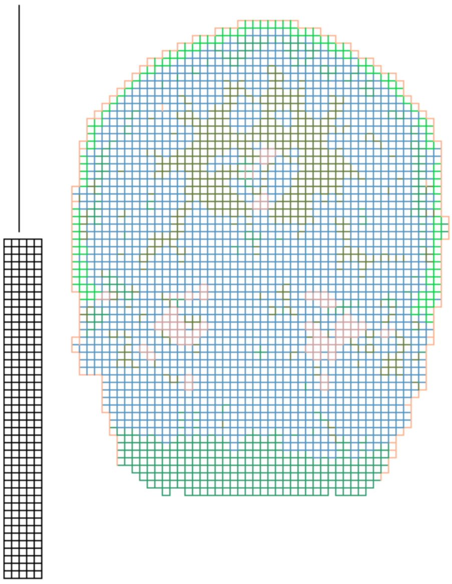
COST 244

National research
programme in Finland

RESEARCH PROGRAMME

BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS



Summary of research projects

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COST 244 national research programme in Finland:

BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS

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1 INTRODUCTION

The interest and concern about the possible biological effects associated with exposure to electromagnetic fields used in mobile communication devices has grown considerably during the last few years. This increase has been due to the enormous increase in the number of users of these devices, which has resulted in many questions about the possibility of hazardous effects of these fields. The interest is even accentuated by the fact that the hand-held mobile telephone is used close to the user’s head, thereby exposing the user to electromagnetic fields.

The present basic restrictions for human exposure to electromagnetic fields are based on information gathered during the past decades and reflect the present understanding of the level of these fields, which is considered to be non-harmful for humans. However, the list of alleged effects is rather long and at present there is quite an extensive research work going on around the world in studying the possible effects of electromagnetic fields. Many of these studies concentrate on mobile communication equipment and include, for example, epidemiological studies, biological research, evaluation of reported findings, assessment of the present exposure guidelines, etc.

The present exposure guidelines are set in terms of the specific absorption rate (SAR, in W/kg) of the electromagnetic energy absorbed at (or dissipated in) a certain volume in human tissues. This kind of definition causes a technical problem, because the SAR inside a person cannot be measured. Therefore, some indirect way is needed to establish the compliance of a certain device with the basic restrictions. At present, the European Committee for Electrotechnical Standardisation (CENELEC) is defining the requirements for compliance testing for mobile communication equipment. The tests will include dosimetric measurements with a human phantom.

Following the formation of the European COST 244 project, and taking into account the national interests in the field, a national research programme was set up in Finland to study both biological and technical aspects related to the radio-frequency fields used in mobile communication equipment.

The national research programme was organised into five projects as follows:

1. International cooperation and project management.
2. Modelling of electromagnetic power absorption in man.
3. Potential influence of RF fields emitted by cellular phones on the human EEG.
4. Determination of RF energy absorption in human head.
5. Effects of 900 MHz radiation on the development of cancer in mice.

In the biological part of the programme two possible biological effects were studied - whether the radio-frequency fields of cellular telephones have the potential to influence the electric functions of the human brains (EEG) and whether they promote the development of cancer in laboratory animals. The projects were, respectively, numbers 3 and 5. The results from project 5 include also the results from a parallel study, were extremely low frequency (50 Hz) magnetic fields were used as the stimulus in exposure.

In the technical part of the programme computational facilities and dosimetric measurement capabilities were developed. These projects were, respectively, numbers 2 and 4. Computational facilities are needed to model and simulate exposure conditions. Development of dosimetric measurement capabilities are related to the compliance testing procedures now under development within the CENELEC. Both these technical aspects are considered to be valuable in testing, for example, the existing hand-held mobile telephones, or especially, when designing new models.

The main interest in the programme has been in mobile communication equipment at frequencies 450 MHz, 900 MHz and 1800 MHz, with emphasis at 900 MHz.

The research programme commenced in 1994. It is now completed otherwise, but in project 5 the histopathological examinations are yet to be completed.

2 CONTENTS AND RESULTS OF PROJECTS

2.1 International cooperation and project management

The management and administration of the whole research programme has been performed by VTT Information Technology. Project no. 1 has also covered the cooperation with the European COST 244 project " Biomedical Effects of Electromagnetic Fields". The name of the national research programme has been taken almost directly from that of the COST 244.

