonic absorption and fetal death. The rates of embryonic absorption, curved tails, short tails, fetal body weight, fetal body length, enlargement of subarachnoid space, and abnormal skeletons in the former four groups are significantly higher than the negative group. It also demonstrates that nerve systems and skeletons are more sensitive to microwave radiation.

F-3-5 **ELECTROENCEPHALOGRAPHIC CHANGES AND BLOOD PRESSURE LOWERING EFFECT OF LOW ENERGY EMISSION THERAPY.** Boris Pasche, Jean-Pierre Lebet[1], Alexandre Barbault[1], Claude Rossel[1], Niels Kuster[2]. Department of Experimental Surgery, Karolinska Institute, 5-104 01-Stockholm, Sweden; Symtonic SA[1], Av. des Baumettes 9, CH-1020-RENENS; and Swiss Federal Institute of Technology[2], Electromagnetics Group. CH-8092-ZURICH, Switzerland.

Low Energy Emission Therapy (LEET) consists of the intrabuccal emission of amplitude modulated 27.12 MHz EM fields with modulation frequencies ranging from 0 to 10 kHz (US patent no. 4,649,935) resulting in a SAR below 0.1 mW/kg. In a double-blind cross-over study performed on 50 healthy patients sitting on a chair, eyes closed with the antenna of the emitting device in the mouth, the physiological effects of LEET were assessed by recording the electroencephalogram (EEG), the blood pressure and the pulse following 20 minutes of either active or inactive LEET treatment with a 44-Hz square-wave modulation. EEG analysis according to the Loomis classification showed a significant sleep inducing effect ($p < 0.05$) in the active treatment group. The decrease in systolic (7.24 ± 4.74 mm Hg) as well as diastolic (1.84 ± 4.48 mm Hg) blood pressure was highly significant ($p < 0.01$) in the active as compared with the inactive treatment group. The pulse rate remained the same in both groups. These data indicate that the LEET has an effect on the CNS opening new therapeutic perspectives in the field of insomnia and hypertension.

SESSION F-4: RF HYPERTHERMIA AND TUMOR TREATMENT

Moderators: C. K. Chou and T. C. Cetas

F-4-1 **DETERMINATION OF SAR PATTERNS OF INTERSTITIAL HYPERTHERMIA APPLICATORS BY THREE METHODS: MINIATURE FIELD PROBE, HIGH RESISTANCE THERMISTOR AND FLUOROPTIC THERMOMETRY.** Mark J. Hagmann, Charles F. Gottlieb[1], Tadeusz M. Babij, Andre A. Abitbol[1], Alan A. Lewin[1], Pavel V. Houdek[1], James G. Schwade[1]. Florida International University, Miami, FL 33199; and University of Miami School of Medicine[1], Miami, FL.and 33136.

We have previously used electric field measurements for SAR determination of interstitial applicators, while others have used temperature measurements for this purpose. We are concerned about errors due to heat transfer in

determining SAR from temperature measurements because the fields vary rapidly close to these applicators. We measure temperature using a BSD-500 with standard Luxtron and Bowman probes. Special 0.2-mm diameter fluoroptic probes will also be used. SAR is estimated from the time rate of change of temperature, as has been done by others. Additionally, we use a miniature (3.0-mm diameter) electric field probe to determine SR. Thus, we determine SR on the same phantom and applicator configuration using both temperature and electric field measurements. The BSD MA-251 and the Clini-Therm applicators are used. All measurements are made in a muscle-simulating phantom that is optically clear, has all ingredients in solution, and is, therefore, truly homogeneous. Homogeneity is essential due to the rapid spatial variation of SAR. Gelling of the phantom is not required for electric field measurements, but is needed to limit convection when making temperature measurements. SAR determinations from electric field measurements have greater precision, require less RF power, and do not require interpolation, hut presently have decreased resolution due to the larger size of the sensor. Supported in part by ACS, Florida Division Martha H. McDonald Research Grant No. F88UM-2 (Gottlieb).

F-4-2 **ON THE FEASIBILITY OF ELECTROMAGNETIC PHASED ARRAYS AT 434 MHZ FOR INDUCING HYPERTHERMIA IN LUNG TUMORS.** Mikaya L. D. Lumori, Jorgen B. Andersen[1], and Thomas C. Cetas. Departments of Radiation Oncology, Aerospace and Mechanical Engineering, and Electrical and Computer Engineering, University of Arizona, Tucson, AZ 85724; and Institute of Electronic Systems, Aalborg University[1], Aalborg, Denmark.

Controlled heating of lung tumors remains uncertain. We have developed a fast, convenient method for computing the specific absorption rate (SAR) from microwave aperture sources radiating into layered media. The theory is based upon an analytical Gaussian beam function using complex coefficients. It has been verified experimentally for homogeneous and for layered heterogeneous media. While not applicable to the generalized heterogeneous properties of tissues required in realistic treatment planning programs, it is applicable to many cases such as lung tumors where the heterogeneities are layered rather than having sharp ridges or corners. This model can be used to guide development and for parametric analysis. Typical computer run times for an entire field are of the order of 40 sec. This model has been used to determine the theoretical feasibility of using wide field microwave phased arrays operating near 434 MHz for treating various types of lung tumors. Specifically, we calculate the SAR pattern for a variety of conditions including applicator configuration, the thickness of tissue layers overlying the lung and the location within the lung.

F-4-3 **PHASED MICROWAVE ARRAY FOR SUPERFICIAL HYPERTHERMIA.** M. K. Gopal, J. W. Hand, K. D. Paulsen, M. L. D. Lumori, S. Alkhairi, T. C. Cetas, and Jeff Hand[1]. Departments of Radiation Oncology, and Electrical and Computer Engineering, University of Arizona, Tucson, AZ 85724; and MRC Cyclotron Unit, Hammersmith Hospital[1], London, UK.

A planar array with large effective area is investigated. The individual elements of the array are an adaptation of the inductive applicator (Johnson et al., 1987). Arrays consisting of 2 x 1 and 2 x 2 are arranged over a 1-cm thick simulated fat layer with muscle equivalent liquid phantom in front.

Electric field intensity measurements were made 1-cm deep inside the liquid phantom using a matched miniature dipole and HP network analyzer. Both horizontal and vertical polarizations are investigated. These intensity contours are compared to the contours generated using the Gaussian model analysis (Bach Andersen et al., 1986) using the characteristics of the individual elements. The agreement is very good. In contrast to the radiative type applicators with cosine square intensity distribution, the above array gives about 57% coverage of the applicator area at the 50% power contour. Using the 2 x 2 array, shaped contours could be generated by controlling the power to the individual elements. The theoretical simulation also shows that there is an optimum focussing point at about 40 mm along the center axis of the array.

F-4-4 **NUMERICAL SIMULATION OF ANNULAR-PHASED ARRAYS OF DIPOLES FOR DEEP-SEATED TUMOR HYPERTHERMIA.** Jin Yuan Chen, Om P. Gandhi, and Frederic A. Gibbs, Jr. University of Utah, Salt Lake City, UT 84112.

We have used the finite-difference time-domain (FDTD) method to calculate the SAR distributions in an anatomically-based model of the human torso and the thighs to obtain the optimum applicator arrangements for hyperthermia of deep-seated tumors. Annular-phased arrays of eight dipole antennas couple to the human body through either a homogeneous or a tapered water bolus with air assumed outside the ring of dipoles. The objective of the calculations was to focus the energy to a couple of assumed tumor sites in the liver or the prostate. Toward this end, different frequencies (100 or 120 MHz); lengths (17 to 38 cm), magnitudes and phases of power to the various dipoles; and tapers of the bolus were tried. In the absence of exact knowledge on conductivity (δ) and permittivity (ε) of tumor vis a vis the normal tissues, tumor δ and ε similar to and somewhat higher than those for the normal tissues were assumed. Considerably focused SAR distributions could be obtained for the assumed tumor sites in the liver and the prostate using tapered boluses and optimized magnitudes and phases of power to the various dipoles. In the future, it should be possible to use this technique coupled with a patient-specific model obtained from the CT scans for pretreatment planning of hyperthermia using annular-phased arrays.

F-4-5 **EFFECTS OF CATHETER AND ANTENNA SIZE ON HEATING PATTERNS OF MICROWAVE INTERSTITIAL OR INTRACAVITARY HYPERTHERMIA APPLICATOR.** C. K. Chou, Kwok W. Chan, John A. McDougall, Kenneth H. Luk, and Vidya Bobba. Department of Radiation Research, City of Hope National Medical Center, Duarte, CA 91010.

In a previous study, we have shown that heating patterns of interstitial microwave antenna arrays change with different insertion depths. This phenomenon was not seen with a single antenna. While developing a larger antenna for intracavitary heating of patients with nasopharyngeal or esophageal cancer, we found that heating patterns could change due to the different catheter or tubing thickness used with this larger antenna. The antenna is made of RG-316 coaxial cable with a 5.5 cm tip. The outer conductor of this tip was connected to the inner conductor at the junction. When the antenna was placed in a 3.75 mm thick wall Silastic tubing for insertion into the esophagus or nasopharynx, the heating patterns as simulated on a homogenous muscle phantom showed maximum heating at the junction of the

antenna as expected. When the antenna was insulated with thin wall Teflon heat shrink tubing for direct insertion, the maximum heating was shifted 2 cm from the junction toward the tip. Wave propagation and, therefore, energy deposition are very complicated in this region which consists of the antenna, dielectric catheter or tubing, air spaces and the surrounding lossy tissues. It is important to realize that the hot spot can shift and not to assume maximum heating is always at the junction. Detailed dosimetry is necessary for clinical applications that require different combinations of antenna, and catheter or tubing sizes.

SESSION G-1:	**SYMPOSIUM ON NEW PROBES FOR BIOLOGICAL ASSESSMENTS**
Moderator:	R. P. Liburdy

G-1-1 **FLUORESCENT PROBES AS MICRODOSIMETERS.** Robert P. Liburdy. Bioelectromagnetic Research Facility, Research Medicine and Radiation Biophysics, Lawrence Berkeley Laboratory, UC Berkeley, Berkeley, CA 94720.

Microdosimetry can be defined as dosimetry that takes place at the cellular or molecular level. At present, standard dosimetry approaches involve mapping animal or tissue systems using hand-held or implanted probes sensitive to electrical or magnetic fields or tissue temperature -- these parameters are measured by integrating over the active element of the probe at a resolution of millimeters or larger. Bioeffects research is evolving towards efforts to characterize interactions at the cellular and molecular levels and this requires, if technically feasible, a microdosimetry analysis of the target area of interest. Fluorescent probes are molecular-level reporting agents that hold promise as tools for microdosimetry. Two potential applications are mapping molecular-level temperature alterations and also induced potentials in structures associated with the cell, e.g., the cell membrane, or in intracellular components such as DNA or proteins of interest. A discussion of these applications and others will be presented along with a discussion of requirements necessary for fluorescent probes analysis and how to characterize a probe for microdosimetry applications. This work is supported by the Director, Office of Energy Research, Office of Energy Storage and Distribution, of the US Department of Energy under Contract DE-AC03-76SF00098.

G-1-2 **MOLECULAR PROBES: FLUORESCENT PROBES FOR MEASURING THE PROPERTIES OF PROTEINS AND CELLS.** Richard Haugland. Molecular Probes, Inc., 4849 Pitchford Avenue, Eugene, OR 97402.

Fluorescent probes are frequently introduced into proteins, biological cells and polymers to yield qualitative and quantitative information on the location or properties of specific sites. The exceptional utility of fluorescence is the result both of the high detectability of the signal and to the number of parameters possible for fluorescence measurements, including intensity, lifetime and polarization, and the associated properties of quenching, energy transfer, bleaching and interaction with solvent. The spectral properties of

fluorescent dyes have been used to develop specialized probes to determine location, structure, distances and solvation of binding sites, and the rotational, translational and electrical properties of biomolecules. The rational design and applications of several types of probes whose fluorescence properties can be used to measure protein and cellular properties will be discussed.

G-1-3 **EFFECTS OF 2.45-GHZ-MICROWAVE RADIATION ON THE PERMEABILITY OF UNILAMELLAR LIPOSOMES CONTAINING THE FLUORESCENT MARKER 5(6)-CARBOXY-FLUORESCEIN.** E. Saalman, B. Nordén, L. Arvidsson, Y. Hamnerius. Department of Physical Chemistry, Department of Biochemistry and Biophysics, Department of Applied Electron Physics, Chalmers University of Technology, S-412 96 Gothenburg, Sweden.

The influence of 2.45-GHz-microwave radiation on the membrane permeability of unilamellar liposomes has been studied, using phosphatidylcholine liposomes containing trapped fluorescent 5(6)-carboxyfluorescein. The liposome preparation method involved freezing/thawing, freeze-drying and extrusion techniques and produced liposomes of very homogeneous size as determined by dynamic light scattering. The release of the trapped marker was determined by spectrofluorimetry, after 10 minutes exposure to either microwave radiation or heat alone. A significant increase of the permeability of carboxy-fluorescein through the liposome membrane was observed for the microwave-exposed samples compared to normally heated samples. In contrast to earlier studies, this study was carried out far from the phase transition temperature of the liposome membrane. Despite this, an increased liposome permeability was observed. A fiberoptic thermometer was used, allowing temperature measurements at several points in the solution volume during microwave-exposure. Possible mechanisms of increased membrane permeability are discussed.

SESSION G-2: EXPOSURE ASSESSMENTS AND HUMAN EFFECTS OF ELF

Moderators: A. Bellossi and W. T. Kaune

G-2-1 **EXPOSURE OF ELECTRIC UTILITY WORKERS TO POWER-FREQUENCY MAGNETIC FIELDS.** William T. Kaune, Sandy West, Michael Flynn, J. Michael Silva, and David A. Savitz. Enertech Consultants, Campbell, CA 95008; and University of North Carolina, Chapel Hill, NC 27514.

We are measuring the exposure of electric utility workers to power-frequency magnetic fields as part of a large epidemiological study of cancer mortality in electric utility workers. Workers were asked to wear EMDEX personal exposure meters during one 8-hr shift. The meters were programmed to measure, every 10 sec, the x, y, and z components of magnetic flux density. As of January, 1989, we have obtained data for 163 workers from the following job-title categories: workers at power plants that are either (1) generating electric power or are (2) on standby status; distribution linemen working on (3) overhead or (4) underground electric facilities; (5) substation electricians; and (6) transmission linemen. Flux density measurements for an

individual worker generally exhibit multi-modal distributions. We are characterizing these distributions using the mean, median, and 90th percentile values. The distribution of any of these summary statistics for workers in a job-title category approximates a log normal distribution. Parametric tests indicate that there are substantial differences in work-day exposure among the six categories identified above, with workers in power plants on standby status being lowest (geometric means of the median and 90th percentile individual exposures being 1.0 mG and 3.1 mG, respectively) and transmission linemen being highest (geometric means of median and 90th percentile exposures = 5.4 mG and 61.7 mG, respectively).

