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**БЪЛГАРСКО СПИСАНИЕ ЗА ОБЩЕСТВЕНО ЗДРАВЕ**
**ОФИЦИАЛНО ИЗДАНИЕ НА НАЦИОНАЛНИЯ ЦЕНТЪР ПО ОПАЗВАНЕ НА ОБЩЕСТВЕНОТО ЗДРАВЕ**

**ЦЕЛ И ОБХВАТ**

“Българско списание за обществено здраве” е многопрофилно списание, което включва публикации в областта на здравната политика и практика, здравния мениджмънт и икономика, епидемиология на неинфекциозните и заразните болести, здраве на населението (жените,децата), промоция на здравето и профилактика на болестите, околна среда и здраве, трудова медицина, храни и хранене, кризисни ситуации и обществено здраве, психично здраве. Списанието дава форум за дискусия по актуални проблеми на общественото здраве в България, Европа, САЩ и др. страни. В специални приложения се публикуват материали, посветени на актуални теми, проучвания, резюмета и доклади от международни и национални научни форуми и кръгли маси. Списанието има за цел да популяризира и насърчава изследвания, добри практики, политики, управление и образование в областта на общественото здраве. Излиза в 4 книжки годишно на български и английски език, публикувани на интернет страницата на Националния център по общественото здраве анализи (http://ncpha.government.bg)



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# 8th International Workshop on Biological Effects of Electromagnetic Fields

# IWBEEMF

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**VARNA, BULGARIA**


# БИОЛОГИЧНО ДЕЙСТВИЕ НА ЕЛЕКТРОМАГНИТНИТЕ ПОЛЕТА

## КРАТКО ОПИСАНИЕ НА НАУЧНИТЕ РЕЗУЛТАТИ ОТ 8-ТА МЕЖДУНАРОДНА РАБОТНА СРЕЩА, 21–26 СЕПТЕМВРИ 2014 Г., ВАРНА, БЪЛГАРИЯ

*Традиционната за Средиземноморските страни Международна работна среща по биологични ефекти на електромагнитните полета (ЕМП) събра учени от 27 държави, повечето страни-членки на Европейския съюз, а също и от други страни, като Армения, Египет, Индия, Иран, Малайзия, Перу, Русия, САЩ, Турция, Япония.*

*Научните съобщения бяха фокусирани основно върху качеството на научните изследвания, здравето на работещите и населението и съвременното законодателство в Европа в областта на нейонизиращите лъчения.*

***Организираните сесии по:*** *„Качество на научните изследвания“, „Измерване, оценка, моделиране и дозиметрия на електромагнитните полета“, „Биофизика и биология при електромагнитни взаимодействия“, „Медицински приложения на електромагнитните полета и УВ лъчение“, „Комуникация на риска и политика за постигане на принципа на превантивност“, „Здраве и безопасност при работа“, „Обществено здраве“, „Законодателство в Европа по нейонизиращи лъчения“, дадоха възможност за представяне на нови научни резултати и дискусии по теми, които са силно „чувствителни“ в последните години по отношение на противоречията в науката.*

*Някои от основните научни постижения, представени на този форум и публикувани в настоящото списание, са:*

***В областта на качеството на научните изследвания:*** *Научният комитет на Европейската комисия SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks) дискутира приемането и публикуването на „Ръководство за научни изследвания в областта на електромагнетизма“, което включва минималните изисквания за дизайн на научното изследване, с цел намаляване на противоречията в научните резултати и по-високи критерии за оценка на доказателствата за биологичен и вреден ефект от въздействието на нейонизиращите лъчения върху човека. Специално внимание е отделено на потенциалните ефекти върху нервната система - невро-поведенческите нарушения; риска от възникване на неоплазми под електромагнитно въздействие; по-дълбокото разбиране на биофизичните механизми на взаимодействие на полетата с живите организми, особено за доказване на ефекти от епидемиологични проучвания; комбинираното действие на нейонизиращите лъчения с други фактори на средата; въздействието на милиметровия диапазон на електромагнитните полета.*

***В областта на комуникацията на риска:*** *Анализът на резултатите в различните страни показва намаляване на страховете сред населението, което се дължи основно на прилагането на качествени програми за комуникация на риска на национално ниво. Дискусията беше свързана основно с усъвършенстване на тези програми, тъй като те са разработени на основата на „максималния риск“ и поради това не са достатъчно балансирани с реалните условия.*

***„Измервания, оценка, моделиране, дозиметрия“:*** *В тази област са представени нови компютърни методи за моделиране, усъвършенствани и с много по-висока точност за оценка на експозицията. Предложени са нови модели, основани на хомогенни характеристики на човешка глава с метални очила, модели на човек, използващ „smart” устройства, както и модели за анализ на въздействието на излъчването от мобилни телефони в реално време. Новости са представени в областта на измерванията в работната среда с устройства, прилагащи ЯМР технологии.*

***„Новото законодателство в Европа“:*** *Транспонирането на Директива 2013/35/ЕК за работещи в условия на ЕМП трябва да завърши на 1.07.2016 г. в страните-членки. Обсъдена бе готовността на всяка една от държавите за въвеждането на новите гранични стойности, както и на политиката за защита на работещите. Дискусия беше проведена и върху защитата на работещите с изкуствени източници на оптични лъчения, както и на населението, използващо солариуми. Доказателствата говорят за силно завишен риск от кожна меланома, свързана с облъчването с УВ лъчение.*

***В областта на „биофизиката и биологията на електромагнитните взаимодействия“*** *бяха обсъдени основни механизми на биологични ефекти от облъчване с различни честотни обхвати на лъчението. Най-сериозните резултати тук бяха свързани с възможните „нетермични ефекти“, които доскоро бяха неглижирани при разработването на гранични стойности за експозиция. Дискутирани бяха новите подходи за прилагане на научна методология при изследвания с доброволци.*

***„Приложенията на нейонизиращите лъчения в медицината“*** *обедини учените към общ подход при прилагане на различните нейонизиращи лъчения – електромагнитни полета, магнитни импулси, ЯМР, оптични, лазерни лъчения, при оценката на положителния ефект от въздействието им върху пациентите, както и при защитата на медицинския персонал, прилагащ тези технологии.*

***„Здравето и безопасността при работа в условия на нейонизиращи лъчения“*** *се изследва с нови методи за оценка на кумулативния ефект, при оценката на различни допълнителни фактори на средата, както и на неблагоприятни навици на работещите върху здравното им състояние. Рисковите контингенти остават тези, работещи в металургията, военното дело, комуникациите, физиотерапията, ЯМР.*

***Ефектите на въздействие на ЕМП върху населението (обществено здраве)*** *се изследват със сериозни епидемиологични подходи при лица, прилагащи устройства за изкуствен тен, живеещи в сгради с трансформатори, в условия на голяма гъстота на базови станции за мобилна комуникация и на други телекомуникационни източници. Най-сериозните проблеми са свързани с лицата, обявяващи себе си за „свръхчувствителни към ЕМП“, което е заболяване, включено в много страни като нозологична единица, но не свързано с въздействието на лъчения. Дискутирано беше ниското ниво на прилаганата измервателна апаратура за целите на общественото здраве в много страни, което създава несигурност при оценка на резултатите от изследванията.*

*В заключение, представените публикации в списанието са сериозна новост в областта на електромагнитобиологията, особено за последните години. Те представят съвременното ниво на тази наука в Европа и в света. Присъствието и участието в научните дискусии на големи международни организации, на световно известни учени от цял свят, спомогна за сериозно повишаване на научното ниво на традиционните работни срещи на Средиземноморските страни.*

*За осъществяването на тази работна среща, както и публикуването на най-престижните научни резултати, спомогна Проект БГ 07. Програма „Инициативи за обществено здраве“, с финансовата помощ на Норвежкия финансов механизъм 2009-2014 и на Европейския финансов механизъм 2009-2014 г. по тема: „Усъвършенстване на контрола и на информационните системи в превенцията на риска в здравеопазването“.*

***Доц. М. Израел, д.м.,***
*Председател на орг.комитет на*
*8-та международна работна среща*
*„Биологични ефекти на ЕМП“ и*
*Ръководител на Проект БГ 07, ПДПС 01*


# BIOLOGICAL EFFECT OF BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS

## BRIEF DESCRIPTION OF THE SCIENTIFIC RESULTS OF THE 8TH INTERNATIONAL WORKSHOP - 21 TO 26 SEPTEMBER 2014, VARNA, BULGARIA

***Short overview:***

*The 8th International Workshop on Biological effects of Electromagnetic Fields completed. The main challenge of this Workshop was to gather scientists from 27 countries, most of them from Europe, and also from Armenia, Egypt, India, Iran, Japan, Malaysia, Peru, Russia, Turkey, USA.*

*Since this meeting was focused on few directions, mainly "quality of science" and "occupational/public health and new European legislation", it achieved very high quality of presentations in comparison with many other meetings in this field before.*

*The organization of round tables on "European legislation in the field of EMF and optical radiation", "risk communication programmes and policy", "new projects in the field of non-ionizing radiation" were new approach giving the possibility for discussion and possible future research and decisions.*

***Several sessions:*** *"Quality of science", "Measurement, exposure, modeling, dosimetry", "Human exposure standards", "Biophysics and biology", "Medical applications of EMF and UV", "Occupational health and safety", "Public health", covered wide spectrum of the contemporary research studies in the field of non-ionizing radiation focused on human health, and also the main scientific interests of all participants.*

*Exposure and risk assessment of UV radiation in different occupations was discussed together with similar topics concerning other frequency ranges as a part of non-ionizing radiation health and safety.*

*The youth session, and the competition between the students for the "young scientists' award" gave a special spirit of the Workshop.*