COST means Cooperation in the Field of Science and Technical Research. COST as an organisation is only for cooperation within a certain subject. It does not offer any funding for research, for example. In total 21 European countries participated in the COST 244.

COST 244 covered the effects of electromagnetic fields in the most widest sense of the expression, covering the frequency range 0-300 GHz. Questions related to mobile communication equipment formed only a part of the COST 244 activities, although an important part. COST 244 started in 1992 and its four year period ended in 1996. The final report of the COST 244 is expected to be published in 1997. The work will continue with the same content, but under the name COST 244bis for the next four years.

The most important activities within the COST 244 can be summarised as follows:

- a database of national projects was formed, over 200 projects in total.
- in total 11 workshops under different titles were organised, one of them in Kuopio, Finland.
- comparison of different electromagnetic simulation software, the so called numerical phantom project, was organised, including computation and comparison of results for 16 canonical examples.
- the dosimetric phantom project was prepared, it is expected to commence during the COST 244bis.
- cooperation with all active organisations within the area covered by COST 244.
- two large joint conferences were organised, one with WTR, Wireless Technology Research, and the other with EBEA, the European Bio-Electromagnetics Association.

COST 244 has a homepage on the Web at address http://bagan.srce.hr/cost244/.

2.2 Modelling of electromagnetic power absorption in man

The essential task in this project was to develop a computational tool to simulate numerically, how the user of a hand-held mobile phone is exposed to the radio-frequency fields radiated from the phone. Numerical simulation is important, because it is not possible to actually measure the distribution of fields or SAR values inside a person. The SAR value (Specific Absorption Rate, in W/kg) is an important quantity, because the human exposure guidelines are set in terms of SAR.

Such a computational tool is a good technical instrument, which can be used for many purposes. Besides of the simulation of exposure conditions, it can be used for example to verify dosimetric measurements in a dosimetric phantom, or it can be used in antenna design, when designing so called low-SAR antennas for mobile phones.

In the first phase of the project a survey of possible electromagnetic computation methods was made. Finally, the method called FDTD (Finite Difference Time Domain method) was selected. It is a well known and general electromagnetic calculation method. Instead of developing the software by own resources, it was evaluated to be the best solution to acquire a suitable software. Therefore, the software called XFDTD from Remcom Inc., USA, was ordered. A good feature of this software is its graphical user interface. During the project, XFDTD has evolved from version 1.0 to version 3.05. VTT Information Technology has specified the characteristics of the software and has tested and validated it during the development.

For simulation one needs numerical models of the structures to be simulated. In this case at least the person, the phone and the person's hand holding the phone need to be modelled. The total computational accuracy depends on the accuracy of the models.

Human tissues in the model can be described as dielectric materials with suitable electrical properties and density. Variations in electrical properties of different tissues depend mainly on the water content and salinity of the tissue. Information about the properties of tissues can be found in the literature and they have also been collected and reported in the COST 244 project. The tissue properties are frequency dependent. In Table 1 there is an example about properties of some tissues at 900 MHz.

Table 1. Properties of some tissues of head at 900 MHz.

Tissue	permittivity ε_r	conductivity σ (S/m)	density (kg/m^3)
muscle	57	0.8	1040
skin	35	0.9	1080
grey matter and nerve	54	1.2	1030
bone, skull	21	0.3	1850

In the FDTD method the numerical model of human anatomy is made up by a 3-dimensional grid of small cubes (elongated cubes can also be used). The electrical properties of each cube are those of the corresponding tissue in that place. The anatomical shape of tissues in human body can be found, for instance, from Magnetic Resonance Images (MRI-pictures). Medical expertise is needed in that phase of the model making.

At the moment, there exists two head models, both acquired from Remcom Inc. Both models are limited to head, because in the case of exposure to fields from mobile phones, the larger SAR values are concentrated to the head and hand.

Usually the calculations in the FDTD method are performed in rectangular coordinates, which models curved surfaces by staircase structures. The effect of staircases can be minimised by using a small cube size in the grid. The size of the cube must be smaller than the wavelength, the upper limit is one tenth of the wavelength.