G-2-2 **MAGNETIC FIELDS DUE TO 60 HZ GROUND CURRENTS: SOURCES AND FIELD STRENGTHS, ABATEMENT METHODS AND ELECTRICAL SAFETY CODES.** Stewart J. Maurer. Department of Electrical Engineering, New York Institute of Technology, New York, NY 10023.

Ground currents have been shown to produce significant magnetic fields in residential and business environments. Magnetic field measurements made in a variety of structures are presented. These fields are many times larger than the ambient levels often contributed by nearby power distribution lines. Further, unlike the fields produced by electrical appliances, they are not localized and can extend well into living or working spaces. Both the sources of ground currents, and how grounding requirements of local and national electrical codes affect the distribution of these currents and their resultant magnetic fields are shown. Various magnetic field abatement methods and their possible conflict with electrical safety code are presented.

G-2-3 **ELF AND RF ELECTROMAGNETIC EMISSIONS FROM VDT'S ASSOCIATED WITH MISCARRIAGES.** Maila Hietanen, and Kari Jokela. Institute of Occupational Health; and Finnish Centre for Radiation and Nuclear Safety, Helsinki, Finland.

Several epidemiological investigations have aroused the suspicion that low frequency FM emissions from video display terminals (VDTs) may cause miscarriages. However, exposure has been estimated mostly on the basis of questionnaires. In this study, which is part of a study on spontaneous abortions among the users of VDTs, the exposure will be assessed on the basis of the measurements of the electric and magnetic fields. The electromagnetic emission from 18 different types of VDTs used by the case mothers was measured. The parameter determined was the magnetic flux density B (and its time derivative dB/dt) at the extremely low frequency (ELF) and at the radiofrequency (RF) ranges. In addition, the electric field strength E was measured at RF range. The measurements were carried out in front of the screen, and at the position approximated for the fetus. The maximal emissions varied markedly among the types of VDTs. The differences were highest for the dB/dt values (RF) range varying from 4 mT/sec to 280 mT/sec at the distance of 30 cm. The highest B (ELF) measured was 2.6 μT and the lowest values were at the background level of 0.4 μT. For electric fields, the highest field strength was 22 V/m and the lowest 2.6 V/m. The results indicate that the exposure of the pregnant women to electromagnetic fields was generally low. The measured values were in most cases at least two decades below recently proposed exposure limits (DIN, NRPB). Only a few of the results were about one decade less than occupational threshold limits of ACGIH at RF frequencies.

G-2-4 COULD YOU EXPLAIN IT? THREE HEALING CASES OF SINUSITIS THROUGH ELF PULSED MAGNETIC FIELD.

André Bellossi. Laboratoire de Biophysique, Faculté de Médecine, Av. din Pr. Léon Hernard, 35043 Rennes Cédex, France.

Sinusitis is an inflammatory state of face sinuses. It can either be acute or chronic. It can give a continuous pulsatile pain and a purulent rhinorrhea. The treatment consists in taking analgesics, anti-inflammatories, relieving-congestion drugs, and antibiotics. The chronic sinusitis often requires a puncture and the washing of the sinus. For these three following patients the classical treatments failed. Mrs. B., 58 years old, had been suffering from a bilateral frontal sinusitis for about 10 years. The pain was absent only in summer. As soon as the weather was cold and wet, the left finger tips became puffy and painful. Mr. R. 58 years old, had been suffering from a right frontal and maxillary sinusitis for about 8 years; the pain had the particularity of being more severe in summer and was accompanied by a bloody purulent nasal flow. B., 9 years old, had been suffering from the left frontal sinus for 4 months. A pulsed magnetic field (PMF) produced by a Magnobiopulse apparatus (Société ATLAS, France) was used. The PMF was delivered through discs, each 12 cm in diameter. For the exposure, the discs were applied on the patients' faces once or twice a week, for a 10- to 20-min session. The field strength was generally 6 mT, the frequency either 100 or 12 Hz. The treatments respectively lasted 6 months, 2 months, 7 weeks, and respectively ended 3 years, 2 years and 3 years ago. There has been no relapse. So the question is how did the PMF succeed in releasing the immune system which was inefficient?

SESSION H-1: MODELING AND MECHANISMS OF INTERACTION

Moderators: F. X. Hart and C. H. Durney

H-1-1 CALCULATION, MEASUREMENT, AND INTERPRETATION OF MAGNETIC RESONANCE INHOMOGENEOUS LINE BROADENING IN MODELS OF LUNG AND OTHER HETEROGENEOUS STRUCTURES.

Carl H. Durney, James A. Bertolina[1], David C. Ailion[1], Craig Goodrich[1], Rebecca Christman[1], Antonio G. Cutillo[2], and Alan H. Morris[2]. Electrical Engineering, Physics[1], and Medicine[2], University of Utah, Salt Lake City, UT 84112.

The diamagnetic, foam-like structure of inflated (in contrast to collapsed airless) lung perturbs the dc magnetic fields in magnetic resonance imaging (MRI) and causes inhomogeneous line broadening. Understanding this mechanism is important for using MRI effectively in the lung, and it may also lead to methods for determining the state of the lung by using measurements of the inhomogeneously broadened nuclear magnetic resonance (NMR) line shape. We previously reported calculations of inhomogeneous line broadening in two models: (1) a single spherical shell, and (2) an array of spherical air bubbles in water. In order to understand better the contribution to the NMR broadening of pockets of water and thin water regions in the lung, we extended these calculations to different geometries. We now report additional calculations in other models: (1) a single cubical shell, (2) rectangular slabs, and (3) an array of cubical air bubbles in water. We also report NMR

lineshape measurements in water cubes, cubical shells, and slabs. The calculated lineshapes agree well with the measured ones. We are able to explain the NMR lineshapes and their relationships to the structure of the models in terms of the effects of "thick" and "thin" water. This correspondence between lineshape and geometry may lead to methods for quantitating "thin" lung tissue (alveolar septa), and "thick" lung tissue (alveolar corners) by measurements of inhomogeneously broadened NMR lineshapes.

H-1-2 **LORENTZ MECHANISMS AND FREQUENCY SPECTRA IN ELECTROMAGNETIC BIOEFFECTS.** A. A. Pilla, J. J. Kaufman, A. Chiabrera[1], B. Bianco[1], and J. T. Ryaby. Bioelectrochemistry Laboratory, Department of Orthopaedics, Mount Sinai School of Medicine, New York, NY; and DIBE, University of Genoa[1], Italy.

Study of the physical mechanisms involved in the bioeffect of weak electromagnetic fields necessitates a consideration of both electric and magnetic components. In all cases signal frequency content and power are integral parts of dosimetry. Signals with most of their energy in the high frequency portion of the spectrum (>1 kHz) appear to operate using the electric component as the primary effector. However, it is predicted that certain pulsed EMF signals could exhibit a dependence on weak magnetic fields with the relationship governed by the signal frequency and the charge/mass ratio for, e.g., Ca^{++}. Under these conditions, which also assume a long time between encounters (collisions) of charge species at the membrane interface, maximal bioeffects will only be observed at the AC/DC magnetic field relationship governed by a specific ionic charge/mass ratio. On the other hand, if the electric component is the principal force input, then there should be no dependence of bioeffect on small DC magnetic fields (<5 G). This is tested by comparing the effect of a pulsed waveform containing significant energy at the signal repetition rate and the same pulse with all energy at this rate removed by a high-pass filter. Ca^{++} uptake in Swiss 3T3 fibroblasts depended upon pulse width, did not depend on repetition rate (10-100 Hz) and showed no effect of weak DC magnetic fields (< 5 G). These results suggest that, in this system, dosimetry is more dependent upon signal frequency and power content than on AC/DC magnetic field coupling.

H-1-3 **A MATHEMATICAL MODEL FOR THE EFFECT ON CELLULAR TRANSCRIPTION OF LOW FREQUENCY ELECTROMAGNETIC RADIATION.** T. A. Litovitz, C. J. Montrose, Reba Goodman[1], Edward C. Elson[2]. Vitreous State Laboratory, Catholic University of America, Washington, DC 20064; Department of Pathology, Columbia University Health Sciences[1], New York, NY 10032; and Walter Reed Army Institute of Research[2], Washington, DC, 20307.

It has been rather widely reported that the exposure of cells to relatively low intensity pulsed and low frequency electromagnetic fields results in a transient augmentation of transcriptional activity. Surprisingly the increases have been seen under certain irradiation conditions to exhibit maxima when regarded as a function of the strength of the electromagnetic fields. We present here a simple multi-step chemical reaction model that accounts for the principal features that are observed both in the time and power variation of the transcriptional effects. The crucial hypothesis of the model is the supposition that the direct effect of cell exposure to electromagnetic fields is an increase in the rate constant characterizing one of the

sequential reactions in the mRNA synthesis. The model also leads to several predictions of hitherto unobserved phenomena; experiments to test these predictions are currently underway. In addition, it suggests that the usual notions of predicting "safe" levels of electromagnetic exposure have little relevance to phenomena such as those described above. This research was supported by Contract Number DAMD17-86-C-6260 with WRAIR.

H-1-4 ION MOTION ALONG HELICAL BIOLOGICAL STRUCTURES FROM ELLIPTICALLY POLARIZED ELECTRIC FIELDS.

D. L. Lessor. Pacific Northwest Laboratory, Richland, WA 99352.

Oscillatory electric fields usually generate only bounded oscillatory motion of a charge particle. We show that constraint of a charged particle to a helix can allow an elliptically polarized oscillatory electric field to produce a continuing, progressive displacement. Motion of an ion or electron between electrostatic binding sites along an α-helix polypeptide or similar structure might be represented by a classical model of damped motion of a charged particle on a helix. Weak, electrostatic, periodic binding locations should exist, even for polypeptides with neutral side chains, because the partial double-bond character of the C-N bond there makes the O and N slightly ionic. Classical equations give requirements for progressive ion displacement in terms of ion charge, field strength, mobility, and ellipticity of the field. The mobility of the charge is the most uncertain parameter in applying this classical mechanics model in biological structures. If such ion or electron transport has potential biological significance, experiments should be done with elliptically polarized electric fields. This project was supported by the US Department of Energy/Office of Energy Storage and Distribution under contract DE-AC06-76RLO-1830.

H-1-5 USING A SPREAD SHEET TO MODEL THE FIELDS AND CURRENTS PRODUCED BY SURFACE ELECTRODES.

Francis X. Hart. Department of Physics, The University of the South, Sewanee, TN 37375.

In many situations electric field sources are in contact with or in close proximity to an object. This paper examines the use of a commercially available spread sheet program to provide numerical solutions for such cases. The method is validated for a two-layer, coaxial, conductive cylinder on which surface electrodes have been placed. The value of a spread sheet cell represents the potential of a spatial element within the cylinder. The results of a finite difference calculation on the spread sheet are in excellent agreement with the analytical solution for this case. The method is next applied to a three-dimensional, inhomogeneous, anisotropic, irregularly shaped model of the calf to which patch electrodes have been placed on the frontal and distal surfaces. A gap in the tibia in several subsheets represents a non-union. As the fracture heals and the gap conductivities decrease, the radial components of the field approximately double and the longitudinal component decreases steadily toward zero. This method could also be used to study the internal current distributions produced by sources such as defibrillators and electric blankets. This research is supported by the Electric Power Research Institute.

SESSION H-2:	NEUROLOGICAL AND ENDOCRINE EFFECTS OF ELF
Moderators:	S. M. Michaelson and L. Zecca

H-2-1 BRAIN TRANSMITTERS IN RATS EXPOSED TO 50 HZ PULSED MAGNETIC FIELDS.

L. Zecca, V. Margonato[1], G. Esposti[1], V. Lucini[1], F. Fraschini[1], and P. Ferrario. CNR-ITBA, Milano, Italy; and Physiology and Pharmacology Dept., University of Milano[1], Milano, Italy.

In previous works was reported the variation in neurotransmitter levels in animals exposed to ELF electric fields (50-60 Hz). In this study the influence of pulsed magnetic field on the content of transmitters (GABA: θ-aminobutyric acid; dopamine and serotonin) and acidic metabclites HVA, DOPAC and 5-HIAA (homovanillic, 3-4-dihydroxyphenylacetic and 5-hydroxyindoleacetic acids) in brain areas of rats was evaluated. Rats were placed inside an airgap coil and exposed to magnetic field (58 G, 50 Hz) 12 hr/day for 14, 21 and 28 days. Animals were sacrificed by microwaves 3 hr after the end of the dark period and the brain removed. Then striatum, hippocampus and hypothalamus were separated and frozen. Analyses were performed by HPLC with electrochemical detection. Pineal gland was also removed and the melatonin measured by RIA. Striatal levels of dopamine slightly increased after 14 days and decreased after 28 days of exposure while concentration of DOPAC increased (15%, $p = 0.05$). Striatal levels of 5-HIAA was higher than sham-exposed (14%, $p = 0.05$) at 21 days while serotonin concentrations decreased (13%, $p = 0.05$) after 28 days of exposure. No variations were found in GABA concentrations for any areas and in pineal melatonin. These findings seem to be related to an effect of magnetic field in modifying the synthesis and metabolism rate for the mentioned amines. The pineal gland does not appear to be involved in the observed changes, thereby suggesting that field can also affect directly biochemical processes at synaptic level.

H-2-2 EVIDENCE OF STRESS IN RATS EXPOSED TO 60-HZ ELECTRIC FIELDS.

F. C. Leung, C. A. Poindexter, D. N. Rommereim, J. A. Creim, and L. E. Anderson. Pacific Northwest Laboratory, Richland, WA 99352.

Two separate experiments were conducted to test the hypothesis that 60-Hz electric fields may be stressful to rats. In experiment one, eighty 55-day old female rats were exposed or sham exposed to a 100 kV/m field, 20 hr/day for 100 days. In experiment two, ninety six adult (48 male, 48 female) rats were exposed or sham exposed to 85 kV/m fields 20 hr/day for 30 days. Light/dark regimes of 8:16 and 14:10 were used in the 2 experiments respectively. In both experiments rats were individually caged, weighed, and scored for chromodacryorrhea twice weekly. At the end of each experiment, one half of the rats (E-field exposed and sham-exposed) were killed at mid-day, one half at mid-night. At each time period 112 of the animals were subjected to 30-min in a restraining apparatus prior to sacrifice. Exposed female rats showed a significant increase in the incidence and severity of chromodacryorrhea when compared to sham-exposed animals. A similar alteration did not occur in exposed male rats. Pineal melatonin levels were significantly reduced in exposed animals in the first but not in the second experiment. Serum melatonin, PRL and corticosterone concentrations did not show consistent

differences between exposed and sham exposed rats in the two experiments. These studies suggest that female rats exposed to E-fields evidence a stress response as indicated by an increased incidence and severity of chromodacryorrhea, however, there was no evidence of consistent alteration in the endocrine system. Supported by US Department of Energy under Contract DOE-AC06-76RL0-1830.