*Some of the main outcomes from the different sessions are as follows:*

***Quality of science:*** *Risk communication and management*

*Council Recommendations invites the Commission to encourage research, to promote consensus on guidelines and to keep the matter under review. The EU policy is based on best available scientific knowledge, and the SCENIHR looks for gaps in knowledge. It gives particular attention on potential adverse effect on nervous system, including neurobehavioral disorders and on the risk of neoplastic diseases, understanding biophysical mechanisms of biological effects and epidemiological findings, the potential effect of co-exposure to other factors in the environment, adverse effects of THz range. The new idea is to develop a set of prioritized research recommendations updating previous efforts in this area (in particular by the SCENIHR and the WHO). These recommendations should include methodological guidance on the experimental design and minimum requirements to ensure data quality and usability for risk assessment.*

*Public concern on EMF exposures decreases in most of the countries in the world. This phenomenon is a result of implementation of risk communication programmes as some countries presented (Japan, Bulgaria and others).*

*Meanwhile, risk communication programmes needs to be improved because it is based only on pick out worst case results, and it is imbalanced.*

***Measurement, exposure, modeling, dosimetry***

*New approaches in the field of measurements and exposure assessment in the near field zone were presented, also for evaluation of the SAR values in the close proximity to the source.*

*Modelling of human exposure in the low and RF* *ranges were proposed for improving the uncertainty in exposure assessment and dosimetry. New models, as surface-based model of the human body, numerical model of human homogeneous head with metallic glasses, models for evaluation of the exposure from smart meters and for real-time signal analyses by mobile phones' exposure were presented.*

*Several papers concerning methods for assessment of SAR values from mobile phones, smart meters presented original methods for evaluation.*

*One of the main focuses in this session was the improvement of the calibration methods, far vs. near field assessment of the exposure, the influence of the human body on the uncertainty of measurements.*

*Power frequency magnetic field was discussed concerning details in exposure assessment.*

***Human exposure standards***

*The main topic of the presentations, also of the discussion on the round table was the EU Directive 2013/35/EU that is in a stage of transposition in national legislation of the Member states. Most of the countries are not prepared for this transposition, and they wait for the Practical Guide that should be prepared by the European Commission.*

*The discussion covered also the methods for compliance with this Directive, also the way for harmonization in the field of EMF human exposure between European countries and others, as Russia, Latin America.*

*Similar situation exists concerning the Directive 2006/25/EC for optical radiation: the Practical Guide is not transposed in national legislation in some countries (including Bulgaria) that complicates the practical implementation of the measures.*

*Special questionnaire for determining of various measures used in international guidelines and EU Directive 2013/35/EU was discussed and disseminated amongst the participants. Results are in processing, and general conclusions will be available in the near future.*

***Biophysics and biology***

*First, in this session, the hypersensitivity phenomena were discussed. The question was: if these phenomena exist or this is other type of sensitivity that people associate with EMF exposure. Cell hydration was one of the discussed markers for studying weak biological effects, and contrariwise was the dosimetric considerations for observing the reason of every RF biological effect.*

*In addition, big variety of laboratory studies of the interaction of static and pulsed magnetic fields, ELF, intermediate frequencies, RF, millimeter waves, were presented. Some experimental studies could be addressed to low level of exposure (low dose), and others to non-thermal effects.*

*There were presentations concerning dielectric properties of tissues, also possible cancer development due to EMF exposure. Water characteristics under EMF exposure were in discussion, as well.*

*Of course, the permanent discussions on Ca2+ efflux, growth parameters of cells, the possible effects from weak exposure of pulsed fields were considered.*

*Several studies of EMF exposure to humans (volunteers) of mobile phones were presented.*

*It was very important that non-ionizing and ionizing radiation were discussed for biological and adverse effects or for synergism. The risk assessment and the risk policy concerning non-ionizing radiation exposure should follow the used policy in the field of ionizing radiation.*

***Medical applications EMF and UV***

*New methods for applying low frequency magnetic fields, direct currents, ultrasound, magnetic nanoparticles were presented at this session.*

*One important outcome is that speaking about health effects, both adverse and beneficial effects on health should be considered. Medical applications of the whole frequency range of EMF, also of the optical radiation (UV) have to be studied. The wide spread of devices with sources of non-ionizing radiation moves the medical diagnosis and treatment to new challenges. In other case, medical personnel (in MRI, physiotherapy) and patients are exposed to non-ionizing radiation that could be harmful for their health.*

***Occupational health and safety***

*Results show high risk for workers exposed to ELF in energetics, for workers with RF exposure in military application of radars and other radio equipment, for radiographers in medical diagnosis with MRI equipment, for medical staff in physiotherapy, for workers exposed to magnetic fields in industry. New methods for evaluation of cumulative solar radiation in outdoor workers, also new aspects of ELF safety were discussed.*

*Combination of EMF and co-factors, as smoking habit, shift work was investigated.*

***Public health***

*There were several aspects of non-ionizing radiation exposure to general population concerning the use* *of sunbeds for tanning, power lines, transformer stations, digital TV and LTE base stations. Results of measurements in the vicinity of the cited sources, also in metro stations were presented. Some results were focused on exposure to children concerning possible adverse effect on their health and childhood leukaemia.*

*Legislation concerning the use of solaria was discussed, and the opinions were that stringent requirements should be applied.*

*Some of the general challenges were connected with new methodology in laboratory, human and epidemiological studies, investigations in the whole frequency range, including optical (mainly UV) radiation, intermediate frequencies, millimeter waves, ionizing radiation, as well. Other achievement is the study of combination of factors, including EMF, as smoking habit, ionizing radiation, a shift work.*

*As a chair of the organizing committee, I want to express my gratitude to all guests for their participation, and for their excellent presentations, and especially to those that were so busy to attend the meeting for the whole time, as the representatives of the European Commission (SCENIHR) – Giulio Gallo, Theodoros Samaras, Donata Meroni, WHO – Emilie van Deventer (attending online).*

*I, also, want to thank to our partners: ICOH (Scientific Committee Radiation and Work), especially to Fabriciomaria Gobba, to the European Commission, to the Director of the National Centre of Public Health and Analyses, the Dean of the Faculty of Public Health and the Rector of the Medical University of Pleven, and of the Medical University of Varna.*

*Special thanks are for the support from the BG 07: Programme "Public Health Initiatives" with the financial contribution of the Norwegian Financial Mechanism 2009-2014 and EEA Financial Mechanism 2009-2014: "Improving control and information systems in risk prevention and healthcare".*

*I express my personal gratitude to all members of the Committee: prof. P.Kostarakis, prof. M.Markov, prof. Ch.Sammut, prof. T.Kalkan, to the International Advisory Committee, helping in arranging the programme, and giving advices in the process of organization of the meeting.*

*It is very important for me to express my special gratitude to the Bulgarian organizers of the meeting, mainly to V. Zaryabova, T. Shalamanova, also to M. Ivanova, V. Topalova, Chr. Petkova, P. Ivanova, R. Petrova, M. Dimitrova, A. Kostova, L. Israel, V. Staneva. All they worked hard for the real organization of the meeting and for the comfort of the participants.*

*Finally, as you understood, the next meeting will be held in Armenia. We wish to prof. Sinerik Ayrapetyan to continue the process of gathering scientists all over the world, and to follow the traditions of these meeting created by prof. Panos Kostarakis and improved by the next chairs, and to organize a meeting with high level of research quality in the field of non-ionizing radiation.*

*Thank you!*

***Michel Israel,***
***Chair of the 8th IWBEEMF,***
***Varna, Bulgaria***

8th International Workshop on Biological Effects of Electromagnetic Fields

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# RISK COMMUNICATION ACTIVITIES ON EMF IN JAPAN

***Chiyoji Ohkubo***
*Japan EMF Information Center*

*ABSTRACT*

*Possible health effects of exposure electromagnetic fields (EMFs) are one of the public concerns in the environmental issues. In 2007, the Japanese Ministry of Economy, Trade and Industry (METI) formed a Working Group on Electric Power Facility and EMF Policy. The Working Group recommended that a neutral and permanent EMF information center should be established to promote risk communication and facilitate peoples' understanding based on scientific evidences. In response to this recommendation, the Japan EMF Information Center (JEIC) was settled in July 2008. Activities of the JEIC and other organizations will be described at the meeting.*

***Key words:*** *Risk communication; Risk perception; EMF*

Electromagnetic fields (EMFs) are unavoidably produced wherever electricity is used, and are thus inherent in modern societies. Throughout the world, peoples in general public concern about exposure to EMFs emitted from such sources as power lines, domestic electric appliances, mobile telecommunication devices and their base stations could lead to adverse health consequences, especially in children and pregnant female. As a result, the construction of new power lines and mobile telephone base stations has met with considerable opposition not only in Japan but in many countries. Lack of knowledge about health consequences of EMF exposure may not be the sole reason for social opposition to innovations. Ignorance of differences in risk perception that are not adequately reflected in risk communications of EMFs among scientists, governments, industry and the general public, is also to be accused.

The scientific evidence on EMFs and their potential health effects has been reviewed many times, mostly by the World Health Organization (WHO). In 2007, the World Health Organization (WHO) issued the Environmental Health Criteria monograph 238 and Fact Sheet 322 on extremely low frequency (ELF) EMFs for supporting the needs of the health ministries of Member States of the WHO International EMF Project and one of its aims is to help the relevant national authorities develop their risk commination strategies.

Public perception of EMF risks in Japan is very high. It was shown in a survey conducted in 2003 that perceived risk of EMFs is higher than that of smoking. The Ministry of Economy, Trade and Industry (METI) formed a Working Group on Electric Power Facility and EMF Policy in June 2007. The Working Group compiled their report in which their recommendations to the METI were incorporated.