As an example of model and calculated results of XFDTD, the distribution of SAR values in head is presented in Figure 1.

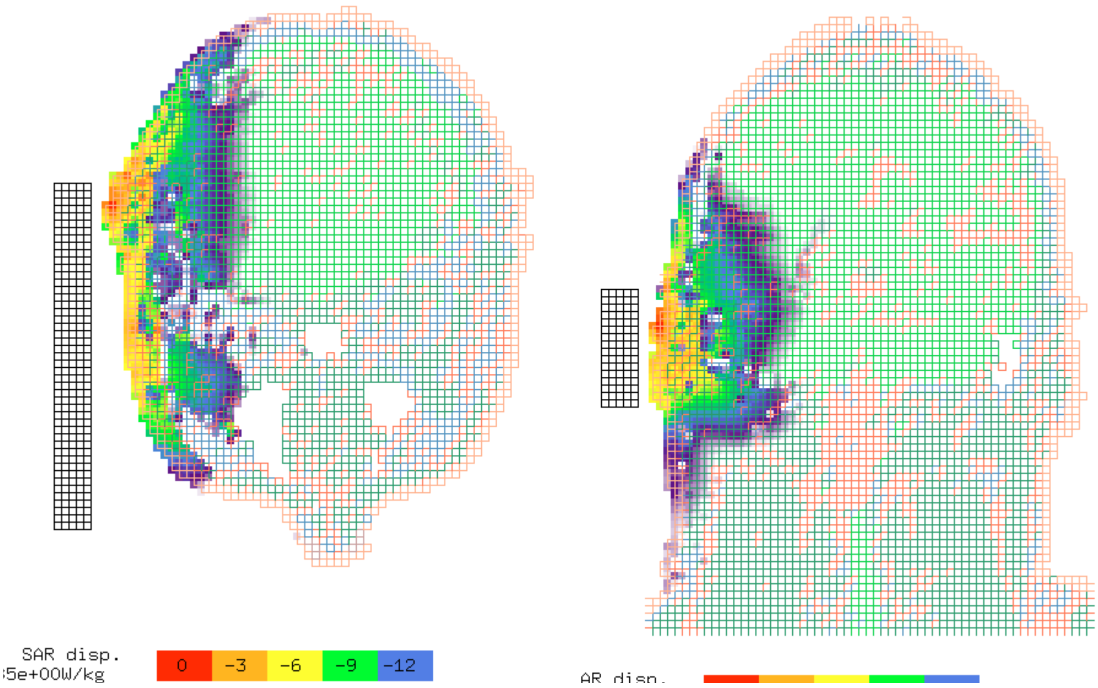

Figure 1. Distribution of SAR in head caused by a mobile phone. The phone has a monopole antenna (wire antenna). The geometry cuts are horizontal and vertical. The phone is horizontally with respect to the head. The antenna is 15 mm from the ear. Frequency is 900 MHz. Colour scale of SAR is in dB, 0 dB is the maximum value of SAR, -3 dB is half of it. The grid size is 3.0 mm.

The operational tests and validation calculations of the software have formed an important activity in the project. Validation and some of the operational tests have been done in modelling and calculation of the canonical models defined in the European COST 244 project. Also, calculated and measured results have been compared for some antenna structures. The ability of the software to handle and combine separate models into one model has been tested. The hand has been added around the phone and the results of different models have been compared. Modelling of different antenna types has been tested. A helix structure was found to be a difficult one, requiring large memory and computation time.

According to the experience obtained by extensive use of the software, it is a feasible and appropriate tool for modelling and simulation of the exposure from a mobile phone. The software has also been used in modelling of calibration systems in project number 4 ”Determination of RF energy absorption in human head”. According to the calculation results, one original approach was abandoned and replaced with a new structure, with much better properties for the calibration of E-field probes.

Being a general electromagnetic software, XFDTD can be applied to various modelling problems. Within a year it will be used for modelling mice in an exposure chamber. More advanced properties to the software will be developed in another project. The new properties are: the ability to turn the model in the grid, calculation of the SAR averaged over 1 and 10 g of mass, etc. In addition, a more extensive and detailed human model will be made in Finland.