H-2-3 HORMONE RESPONSE OF RATS EXPOSED TO SUSTAINED AND INTERMITTENT 60 HZ ELECTRIC FIELDS.

Sol M. Michaelson. Department of Biophysics, University of Rochester Medical Center, Rochester, NY 14642.

Male, Long-Evans rats were subjected to 80-kV/m 60-Hz electric field (EF) sustained or intermittent (1 min on, 1 min off) exposure. After 1 hr (1000-1100 hr) or 3 hr (1000-1300 hr) exposure, animals were decapitated and serum levels of corticosterone (CST), prolactin and thyrotropin (TSH) were measured by radioligand assay. Similar measurements were made on sera obtained from rats subjected to 100 kV/m sustained or intermittent (random schedule interruption between 6 sec and 120 sec) exposure. In general there were no significant differences among rats exposed to sustained or intermittent exposure, or between sham- and field-exposed animals. The hormone response among sham and field exposed animals compared to control animals residing in their home cages, reflected intrinsic or extrinsic influence(s). Environmental or endogenous stimuli encountered by the animal species in the experimental setting rather than the 80-100 kV/m electric fields appear to be the implicating factors. This work was supported by the Department of Energy, Office of Storage and Distribution under contract numbers DE-AC02-76EV-3490 and DE-AC02-85CE76254. Materials for radioimmunoassays were partially supplied by the National Hormone and Pituitary Program of the National Institutes of Health.

H-2-4 CIRCADIAN EFFECTS OF 60-HZ ELECTRIC FIELD EXPOSURE IN RODENTS.

Kenneth R. Groh and Marijo A. Readey. Biological, Environmental, and Medical Research Division, Argonne National Laboratory, Argonne, IL 60439.

The objective of our research is to determine the circadian effects of 60-Hz electric-field exposure in small rodents. Studies in rats under two different light-dark cycles (LD 12:12 and 16:8) have shown a phase delay that is nonphase specific in response to 60-Hz electric field exposure. The mouse, Peromyscus leucopus, exhibits a response threshold to electric field exposure, with the majority of the mice showing an aversive "startle" immediately after being exposed and significant, stable circadian phase shifts. We have identified three factors that clearly influence the strength of the response to the electric field exposure. These factors are (1) field strength - >20 kV/m; (2) LD-ratio effects ("seasonality"); and (3) the circadian phase at which the animal is exposed to the electric field. The "startle" response and circadian phase shift are positively correlated in the LD 16:8 entrained animals only at the transition from the inactive to the active phase of the cycle; both of these responses appear to be species specific. No internal desynchronization of activity, O_2 consumption, or CO_2 production followed exposure. Thus, electric field exposure disrupts established chronobiological rhythms, which can have far-reaching biochemical, physiological, and neurological consequences. (Work supported by the US Department of Energy, Conservation and Renewable Energy, Office of Energy Storage and Distribution, under contract No. W-31-109-ENG-38).

SESSION A-4:	**POSTER SESSION 1**
Moderators:	H. Wachtel and D. L. Hjeresen
SESSION D-3&4:	**POSTER SESSION 2**
Moderators:	J. C. Monahan and W. Rogers

ELF EXPOSURE SYSTEMS

P-1-1 **A COMPACT 60-HZ MAGNETIC-FIELD EXPOSURE SYSTEM FOR *IN VITRO* STUDIES.** Michael Bourdages. Institut de recherche d'Hydro-Québec, Varennes, Québec, J0L 2P0, Canada.

A magnetic-field exposure system has been developed for experiments on cell cultures. The design criteria were compactness, uniformity of the magnetic field and uniform current density. The four-coaxial-coil configuration allows substantial reduction of dimensions compared with conventional Helmoltz coils: the spacing between the two inner coils (16 turns) is 101 mm and between external coils (25 turns) is 308 mm; the coil radius is 129 mm. This configuration produces a uniform field ± 3%) in a cylindrical volume 160 mm long with a 70-mm radius. This volume can accommodate four rectangular bottles (500 ml) horizontally, with the coils vertical. Systems have been built for simultaneous exposure of cell cultures at three field intensities: 10, 30, and 100 μT. The spatial distribution of the current induced in the cell culture medium has been calculated: the current density is maximum on the top and bottom of the medium. The current is uniform (± 1.5%) over 80% of the bottom surface.

P-1-2 **A NEW DC-ELF EXPOSURE SYSTEM WITH BEHAVIORALLY NON-PERTURBING SENSORS.** Rex L. Clarke, Robert F. Smith, and Don R. Justesen. Behavioral Radiology Laboratories (151R), Kansas City Veteran's Administration Medical Center, Kansas City, MO 64128.

Cubic-surface coils have been made that produce a relatively large volume in which DC, Sub-ELF and ELF magnetic fields are nearly uniform. Rats or mice may be placed within the coils and measures of locomotor activity, operant and classical conditioning, core temperature, vocalizations, and/or respiratory-metabolic activity can be collected. Environmental variables such as temperature, humidity, and air flow can also be recorded. The fully automated experiments will be conducted in sound attenuating chambers. Under control of microprocessors, the system will be used in tests of generality and in attempts to extend our earlier findings of field sensitivity by mice and rats. The system will incorporate state-of-the-art devices, which were developed in our laboratory, that detect sonic and ultrasonic vocalizations, locomotor activity, and which can differentiate emotional states.

P-1-3 **HORIZONTAL AND VERTICAL MAGNETIC FIELD CAPABILITY ADDED TO THE EPRI ELECTRIC-FIELD EXPOSURE SYSTEM.** D. L. Miller, M. C. Miller, and L. E. Anderson. Battelle, Pacific Northwest Laboratories, Richland, WA 99352.

Six electric-field electrodes spaced 30 cm apart, were arranged vertically into two groups of three. Each group was surrounded by four horizontal-field coils, and had two electrodes fitted with animal cages. The multiturn coils were connected in upper/lower parallel pairs to provide a horizontal field in one direction in the upper group and the other direction in the lower group. In this configuration, the fringing fields of the two groups tend to cancel each other at a distance. The electrode stack and horizontal-field coils were surrounded by seven vertical-field coils. Five inner coils were connected together in series. Two additional outer coils were also connected in series, but in the opposite sense, to act as nulling coils. In this configuration, the outer-coil field subtracts from the inner-coil field, so that the fringing fields tend to cancel at a distance. The coils were energized by computer-controlled function generators with power-supply amplifiers and power factor correctors. Heating and vibration are virtually absent from the system. The paired-coil and nulling-coil designs minimize leakage fields reaching sham exposure units, allowing four units to remain in one exposure room. The overall system allows vertical and/or horizontal magnetic fields up to 10 G, with vertical electric fields up to 130 kV/m for exposure of 192 animals per unit. This project was supported by the Electric Power Research Institute.

ELF DOSIMETRY AND MEASUREMENTS

P-1-4 **CALCULATION OF ELECTRIC FIELDS INDUCED BY LOW FREQUENCY MAGNETIC FIELDS INTO INHOMOGENEOUS BIOLOGICALLY IMPORTANT STRUCTURES.** J. H. Song and C. Polk. Department of Electrical Engineering, University of Rhode Island, Kingston, RI 02881.

Low conductivity (σ < 5 S/m) non concentric, cylindrical structures with different electrical properties are considered. The configurations simulate, for example, bone embedded in muscle. A "primary" electric field can be calculated by the application of Faraday's law; however the total electric field also contains a "secondary" component which must satisfy Laplace's equation. The latter field is due to electric charges which come from two sources: some are required to satisfy boundary conditions where electrically dissimilar media meet, and others are due to electric polarization when the frequency is high enough (or the conductivity sufficiently low) for the dielectric permittivity to become as important as electrical conductivity. The total electric field is given by $\bar{E} = -(\partial \bar{A}/\partial t) - \nabla V$, where the first term, the time derivative of the magnetic vector potential, represents the "primary" field and the second term, the gradient of a scalar potential, is the "secondary" field due to electric charges. It is shown that in electrically inhomogeneous structures the usual approximation $E = (\omega Br)/2$, where ω is the radian frequency ($= 2\pi f$), B the magnetic flux density and r an appropriate radial distance, can give very misleading results. When the electric field is due to a time varying magnetic field, numerical solutions for low conductivity inhomogeneous structures converge very slowly and require therefore substantial computer time. It is shown, however, that results which

do not differ substantially from the results obtained by numerical methods can be obtained by approximate analytical methods for some physically important problems.

P-1-5 **RESONANT RESPONSE OF IONS IN MEMBRANE CHANNELS TO AC-DC MAGNETIC FIELDS: NUMERICAL SOLUTIONS.** Sheila Galt, John Sandblom[1], and Yngve Hamnerius. Department of Applied Electron Physics, Chalmers University of Technology, S-412 96 Göteborg, Sweden, and Department of Medical Physics, Gothenburg University[1], Box 33031, 5-400 33 Göteborg, Sweden.

Numerical solutions to the equation of motion for an ion confined within a membrane channel molecule will be presented. Experimental evidence of resonant responses to AC and DC magnetic fields (cyclotron resonance) has motivated this work. We have expanded upon the theoretical work of Durney et al. [Bioelectromagnetics 9:315 (1988)], by including the potential well of the channel molecule as a confining factor. This additional term in the equation of motion, being non-dissipative, could allow for the build-up of stored energy within the system to a level necessary to result in a macroscopic resonant phenomenon. Specifically, the trajectory of an ion confined within a gramicidin A channel has been calculated, with emphasis placed on the appearance of both amplitude and frequency windows. Implications of these results are discussed in relation to experimental data for gramicidin A channels exposed to magnetic fields.

P-1-6 **HYGIENIC CHARACTERISTIC OF 50-HZ ELECTRIC FIELD INDOOR SOURCES.** V. Ya. Akimenko and V. P. Paketa. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev 252660, USSR.

The aim of the work is to characterize household electric machines and devices as possible sources of 50-Hz EF in residential houses. To determine 50-Hz EF space distribution near household electrical devices, a special system was developed. With the help of this system the character of EF space distribution for widely used household electrical machines (frig, TV set, vacuum cleaner, coffee mill, mixer, washer and others) was studied. As the hygienic evaluation criterion of this factor concerning population, 50-Hz EF limit level is applied for round the clock exposure equal to 0.5 kW/m. The demand which limits 50-Hz EF quantity should find its reflection in technical documentation for designing recommendations concerning adverse effect prevention of 50-Hz EF upon population from indoor sources. One should take into account space/time characteristics of [field] distribution in closed premises and human exposure conditions, proceedings from ergonomic peculiarities of each type household electric machines and devices.

P-1-7 **MEASUREMENTS OF OCCUPATIONAL AND PUBLIC EXPOSURE TO 50-HZ EM-FIELDS IN FINLAND.** J. E. Valjus, P. K. Mäkinen, P. J. Järvinen, and J. P. Juutilainen[1]. Imatran Voima Oy, SF-01600 Vantaa, Finland; and University of Kuopio[1], SF-70211 Kuopio, Finland.

To obtain comprehensive and representative knowledge of exposure to EM-fields among electrical workers and to study the status of dosimeter technology, we

have collected data on occupational exposure to 50 Hz EM-fields in 110 ... 400 kV substations, powerline work environments as well as at power plants. Substations and power plants contain a considerable number of primary and secondary voltage devices that are remote controlled. Repair and maintenance personnel move around these devices frequently because of the central location of supervision and service bases. A pocket-size portable dosimeter (IREQ-type) is, in most cases, the only reasonable way to obtain information on personal exposure at work, and, to some degree, of the fields characteristic of the workplace. Over 100 electrical workers have worn dosimeters in their daily work, usually for a period of several days each. Recorded magnetic fields have been compared with the fields measured in Finnish homes with a specially designed device. Data collection in 62 residences varied from one day to one week. Space-specific information in limited home environments are probably sufficient to characterize magnetic fields. The 24-hour average of magnetic flux density in a Finnish home typically ranges from 0.02 to 0.12 μT, whereas the daily average of magnetic field exposure of an electrical worker at work was found to be about 2 μT. The occupational exposure to magnetic fields may thus exceed by more than tenfold the exposure in homes. High electric fields may also be present in some electrical work.

ELF IN VITRO STUDIES

P-1-8 **CO-CULTURE ASSAY OF C3H10T1/2 CELLS AND TRANSFORMANT FOR TESTING INFLUENCE OF 60-HZ ELECTRIC FIELDS ON INTERCELLULAR COMMUNICATION.** Christopher D. Cain, Eugene Q. Salvador, and W. Ross Adey. Jerry Pettis Memorial VA Hospital, Loma Linda, CA 92357.

We hypothesize that 60 Hz electric fields can disrupt intercellular communication so to allow transformed cells to be expressed in the presence of normal cells. Implicit in this hypothesis is that disruption of intercellular communication is important in the cancer process. Our finding that 60 Hz electric fields modify the ornithine decarboxylase response to the tumor promoter tetradecanoylphorbol acetate (TPA) in C3H10T1/2 fibroblasts supports this idea (BEMS 1988). Additionally, Balcer-Kubiczek *et al.* have reported that microwave exposure increased transformation of C3H10T1/2 cells (Radiation Research, in press). The primary phenotype of C3H10T1/2 cells is the post-confluent inhibition of cell division. However, a transformant of C3H10T1/2 cells (UV-TDTx cells), developed by Herschman and Brankow (Science 234:1385, 1986), does not exhibit post-confluent inhibition of cell division and these cells pile up in culture to form foci. When the parental C3H10T1/2 cells and UV-TDTx cells are co-cultured, the former can inhibit foci formation of the latter. The interpretation is that parental cells can communicate with the UV-TDTx cells to prevent piling up. However, if co-cultured cells are treated with TPA in a tumor promoting protocol, foci formation occurs. Thus parental C3H10T1/2 cells can suppress foci formation by UV-TDTx cells and TPA can remove this suppression. We have replicated the essential aspects of this co-culture system and plan to expose it to 60 Hz electric fields. Supported by the DOE Office of Energy Storage and Distribution under Contract ED-AI01-85CE76260 and SCE.

P-1-9 **SHORT TERM EXPOSURE TO 60-HZ ELECTRIC FIELDS DOES NOT AFFECT RELEASE OF CATECHOLAMINES FROM RAT BRAIN SLICES.** B. J. Vasquez and W. R. Adey. Loma Linda University and VA Hospital, Loma Linda, CA 92357.