To address issues related to possible long-term exposure effects of ELF-EMF, the Working Group recommended that a neutral and permanent EMF information center should be established to promote risk communication and facilitate peoples' understanding based on scientific evidences. In response to this recommendation, the Japan EMF Information Centre (JEIC) was established in July 2008. The JEIC is funded by the Japan Electrical Safety & Environment Technology Laboratories (JET) that was established in 1963 as an authorized testing body, designated by the Government of Japan under the Electrical Appliance and Material Control Law. The Administration Audit Committee was founded in order to ensure and monitor the neutrality and transparency of JEIC operations.

The JEIC institutional system is determined to develop itself into a world-class risk communication center with expertise in EMFs. Challenge is to provide an accurate translation of scientific information and terminology for the media, policy-makers and the general public. JEIC's philosophy and purpose are to provide easy-to-understand scientific information on EMFs and its possible health effects and minimize the gap of risk perception among stakeholders and promote risk communication from a fair perspective.

JEIC's work to achieve its purposes includes

(1) creating an EMF information database including EMF research,

(2) communication with mass media,

(3) organizing public meetings and

(4) Q&A by telephone and email.

Besides the JEIC activity, risk communication activities on EMFs are also conducted in several governmental bodies (the METI, the Ministry of Internal Affairs and Communications, and the Ministry of the Environment). They have been disseminating information of EMF risks on their websites, publishing brochures (booklets), consulting the public or organizing public meeting all over Japan.

Outlines of the EMF risk communication activities in Japan will be introduced at the meeting.

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# PUBLIC PERCEPTION ON RF/MW RADIATION AND THE RADIATION MEASUREMENT FROM MOBILE TELEPHONE BASE STATION (MTBS) IN MALAYSIA

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*ABSTRACT*

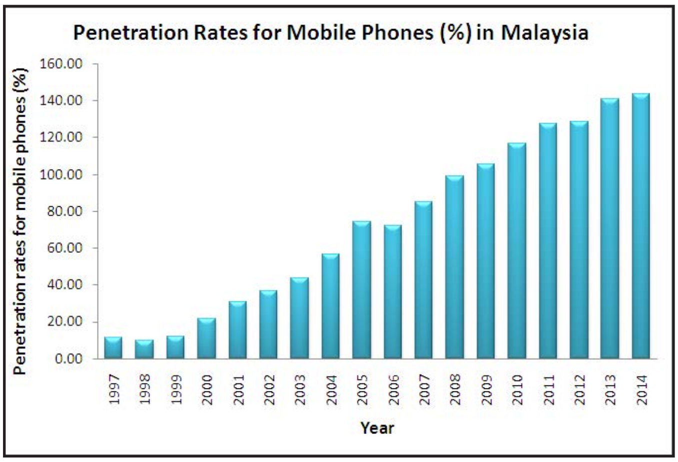
*The use of mobile telephone among the public in Malaysia is became necessity and widely accepted. The increment in the number of user particularly after the year 2000 is tremendously high from 5,122millions to over than 43.1millions in the first quarter of 2014, in comparison to the Malaysian population of 30million, this represent the penetration rate of about 143.7%. The distribution of users is not limited in the urban area but also spread across the country with variation in density. Recent development shown the concerned among the public related to the health effect of RF radiation emitting from the mobile telephone base station (MTBS). This is obvious from the frequent report in the newspaper and the electronics media concerning the complaint of residence nearby MTBS. As results, the telecommunication company has faced many problems and protest from the public in the installation of new MTBS. This paper will discuss about the public acceptance and awareness concerning the health effect of RF and the measurement related to the RF radiation levels at the MTBS from various telecommunication companies in Malaysia since the past 10years. Result of measurement indicates that the trend of RF radiation level from MTBS is reduced to less than 0.5% of the maximum permissible level sets by the ICNIRP and the Mandatory Standard 2010 of Malaysian Telecommunication Act 1988 in the past few years.*

***Keywords:*** *Health Effect, MTBS, RF radiation, mobile telephone*

## *1. INTRODUCTION*

The cellular phone market in Malaysia started in 1995. The GSM900 service was initially offered with the great response from the public. The growing number of cellular phone user from just only about 5.2 million user in the year 2000 to increase over 43.1 million in the first quarter which shown the increments of about 35millions user in just about 14 years. The trend of cellular phone user as shown in Figure 1 is seems to increase drastically with the introduction of 4G LTE with the low charge of data plan in 2013. In comparison to the Malaysian population of 30millionsthis represents the penetration rate of about 143.7% or in average of 143.7 per 100 inhabitants. The increase number of telephone user and the penetration rate in the urban and rural areas required demands of large area with good coverage where user can use their mobile phone without any interruption. However with the growing number of cellular phone user the number of mobile telecommunication base station (MTBS) followed with the same trend. There are three types of base station that most commonly available in Malaysia namely tower, rooftop and lamp post base station. Generally, majority of installation in the urban and suburban area are rooftop and lamp post types, whereas in the rural areas are of tower type. The installation of these base stations can be seen everywhere which particularly in urban area. The number of MTBS is reached to about 24000 in the early of the year 2014, this number is expected to increase much higher in the resent year. This trend has created the environment where people looks the growing of wireless telephone technology in negative perspective even though they have accepted this technology as necessity in their daily social and economic activities, as can been seen from the growing of penetration rate since the year 1997 as shown in Figure 1[3,4].

***Figure 1.*** *Penetration rate of mobile phones (%) in Malaysia (1997-2014)*




## *2. PERCEPTION OF PUBLIC / NEWSPAPER COVERAGE*

Along with popularity of mobile telephones, the increase in number of mobile telephone base stations (MTBS) installation in the country provide better coverage services to consumer have raised anxiety to the general public about whether it have an adverse effect on human health. They are generally perceived as hazardous because of the radiation they produced. Misconceptions held by the general public in Malaysia regarding term of this radiation (non-ionising radiation) of the electromagnetic waves as used for telecommunications especially from MTBS. This perception has often led to public opposition on the construction and existence of these facilities in many parts of the country. Public misunderstood that non-ionizing radiation produced by the MTBS as an ionizing radiation that can cause cancer induction. Although both forms of energy are correctly called radiation, their biological effects are vastly different. Half-true or inaccurate information written in web sites, newspaper and circulated materials by some groups of people with vested interest has caused a lot of opposition by public on the development of MTBS infrastructures. Public have believing area under base station is highly irradiated and energy transmitted by MTBS can cook like microwave oven. Misinformation is available on many web sites where the public can assess and may not distinguish between good sites and the bad sites.

It is a known fact that microwave radiate cause immediate observable health effects if exposed at very high level. However, for exposure at very low level, such as those produced by mobile telephone handsets and MTBS, the actual effects are still unknown. Scientific evidences gathered so far are conflicting and inadequate to prove the casual relationship between the health effects and exposure to radiofrequency radiation at very low level. Such unknown or unclear situation coupled with half-truth or inaccurate information circulated by some groups of people with vested interest has caused a lot of anxiety among members of the public. This fear is further enhanced by lacking of local data and information on mobile telephone to which people can get access in order to get better understanding and facts about the technology. Such lacking of understanding on reality of mobile telephones and inadequate communication with members of the public on the issue often leads to demonstration and opposition by some members of the public on the development of mobile infrastructures, in particular, the erection of new MTBS, as frequently seen and reported in the local newspapers. In this situation media should play an important role in educating people and to create awareness of people about the effect of radiation from the telecommunication facilities. They should do some homework or get the right information from the right persons before publishing the news. They have to report based on the fact and should not sensationalized the issue for the interest in saleable story that will make thing getting worse, were the factual information becomes a second priority.

Several initiations have been taken by government agencies such as Malaysian Communications and Multimedia Commission (MCMC), Malaysian Nuclear Agency, Ministry of Health and other research institutes to provide local information and educated Malaysian General Public such as “RF Radiation Info-Kiosk”, public awareness seminar and road shows, web-based educational portal on EMF [2], and study the possible health effect of EMF.

## 3. FUND OF RESEARCH

Several research projects in Non-Ionizing Radiation especially on electromagnetic frequency (EMF) radiation have been carried out in Malaysia. MCMC has conduct research collaborations with the local universities to built local competence and knowledge. Among the research project are as follow;

***a. Electromagnetic hypersensitive***

A collaborative research on electromagnetic hyper sensitivity (EHS) was conducted by MCMC and local university (UniMAP). This one year research was completed in December 2012. It involved the participation of 200 volunteers of various races and ages in Malaysia. These participants were exposed to a weak electromagnetic emission to find out if there is an effect or reaction as a result of this exposure. Some volunteers were exposed to GSM 900, GSM 1800 and WDCMA 2100 frequencies while the control group was not, and tested with several tests including Electroencephalogram (EEG), Cognitive Tests, Personal Well-being, EMF Perception and Physiological study. Temperature, pulse and blood pressure of the volunteers were taken before, during and after the test. Overall, there was no conclusive evidence from the study between weak electromagnet exposure and its effects on human health.

***b. Media and the public perception***

How media influence public perception on radio frequency electromagnetic field (RF-EMF) radiation risk: a Malaysian case study, the result of the study was published under the title of "Risk communication research for Electromagnetic Field (EMF) from Radio Frequency (RF): An investigation into public perception of RF-EMF's effect on health risks and well-being", at UM Researchers' Conference 2012, 23 Apr 2012 to 24 Apr 2012, UM, (University).

***c. Real time monitoring***

Installation of remote monitoring stations and system installed at different geographical areas in Malaysia to study the consumer usage and EMF emission pattern within a period of time (in a day, month, etc). Future deployments are to display the EMF emission in real-time monitoring through website.

***d. Establishment of SAR laboratory***

The objective of establishment the SAR Lab are to verification of the compliance of wireless components and devices such as mobile phones, laptops and antennas, to have reliable validation values of SAR, as well as locations inside the human head and to have high resolution evaluation for the analysis of thermal effects.