2.3 Potential influence of RF fields emitted by mobile phones on the human EEG

The purpose of this study was to evaluate whether radio-frequency exposure from portable cellular telephones has the potential to influence the electric functions of the human brains.

The exposed study population consisted of 19 healthy volunteers: 9 females (32-57 years) and 10 males (28-48 years). The radio-frequency exposure was generated by six different types of mobile phones, which included both analogue and digital models. Types of cellular phones and their operation frequencies are given in Table 2.

Table 2. Phone types and their operation frequencies.

Phone type	Frequency (MHz)
Benefon NMT	450
Benefon NMT	900
Ericsson NMT	900
Nokia GSM	900
Nokia NMT	900
Nokia PCN	1800

For each volunteer, seven EEG recordings were made, one of which was a null recording with a sham exposure. All recordings made with the Benefon NMT phone operating at 450 MHz had to be rejected because of the interference it caused to the EEG recording at the frequency of 2.9 Hz. Each EEG recording lasted 30 minutes, consisting of a 20 minutes field exposure and a 10 minutes sham exposure. During the EEG-recordings, the volunteer was sitting comfortably, resting and eyes closed, but awake. The phones were operated via a computer in order to avoid the exposed persons to be aware of whether the telephone was on or off.

The brain function was investigated using quantitative analysis of electroencephalograms (Q-EEG). EEG recordings were done with the Cadwell Spectrum 32. All registrations were recorded on an optical mass storage device for later analysis. The statistical analysis was based on comparing the change caused by a real exposure to the change caused by a sham exposure. The average, standard deviation and 95% confidence intervals of variables were calculated. The statistical significance of differences were tested with t-tests. Only one statistically significant p-value ($p<0.005$) was obtained in the absolute power in the delta band. However, no difference between the exposure and sham exposure in the relative power in the same derivation (centroparietal) was observed. The observation is probably caused by the statistical chance. On the basis of this study, it is evident that radio-frequency fields emitted by cellular phones do not affect on the human brain activity.

2.4 Determination of RF energy absorption in human head

In this project a test equipment has been designed and built for SAR measurements of mobile telephone equipment and calibration facilities have been developed for small-sized electric (E) field probes used in the measurements. In addition, an exposure system has been designed and built for animal experiments in the project number 5.

A computer-controlled SAR measurement system was developed for testing of mobile phones at 900 MHz. The system consists of a phantom, an SAR probe, its positioning system and data acquisition system. The phantom simulates the anatomical shape of the upper part of a human body and the average dielectric properties of the human brain. The SAR probe is a miniature E-field probe with three orthogonal electric field sensors manufactured by SPEAG. The accuracy of the positioning system is ± 0.5 mm. The measurement range extends from 0.01 W/kg to 50 W/kg and the estimated uncertainty is ± 16 %. A complete compliance test of one mobile phone, which includes measurement of the maximum SAR and handling of the data, takes less than an hour. The costs of this system are only one tenth of the costs of commercial measurement systems including complicated robot-based positioning systems. The applicability of the facility was tested by measuring the SAR distribution caused by a typical NMT900 mobile phone.

A waveguide system was constructed and tested at 900 MHz for calibration of small-sized E-field probes, SAR probes, in a material simulating the dielectric properties of human brain or muscle. The central part of the system is a vertically mounted rectangular waveguide. RF power is fed to the waveguide through a conventional coaxial-to-waveguide adapter located at the bottom. The electromagnetic wave excited by the post of the adapter propagates through the lower sections filled with air and acrylic plastics and is absorbed in the upper section filled with tissue simulating liquid. Two different liquid mixtures composed of water, sugar and salt (NaCl) are used to simulate muscle and brain. The section filled with acrylic plastics acts as an impedance transformer matching the empty waveguide to that filled with liquid.

The calibration space is located in the centre of the liquid section where temperature and SAR probes are inserted. An optimally uniform SAR distribution is achieved by adjusting the thickness of the liquid section which changes the amplitude and the phase of the wave reflected from the liquid-air interface. In the uniform space the decay of the E-field due to the losses is compensated by the in-phase summation of forward propagating and reflected waves. In addition, E-field scans indicated no signs of higher order modes. The SAR in the calibration position is determined by measuring the temperature rise ΔT during an irradiation time Δt with a non-perturbing thermistor-type Vitek temperature sensor supplied by BSD Medical. SAR is calculated from $SAR = c\Delta T/\Delta t$ where c is the specific heat of the liquid mixture. The termistor sensor is calibrated from 18°C to 30°C against a calibrated mercury thermometer. The specific heat of the liquid mixtures were determined with a simple calorimetric procedure. The estimated uncertainty of the SAR probe calibration at 900 MHz is ± 8 %.