We have studied the effects of 60 Hz electric fields on the in vitro release of two endogenous catecholamines, norepinephrine and dopamine, from slices of striatum, hippocampus, and hypothalamus. The equipment used was a continuous flow perfusion system that feeds six minichambers with Ag-AgCl coiled wire electrodes mounted at each end. Tissue slices were perfused and exposed to electric fields (10, 50, 100 or 200 mV/cm, rms) under one of two conditions: (a) Sustained exposure (field on for 30 min) or (b) Pulsed exposure (2 min field on every 15 min for a 75 min session). Perfusates were collected for 5 min and injected into a HPLC-EC system for detection of catecholamines. The results consistently showed typical curves for release and good response to the depolarizing effects of a high concentration (55 mM) of potassium. However, no field-related effects on release were observed at any of the conditions under study. These data suggest that low level electric fields do not interfere with the presynaptic modulation of transmitter release. Thus, the effects we have observed in levels of rat brain biogenic amines after in vivo exposure to 60 Hz electric fields [Bioelectromagnetics 9:229 (1988)] may not reflect changes in release of the neurotransmitters. Supported by the DOE Office of Energy Storage and Distribution under Contract DE-AI01-85CE76260.

P-1-10 **INCREASED ACTIN AND FIBRONECTIN IN NORMAL HUMAN CELLS INDUCED BY EXPOSURE TO 60-HZ MAGNETIC FIELDS.** W. D. Winters and B. Darnell. Department of Microbiology, University of Texas Health Science Center, San Antonio, TX 78284.

Fibronectin, a multifunctional matrix protein, which mediates cell adhesion, binds to collagen and actin via special receptors requiring Ca^{++} or Mg^{++}. Our earlier studies showed that marked changes in collagen contractile activities in fibroblasts were induced by short term exposures to cyclic 60 Hz magnetic fields (IF). Our present objectives were to detect changes in levels of actin pools, fibronectin, and fibronectin receptors in normal human fetal lung fibroblast cells following exposures to cyclic 60 Hz IF. Both monomeric (G) and filamentous (F) actin pools in control and IF exposed cell extracts were measured by inhibition of deoxyribonuclease (DNAase I) in the presence and absence of guanidine hydrochloride. Indirect fluorescent antibody (IF Ab) techniques demonstrated intracellular locations and conformations of fibronectin and fibronectin receptors. IF exposures were for 15, 30, 60, or 120 minutes at an intensity of 0.5 G. Results indicated that a minimum of one hour of IF exposure was required to consistently affect actin pools. Eight of eight sets of cells after 1 hr and 5 of 8 sets after 2 hr of IF exposure showed up to 80% higher levels of G actin than those in unexposed cells, while F actin levels were slightly increased. IF Ab assays revealed marked increases with time of MF exposure in the numbers of short, transverse fibronectin fibers and long fiber bundles, while fibronectin receptors in MF exposed cells were rearranged into networks. These results indicate that short term exposure of normal cells to cyclic 60 Hz MF can modify levels of cellular actin pools and the intracellular locations and conformations of fibronectin and fibronectin receptors, in addition to changing fibronectin-associated collagen contraction responses.

P-1-11 **INDUCTION OF C-*MYC* AND HISTONE H2B IN HL-60 CELLS BY EXTREMELY LOW FREQUENCY (ELF) ELECTROMAGNETIC RADIATION (EMR).** David Krause, Julie A. Brent, J. Michael Mullins, James J. Greene, and Roland M. Nardone. Department of Biology, The Catholic University of America, Washington, DC 20064.

Some recent studies have indicated that EMR in the ELF range can cause modifications in the rates of cellular macromolecular synthesis. However, the mechanisms by which these rate modulations are induced remain obscure. In order to investigate the contributions of the electric and magnetic field components to these effects, transcription of messenger RNA (mRNA) for the c-myc and histone H2B genes was studied in human leukemia HL-60 cells exposed to a continuous 60-Hz sinusoidal wave. Exposures were performed in a solenoid with maximum magnetic fields measured at 10 G and maximum electric fields calculated to be 1.5 mV/m. The amounts of c-myc and H2B mRNA were measured by immobilizing total cellular RNA on Nytran (Schleicher and Schuell) filters either by dot blot or northern blot and then detecting the specific mRNA with ^{32}P-labeled complementary DNA (cDNA) probes. Irradiation resulted in approximately 2- to 3-fold enhanced levels of detectable mRNA for both c-myc and H2B at 45 to 60 min of exposure. These results confirmed those of R. Goodman and others. The relative contributions of the magnetic and electric fields' components on the expression of these mRNAs were evaluated using culture dishes containing concentric incubation chambers that allowed for the exposure of cells at various radii and therefore at different electric field strengths while maintaining a constant magnetic field. (Supported by grant #DAMD 17-88-C-6260 from the Department of Defense).

P-1-12 **DELINEATION OF THE MAGNETIC AND ELECTRIC FIELD CONTRIBUTIONS TO THE ENHANCEMENT OF TRANSCRIPTION BY LOW FREQUENCY RADIATION.** James J. Greene, William J. Skowronski, David Krause, J. Michael Mullins, and Roland M. Nardone. Department of Biology and The Institute for Biomolecular Studies, The Catholic University of America, Washington, DC 20064.

Extremely low frequency electromagnetic radiation (ELF) has been shown to exert a profound influence on a variety of cellular processes including transcription. However, the molecular basis for the modulation of transcription as well as the relative contributions of the electric and magnetic radiation components in inducing these effects remain obscure. To address these questions, transcription was examined in human leukemia HL-60 cells exposed to ELF within a solenoid. The solenoid chamber allowed exposure of cells to a homogeneous magnetic field and a coincident electric field whose strength varied directly with distance from the center of the culture dish containing the cells. The sine wave ELF radiation was at 60 Hz with the magnetic field measured at 10 G and the electric field at the periphery of the dish was calculated at 1.5 mV/m. Irradiation resulted in transient and cyclical enhancement in the transcriptional rates as determined by pulse labeling with ^{3}H-uridine. Transcription rates increased to a maximum of 50-60% enhancement at 30-60 minutes of irradiation, declined by 3 hours and increased again to near maximal levels by 4.5 hours. The populations of RNAs affected by these changes were characterized by size fractionation using sucrose gradients. The relative contributions of the magnetic and electric components of the radiation to the transcription effects were evaluated using culture dishes containing concentric incubation chambers that allowed for the exposure of cells at various radii and therefore at different electric field strengths. Irradiation of cells in these concentric dishes under different

field strengths enabled the quantitation of magnetic and electric field contributions independent of the other. (Supported by a grant DAMD17-88-C-6260 from the Department of Defense).

P-1-13 **A CONFIRMATION OF DIATOM MOBILITY AT 16-HZ ELECTROMAGNETIC FIELDS.** J. A. Reese, M. E. Frazier, J. E. Morris, and D. L. Miller. Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352.

The purpose of this study was to replicate certain observations of Smith et al. ("Calcium cyclotron resonance and diatom mobility," Bioelectromagetics 8:215-227, 1987). Because the cloned diatom culture described in that publication is not generally available, we repeated the experiments using an easily obtained strain of Amphora purchased from the Culture Collection at the University of Texas, Austin. The effect of a 16-Hz electromagnetic field on the mobility of the diatom Amphora coffeaeformis was examined on agar plates containing no added calcium and on agar plates containing 0.25 mM or 2.5 mM exogenous Ca^{++}. The exposure conditions consisted of an AC field, of 16 Hz with an amplitude of 20.9 μT parallel to the horizontal component of the DC field B_H = 20.9 μT, where B_V = 0. To assess results, the percentage of diatoms that moved more than their body length was determined; the individual counting the diatoms did not know which exposure regimen the sample had been subjected to. We observed the field-associated increase in diatom motion at 0.25 mM Ca^{++} that was reported by Smith et al. The percentage of diatoms that moved was significantly greater for 16-Hz-exposed cells than for controls. We have repeated the initial experiment more than 20 times. Although the magnitude of the effect at 16-Hz was significant, the percentage of cells that moved was not reproducible enough to allow examination for frequency dependence. Diatom growth and exposure conditions may have affected reproducibility; culture age and pH appeared to be particularly critical. Supported by the US Department of Energy under contract #DE-AC06-76RLO-1830.

P-1-14 **ASSESSING THE TRANSFORMATION AND/OR PROMOTION POTENTIAL OF 60-HZ MAGNETIC FIELDS IN C_3H $10T_{\frac{1}{2}}$ CELLS.** M. E. Frazier, J. A. Reese, and J. E. Morris. Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352.

Experimental evidence indicates that EM fields do not directly damage DNA. Therefore if exposure to EM fields increases cancer incidence they must do so by another mechanism. One possibility involves a promoting effect of EM fields on initiated cells. In the in vitro correlate to initiation-promotion, C_3H $10T_{\frac{1}{2}}$ cells first receive an initiating dose of radiation. The promoter, 12-O-tetradecanoylphorbol-13-acetate (TPA) is then added 24 hours after irradiation and at weekly intervals thereafter. In 6 weeks, cell transformations are scored. The TPA treatment, causes approximately a tenfold increase in the transformation frequencies of initiated cultures compared to frequencies in unpromoted cultures. Studies were conducted to determine if 60-Hz AC magnetic fields, of 0.1 or 0.75 G, can either directly transform C_3H $10T_{\frac{1}{2}}$ cells or enhance transformation frequencies resulting from previous radiation exposure. Cells were divided into two treatment groups. One group received no radiation; the second group received ^{60}Co irradiation. After irradiation, each treatment group was trypsinized, counted, and split into four subgroups. One subgroup from each treatment received no further exposure (control). A second subgroup was treated with medium containing approximately 0.1 μg/ml of TPA, starting 24 hours after irradiation was completed; TPA was replenished at each feeding of the cultures. The third and fourth subgroups were exposed

or sham-exposed, respectively, to 60-Hz AC magnetic fields. Radiation exposures significantly increased the transformation frequencies and, as predicted, TPA increased transformation frequencies tenfold. However, exposure to 60-Hz magnetic fields did not significantly affect transformation frequencies of either "initiated" or "promoted" cells compared to sham-exposed cells. Supported by the US Department of Energy/Office of Energy Storage and Distribution under Contract #DE-AC06-76RLO-1830.

P-1-15 **MAGNETIC CIRCULAR DICHROISM STUDIES ON THE CONFORMATION OF NATIVE AND X-IRRADIATED DNA-PROTEIN CONDENSATES.** T. S. Tenforde, M. F. Maestre[1], R. P. Liburdy[1], and E. J. Gibbs[2]. Life Sciences Center, Battelle Pacific Northwest Laboratory, Richland, WA 99352; Lawrence Berkeley Laboratory[1], Berkeley, CA 94720; and Department of Chemistry, Goucher College[2], Towson, MD 21204.

A unique magnetic circular dichroism (MCD) spectrometer was developed by combining a 7.5-T superconducting magnet and a Cary 61 circular dichrograph. Both natural circular dichroism (CD) spectra and MCD spectra were obtained in the UV spectral range for DNA-protein condensates (psi-type DNA), and analyzed for evidence of conformational changes induced by ionizing radiation. The psi-condensates were prepared from poly(lysine-alanine) and purified calf thymus DNA at an initial nucleotide concentration of 0.05 mM and a lysine:phosphate ratio of 0.75. This type of psi-condensate gives a positive CD spectrum with broad UV peaks centered at 270 and 215 nm. The MCD spectrum exhibits similar positive peaks with a substantially larger amplitude than those observed in the CD spectrum. CD and MCD spectra of psi-condensates in the unirradiated state were compared with spectra obtained for psi-condensates exposed to 10 Gy of 225-kVp X rays. Spectra of the unirradiated and irradiated DNA-protein condensates were compared at times ranging from 15 min to 28 days postirradiation. No spectral evidence was obtained for significant changes in the chiral configuration of the psi-condensates at early or late times following X-irradiation. (Research supported by US Department of Energy Contract DE-AC03-76SF00098 with the Lawrence Berkeley Laboratory and Contract DE-AC06-76RLO-1830 with the Pacific Northwest Laboratory.)

NON-UNIFORM B-FIELD - *IN VITRO*

P-1-16 **EFFECTS OF PULSED MAGNETIC FIELDS AND NEURITE ELONGATION FROM CHICK DORSAL ROOT GANGLIA.** R. W. Gunderson, B. Greenebaum, and C. Sutton[1]. B. R. I. and Dept. of Biological Sciences, University of Wisconsin-Parkside, Kenosha, WI 53141; and VA Medical Center[1], Milwaukee, WI.

Certain pulsed magnetic fields may enhance neurite elongation in chick dorsal root ganglia. Ganglia were excised from 7-day embryos and maintained at 34° C in a 90% air-10% CO_2 atmosphere at 95% R.H. in Dulbecco's Modified Eagles medium supplemented with 0.5% fetal calf serum and 100 μg/ml gentamycin; the substrate was type IV collagen. Both exposed and sham-exposed cultures were housed in the same incubator, with shielding between the two areas. Ganglia were allowed to attach to the substrate for 24 hr. Then fields were applied with an Electrobiology, Inc., Bio-Osteogen Model 204 system for 12 hr; the waveform consisted of a burst of 22 sawtooth-shaped 220 μsec pulses, repeated at a 15-Hz rate. After the cultures grew without fields for an additional 12

hr, ganglia and their neurites were recorded on videotape; and neurite length was quantified using a video digitizer system. Neurite length was measured 8 times on each ganglion, each time in a different direction from the center, with the average used as an estimate of the ganglion's neurite length. Sham exposed lengths averaged 277 ± 3.6 μm (n=740); exposed lengths averaged 316 ± 1.6 μm (n=714), a significant increase ($p < 0.05$) of about 14%. With neither coil energized, the sham-exposed coil cultures' average length was 279 ± 3.6 μm (n=254), not significantly different from the nominal exposure coil cultures' 273 ± 3.6 μm (n=225). When the roles of the coils were reversed, the sham exposed length averaged 272.4 ± 4.4 μm (n=137), again a significant 14% increase compared to the exposed cultures' 310.4 ± 5.6 μm (n=156). Temperature differences of cultures in the energized and inactive coils were <0.1° C.

P-1-17 **PURGING CANCER CELLS FROM BONE MARROW USING NONUNIFORM MAGNETIC FIELDS.** W. J. R. Dunseath, Jr., W. T. Joines, E. J. Shpall, and R. C. Bast. Duke University, Durham, NC 27706.

Ferromagnetic microspheres, attached to cancer cells, are precipitated from bone marrow suspensions due to the force generated by an applied nonuniform magnetic field, thus purging the bone marrow of cancer cells. The ferromagnetic microspheres (4.5 μm in dia.) are attached to the cancer cells by the attraction of polyclonal antibodies (coating the microspheres) and monoclonal antibodies (coating the cancer cells). Since the polyclonal antibodies attach themselves to the monoclonal antibodies, the surface of each cancer cell has a number of microspheres rather firmly attached. The nonuniform magnetic field is produced by an array of (0.5" x 0.5" x 0.125") permanent magnets (samarium-cobalt or neodymium-boron) located directly below a rectangular plastic tube containing the slowly-flowing bone marrow suspension. Equations are given for determining the force on microsphere/cancer cell aggregates due to different strengths and configurations of applied magnetic fields. In addition, a computer-aided design for a user-specified optimum system is presented. This work was supported in part by the Duke University Cancer Center.