Meanwhile, Malaysian Nuclear Agency (Nuclear Malaysia) has a role to provide technical support and expertise on RF radiation assessment for MCMC and other authorities and agencies. Nuclear Malaysia has done many RF radiation assessments around RF facilities in Malaysia such as from TV/radio broadcast antenna, radar, RF equipment, RF medical devices, ground satellite and etc. One of the popular requests is from the MTBS infrastructures. The MTBS sites selected for the assessment usually were based on the request made by service providers (TELCOs), local councils, and relevant government agencies. These ad-hoc requests were mostly made because of complaint received from the public living nearby the MTBS area. But in 2003-2005, Nuclear Malaysia collaborate with the Atomic Energy Licensing Board (AELB) to conduct RF radiation measurement project around 128 MTBS, the objective of the project was to have local information regarding the RF radiation level around MTBS in Malaysia. In 2011, the RF radiation measurements around 52 sites of telecommunication structure were conducted in state of Penang (Northern Part of Malaysia) in collaboration with MCMC. The collaboration with MCMC was extended for Central and Southern State of Malaysia. The Nuclear Malaysia has so far monitored over 450 base station over the past 10 years and most of the monitored stations were based from the protest of the public and concerned local authorities.

## 4. REGULATORIES AND TELECOMMUNICATION OPERATOR RESPONSIBILITY

In the earlier stage of introduction of wireless telecommunication there was no act related to the safe use of the equipment generating electromagnetic radiation and other non-ionizing sources in Malaysia, however the Occupational Safety and Health Act (OSHA), Act 514, 1994 which only cover the safety activities of workers at workplace and not included the safety of the public as a whole was referred, even though the act is rather general. In 1998, Malaysian Communication and Multimedia Commission Act 1998/ Act 589 enacted, the MCMC is the authority body to regulate the obligations and responsibilities of each network operator to supply telecommunication services to the customers in an effective and efficient manner, adopted and used the following standard guidelines that is based on ICNIRP standard guidelines.

***a. Regulatory Frame work***

The first relevant local guidelines available in Malaysia are the one issued by Malaysian Telecommunication Department (JTM) entitled 'Regulatory Framework on the Sharing of Radiocommunications Infrastructure (REG – R 002)', which were published in 1998 (JTM 1999), this framework is not specifically mentioned on radiation safety assessment pertaining to erection of MTBS in Malaysia. However, there is a requirement for a service provider to carry out measurements to ascertain that the radiation levels transmitted along the beam centre line of an antenna at the perimeter of the premise is below than the permissible exposure limit for workers and members of the public. Current practice observed for most of the erected MTBSs is that the requirement is seldom fulfilled because of basic understanding that the transmitted power of the antennas is very low and the antennas themselves are located high above the ground and away from any members of the public. The requirement to confirm safe radiation level and erection of physical barrier around the safe distance of the MTBS are most of the time done based entirely on calculations instead of measurements. There is also not mention in the guidelines about standard procedures and method to carry out measurements in order to comply with the stipulated exposure limits.

***b. Mandatory Standard***

In 2010, MCMC published new guidelines namely, "Commission Determination on the Mandatory Standard for Electromagnetic Field (EMF) Emissions from Radiocommunications Infrastructure, Determination No.1 of 2010" which came into operation on 1st January 2011.This Mandatory Standard contained a comprehensive guidelines of the equipments used in telecommunication infrastructures which includes of emission limits for workers and public. This standard is the adoption of International Commission and Non-Ionizing Radiation Protection (ICNIRP 1998) for the EMF emission from radio telecommunications infrastructures in Malaysia. The safety limits and the radiation analysis adopted in this standard is globally accepted and recognized by World Health Organization (WHO). Level of RF radiation can be access by actual measurement and using standard approved software simulation as proposed in ITU-T Recommendation K-52 and ITU-T Recommendation K-61. It suggests optimization and ALARA concept in working with RF sources by considering parameters involving time, distance, shielding, restrict access, signage etc. Workers and general public exposure to RF radiation should be kept as low as reasonably achievable without affecting the quality of telecommunication operations. The Section 8 of this standard provides details on the requirement of telecommunication companies to fulfill the safety requirements, before and after the erection and installation of the antenna at MTBS.

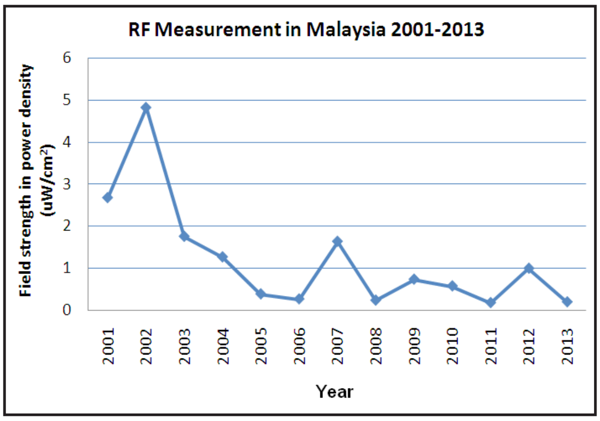
In additional, there is Malaysian Standards (MS) prepared by the collaboration of Ministry of Health, Standards and Industrial Research Institute of Malaysia (SIRIM), Malaysian Nuclear Agency and various agencies. The standard consist of two parts namely Guidelines For Limiting Exposure To Time-varying Electric, Magnetic and Electromagnetic Fields –Part 1: For Frequency Up To 3KHz, MS 2232-1:2009 and Guidelines For Limiting Exposure To Time-varying Electric, Magnetic and Electromagnetic Fields –Part 2: For Frequency From 3KHz To 300 GHz, MS 2232-2:2009.

Operator or telecommunication companies have to collaborate with regulator regarding the erection of new MTBS near residence area. Telco Tower Facility Operator act as one stop centre, provide tower structures to be sharing among telecommunication service providers, particularly in rural area. In urban and suburban areas telecommunication service provider also initiate to built MTBS with aesthetic structure such as fake tree, lamp pole and also hidden the antenna with signboard or camouflage.

## 5. RADIATION MEASUREMENT AT MOBILE TELEPHONE BASE STATION (MTBS)

The radiation is typically transmits and receive by MTBS within the frequency range as allocated according to the license issued by the Malaysian Communications and Multimedia Commission (MCMC), the allocation frequencies to the service providers recently to reach the frequency of 2.6GHz. The transmitted power is low and within the range of 10 watts for mobile telephone and about 6 watts for the WiFi broad band internet applications. The measurements conducted for about 450 MTBS throughout the country since the past 13 years, about 12 to 15 measurement points were conducted for each MTBS, the MTBS selected are normally in the region where the number of complaint from the public is higher, mostly in the urban and suburban areas. Most measurements were based on the request from authority and the telecommunication providers.

*Figure 2. Trend of RF radiation level from mobile telephone base station (MTBS)*




Result of measurement indicates that the trend of RF radiation level from MTBS in the past 13years is reduced to lower than 0.5% of the maximum permissible level sets by the ICNIRP and the Mandatory Standard, Determination No.1 of 2010. The level of radiation measured in most cases is lower than 5μW/cm2, which corresponds to about 0.5% or over 200 times lower than the ICNIRP limit (1000 μW/cm2 for frequency range between 1.5GHz to300GHz) for the general public. This trend shows that the MTBS installed with a close distance, it means more cell introduced in that area and the size of the cell becomes smaller. The smaller cell size will require the lower transmitted power from the MTBS. It means that the RF radiation level also will be reduced as can be seen from the trend of field strength pattern given in Figure 2.

## 6. CONCLUSION

The mobile telephone base station has an excellence communication system in Malaysia where people accepted the technology despite the wrong perception and protest on issues of hazard related to the use of telecommunication technology. The active research carried out by the local institution is more effective to convince people than the use of external research evidence. The authorities such as MCMC have to take an aggressive role to educate people on the actual fact of the radiation induced from the MTBS. The regulatory infrastructures and standards related to the use of the mobile telephone technology has appropriate with the current demand but need to implement effectively. The level of RF radiation generating from MTBS is well below than 0.5% of the maximum permissible level set by the regulations and ICNIRP since mobile telephone is widely used in Malaysia.

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# SAR PROBE CALIBRATIONS IN THE 490 MHZ TO 750 MHZ BAND

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ABSTRACT

*To provide traceable RF dosimetry, the electric field probes used to measure specific absorption rate (SAR) of RF energy in human phantoms must be calibrated in a liquid or gel having very similar complex permittivity to the phantom. NPL has developed facilities over a number of years to calibrate SAR probes, including a coaxial system for 100 kHz to 400 MHz a dielectric-filled waveguide for the TETRA band (380 MHz to 460 MHz), and numerous waveguide systems for use between 750 MHz and 5.85 GHz. This paper presents the design and implementation of a new waveguide system with internal dimensions 381 mm by 95 mm, (half-height WR-1500) to cover the 490 MHz to 750 MHz band. A half-height waveguide was chosen since it halves the volume of liquid required for the calibration. The system design is outlined, the validation and characterisation measurements described and a full uncertainty analysis for the system is presented. A SPEAG ET3DV5R probe was calibrated at several frequencies inside the new system and at frequencies above and below the waveguide band in previously established systems to validate the results.*

***Key words:** Specific Absorption Rate, SAR, Probe, Calibration.*

## 1. INTRODUCTION:

Dosimetric electric field probes are used to measure the specific absorption rate (SAR) induced inside a phantom with dielectric properties similar to those of the human head [1] or the human torso [2]. Prior to using a SAR probe for such a measurement, the SAR probe is to be calibrated inside a medium with nominally identical electrical properties to that in which it is to be used [3]. To this end a calculable electric field needs be generated inside a dissipative medium, which is most commonly done using a waveguide system. Narrowband systems are currently widely used to calibrate probes at the more common spot frequencies but the continuous introduction of new technology is providing the incentive to develop broadband calibration systems.