For the project number 5 a waveguide system for exposing mice to 900 MHz NMT and GSM mobile phone fields were built and tested. Three identical waveguide chambers with dimensions of 125 cm x 24.8 cm x 20 cm were constructed for NMT and GSM signals and for a sham exposure. RF fields were fed into the chambers by using modified mobile communication devices, consisting of an NMT and a GSM mobile phone with a booster for a vehicle use. Twenty-five mice were placed in each chamber for each 1.5 hour exposure period per day. Mice were set in acryle holders which restrict body movements and align the longitudinal axis of the mice perpendicular to the E field. The holders were placed on a styrofoam carriage so that each holder was situated in the middle of the centre of the cross-section of the waveguide and the separation distance between the holders was 5 cm. The input, reflected and output powers were measured with power meters. Coaxial terminations were used for the absorption of the output power.

The average whole-body specific absorption rate (SAR_{ave}) of a mouse was calculated by dividing the power absorbed by the mice with the total weight of the mice. For a full-grown mouse SAR_{ave} was 1.7 W/kg in the NMT system and 0.4 W/kg (peak SAR was 3.2 W/kg) in the GSM system. The SAR_{ave} was verified by calorimetric measurements performed with phantoms simulating average dielectric properties of the mouse. The phantoms were made of plastic cylinders filled with liquid mixture consisting of water, sugar and salt (NaCl). The dielectric properties of the mixture were measured by using a network analyzer provided with an open-ended coaxial dielectric probe. The estimated uncertainty of SAR_{ave} was ± 15 % in a long-term exposure when each mouse within the same group was randomly placed in the waveguide chamber for each 1.5 hour exposure period.

2.5 Effects of 900 MHz radiation on the development of cancer in mice

2.5.1 INTRODUCTION

Human exposure to radio-frequency (RF) fields is increasing due to the rapid development of technology, including the exponential growth in the use of mobile telephones. The relatively weak RF radiation from mobile telephones is generally not believed to pose any health risks. It has been suggested, however, that the amplitude-modulated RF fields emitted by some mobile phone systems might cause biological effects similar to the purported cancer-related effects of extremely low frequency (ELF) magnetic fields (MF).

Based on the available experimental evidence and biophysical considerations, it does not seem probable that RF or ELF electromagnetic fields could initiate cancer by damaging DNA. Carcinogenesis, however, is a multistage process, and there is some evidence that ELF magnetic fields could possibly influence carcinogenesis during the promotion or progression stages if given together with a cancer initiating agent (Rannug et al. 1993, Mevissen et al. 1993, Löscher et al. 1993).

2.5.2 OBJECTIVES

The study aimed at evaluating whether amplitude modulated or continuous RF radiation (902 MHz) or 50 Hz MFs can promote the development of cancer in female CBA/S mice exposed to ionising radiation.

2.5.3 MATERIALS AND METHODS

2.5.3.1 Testing facilities

The study was conducted at the department of Environmental Sciences of the University of Kuopio in close collaboration with several departments of the university of Kuopio and Kuopio University Hospital, National Public Health Institute and the Finnish Centre for Radiation and Nuclear Safety.

The animal experiment took place at the laboratory animal facilities of the Toxicity Testing Unit of the National Public Health Institute. The Toxicity Testing Unit, working together with the Department of Pathology of the University of Kuopio, is the only governmental testing laboratory that has passed the national GLP (Good Laboratory Practice) inspection for toxicity studies in Finland. In this study the GLP SOPs (Standard Operation Procedures) were followed always when possible, without formal inspections by the Quality Assurance Unit.