ELF IN VIVO STUDIES

P-1-18 **RESPONSE OF EARLY EMBRYOS TO A COMBINATION OF WEAK DC AND AC MAGNETIC FIELDS DETERMINED TO PRODUCE CYCLOTRONIC RESONANCE OF CALCIUM IONS.** L. Chacon, M. A. Martinez, V. Madurga, A. Nuñez, A. Ubeda, M. A. Trillo, M. L. Tejera, and J. Leal. Department of Research, Hospital Ramon y Cajal, Carretera de Colmenar Km 9, Madrid 28034, Spain.

Previous studies were performed to know if early chick embryos are sensitive to a combination of DC and AC magnetic fields (MFs) determined according to the theoretical model for cyclotronic resonance of calcium ions. The embryos were exposed, in vivo, to a DC horizontal MF, oriented to geomagnetic north, with a 25-μT magnetic flux density (MFD) and to a sinusoidal field, parallel to the DC field, with a 25-μT rms MFD and 19 Hz frequency. The test apparatus consisted of three pairs of Helmholtz coils in which 10 eggs were horizontally located, their narrow ends pointing north. The exposure was started at time

zero of the eggs incubation and maintained up to 48 hr. At this time the embryos were described and the proportions of normal and not normal organisms compared in the field-exposed and the sham-exposed groups. Preliminary results of a series of ten experiments have shown a significant increase of not normal organisms in the MFs-exposed population. However, the effects of the fields were expressed as slight organogenetic anomalies. When the MFD of the AC field was changed to 18 μT rms, the DC-AC combination had no appreciable effect on the embryonic development. These results suggest that early embryos can respond to a DC-AC weak magnetic field exposure supposed to provoke cyclotronic resonance of calcium ions, and that small changes of the fields combination could be determinant for the embryonic response.

P-1-19 **WEAK, ELF PULSED MAGNETIC FIELDS AND EMBRYONIC DEVELOPMENT: LONG-TERM EFFECTS OF EXPOSURES OCCURRED DURING EARLY STAGES.** A. Ubeda, M. A. Trillo, L. Chacon, and J. Leal. Department of Research, Hospital Ramon y Cajal, Carretera de Colmenar Km 9, Madrid 28034, Spain.

Our previous results showed that chick embryos exposed to weak PMFs, in vivo, during the first two days of development post laying, exhibited at the end of the exposure time increased proportions of developmental abnormalities. The effects of the PMFs seemed to be dependent on the magnetic flux density (MFD) and the wave form. The aim of the present work was to study the effects of three different PMFs on embryos left to develop for a relatively long period after the exposure. For that purpose, fertile eggs were exposed during their first 48 hours of incubation to PMFs with a 100-Hz pulse repetition rate and different magnetic flux density or wave form (1.0 μT or 104 μT, 85-μsec rise time; 1.0 μT, 2-μsec rise time). They were then left to develop for nine additional days in a poultry incubator. At this time, the gross morphology of the embryos was double blind described. A total of 219 PMF-exposed organisms were compared to 225 controls. The results support those previously obtained by the analysis of the exposed and control populations at the end of the 48 hours. The long-term effects of the fields lead to embryonic death, occurring during the first week of development, or to malformations in alive organisms, being the incidence on the population dependent on the magnetic flux density and the wave form of the fields.

P-1-20 **THE INFLUENCE OF ULTRAHIGH MAGNETIC FIELDS ON CEREBRAL CORTICAL MORPHOLOGICAL DEVELOPMENT: A PRELIMINARY STUDY.** M. C. Diamond, T. S. Tenforde, R. P. Liburdy, E. R. Greer, K. Hedges, B. Steinke, E. Davies, J. Yu, and D. Nguyen. Department of Physiology-Anatomy, University of California, Berkeley, CA 94720; and Research Medicine and Radiation Biophysics Division, Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720.

Six 10-day-old male, unanesthetized, Long-Evans rats were housed in well ventilated lucite holders and exposed for 17 minutes to a 2.3-T field (23,000 G). Six 9-day-old males were similarly housed and exposed for 30 min to a 7.5-T field in a superconducting magnet. Six matched controls for each of the two experiments were placed in lucite containers in separate rooms. At 41 days of age, rats were anesthetized, perfused, and their brains removed; twenty micro, transverse, frozen sections were taken from the frontal, somatosensory, and occipital cortex. On thionine stained sections, cortical thickness measurements of 9 areas per brain were made on microslide projected images (22.5X). All cortical measurements were performed "blind", codes were

broken after all measurements were completed. No significant differences in thickness were noted between the controls and experimental rats exposed to the 2.3-T magnetic field even though six out of nine areas measured were thicker. However eight out of nine areas were thicker in the rats exposed to the 7.5-T magnetic field with three areas statistically significantly different: area 4, right hem. (8%; $p < 0.005$); area 10, right hem. (4%; $p < 0.05$); area 3, left hem. (4%; $p < 0.05$). The results suggest that exposure of neonatal rats to high intensity magnetic fields promotes cortex development. This work is supported in part by the Director, Office of Health and Environmental Research, US Department of Energy, under Contract No. DE-AC03 76 SF00098.

P-1-21 EFFECTS OF MAGNETIC FIELDS ON CA^{++} ION-RELATED NEUROLOGICAL FUNCTION.

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Long term potentiation (LTP) in the hippocampal slice and the rat's memory in a radial arm maze (RAM) are neurological functions known to be causally dependent on movement of free Ca^{++} ions. Both of these functions rely on glutamate binding to the NMDA receptor causing conformational changes in the Ca^{++} ionophore. Exposure to ELF fields has been shown to affect the movement of Ca^{++} ions in animal cortex. If the ELF field effects on Ca^{++} ion efflux are functionally significant, such fields should disrupt RAM memory in rats. We are using a RAM to test this hypothesis. The exposure system produces uniform (±5%) ELF and DC magnetic fields (vertical and horizontal) within the RAM. Initial field strengths are a DC magnetic field of 2.6×10^{-5} T (0.26 G) combined with a 60-Hz magnetic field of 5×10^{-5} T rms (0.5 G). The RAM consists of 8 equal length arms radiating out from a central arena. Each arm has a door at the entrance and a food cup at the terminal end. The rats location is monitored by 3 IR photobeam pairs/arm (entrance, midpoint and food cup). Thirty, male rats, food deprived to 80-85% of their free feeding weight are individually assessed daily in the RAM. The rats are divided into 3 groups ($n = 10$/group), an exposed group, a sham-exposure group and positive control group (given either NMDA channel blocker or a Ca^{++} chelator) to validate the test procedure. Behaviors assessed include the percent correct of first 8 choices, the number of choices to obtain 8 food pellets, correct choices/min, and total choices/min. Supported by the US Department of Energy under Contract DOE-AC06-76RLO-1830.

P-1-22 EFFECTS OF STRONG ELF MAGNETIC FIELDS ON NATURAL KILLER CYTOTOXIC ACTIVITY *IN VIVO*.

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The effect of slowly varying (0.2 to 0.8 kHz, square-wave) magnetic fields (up to 1500 G) on NK cytoxic activity was studied in vivo. The mice (Balb/C, 3 mth old) were placed in the homogeneous field produced by 2 Helmholtz coils for 5 days (10 hr/day). Following exposure, the mice were sacrificed and the spleens removed. NK activity was measured by the release of ^{51}Cr when prelabeled YAC tumor target cells were lysed by active effector cells isolated from the spleen. At intensities of 600 or 1200 G the NK activity was significantly increased by a factor of 2. Experiments are being carried out to determine the role of each of the physical parameters (intensity,

modulation frequency, time derivative of the field, homogeneity, etc...). The ^{51}Cr release assay only allows evaluation of the killing activity of NK cells and we are thus planning to study the effect of the magnetic field at the biochemical level (intracellular calcium, protein kinase C).

P-1-23 **CELL-MEDIATED IMMUNITY IN RATS EXPOSED TO 60-HZ ELECTRIC FIELDS.** J. E. Morris, M. E. Frazier, B. J. McCLanahan, R. L. Buschbom, and L. E. Anderson. Battelle, Pacific Northwest Laboratories, Richland, WA 99352.

In vivo and in vitro measurements of cell-mediated immunity were used to evaluate the immunological responses of female sprague dawley rats exposed to 60-Hz electric fields from conception to 28, 55, 103, and 166 days of age. Exposures were for 19 hr/day to either ambient, 10, 65, or 130 kV/m. In the in vivo studies, a radiometric assay was used to measure delayed hypersensitivity in rats challenged with keyhole limpet hemocyanin. For the in vitro studies, the incorporation of ^{125}I-labeled iododeoxyuridine into newly synthesized DNA was used to measure the mitogenic response of spleen cells and peripheral blood lymphocytes to concanavalin-a, phytohemagglutinin, pokeweed mitogen, and lipopolysaccharide. Statistical analysis of the data was conducted in two phases. There was a preliminary one-way analysis of variance testing for exposure effects at each age for each measurement. The second phase of data analysis was a nested analysis of variance with litters nested within each exposure group. Three separate hypotheses for effects were tested including exposure, age, and the interaction of exposure and age. Changes in both in vivo and in vitro measurements of cell-mediated immunity were observed when the data was analyzed on the basis of age. Statistical analysis of the data based on exposure or the interaction of exposure and age did not detect any significant differences between exposed and sham-exposed animals in either in vitro or in vivo measurements of cell-mediated immunity. Supported by Electric Power Research Institute.

P-1-24 **CANCER PROMOTION BY ALTERNATING MAGNETIC FIELD: A STUDY DESIGN USING THE MOUSE SKIN MODEL.** Diana Wilkinson, Maria A. Stuchly, Jack McLean, Eva Callary, and David W. Lecuyer. Bureau of Radiation and Medical Devices, Ottawa, Ontario, K1A 0L2 Canada.

Some of the recent epidemiological studies have shown positive association between cancer incidence and exposure to electromagnetic fields. Evidence from in vitro studies indicates that this effect may be due to cancer promotion or copromotion rather than cancer initiation. The lack of relevant animal studies prompted us to examine putative promotor effects of magnetic fields in the Sencar mouse skin cancer promotion system. In our experiment, 32 female Sencar mice are exposed in one apparatus (2 mice per cage). Exposure conditions of 2 mT (6 hr/day, 5 days/wk for 20 wk), are designed to simulate high field occupational exposures. There are 4 experimental groups. In all groups the skin is initiated with a topical application of DMBA. Two groups are treated weekly with acetone and then one of them is sham exposed and the other field exposed. Two other groups are treated weekly with subthreshold application of TPA in acetone, a known tumor promotor, and then sham or field exposed. The object of this regimen is to test whether the magnetic field can act as a copromotor. Additionally, 20 animals serve as positive controls (DMBA initiated, 2 mg TPA twice per week). All mice are examined for skin lesions weekly. The endpoints analyzed are the number of papillomas per mouse, the number with papillomas, and the time delay to papilloma appearance.

RF DOSIMETRY AND INSTRUMENTATION

P-2-1 **RODENT WHOLE-BODY SPECIFIC ABSORPTION RATES FROM CONTINUOUS-WAVE EXPOSURE TO MILLIMETER-WAVE ELECTROMAGNETIC RADIATION.** R. Richard Bixby and William D. Hurt. Radiation Sciences Division, School of Aerospace Medicine, Brooks AFB, TX 78235-5301.

Euthanized, male Sprague-Dawley rats were exposed to far-field, continuous-wave, millimeter-wave electromagnetic radiation of either 35 or 94.5 GHz. The subjects were arranged in either the E or H orientations, and the whole-body specific absorption rates were measured by Dewar-flask calorimetry. Since energy deposition at these frequencies is superficial, both furred and sheared rat carcasses were irradiated. At 35 GHz, for example, there was no significant difference between the whole body SARs for the hirsute and shorn subjects. Preliminary data are comparable to predicted values based on a prolate spheroidal rat model as published in the Radiofrequency Radiation Dosimetry Handbook, 4th edition, USAFSAM TR-85-73.

P-2-2 **A SIMPLE, HIGH-POWER PULSED MICROWAVE EXPOSURE SYSTEM.** C. Gambrill, Dolores Beblo, and H. Bassen[1]. ERC BioServices Corporation, Rockville, MD 20850; and Walter Reed Army Institute of Research[1], Washington, DC 20307-5100

A 1.25 GHz microwave exposure system was developed to produce localized, high peak specific absorption rates in selected areas of the bodies of individual, medium and large laboratory animals, or throughout the entire bodies of individual, smaller animals. Dosimetric characterizations were performed using multi-sensor fiber optic thermometers in the eyes and/or brain of fresh cadavers of monkeys and rabbits. Exposures were performed with the subject's head placed directly in front of an open-ended WR650 waveguide while avoiding direct contact of the waveguide aperture with the subject. Impedance matching tuners were used to provide a VSWR of less than 1.4 throughout the exposure period. Peak SARs produced in the brain and eyes of monkeys were 1.6 MW/kg and 3.1 MW/kg respectively. Pulse widths of 0.2 to 10 μsec and low repetition rates (0.2 to 12 pulses/sec) enabled continuous exposures of gas-anesthetized animals at low average powers (less than 2.5 W) for periods of 4 hr per day. During the entire exposure no elevations above normal body temperature exceeded a few tenths of a degree Celsius, in any part of the subject.

P-2-3 **AN IMPLANTABLE BROADBAND E-H PROBE OF MILLILITER DIMENSIONS.** Tadeusz M. Babij and Mark J. Hagmann. Department of Electrical Engineering, Florida International University, Miami, FL 33199.

An implantable E-H probe has been constructed and tested, and will be used for measurements with full-scale phantom models of Man. The models are made of thin Fiberglas, and filled with synthetic tissue material having dielectric properties similar to those of actual human tissue. The reduced size of the probe provides the high spatial resolution required to map fields with steep spatial gradients. The E-H probe uses loop and dipole antennas, and Schottky diode detectors that all fit in a cubic volume with dimensions of less than 10 mm per side. The dipole and loop antennas are deposited by a thin film

process on a dielectric substrate so as to be independent of the media in which the measurements are made. The analysis and experimental data are presented for prototypes tested over the frequency range of 30 to 1000 MHz. Computations and experimental data are presented for low-sensitivity probes which can measure field strengths of 25 to 1000 V/m (0.17 - 265 mW/cm^2) and 0.1 to 2.7 A/m (0.38-274 mV/cm^2), and high sensitivity-probes which can measure 1.2 to 28 V/m (0.00045-0.21 mW/cm^2) and 0.024 to 0.56 A/m (0.021-11.9 mW/cm^2).

P-2-4 NON-PERTURBING MEASUREMENT OF RF CURRENT FOR DOSIMETRY.

Mark J. Hagmann and Tadeusz M. Babij. Department of Electrical Engineering, Florida International University, Miami, FL 33199.