ICNIRP guidelines [4], recently adopted into EU law [5] restrict both whole-body SAR and localized SAR in the 100 kHz to 10 GHz range, although SAR probes for use above 6 GHz are currently not widely available. A low- frequency facility has been established at the UK's National Physical Laboratory (NPL) for the calibration of SAR probes in the 100 kHz to 400 MHz range [6], and several waveguide systems have been built at NPL for the calibration of SAR probes in the 750 MHz to 5.85 GHz range [7, 8]. The systems currently available at NPL are detailed in Table 1.

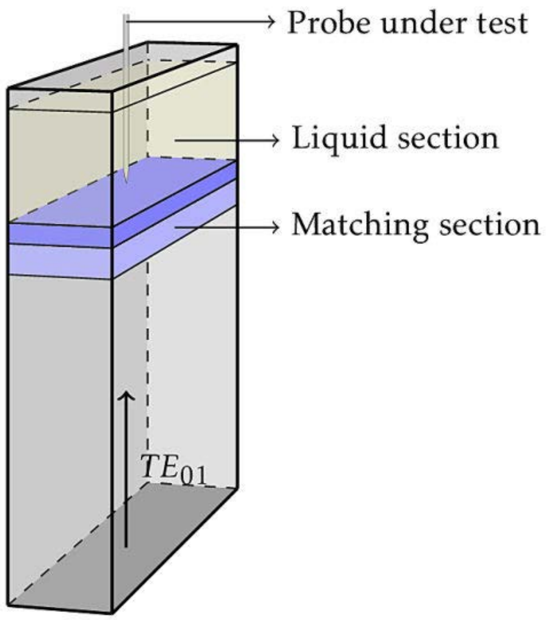


**Table 1.** *SAR probe calibration systems at NPL*

| | *Frequency Range* | *Uncertainty (k=2)* |
|---|---|---|
| ***Coaxial Low-Frequency System*** | 100 kHz – 400 MHz | 8.6% |
| ***Dielectric-Filled Waveguide TETRA System*** | 380 MHz – 450 MHz | 8.5% |
| ***900 MHz Tuned WR-975 Waveguide System*** | 900 MHz | 6.7% |
| ***1.8 GHz Tuned WR-430 Waveguide System*** | 1.8 GHz | 7.1% |
| ***2.45 GHz Tuned WR-430 Waveguide System*** | 2.45 GHz | 6.1% |
| ***5.2 GHz Tuned WR-187 Waveguide System*** | 5.2 GHz | 9.2% |
| ***5.8 GHz Tuned WR-187 Waveguide System*** | 5.8 GHz | 9.3% |
| ***WR-975 Broadband Waveguide System*** | 750 MHz – 1.12 GHz | 10.0% |
| ***WR-650 Broadband Waveguide System*** | 1.12 GHz – 1.7 GHz | 10.0% |
| ***WR-430 Broadband Waveguide System*** | 1.7 GHz – 2.6 GHz | 7.3% |
| ***WR-284 Broadband Waveguide System*** | 2.6 GHz – 3.95 GHz | 7.4% |
| ***WR-187 Broadband Waveguide System*** | 3.95 GHz – 5.85 GHz | 11.4% |

Inspection of Table 1 reveals a conspicuous gap in the frequency coverage from 460 MHz to 750 MHz. This gap corresponds to a region in the spectrum where the frequency is too high for coaxial SAR probe calibration systems, as the diameter of the coaxial line required to produce homogeneous fields becomes small to the point that introducing a SAR probe significantly perturbs the fields. The 460 MHz to 750 MHz frequency range is also too low for waveguide SAR probe calibration systems, as 15 L of liquid would be required to fill the waveguide liquid section. In the case of the TETRA system [9], this issue was resolved by filling a WR-975 coaxial waveguide launch with high-permittivity dielectric to bring down the cut-off frequency. As it is difficult to quantify the power loss in a dielectric-loaded coax-to-waveguide adapter, an alternative solution is proposed here involving the use of a half-height waveguide.

## *2. SYSTEM DESIGN & TESTING*

A schematic of a waveguide system for SAR probe calibrations is given in Figure 1. A TE01 mode is launched into the waveguide and propagates through into the liquid section. The SAR induced in the liquid section at the centre of the waveguide cross-section can then be calculated from Equation 1, where P is the power entering the liquid section, ρ is the density of the medium, δ the decay depth of electric fields in the medium, z the height to which the probe has been lowered and ab the cross-sectional area of the waveguide.

$$SAR = \frac{4P}{pab8} e^{-2z/8} \quad (1)$$

A matching section is used to ensure a maximum of power is transmitted into the liquid section. Previous section designs have included quarter-wave matching sections [10], multi-layered sections to provide a significantly better match at a spot frequency [11], or multi-layered sections to provide an acceptable match across the entire waveguide band [7,8]. The design of the matching sections for these systems is detailed in [7], and consists of considering the wave impedance at each medium boundary along the axis of propagation. This yields a system of equations that can be expressed in terms of the reflection coefficient from each boundary. This system of equations can be solved by assuming zero reflection off the final liquid/air boundary: i.e. that the fields have decayed completely in the liquid. The match into the waveguide system has to be sufficiently good to ensure a measurable field is induced at a range of depths inside the liquid section, and to ensure a low-uncertainty power measurement.

Using the approach described in the previous paragraph, a two-layered matching section has been designed for a WR-1500 half-height waveguide (Figure 2). The thicknesses and dielectric properties of each individual layer are detailed in Table 2. When connected to an ideal adapter this matching section provides an input return loss of at least 6 dB across the entire band, with an input return loss in excess of 15 dB at the centre of the band (Figure 3a) The necessary presence of a coax-to-waveguide adapter and subsequent straight superimposes a ripple on the return loss (Figure 3c), but the 6 dB criterion across the band is still met. Characterisation of the adapter and straight [12] allows the adapter loss to be quantified, which was found to be approximately 1%. It is noted that, although the half-height waveguide straight section has a higher attenuation per unit than a waveguide of regular aperture dimensions (0.0038 dB/m at the cut-off frequency, compared to 0.0024 dB/m), this still only accounts for approximately a tenth of a percent of the loss - the remainder is due to losses in the adapter itself.

***Figure 2.** Matching Section for WR-1400 half-height waveguide*

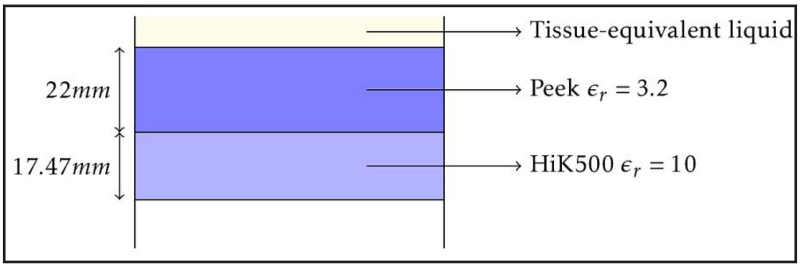
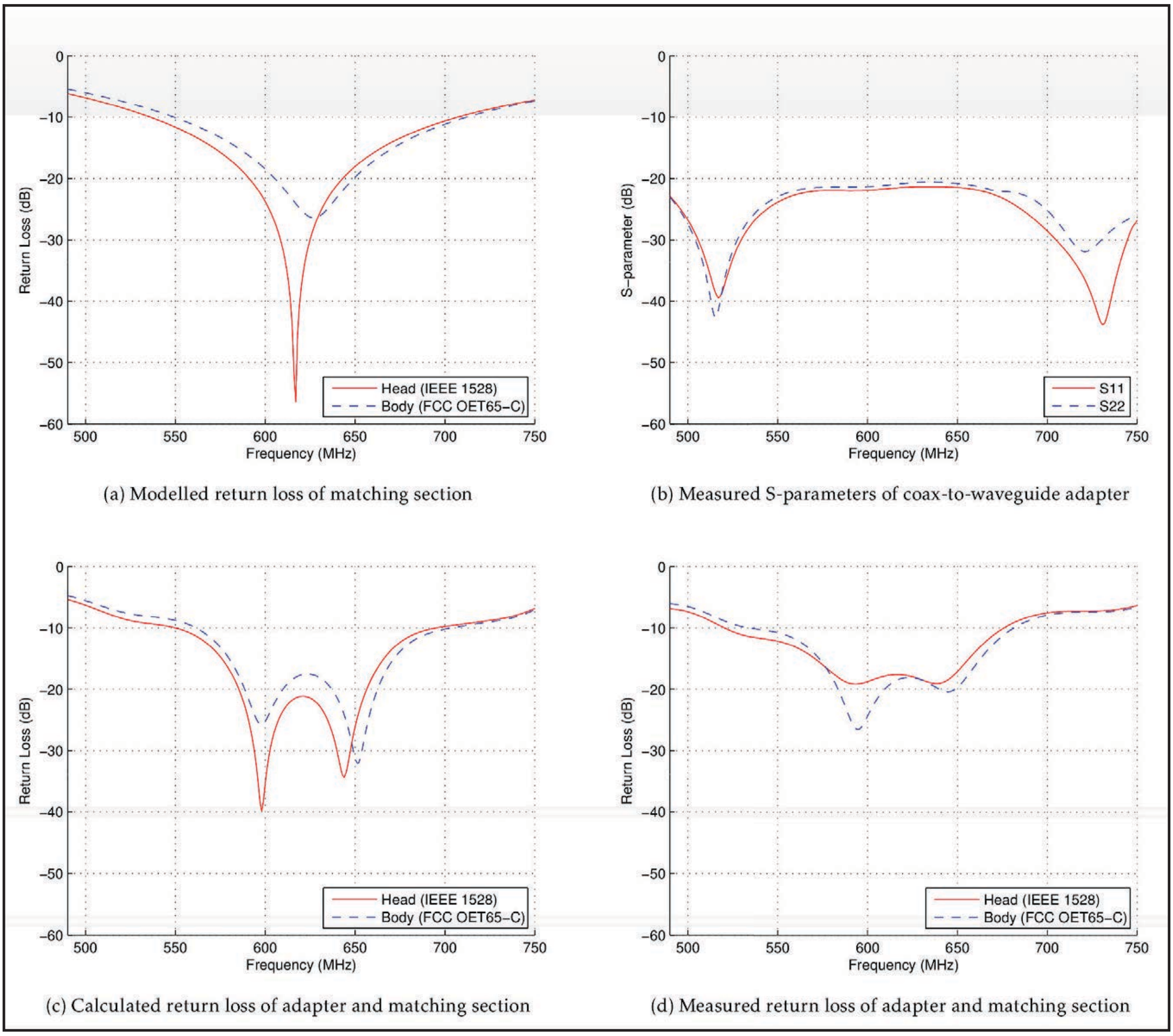
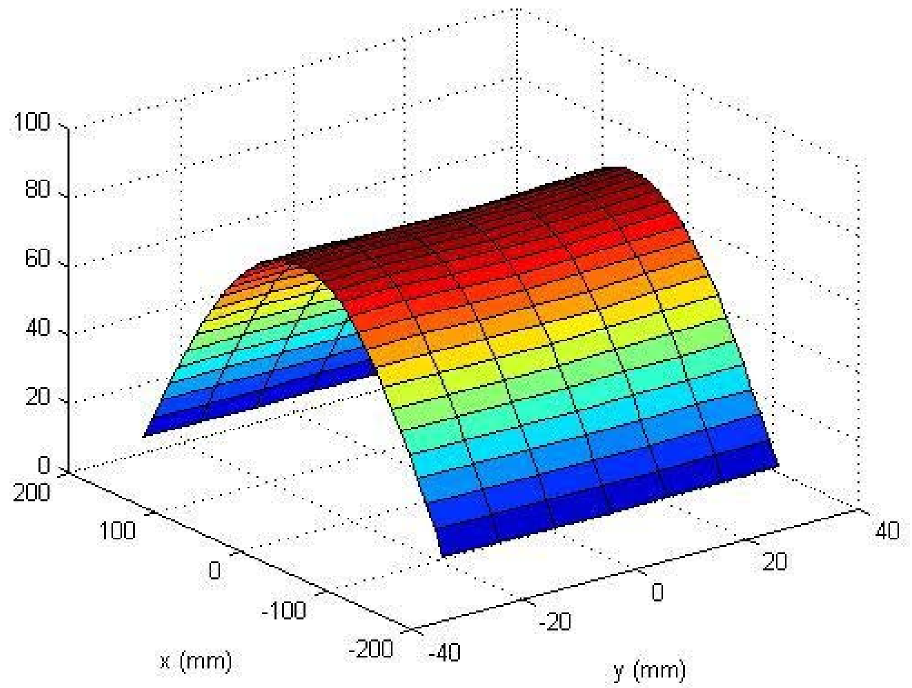