2.5.3.2 The set-up of the study

Animals And The Group Division : 300 female CBA/S mice were randomized into 6 groups . The animals were 3 to 5 weeks old when they entered the study. Group A was the 'cage-control group'**.** Mice in all the other groups were exposed to ionising radiation in the beginning of the experiment. In Groups B,C and D the mice were kept immobilised in small acryl tubes in a rectangular (24.8 cm x 20 cm x125 cm) waveguide. Group B was the sham-exposed group. In group C) the mice were exposed to continuous RF-radiation (SAR 1.5 W/kg) and in group D to pulsed RF-radiation (time-average SAR 0.35 W/kg) for 1.5 hours per day, 5 days a week. In Group F the mice were exposed 24 h per day to a 50 Hz magnetic field. The intensity of the MF varied regularly between 1.3, 13 and 130 µT. Each intensity was on for 20 minutes. Group E was the sham magnetic field exposure group.

Group	**Gamma radiation**	**RF**	**ELF**
A	-	-	-
B	+	sham RF exposure	-
C	+	902,5 MHz continuous	-
D	+	902,4 MHz pulsed	-
E	+	-	sham MF exposure
F	+	-	50 Hz MF

Treatment of Animals: Animals were observed daily. Once a week the animals were examined in detail and palpated. Every animal was weighed and the use of feed and water was measured every other week.

Samples: When an animal was sacrificed blood samples were taken for hematological analyses. Tissue samples from about 40 tissues were taken for histopathological, biochemical and molecular biological analysis.

2.5.4 RESULTS

2.5.4.1 Food Consumption

In the beginning of the study all mice exposed to ionising radiation consumed slightly less food than the control animals. After about 300 days the control group, the 50 Hz MF group and the group sham-exposed to MF consumed food equally, but the groups exposed or sham-exposed to RF radiation consumed about 20 % less food. The lower food consumption in these groups was probably due the stress caused by immobilisation of the animals during exposure.

2.5.4.2 Body Weight

The growth curves indicate that the immobilized groups (exposed or sham-exposed to RF radiation) gained weight more slowly and the group mean body weight remained lower than in other groups. The reduced food consumption in the same groups is most likely the main contributing factor.

2.5.4.3 Survival

Almost all animals of the control group were alive at the end of the experiment. The survival was lower in all other groups (Figure 2). Although not yet confirmed by histopathology, the lower survival in these groups is probably due to increased cancer incidence caused by ionising radiation. There were no significant differences in survival between the RF exposed and the sham-RF exposed animals.

The difference between the MF-exposed and the sham MF animals (Fig. 3) has not been tested statistically. If statistically significant, the difference would suggest a weak protective effect by MF exposure.

2.5.5 CONCLUSIONS

The survival curves do not indicate any differences between the RF and sham RF groups. However, final conclusions about possible cancer-promoting effects of RF exposure cannot be made before the ongoing histopathological analysis has been completed.