There is considerable need for a non-invasive dosimeter. In the tenth annual meeting (BEMS 1988) we describe a new device that is closely related to commercial clamp-on ammeters, but is nonperturbing because it does not have a ferromagnetic core or conductive coil. We have shown that this device may be used to measure current in man or phantoms, and that the SAR may be accurately determined from the measured current. This last year much of our effort has been focused on the development of an improved model of the device that will be more appropriate for both field and clinical usage. Battery operated readout electronics have been used to facilitate hand-held operation as well as to reduce the susceptibility of the device to ambient fields. Shielding techniques have been improved, and the ruggedness of the instrument has been increased. Results of our tests with phantom models will be presented, including comparison of SAR values determined by (1) our instruments, (2) implantable temperature probes, and (3) a miniature implantable three-dimensional electric field probe.

P-2-5 WHOLE-BODY AND PART-BODY DOSIMETRY: RHESUS MONKEY MODEL EXPOSED AT 1.3, 2.3 AND 5.6 GHZ.

John A. D'Andrea, James Knepton, and Brenda L. Cobb. Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700.

Specific absorption rates (SAR) in rhesus monkey models have been measured as an adjunct to behavioral tests for the effects of high power pulsed microwaves. Whole-body SAR was determined using saline filled plastic bottles. Part-body SAR was determined using plastic bags sewn in the shape of a rhesus monkey and filled with simulated muscle tissue. Exposures were conducted in anechoic chambers at NAMRL using three microwave sources. Exposures at 1.3 GHz were conducted using an FPS-7 radar. At 2.3 GHz an MCL signal source and 1 kW amplifier were used. At 5.6 GHz a FPS-26A radar was used. The SARs obtained were near the values predicted by the Radiofrequency Dosimetry Handbook.

P-2-6 **NEAR-FIELD OUTDOOR MEASUREMENTS OF AVERAGE AND LOCAL SAR IN A FULL-SIZE HUMAN MODEL AT 16.6857 MHZ.** Toby A. Griner and Richard G. Olsen. Bioenvironmental Assessment Department, Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700.

To learn more about radio frequency energy deposition caused by near-field irradiation from a typical shipboard antenna, we measured average and localized specific absorption rates (SARs) in a full-size muscle-equivalent human model exposed to 16.6857 MHz. The model was positioned erect on a wire-mesh groundplane 48" from the base of a 35' whip antenna irradiating continuous wave energy at a power of 1.0 kW. Nonperturbing temperature probes were used to obtain localized SAR at 12 body locations. Full-size (72" x 24" x 18") gradient-layer calorimeters were used with two identical models in twin-well measurements of average SAR. Results show that the highest localized SAR (0.6 W/kg) occurred in the ankle; mean average SAR was 0.39 W/kg, which was about half of that obtained at 29.9000 MHz under similar conditions. From these results, we conclude that the traditional shipboard 48" guardrail distance is sufficient to keep average SAR within the currently allowed limit (0.4 W/kg) for 1.0-kW irradiation at 16.6857 MHz.

P-2-7 **CURRENT-TO-GROUND MEASUREMENTS IN HUMAN SUBJECTS NEAR A 35' WHIP ANTENNA ON A GROUND-PLANE.** Richard G. Olsen and Toby A. Griner. Bioenvironmental Sciences Department, Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700.

To learn more about radio frequency (RF) energy deposition in workers near high-frequency (HF) transmitting antennas, we measured RF current-to-ground in five human subjects who stood 48" from a 35' whip antenna on a wire-mesh ground plane. Three HF frequencies were used: 10.2250, 16.6857, and 29.9000 MHz. Each subject stood briefly atop a GC-2 RF current meter (University of Utah) while the current was recorded. Continuous wave (CW) irradiations typically used a 1.0 kW-power as measured with an inline power meter at the coupler that was located near the base of the antenna. Two sets of measurements were made: in the first set, the subjects wore street shoes, and in the second set, the subjects did not wear shoes. Both the magnitude and direction of the electric field (E-field) vector were measured at the chosen location with the aid of a switchable isotropic field intensity monitor. Results showed RF current-to-ground to be highest at 29.9000 MHz. Mean RF current was 461 mA at 29.9 MHz (shoes on). Values with shoes off were about 50% higher. At the measured location, we found that the E-field vector was predominantly horizontal rather than vertical. The horizontal component, moreover, showed a large variation from head to foot, but the vertical component was relatively constant. We conclude that on-site RF current studies are possible with the GC-2 meter and that correlations of RF current-to-ground to average SAR are possible, at least for simple configurations.

RF EFFECTS: BEHAVIORAL AND PHYSIOLOGICAL

P-2-8 **BEHAVIORAL EFFECTS OF MICROWAVES.** Mary Ellen O'Connor and Robert Strattan[1]. Department of Psychology and [1]Electrical Engineering, The University of Tulsa, Tulsa, OK 74104.

The goal of this research was to compare the relationship of whole body averaged specific absorption rate (SAR) and specific absorption (SA) to determine if dose rate or dose was a better predictor of biological effects. Sperm positive Long-Evans female rats were exposed to 2450-Mz CW microwave radiation for 1-3 hr at approximately 10 W/kg. The maternal subjects were then observed for natural delivery of their litters. Sensitivity to thermally induced seizures and huddling were studied in the offspring. Analyses revealed that there were no statistically significant differences between exposed and control offspring on the behavioral indices. The behavior did not appear to be effected by prenatal exposure to microwave radiation at this level. The huddle sizes became smaller as the pups aged both in exposed and control offspring. Funded by US Environmental Protection Agency, Contract # 68-02-4120

P-2-9 **BEHAVIORAL EFFECT OF SINGLE MICROWAVE EXPOSURE ON RATS.** M. A. Navakatikyan. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

Animals (white random-bred male rats, 220- to 290-g weight) were exposed to continuous-wave microwaves for 7 hr (2375 MHz; 0.1, 1.0, 10 mW/cm^2; 0.27 mW/g). There were no alterations in the animals' motor activity during open field and maze testing, passive avoidance conditioned reflex, and light avoidance reaction that were registered right after the exposure. The behavioral structure change was defined according to the duration of 10 behavioral elements with exposure to 10 mW/cm^2 PD. The activity inhibition was registered in the exposed animals that were lying prevailingly stretched. Similar changes were found under the influence of high temperature air that might be regarded as an equivalent to 10 mW/cm^2 PD MW additional absorbed energy. Thus, behavioral structure change may have a connection with thermoregulatory behavioral reaction.

P-2-10 **BEHAVIORAL AND BIOCHEMICAL INDICES OF WHITE RATS STATE UNDER MICROWAVE EXPOSURE.** M. I. Rudnev, M. A. Navakatikjan, and V. P. Art'ukh. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

This studies were carried out by the Soviet side in accordance with Duplicate Project in the frames of US-USSR cooperation on "Biological Effects of Environmental Physical Factors Studies." Animals (Fisher 344 male rats, 200-250 g) were exposed to 2450 MHz CW in anechoic chambers in far field zone (top exposure) at power density of 1 and 0 mW/cm for 7 hours per day. SAR was 0.27 mW/g. After 30 days of exposure and 15 days after exposure there were no differences in either total (for all 30 min of test) nor differential (for 6 min intervals) maze activity between the animals of exposed and sham exposed groups. Among parameters of behaviour in shuttle (conditioned, unconditioned and interstimulus reactions, missing of unconditioned reactions) the exposed animals significantly differed from sham exposed only by a larger number of intersignal reactions in 15 days after exposure termination. Epinephrine and

norepinephrine content in hypothalamus brain region identified 15 days after exposure termination did not differ in exposed and sham-exposed groups. Significant increase of left adrenal was found in the exposed group. This experiment set up a whole number of methodological problems.

P-2-11 **THE INFLUENCE OF 13 MHZ PULSE ELECTROMAGNETIC FIELD ON ENDOCRINE GLANDS' STRUCTURE AND FUNCTION.** T. V. Kalyada and V. N. Nikitina. Institute of Industrial Hygiene and Occupational Diseases, Leningrad, USSR.

The endocrine glands' condition and hypothalamic neurosecretory neclei in male rats was studied under 13 MHz pulse EMF action, intensity 50 and 250 W/m. There is a neurosecretion activation in hypothalamus, suppression of adrenocorticotrophic and gonadotropic hypothalamus function and adrenal cortex. The similar testes' changes were determined by histologic examinations (spermatogenesis disturbance, generative-dystrophy changes, vessels plethora, hemorrhages). Male rats genital system is mostly damaged. The injury is getting worse by increase in EMF intensity and it also depends on time duration.

P-2-12 **ORIENTATION AND FREQUENCY EFFECTS ON CARDIOVASCULAR RESPONSES OF RADIOFREQUENCY IRRADIATED RATS.** Melvin R. Frei and James Jauchem[1]. Trinity University, San Antonio, TX 78284; USAF School of Aerospace Medicine[1], Brooks AFB, TX 78235-5301.

Ketamine-anesthetized Sprague-Dawley rats were exposed in E and H orientations to far-field 700, 1200, 2450, 5600, and 9300-MHz continuous-wave radiofrequency radiation at average SARs of 8-14 W/kg. At each frequency, exposures were conducted in both orientations in the same animal to increase colonic temperature from 38.5 to 39.5° C. Tympanic, colonic, subcutaneous, and tail temperatures, heart rate, arterial blood pressure, and respiratory rate were continuously recorded. The pattern of heat distribution within the animals, and the cardiovascular responses, were both frequency and orientation dependent. There was an inverse relationship between exposure frequency and depth of energy penetration; lower frequency exposure resulted in greater core heating, while higher frequency irradiation resulted in greater peripheral heating. Also, in general, irradiation in H orientation resulted in greater core heating, while exposure in E orientation resulted in greater peripheral heating. At all frequencies and orientations tested, heart rate and blood pressure increased during irradiation; however, the magnitude of change was linearly related to the exposure frequency, and the increases were greater during E- than during H-orientation exposure. These results illustrate the relationship among frequency, orientation, and pattern of heat distribution within irradiated animals, and the significance of thermal distribution to cardiovascular change. Supported in part by the USAFSC Resident Research Professorship Program, and HSD Research Scholarship Program.

P-2-13 **THERMAL AND CARDIOVASCULAR RESPONSES TO 1200-MHZ RADIOFREQUENCY RADIATION: DIFFERENCES BETWEEN EXPOSURE IN E AND H ORIENTATION.** James R. Jauchem and Melvin R. Frei[1]. USAF School of Aerospace Medicine, Brooks AFB, TX 78235-5301; and Trinity University[1], San Antonio, TX 78284.

Ketamine-anesthetized Sprague-Dawley rats were exposed to far-field 1200-MHz continuous-wave radiofrequency radiation in both E and H orientations (long axis of animal parallel to electric or magnetic field, respectively). Power densities were used resulting in equivalent whole-body specific absorption rates of 8 W/kg in both orientations (20 mW/cm for E and 45 mW/cm for H). Exposure was conducted to repeatedly increase colonic temperature from 38.5 to 39.5° C in both orientations in the same animal. Irradiation in E orientation resulted in greater colonic, tympanic, left subcutaneous (side toward antenna), and tail heating. The results indicated a more uniform distribution of heat than that which occurred in previous experiments of 2450-MHz irradiation in E and H orientation (BEMS Abstracts, 1988, p. 87). A lack of significant difference in blood pressure responses between exposures in the two orientations in the present study suggests that a larger core-to-periphery temperature gradient, which was seen in the earlier study of 2450 MHz, is necessary for this difference to occur. (Supported in part by Air Force Systems Command University Resident Research Professorship Program and Human Systems Division Research Scholarship Program.)

P-2-14 **THE *IN VIVO* ELECTRICAL PROPERTIES (COMPLEX PERMITTIVITY) OF SKIN IN THE 0.1 TO 100 MHZ FREQUENCY RANGE.** W. T. Joines, W. D. Palmer, and R. J. Spiegel[1]. Department of Electrical Engineering, Duke University, Durham, NC 27706; and US Environmental Protection Agency[1], Research Triangle Park, NC.

We have developed a very accurate (less than 2% error) method for measuring the complex permittivity ($\epsilon^* = \epsilon - j\frac{\sigma}{\omega}$, where ϵ is the real permittivity in F/m, σ is the conductivity in S/m, and ω is $2\pi f$ with f in hertz) of skin at frequencies between 0.1 and 100 MHz. The probes we use consist of a two conductor, printed-circuit pattern terminating the end of a coaxial line connected to a network analyzer. Measurements of ϵ^* are made by pressing the probe against the skin surface. The network analyzer measures the admittance of the skin terminating the probe as:

$$Y = G + j\omega C = \sigma(A/d) + j\omega\epsilon(A/d) = j\omega\epsilon^*(A/d)$$

where the shunt elements G (conductance) and C (capacitance) of the skin relate to ϵ^* through the effective area to separation (A/d). As a calibration factor, the A/d ratio is simply determined by measuring a material with known ϵ^* versus frequency. Using the calibrated, printed-circuit probe (that monitors an area 2.5 x 5 cm to a depth of about 2 mm) we have measured ϵ^* over the 0.1 to 100 MHz range for a number of human subjects. From these measurements we determine the relative moisture content of the skin and the presence of substances (toxic or otherwise) excreted through the sweat glands that alter ϵ^* of the skin. This work was supported in part by the US Environmental Protection Agency and in part by the National Cancer Institute, DHHS, under PHS Grant 1 po1 CA42745-01A1.

P-2-15 **MEMBRANE PERMEABILITY IN ERYTHROCYTES EXPOSED TO HIGH-PEAK PULSED MICROWAVES.** W. Gregory Lotz and Jack L. Saxton. Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508-5700.

As part of an ongoing study, rhesus monkey (Macaca mulatta) erythrocytes (RBC) were exposed in vitro to high-peak pulsed microwave radiation to determine if the pulsed energy can alter membrane permeability in a manner independent of average specific absorption rate (SAR). Freshly prepared RBC suspensions were exposed in a waveguide system to pulsed 5.6-GHz microwaves. Pulse height was about 150 kW, pulse width was 0.5 μsec, pulse repetition rate ranged from 16 to 100 Hz, and average SAR ranged from 18 to 103 W/kg. The exposures were conducted with the RBC suspension at carefully controlled temperatures between 24.0 and 30.0° C to bracket the membrane transition temperature, as suggested by an Arrhenius plot of sodium transport. Passive sodium influx or hemoglobin leakage from the cells was measured after a 60-min exposure to microwaves. Membrane permeability of the RBCs was not altered in microwave-exposed cells as compared to sham-exposed cells at any SAR tested. Sodium transport increased slightly in suspensions exposed to 103 W/kg near the membrane transition temperature, 28.5° C. The hypothesis that high-peak pulsed microwave radiation causes field-specific effects independent of average SAR was not supported by these findings.