***Figure 3.** The coax-to-waveguide adapter imposes a ripple on the matching section return loss*



Equation 1 assumes a TE01 distribution inside the liquid section of the waveguide. To demonstrate that this is the case, the relative magnitude of the electric fields was mapped at 490 MHz, 620 MHz and 750 MHz (see Figure 4). This was done using a SPEAG EX3DV4 electric field probe with a tip diameter of 2.5 mm. Use of a probe with a larger tip-size would increase the error due to the probe spatial resolution when measuring fields with a gradient transverse to the probe axis. These field maps allowed the deviation of the fields from the TE01 to be calculated, with a worst-case of 2% being observed.

*Figure 4. Relative electric field map, f = 750 MHz, z = 5mm*




### 3. MEASUREMENTS & UNCERTAINTIES

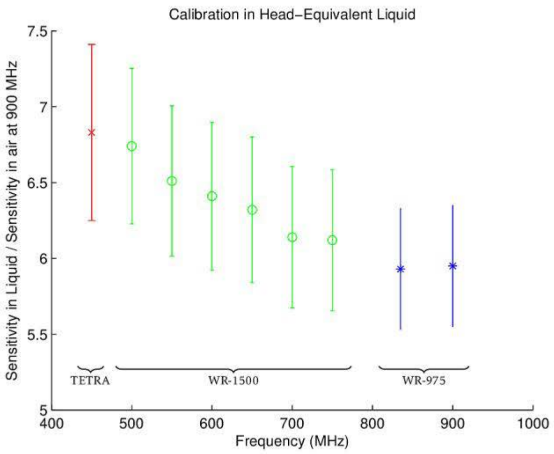
The power into the waveguide is measured using a uni-directional coupler, and is corrected for losses in the coax-to-waveguide adapter and subsequent waveguide straight. The decay depth in the liquid can be calculated from the dielectric properties of the liquid, or alternatively can be measured using the probe under test. By measuring the relative change in field at various heights in the waveguide, the rate of decay of the electric fields and hence the decay depth can be calculated. It is the latter approach that is adopted here.

Equation 1 then allows the SAR at a given height in the waveguide to be calculated. The sensors in the probe under test are lowered to this height, and the probe is rotated on its axis, taking measurements at regular angular intervals. Correction factors for each of the three sensors can then be calculated such that the SAR probe gives a true SAR reading, irrespective of its rotation angle.

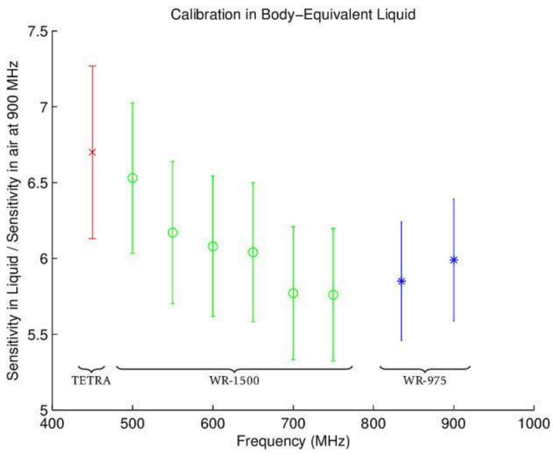
A SPEAG ET3DV5R probe was calibrated at six frequencies inside the waveguide band: 500 MHz, 550 MHz, 600 MHz, 650 MHz, 700 MHz and 750 MHz in both body and head liquid. The probe was then also calibrated at 450 MHz in the TETRA system and at 835 MHz and 900 MHz in the narrowband 900 MHz system in body and head liquid for comparison. The results of the calibration are illustrated in Figure 5. The measurements taken in the WR-1500 system can be said to agree with the trend set by the measurements taken in the TETRA and 900 MHz narrowband system.

A simplified uncertainty budget for the system is given in Table 2. Worst-case parameters were assumed when calculating the uncertainty budget, including a deviation of the electric fields from the TE01 mode of ± 2% (see Figure 4, liquid properties that deviate from their target values by up to ± 10% and a return loss of 6 dB (see Figure 3). An expanded uncertainty of ± 7.6% at (k=2) is obtained, which is comparable to the other waveguide systems. It is noted that a return loss of 20 dB, as is observed close to the centre of the waveguide band, only reduces the expanded uncertainty to 7.1% at (k=2).

***Figure 5.*** *Sensitivity coefficients for a SPEAG ET3DV5R probe calibrated in head-equivalent liquid (l) and body-equivalent liquid (r). The probe was calibrated in the 450 MHz narrowband system ('TETRA'), the WR-1500 half-height system ('WR- 1500') and the 900 MHz narrowband system ('WR-975').*




(a) Head-equivalent liquid




(b) Body-equivalent liquid

***Table 2.*** *A simplified uncertainty budget for the WR-1500 half-height SAR probe calibration system*

| *Source of Uncertainty* | *± Ui (%)* |
|---|---|
| Power measurement uncertainty | 1.32 |
| Mismatch error | 1.98 |
| Adapter loss measurement uncertainty | 0.50 |
| Deviation from TE01 mode | 1.15 |
| Decay depth measurement uncertainty | 1.00 |
| Variation of liquid properties with temperature | 3.00 |
| Deviation of liquid properties from target values | 2.00 |
| Liquid properties measurement uncertainty | 2.00 |
| Waveguide dimensions measurement uncertainty | 0.33 |
| Probe depth measurement uncertainty | 0.30 |
| Probe centering accuracy | 0.01 |
| Combined Uncertainty | ± 3.8% |
| ***Expanded (k=2) Uncertainty*** | ***± 7.6%*** |

## 4. CONCLUSIONS

A system has been developed to traceably calibrate SAR probes in the 490 MHz to 750 MHz range, filling a frequency gap in the UK's national measurement capability. The frequency range necessitates a WR-1500 waveguide system, and a half-height designation was chosen to minimise the volume of tissue-equivalent liquid required. A matching section is designed to give a return loss of at last 6 dB across the entire band, including in the presence of the coax-to-waveguide adapter. The field distribution in the liquid section of the waveguide was characterised and confirmed to deviate from the ideal TE01 mode by less than ± 2%. A SAR probe has been calibrated at six frequencies inside the system and at frequencies above and below the waveguide band in previously established systems for comparison. An uncertainty budget has been proposed for the system, giving a worst-case expanded uncertainty of ± 7.6%.