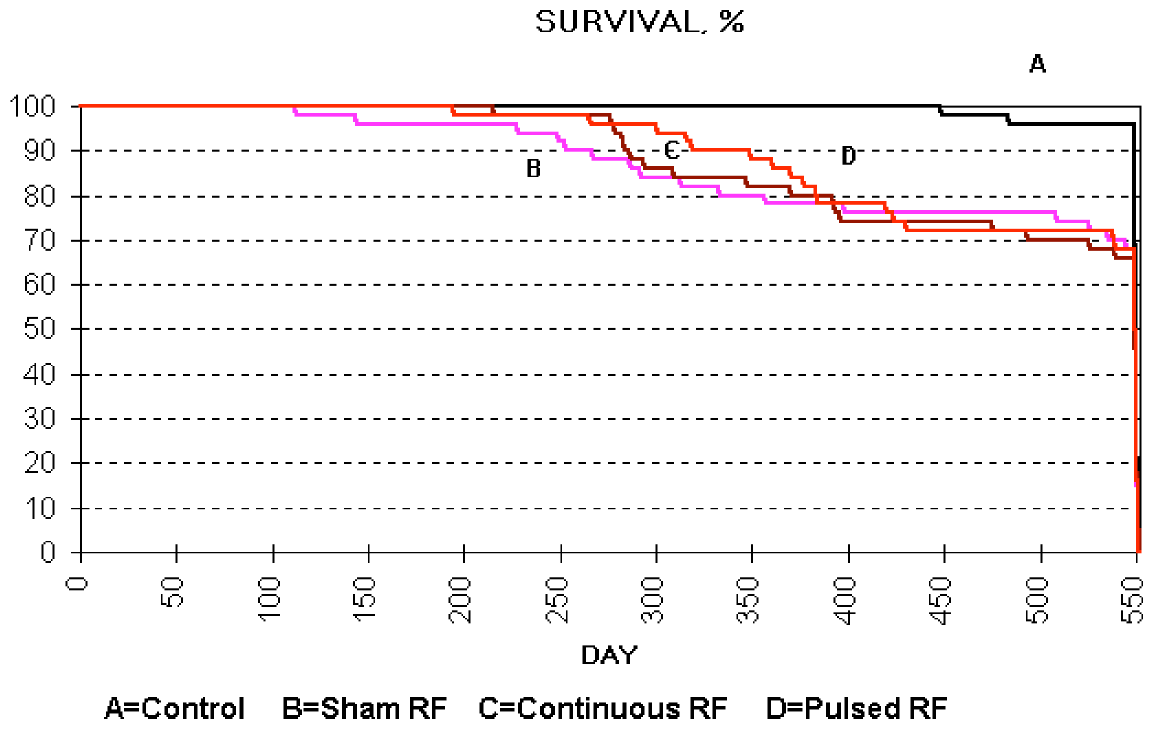

Fig 2. Survival of the mice exposed to RF radiation

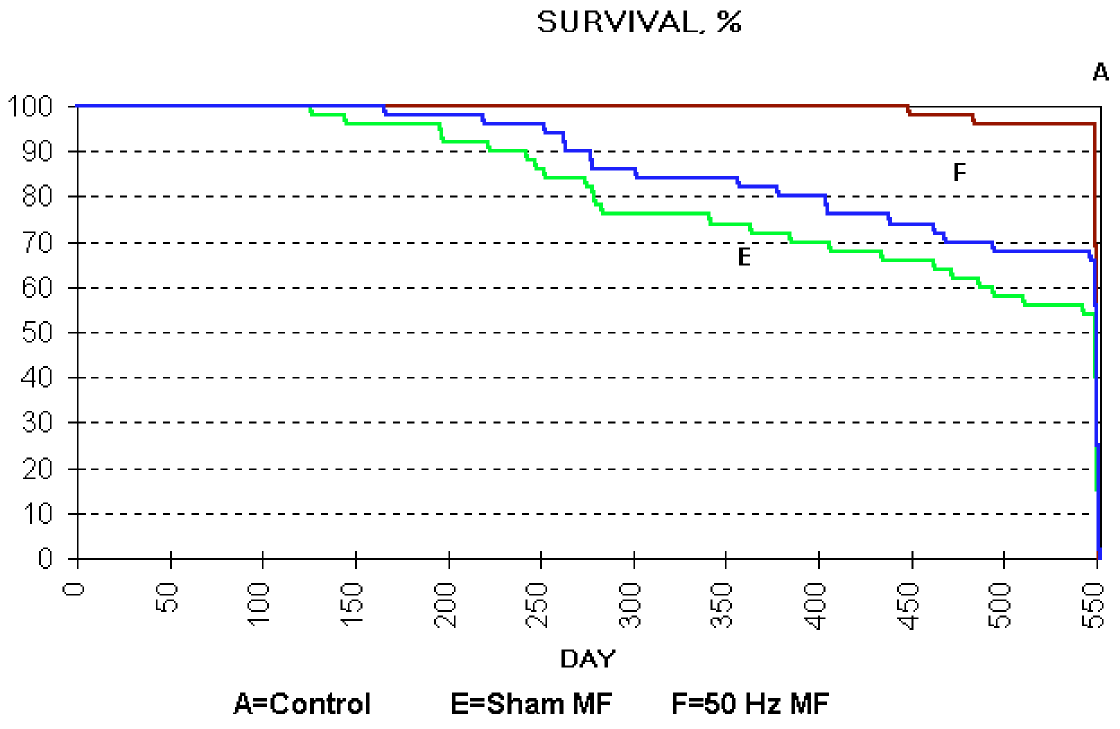

Fig 3. Survival of the mice exposed to ELF magnetic fields