P-2-16 **BIOLOGICAL ACTION OF 850-2750 MHZ PULSE ELECTROMAGNETIC FIELDS.** Yu. D. Dumansky and E. A. Serduk. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

The experiment had been conducted upon white rats for substantiation of the hygienic regulations for civil aviation radar usage. The rats were exposed to a pulsed EMF for 16 hr daily for 4 months at a frequency of 2750 MHz at power densities of 50, 100, and 500 mkW/cm^2 (first series); at a frequency of 1310 MHz at power densities of 20 and 100 mkW/cm^2 (second series); and at a frequency of 850 MHz at power densities of 20, 100, and 500 mkW/cm^2. The metabolic parameters were studied at different levels (tissue, celluar, and subcelluar). The dynamics of succinic dehydrogenase activity was defined as well as cytochrome oxidase of mitochondria; ceruloplasmin, cholinesterase in blood; glycogen levels in liver tissue; cerebrium [sic] and glucose in blood. The experiment's results showed that the pulsed EMF was the cause of changes in the metabolic indices. This is regarded to changes in enzyme activity localized on mitochondrial membranes. Indices of metabolic processes were dependent upon EMF activity intensity, in some cases - upon organs belongings and exposure time. Such a dependence occured in every series. Indices of metabolic disorganization became more marked as the power density level increased. Comparative analysis of the results showed dependence of changes in metabolic indices upon EMF frequency characteristics that were obtained in the three series of experiments.

CLINICAL APPLICATIONS OF RF INCLUDING HYPERTHERMIA

P-2-17 **POWER ABSORPTION IN A FERROMAGNETIC IMPLANT FROM STRONG RADIO-FREQUENCY MAGNETIC FIELD AND THE PROBLEM OF OPTIMIZATION.** Shah A. Haider, James R. Wait, and Thomas C. Cetas. Departments of Electrical and Computer Engineering and Radiation Oncology, University of Arizona, Tucson, AZ 85712.

The power is inductively deposited in surgically implanted ferromagnetic seeds in a tissue volume from an externally applied strong radio-frequency magnetic field to induce interstitial hyperhthermia. The explicit expressions for absorbed power due to induced eddy current circulation through the resistive path can be derived by solving associated boundary value problems using a quasi-static analysis. It is found that optimum power absorption per unit volume of cylindrical implant occurs when the induction number lies within a value of 2 to 3. This result could be used in designing implant geometrical configurations for optimum heating effect. The dependence of absorbed power on the orientation of cylindrical implant with respect to polarization of magnetic field is analytically calculated and found to be in good aggrement with experimental results.

P-2-18 **CHARACTERISTICS OF FERROMAGNETIC IMPLANTS FOR INTERSTITIAL HYPERTHERMIA.** J. S. Chen, R. Sinno, and T. C. Cetas. Departments of Radiation Oncology, Electrical and Computer Engineering and Materials Science, University of Arizona, Tucson, AZ 85724.

Interstitlal techniques have been shown to be effective in inducing hyperthermla for cancer therapy. One approach is to use surgically implanted, thermally regulating ferromagnetic seeds which are heated by a radiofrequency magnetic field. Theoretical studies performed by Halder, Walt, and Cetas (companion abstract) suggest an optimum power absorption per unit size (diameter or amount of material) in terms of the material properties (conductivlty, permeability) and external factors (frequency, implant diameter or configuration). We have measured the relative AC permeability, the AC and DC conductivies, the hysteresis losses (small), and the direct power absorption by calorimetry of the implants, all as a function of temperature. The measurements are all consistent with one another and provide the data to implement and verify the theoretical recommendations. From this, a variety of implant configurations have been designed and tested in phantoms and animal trials. Clinical implementation of the newer configurations will begin shortly. (Clinical trials of the basic modality have been underway for two years with an accrual of more than 16 patients to date.)

P-2-19 **LOW FREQUENCY HYPERTHERMIA APPLICATOR FOR RECURRENT BREAST CANCERS AND ITS LOCAL HEATING CHARACTERISTICS.** Yohsuke Kinouchi, Akira Yoshida, Tadamitsu Iritani, and Tadaoki Morimoto[1]. Department of Electrical Engineering, and 2nd Department of Surgery[1], The University of Tokushima, Tokushima 770, Japan.

Various kinds of general purpose applicators using RF and microwave were developed hitherto for hyperthermia treatments. Recently, a special applicator is, however, required for each kind of cancer to realize effective

local heating. We investigate here an applicator for recurrent breast cancers, which is a noninvasive type consisting of two or three coaxial plate electrodes attached on the breast. It may heat the cancers locally from the breast surface because of their superficiality and no fat (low conductive) near the skin. The use of RF or microwave frequency may cause malfunctions to other electrical equipment because of electromagnetic radiation. Therefore, we have tried to use low frequency (e.g., 10 kHz) which has few problems for radiation and matching, and hence makes circuits simple. The electrical field and temperature distributions have been analyzed by a finite element method (583 nodes and 1080 elements), changing the sizes of coaxial plate electrodes and a voltage ratio in case of three electrodes to find the optimum heating pattern. As a result, e.g., the area of about 2 cm in depth and about 7 cm in diameter just below the inner electrode has been heated more than 42.5° C under the maximum temperature of 45° C by supplying small power (about 20 W). This is enough for local heating of the cancers. The cancers behind the ribs which prevent heating can be also heated if the applicator is set on appropriate position. The area is not so sensitive to cooling temperature of the skin surface. This is convenient for practical use.

P-2-20 **PRECLINICAL EVALUATION OF ARRAYS OF SUB-MILLIMETER MICROWAVE INTERSTITIAL HYPERTHERMIA APPLICATORS IN A PORCINE MODEL.** Charles F. Gottlieb, Frederick L. Moffat, Mark J. Hagmann[1], Tadeusz M. Babij[1], Andre A. Abitbol, Alan A. Lewin, Pavel V. Houdek, and James G. Schwade. University of Miami School of Medicine, Miami, FL 33136; and Florida International University[1], Miami, FL 33199.

We have previously characterized single sub-millimeter microwave interstitial applicators having diameters of 0.20, 0.33, and 0.58 mm in homogeneous muscle-equivalent phantoms. The SAR patterns are similar to those of larger applicators of comparable design. As an intermediate step to patient trials, we are examining the ability of these applicators to provide effective heating of perfused tissue. We are focusing our studies on the heating of porcine thigh and liver models both with and without perfusion. The liver serves as a model for clinical treatment of liver metastases. These applicators, because of their smaller diameter, produce less grossly observable local tissue trauma; the extent of this trauma is being confirmed histologically. Thus the sub-millimeter applicators may be useful for providing hyperthermia to a sensitive organ like the liver. A BSD-500 with the standard Luxtron and Bowman probes is being used for temperature measurements, and special 0.2 mm diameter fluoroptic temperature probes will be used to supplement these measurements. Our results suggest that the 0.33- and 0.58-mm applicators have adequate durability and power handling capability for clinical applications. Supported in part by ACS, Florida Division Martha H. McDonald Research Grant No. F88UM-2 (Gottlieb).

P-2-21 **SAR PATTERNS PRODUCED BY ARRAYS OF SUB-MILLIMETER MICROWAVE INTERSTITIAL HYPERTHERMIA APPLICATORS IN A TISSUE-EQUIVALENT PHANTOM.** Tadeusz M. Babij, Mark J. Hagmann, Charles F. Gottlieb[1], Andre A. Abitbol[1], Alan A. Lewin[1], Pavel V. Houdek[1], and James G. Schwade[1]. Florida International University, Miami, FL 33199; and University of Miami School of Medicine[1], Miami, Miami, FL 33136.

We have previously presented SAR patterns for single sub-millimeter interstitial microwave applicators having diameters of 0.20, 0.33, and 0.58 mm. Since the volume of heating produced by an individual applicator is inadequate for treatment in the majority of human tumors, arrays of a minimum of four applicators are generally required. We have chosen to examine an array of four applicators located on a 2-cm square. Amplitude and phase of the currents supplied to the individual elements have been varied to adjust the SAR pattern produced by the array. We determine SAR patterns from measurements of the electric field intensity made using a miniature implantable three-dimensional electric field probe. All measurements have been made using applicators located in Teflon catheters placed in a tissue-equivalent phantom. Our muscle-simulating phantom is optically clear, has all ingredients in solution, and is, therefore, truly homogeneous. Homogeneity is essential due to the rapid spatial variation of the SAR with these applicators. Our results have shown that a larger volume can be heated in a controlled fashion using an array of applicators, a result consistent with observations of others who have used larger interstial applicators. Supported in part by ACS, Florida Division Martha H. McDonald Research Grant No. F88UM-2 (Gottlieb).

P-2-22 **ABSORPTION AND POWER FOCUSSING OF ELECTROMAGNETIC ENERGY IN LOSSY CYLINDERS.** James R. Wait and Shah Ali Haider. ECE Dept. and Radiation and Oncology, College of Medicine, Tucson, AZ 85721. Sponsored by Prof. T. C. Cetas Radiation and Oncology, AHSC, Univ. of Arizona, Tucson.

A basic problem in electromagnetic hyperthermia is to direct the power to the tumor with minimum heating in the adjacent healthy tissue. By choosing an idealized clyindrical model of a torso or limb we can discuss this problem in a concrete manner. In particular, we wish to solve the relevant inverse problem whereby the aperture electric field at the outer surface of the cylinder can be determined following a reasonable specification of the power density at the center or any other internal point. This mathematical formulation is outlined and some sample calculations are provided. In another approach to the problem we consider a discrete ring aperture array consisting of a finite number of annular gaps which are excited by individual voltage signals with any amplitude and phase. The condition that the power deposition be focussed at an internal point is developed from first principles. The relative advantages of phase and conjugate focussing are itemized. We also outline how the theory can be generalized to a layered cylindrical structure which includes the case of a bolus in phased array horn applicator schemes.

P-2-23 CHRONIC PROLONGATION OF ATRIOVENTRICULAR CONDUCTION TIME FOLLOWING CONTROLLED LESIONS PRODUCED BY RADIOFREQUENCY ENERGY IN DOGS.

Frank I. Marcus and Leonard T. Blouin. University of Arizona Health Sciences Center, Tucson, AZ 85724.

Patients with atrioventricular nodal (AVN) reentrant tachycardia who are unresponsive to or intolerant of drug therapy may be considered for AVN ablation. Small lesions in dogs produced in the approaches to and at the AVN using 750 KHz sinusoidal radiofrequency energy (RFE) resulted in chronic prolongation of AVN conduction time, measured as the atrial to His bundle (A-H) conduction interval. A USCI quadripolar electrode catheter was used to map the His bundle area. The RFE was delivered via the tip electrode to a site selected by mapping and returned to a large electrode placed on the left postero-lateral thorax. A second quadripolar electrode catheter was positioned in the right atrium for stimulation and recording. Both catheters were inserted into a femoral vein and advanced to the heart using fluoroscopy. In 5 dogs showing large His potentials during mapping, the A-H interval increased by 111% on average immediately following RFE delivery. The atrial effective refractory period, AVN functional refractory period and AVN Wenckebach point were also lengthened acutely and the ventricular response to rapid atrial stimulation was decreased, relative to baseline values. In one of the 5 animals, the AVN conduction delay advanced to third degree AV block during the first 24 hours. In the other 4, only the A-H interval prolongation was still present at 1 week and at 2 months. Conclusion: RFE can be used to produce small, controlled lesions near the atrioventricular node that cause chronic AVN conduction slowing without affecting atrial or AVN refractoriness. The effect of slowing AVN conduction without altering refractoriness on AVN reentrant tachycardias is not known.

P-2-24 LOW ENERGY PULSED RF ACUTE WHIPLASH INJURIES. A DOUBLE BLIND RANDOMIZED CONTROLLED TRIAL.

Darragh Foley-Nolan, Kieran Moore, Ciaran Barry, Mary Codd, Robert Coughlan, and Peter O'Connor. Dept. of Rheumatology, Mater Hospital, Dublin, Ireland.

Pulsed RF waves have beneficial effects in soft tissue healing (D. H. Wilson, Br Med J 1972: 253-8) and in nerve regeneration (A. R. M. Raji, Lancet 1982: 444-5). Whiplash is thought to be a soft tissue injury resulting in chronic pain. Acute management of whiplash consists of adequate analgesia and soft collar immobilisation. To assess the imput of treatment with PEMT in acute whiplash injuries a double blind randomised controlled trial of 40 patients, presenting within 72 hours of a rear impact road traffic accident was undertaken. In this study we used 27-MHz pulsed waves with a maximum power output of 3 mW/cm^2 in a pulsed form of 150/sec duration. All patients received soft collars half of these (20, Group A) had PEMT collars encapsulated in them and half (20, Group B) had facimile (placebo) units. The battery powered units were worn at home for at least 8 hr daily. Patients were assessed on entry and at 2, 4, and 12 weeks. At 4 weeks, if satisfactory progress had not been made the patients were referred for physiotherapy. Each assessment included the recording of pain, range of movement, and a subjective assessment. A significant improvement ($p = 0.05$) in pain was observed at 2 and 4 weeks in the active (Group A) compared to (Group B) while at 12 weeks there was no significant difference. While by change alone the movement scores of the PEMT group (Group A) were significantly worse at entry to the trial, they were significantly better at three months ($p = 0.05$). PEMT in the

form described can be used easily and safely in the home setting. This study suggests that PEMT is of benefit to patients in the early management of acute whiplash injuries.

P-2-25 **OBSERVATION ON THE HEALING OF CANINE LIVER INJURY AFTER MICROWAVE IRRADIATION.** Hu Hongkai, Wu Mengchao, and Zhang Xinzhong. Dept. of Hepatobiliary Surgery, Second Military College, Affiliated Shanghai Hospital, Shanghai, China.

A six-needle-like antenna for microwave irradiation was used to induce hyperthermia of canine liver lobes for study of the subsequent healing process. Seven healthy adult dogs were anesthetized with sodium pentobarbital prior to exposure of hepatic lobes. A 2450-MHz microwave of 130 mA was applied for a 12-min interval resulting in localized tissue temperatures of 52-72° C. All dogs received i.v. injection of 10% saline glucose and intramuscular injection of penicillin for 3 days following the operation. Laboratory tests conducted on the 4th, 7th, and 24th days following the operation included RBC and WBC counts, thymol turbidity, thymol floculation, zinc sulfate turbidity, and the enzyme assays GPT, PHI, and rGT. Histopathological examination was done at the 50th, 70th, and 90th day after the operation. The six-needle-like applicator produced a globular injured area, appropriate for treating solid tumors. The data indicated that the thermally-injured normal liver tissue healed within 2 months following microwave irradiation.

P-2-26 **SEARCH FOR NEOPLASTIC TRANSFORMATION *IN VITRO* FOLLOWING PULSED 2.45-GHZ MICROWAVES.** Elizabeth K. Balcer-Kubiczek and George H. Harrison. Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, MD 21201.