## ACKNOWLEDGEMENTS

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# EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC FIELDS FROM MOBILE NETWORKING IN MOTOR-CARS

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## ABSTRACT

*The relevance of the study is prescribed by the rapid development in mobile computer and wireless data transmission technologies. The levels of radiofrequency electromagnetic fields that the population is exposed to have increased likewise. This article investigates the levels of exposure to the radiofrequency electromagnetic fields from mobile networking in motor-cars. The object of the study is the broadband wireless network connection (2G/3G/4G) that creates the exposure conditions inside the car. An intervention scenario is introduced by connecting the external antenna (at the vehicle roof) to the external adapter. Exposure to the radiofrequency electromagnetic fields is measured before and after the intervention. The sitting positions of four persons (driver and the passengers) were all included in to the measurement.*

*Tests were carried out at sites with different reception quality (from service provider's antenna). This allowed capturing exposure situations with various adapter transmission levels, divided broadly into five classes. At each reception quality class the adapter was applicable for testing 2G, 3G and also 4G (if applicable) protocols separately.*

*The results indicate the exposure levels to be functionally connected to the reception quality – the better the reception, the lower the exposure. However, connecting the wireless adapter to the external antenna allowed the highest decrease in exposure levels (commonly -20dB) while also improving connectivity and networking speed.*

***Keywords:*** *Vehicle, car, electromagnetic field, radiofrequency, microwaves, 3G, 4G, UMTS, LTE, PC, computer, laptop, antenna*

## 1. INTRODUCTION

Advancements in computing and wireless data transmission technologies have raised the efficiency of everyday work, introduced mobile working and improved the quality of human life in many other ways. Radiofrequency (RF) electromagnetic fields (EMFs) accompany wireless data connections as a secondary product to data services moving through the invisible data streams in the air. RF EMFs' levels around such devices may be dependent on a number of factors. This study focuses on laptop computers used for mobile networking in motor-cars.

Mobile networking is defined as connecting a portable personal computer (PC) to the local area network (LAN) or to the internet by means of wireless data transmission. Wireless data transmission is established by a wireless adapter connected to a PC either externally (via USB-port) or internally. Several wireless data protocols and adapter technologies have been developed: e.g. GSM-data, GPRS (General Packet Radio Service), EDGE (Enhanced Data rates for GSM Evolution), HSDPA (High-Speed Down-link Packet Access) ja LTE (Long Term Evolution), Bluetooth, WLAN (Sesia et al 2011).

GPRS, (General Packet Radio Service) enhances the GSM standard to transport data in an efficient manner and enables wireless devices to access the Internet. With Enhanced Datarates for GSM Evolution (EDGE), further additions are specified to improve speed and latency. (Sauter, 2011, 63).

The Universal Mobile Telecommunications System (UMTS) is a third generation wireless telecommunication system which follows GSM and GPRS. The UMTS radio network system has been later enhanced and now offers broadband speeds far beyond the original design. These high-speed enhancements are referred to as High-Speed Packet Access (HSPA). (Sauter, 2011, 115)

UMTS is approaching design limitations in a manner similar to what GSM and GPRS did a decade ago. To overcome these limitations, Long-Term Evolution (LTE) is developed. Unlike in HSPA, the baseline for LTE device has been set very high. In addition to the flexible bandwidth support, all LTE devices have to support Multiple Input Multiple Output (MIMO) transmissions, which allows the base station to transmit several data streams over the same carrier simultaneously. (Sauter, 2011, 205-206)

Besides radiofrequency fields, laptop computers also generate a range of other frequencies, namely extremely low frequencies (ELF), ultra-low frequencies (ULF), very low frequencies (VLF), low frequencies (LF) and medium frequencies as classified by the International Telecommunications Union (ITU)[ITU 2005]. These frequencies are not addressed in this study.

Recently more attention has been paid on the safety issues regarding radiofrequency electromagnetic fields. The public is increasingly interested in knowing more about the safety issues in regard to personal exposure to the EMFs. This also includes knowledge on how to minimize one's exposure to the electromagnetic fields.

Based on the to the last EMF Eurobarometer poll, accompanying all EU member states, 58 per cent of the respondents don't believe that authorities protect them from the health risks related to EMFs. Almost half of the public (48 per cent) seek that EU should inform them of these health risks. Only 20 per cent said they had received some information on the health effects of EMFs (TNS 2010).

Although the danger arising from the usage of such devices remains debatable amongst the scientific community, a precautionary principle is recommended. General precautionary principle used in environmental risk management states that environmental risk factors should be reduced to as low as practically possible.

Reducing electromagnetic fields is also a technical issue from the point of view of electromagnetic interference (EMI). Having multiple and strong sources of RF EMFs may also hinder the work and operability of other electronic devices. Electronics is tested till 3V/m [24 mW/m2] (COMAR, 1998). Reducing EMF levels in the environment also helps to guarantee the compliance of a given device with other electronic devices in the environment.

Metallic structures create hot-spots for microwave radiation. This increase was seen in the computed models by Ruddle (2007, 1) who noted: «The presence of the vehicle structures is found to result in higher mean SAR values for all occupant locations, although maximum SAR levels are lower with the vehicle for the driver position.» In Ruddle's simulation the radiating source (a 400 MHz transmitter) was on the back seat (Ruddle 2007). In our measurements we test this computed model by real measurements in a car occupied by a mobile networking set-up.

From Volkswagen Golf TSI Manual, Year 2009, p. 28 (in Finnish): Osa 3.1 Käyttö -

"Jos auton sisällä käytetään matkapuhelinta, jota ei ole yhdistetty ulkopuoliseen puhelinantenniin, muodostuu terveysriski, koska syntyvä sähkömagneettinen säteily voi ylittää voimassaolevat raja-arvot."

Translation for our paper: "If a mobile phone is used inside the car without external car antenna, a health risk is created, because electromagnetic radiation may exceed existing guidelines. " (Volkswagen, 2009, 28)

Hondou (2002) has shown that reference levels for general public exposure (ICNIRP Guideline) can be exceeded with several radiation sources inside the metal carriage. According to Hondou this is caused by the fundamental properties of electromagnetic field, namely, reflection and additivity. This exceeding of ICNIRP guidelines has been contested, for example by Toropainen (2003). However, the results of Hondou (2002) is relevant also for this paper, since in cars and busses there can be several users simultaneously using mobile connections.

Using a mobile phone in a car has been studied through simulations and actual measurements. Anzaldi et al. (2007) comment: «SAR distribution is not likely to produce an increase above the limits in current guidelines for partial body exposure, but may be significant for whole-body exposure.» (Anzaldi, 2007). In a car the main interest in this research paper is the head area of a driver and passengers. This is because of traffic safety reasons, head and brain exposure is seen as an important factor.

Concern has been raised about mobile phone use and it's effect on reaction time of the driver and generally on cognitive functions (Preece 2009).

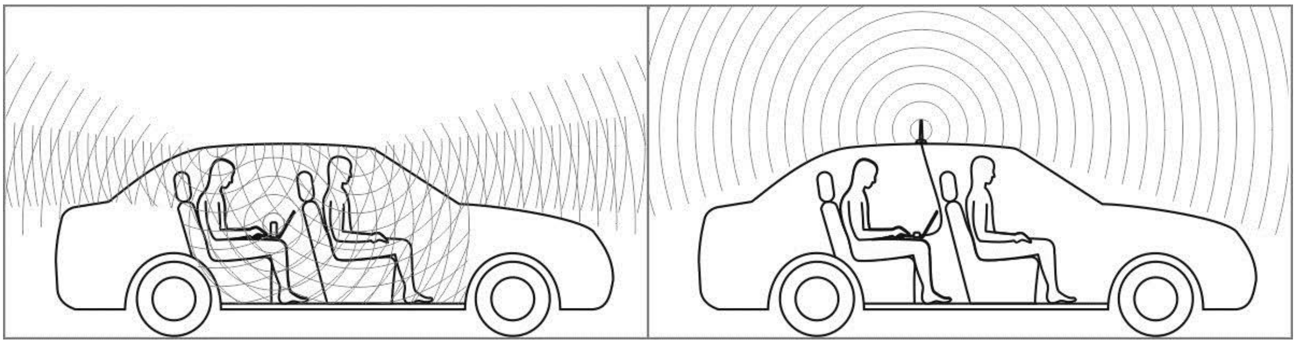
The aim of this study is to test the efficiency of intervention measures in reducing user's exposure to radiofrequency electromagnetic fields from mobile networking inside motor-cars.

## *2. METHOD*

This study investigated radiofrequency electromagnetic fields from mobile devices (portable computer operating on battery) inside motor-cars. The source for the radiofrequency electromagnetic fields was the wireless network adapter connected to the PC via USB port. The wireless adapter utilized whether 2G, 3G or 4G wireless network data transfer protocol; all of these protocols were tested. From the wireless network adapter's software, a selected data transfer protocol was locked, in order to prevent the wireless adapter from switching to another data transfer protocol.

The main intervention was to switch from an internal antenna to an external antenna, positioned on the motor-car's roof (figures 1 and 2). The external antenna was connected to the wireless adapter either a CRC9-type socket (figure 4) or induction plate type connector (figure 5).

***Figure 1.*** *The main intervention measure was to connect the wireless adapter to an external antenna, positioned on the roof; when an internal antenna is used, RF EMFs create countless reflections inside the car, multiplying the exposure levels; when an external antenna is used, almost all of the wireless adapter's transmission power is routed outside of the motor-car's metal casing, reducing the user's exposure levels to minimum.*



The laptop PC was positioned on the back seat, at a thigh height from the seat (figure 3). The elevation from the seat was established by plastic or carton fixture, invisible to radiofrequency fields. The wireless network adapter was positioned towards the center axis of the car.