Actively growing cultures of C3H $10T_{\frac{1}{2}}$ cells were exposed to 2.45 GHz microwaves (MU) for 24 hr and/or x-ray doses of 0.5, 1 or 1.5 Gy. The first series of experiments focused on measurements of transformation frequency and cell survival at a fixed SAR = 4.4 W/kg, with or without the tumor promoter tetradecanoyl-phorbol-13-acetate (TPA) at 0.1 μg/ml added to culture medium immediately following exposure to MU or X rays. The second series was performed at SAR = 0.4 or 1 W/kg with or without subsequent TPA treatment, but without X rays as a second co-stressor. The average number of transformants per dish for cells exposed to a given treatment with MW was compared with that of similarly treated sham-exposed controls, using a chi-square test. Experimental values that yielded $p < 0.95$ were not considered statistically significant. The key results are: (1) There was a statisticaly significant excess of transformants in MW + TPA groups relative to its own negative sham-exposed TPA control. (2) No significant differences in transformation response were observed between MW- and sham-exposed cells without TPA. (3) The presence of an additional component of transformation damage due to MW in combined treatments with X rays and TPA was not established as statistically significant. This work was supported by USPHS/NCI Grant CA 42820.

P-2-27 **NONINVASIVE MICROWAVE DIAGNOSIS OF ESOPHAGAL, NASOPHARYNETEAL HEPATIC CANCER.** X. Xiang, Y. Hu, W. Fang, L. Xu, Y. Zhang, J. Wang, E. Li, D. J. Li, Z. Sun, S. Wang, and H. Yu. Central China University of Science and Technology, Wuhan, Hubei, China.

Previous studies have indicated larger values of dielectric constant, conductivity, and a 1° C higher temperature in cancerous than in normal tissues. Based on these properties, a device has been developed using passive microwave radiation for diagnosing cancer in layered human tissues. Due to the high incidence of esophageal, nasopharyngeal and liver cancer in China, detection of cancer in deep tissues was attempted, as compared to shallow tissues studied by others mainly for breast cancer. The detector (model 846S) operates at 2.25-2.65 GHz with special receiving antennas for different kinds of cancers in deep tissues. Temperature resolution of 0.08 K (5 sec integration time) with a point-to-point map and computer aided diagnosis were possible. This method has been tested on 1100 cases at 8 hospitals. The overall success rates on esophageal cancer are 86% true positive (TP) and 81% true negative (TN), on nasopharyngeal cancer are 86% TP and 67-75% TN, and on hepatic cancer 76% TP and 76% TN. The method is 92% accurate on breast cancer. These results show that the detector and the method are effective for early diagnosis of cancer deep in the body. Methods and design of this microwave radiometry will be presented. The device was approved by the official evaluation organization in Beijing on December 23, 1988.

RF EXPOSURE AND PUBLIC HEALTH

P-2-28 **ESTIMATING HUMAN EXPOSURE NEAR AM BROADCAST TOWERS: COMPARISON OF THEORETICAL AND MEASURED ELECTROMAGNETIC FIELDS.** Robert F. Cleveland, Jr., and Edwin D. Mantiply[1]. Office of Engineering and Technology, Federal Communications Commission, Washington, DC 20554; and Office of Radiation Programs, US Environmental Protection Agency[1], Las Vegas, NV 89193.

In general, only limited data have been available that can be used to define regions near AM broadcast towers where radiofrequency radiation safety standards are likely to be exceeded. In the past, computer models have been used to predict distances at which various field strength levels would occur in the near field of AM transmitting antennas. In particular, theoretical values for electric and magnetic fields have been determined using the Numerical Electromagnetic Code (NEC), a computer program developed by the Lawrence Livermore Laboratory to calculate fields near wire antennas of arbitrary shapes. The purpose of this study was to obtain actual measurement data in the close-in near field of representative AM broadcast antennas and compare the data to values predicted by the NEC model. It was hoped that such a comparison would assist in the development of greater accuracy in predicting environmental exposure to RF fields from AM towers. Results were obtained from measurements made near eight AM broadcast transmitters with varying frequencies, electrical heights, and power outputs. Comparison with results obtained from NEC modeling indicates that, in general, computer techniques overpredict actual electromagnetic field levels. In addition, the existence of metal fencing or other metal objects near a tower base can signficantly affect close-in fields. Results of this study will be presented, and suggestions will be made for refining prediction methods.

P-2-29 **ELECTROMAGNETIC FIELDS' INFLUENCE ON POPULATION HEALTH CONDITION.** A. M. Serduk and E. A. Serduk. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

A study was conducted of the influence of EMF on the population in zones of EMF power sources. The influence of noise, polluted air, and drinking water, as well as other harmful environmental factors, was practically excluded in the places in which population health conditions were studied. There were three approaches to the evaluate the population health condition: the health condition of kindergarten and school children was defined by means of medical and lab examinations; questioning of the population with special forms; the population sickness rate was studied in keeping with applications for medical care. The completed study made it possible to conclude that nonspecific character diseases are more common among people who live within the EMF radiofrequency action zone. The difference is significantly revealed for some diseases of nervous and cardiovascular systems. Population questioning reveals a lot of different subjective disturbances that are not yet diseases (palpitation, feeling of not getting enough sleep, asthenia, sleepiness, eye pain, ear noise, and eyelid tremor). The estimation of the possible harmful EMF influence on the population's health condition are of great importance for the further perfection of scientific research to forecast people's health changes because of more and more wide use of EM power.

P-2-30 **DIFFERENTIATIONAL HYGIENIC STANDARD SETTING OF PULSE EMFS CREATED BY METEOROLOGICAL RADARS.** N. G. Nikitina and D. S. Ivanov. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

Meteorological radar's operational mode was studied to find out its exposure characteristics. Moreover, its specific feature is the presence of space and time discontinuity. Medical biological experiments were done to set hygienic standards for EMF induced by meteorological radars. These experiments were performed in keeping with the existing levels of factor and exposure types. Physiological, biochemical, and immunological methods of research were used as well as the indices to mark the function generative condition of animals' organism. The biological effect character of continuous and discontinuous EMF was studied under the conditions of chronic exposure. White random-bred rats were used for the experiment. A big biological EMF activity was registered in discontinuous-exposure mode compared with continuous-exposure mode under equal energy load. The experimental results make it possible to do a comparative analysis of bioeffects under different exposure modes and to set hygienic standards for the population.

P-2-31 **POSSIBLE APPROACHES TO HYGIENIC RATE SETTING OF MICROWAVES WHILE TAKING INTO ACCOUNT CYTOGENETIC RESEARCHES RESULTS.** M. G. Shandala. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

The influence of athermal-intensity microwaves (MW) on the chromosome stability of mammals in vivo was elicited. It is shown that the influence is of indirect character and depends on the functional condition of the neuroendoncrine system. It was established that rats exposed to continuous wave MWs (2375 ± 50 MHz, 7 hr daily for 45 days, power density 10 mkW/cm^2) have a considerably lower number of hepatocytes with damaged chromosomes.

This effect was reproduced as well after pulsed MW exposure. Its stability wasn't relatively long. The damaged hepatocyte chromosome level for MW-exposed rats doesn't differ from the sham-exposed group already in a month after the exposure cessation. A notable increase in abberant cell number was registered in the rats which had been exposed to a power density of 500 mkW/cm^2 for 30 days. This effect was not different from the one observed in the same test after single 0.5 Gy X-ray exposure. The obtained data give us the right to speculate as to a possibility in principle to exist and/or of a reality to define the optimum of expressiveness for MW levels, as well as of the zones' margins where the compensation is carried out without and with the limits of organism's reserve abilities. This makes preconditions to fulfill special researches in a bid to set standard levels. Simultaneously it should be noted that an organism reaction cytogenetic index at exposure is integral and biologically significant.

P-2-32 **THE PROBLEM OF HYGIENIC STANDARD SETTING OF ELECTROMAGNETIC FIELD INCLUDING SPECIFIC ORGANISM PECULIARITIES AND FACTOR EFFECT DURATION.**

I. I. Karachev. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

When determining the electromagnetic field none-effected level used for substantiation of maximal allowable level (MAL) for the general public, the fundamental question is the subsequent extrapolation of data obtained in animal experiments conducted using a rapid test method, i.e. the duration of the experiment is less then the animal lifespan. At the same time the hygienic standard includes chronic hazardous effects observed during many years. The analytical connections between the time of animal exposure and the equivalent time of human exposure are given. The presence of these connections gives a possibility for setting a coefficient which includes the biologically equivalent time cycles of human beings and animals. The tolerance of this approach in the conditions of identical field structure is confirmed in the experiments, and has been already shown in the adopted EMF radiofrequency (SHF & UHF) protection guides. Furthermore, when evaluating MAL it is necessary to take into account the definite indices including the risk probability of EMF hazardous effects upon humans. It is given the dependence of value amount of risk probability upon the duration of human exposure.

P-2-33 **THE ASSESSMENT OF ELECTROMAGNETIC SITUATION CREATED BY AIRPORTS' COMMUNICATION FACILITIES FOR HYGIENIC STANDARD SETTING.**

V. N. Soldatchenkov, Yu. D. Dumansky, and D. S. Ivanov. A. N. Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR.

The summary level measurement of field intensity for hygienic assessment of airport radio communication facilities which emit electromagnetic energy of 6-8 radiofrequency range in the environment is hampered due to the periodic emission mode, short emission periods, their chance type of proceeding, and the time coincidence of emission periods. This depends on the fact that emitting aerials are located on the same aerial field, thus creating a single transmitting center of the airport. Simultaneous air flight guidance is carried out by controllers - their number might be several dozens in big airports. Probable analysis methods are taken as the basis to work out the way to present the radio stations' total sum working in periodical emission

mode. The claim is that the two most powerful radio stations must be chosen to do the measurements at a small loading of radio center (10-16 radio stations of the same regulated range), three units at a medium loading (17-24 radio stations), four radio transmitters at a considerable loading, etc. The main clauses of measuring principles and the research procedure for hygienic assessment of electromagnetic level of pollution territories are concerned for populated areas. The above approach significantly simplifies the hygienic control of an airport's EM sources.

P-2-34 **THE EFFECTS OF 2.54-GHZ RADIATION ON DMH-INDUCED COLON CANCER IN MICE.** R. Y. Wu, H. Chiang, and B. J. Shao. Microwave Institute, Zhejiang Medical university, PRC.

The purpose of this study is to investigate the effects of 2.54-GHz microwave radiation on DMH-induced colon cancer in mice. The subjects used in this study were 4 week old Balb/c mice. The experimental animals were divided into group A (DMH), group B (DMH + MW), Group C (DMH + TPA), Group D (DMH + TPA + MW). Radiation was performed in E orientation in an anechoic chamber at 10 mW/cm^2 (3 hr daily, eight sessions per week, over a period of 5 months). During the course of radiation treatments, dimethylhydrazine (DMH) was injected subcutaneously at weekly intervals. The tumour promoter 12-O-tetradecanoylphorbol-12-acetate (TPA) was administered 3 weeks after the initial treatment of DMH. It was given in 2-μg doses (i.p.) in weekly intervals over a period of 10 weeks. The incidence of tumors did not differ significantly between the four test groups ($p > 0.25$). However the tumor number, size, incidence of protuberant type and incidence of invasion in tumor bearing animals were higher in group C as compared to groups A and B respectively ($p > 0.05$). No difference was found between groups A and B ($p > 0.25$). In addition, the neoplasm number, size, and incidence of protrubent type and incidence of invasion in group D was significantly lower than group C ($p > 0.05$). Our study shows that 2.45-GHz MW irradiation neither promoted nor co-promoted DMH induced colon cancers in infant mice. TPA could accelerate tumor production if a tumor was initiated. Whether the interesting results of group D was just an incidental phenomenon, or indicated that microwaves possess an inhibiting effect on TPA tumour production, needs further investigation.

P-2-35 **AN ULTRASONIC MICROWATT DOSIMETER.** V. R. Singh. National Physical Laboratory, New Delhi - 110012, India.

In the microwatt range of ultrasonic power output of diagnostic devices, it is difficult to measure the power reliably. A new hydrophone based on sensitive silicon strain gauges was developed. The design, development, fabrication and characterization of such a device for the measurement of ultrasonic power, particularly in the microwatt range are described.

P-2-36 **BEHAVIORAL AND PHYSIOLOGICAL EFFECTS OF HIGH PEAK-POWER MICROWAVE PULSES FROM AN AXIALLY EXTRACTED VIRTUAL CATHODE OSCILLATOR.** Dennis L. Hjeresen and Kathryn O. Umbarger. Neuroscience Section, Life Sciences Division, Los Alamos National Laboratory, Los Alamos, NM 87545.

A battery of behavioral experiments was conducted to determine possible biological effects of high power microwave (HPM) pulses generated by an axially extracted virtual cathode oscillator (TEMPO). Free-space electromagnetic energy in the frequency range 2.01 to 2.57 GHz (mean frequency = 2.11 ± 0.01 S.EM.) was radiated by a conical horn in a TM_{01} mode. The overall pulse length was approximately 85 nsec, with maximum power densities ranging as high as 24.11 kW/cm^2 per pulse (mean peak power density = 10.79 kW/cm^2 ± 0.35 S.E.M. Effects on appetitively motivated behavior were determined with a variable interval schedule (10 sec, VI-10) operant performance task following irradiation and with concurrent irradiation. Effects on aversively motivated behavior were determined with a two-way shuttle avoidance performance task following irradiation. Effects on memory processing were determined with a two-compartment passive avoidance task. The aversive nature of TEMPO HPM pulses was determined with a passive place avoidance task. The results indicate no deleterious effects of TEMPO HPM irradiation after up to 50 HPM pulses presented over a 5-min period. There was no indication of animal perception of HPM irradiation under any test condition in any behavioral paradigm. The results suggest that average power density may be a more relevant factor than peak power in causing behavioral disruption.

P-2-37 **PROTECTION AGAINST NOXIOUSNESS GENERATED BY COMPUTER CATHODIC SCREENS.** Jaques Surbeck. Societé d'Exploitation Industrielle et Commerciale, 3, Rue du Léman - CH 1201 Geneva, Switzerland.

At the international congress of holistic medicine, 1989, in Lausanne, Switzerland, the results of biological experiments on the noxious effects generated by the radiations of cathodic computer screens were presented. A simple apparatus was exhibited at this occasion, the peculiar quality of which being to eliminate such noxious effects. The apparatus is made of two small balls, 20 mm Ø each, containing a component of rare earths. Due to the excitement by the complex radiations generated by the screen, this component comes into resonance to cancel the effect of such noxious radiations which affect human beings. Headaches, general or ocular abnormal tiredness, hormonal disturbance, and, consequently, wasted yield are so eliminated. The protective effects of this apparatus have been scientifically tested in different laboratories on biological standards and have proved to be 100% efficient, whichever experimental method had been used. The device is called "A-NOX/Computer" (Avoid Noxiousness).

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