***Figure 2.*** *External antennas positioned on top of the motor-car's roof. Two antennas are required in LTE protocol.*

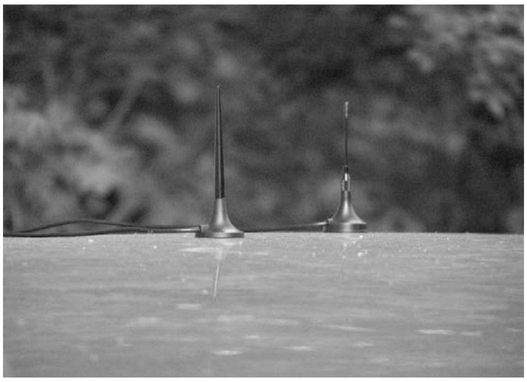


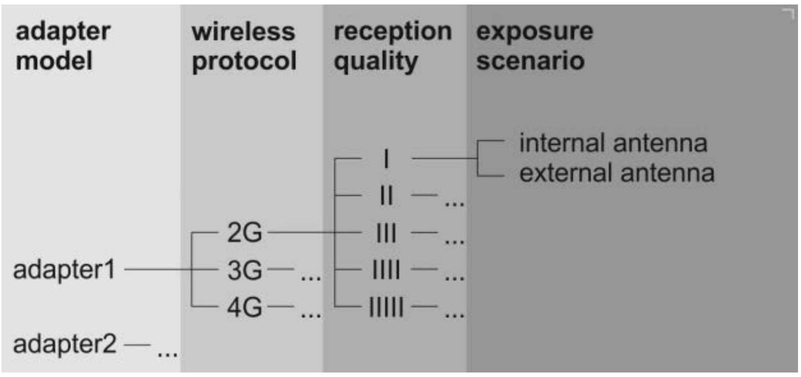
***Figure 3.*** *Measurement setup – a PC connected to a wireless network adapter; no external antenna is used in original exposure scenario.*

***Figure 4.*** *External antennas were connected to the wireless adapter via one or two CRC9 type sockets.*

***Figure 5.*** *Another intervention solution connected wireless network adapter to external antenna by induction plate conductor.*

Another intervention measure was to improve the reception quality – taking the laptop's wireless adapter closer to the network service provider's mast/antenna. This meant moving the car to different places both in urban areas, where the reception is commonly good and to rural areas where weak reception areas can be found. As the reception quality improves the laptop's network adapter automatically switches the antenna to lower output power levels, thereafter exposing the user to lower levels of electromagnetic fields. Figure 6 pictures an overview of possible intervention scenarios applicable for a wireless adapter.

***Figure 6.*** *Intervention scenarios investigated by this study*

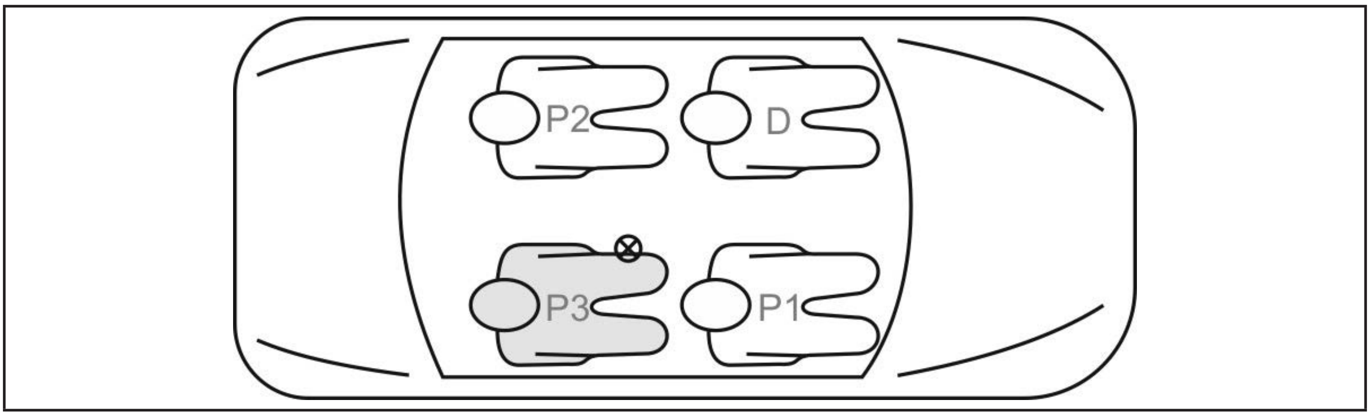



The measurement protocol prescribed scanning the imaginary body area of the person in the car. Measurement was recorded at a location where the strongest signal was obtained (so-called hot spots). Seats for four persons were included in the protocol: a driver and three passengers (figure 7). All four places were measured separately.

No persons (neither the measurer) were sitting in the car while taking the measurements. In order to facilitate the measurement, a car door was opened for the seat from where the measurements were to be taken. Attention was paid, not to take measurements closer than 0,3m from the radiating antenna.

In order to take the measurements, the PC established a network data connection and was set into a continuous upload state. This meant uploading files into a local server. Since network traffic may hinder transfer speed and therefore result in reduced output power from the wireless adapter, the tests were conducted in „good network weather" situation.

***Figure 7.*** *Seating arrangements inside a motor-car (measurement regions). Person P3 is using a PC, where "X" marks the position for the radiating wireless network adapter.*




The measurements were conducted using a radiofrequency analyzers HF59B (antenna HF800V2500LPE174) from Gigahertz Solutions (Langenzenn, Germany). An attenuator of -20dB was also used. The measurements were taken both in RMS-mode (root mean square) and peak mode. The meter also facilitates pulsed signal measurement mode, intended especially for wireless data transmission measurements. As wireless data transmission protocols utilize very short pulsing signals, these may by left unnoticed or registered at much lower intensities by some other measurement devices not accustomed for pulsed signal measurements.

*3. RESULTS*

Altogether 5 different wireless adapters were tested in various interventions (including different reception levels), resulting in 54 unique exposure scenarios. Measurements were conducted in Estonia and Finland. Measurement sites included both urban and rural environments, where the latter ones provided mostly the opportunities to test exposure scenarios under poor reception conditions.

Exposure levels before the intervention (external antenna) are greatly dependent on the reception quality – the poorer signal quality, the stronger the exposure. After the intervention (connecting the external antenna) the exposure levels are as low that dependence on signal quality is irrelevant (e.g. protocol 3G on figure 8).

Secondly, exposure levels both before and after the intervention are also dependent on wireless network protocol, where 2G produces higher exposure (figure 9). 3G and 4G protocols produce the exposure of a same degree.

***Figure 8.*** *When external antenna is not utilized the exposure levels (vertical axis, in mW/m2) are dependent on reception quality (horizontal axis); 3G protocol.*

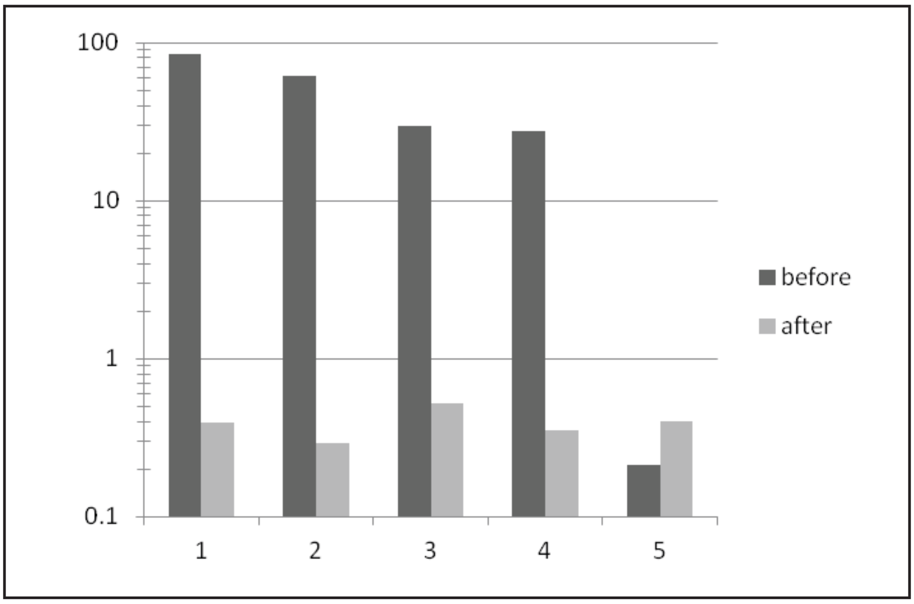
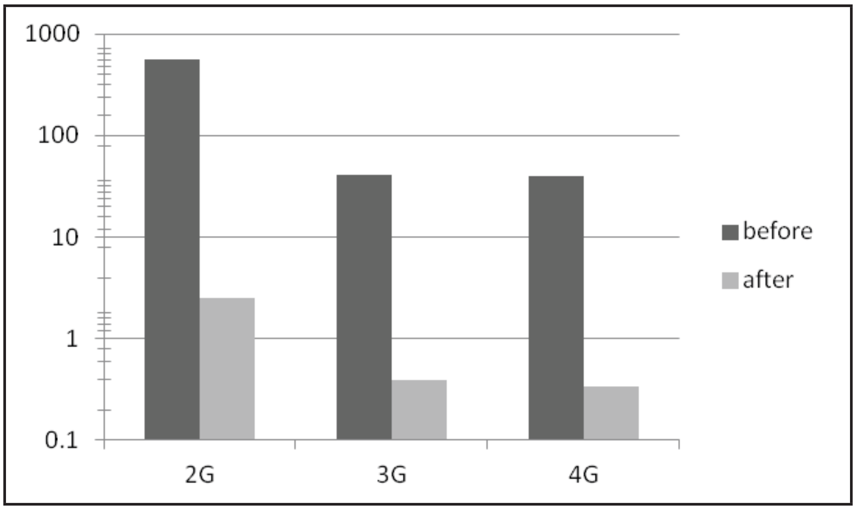
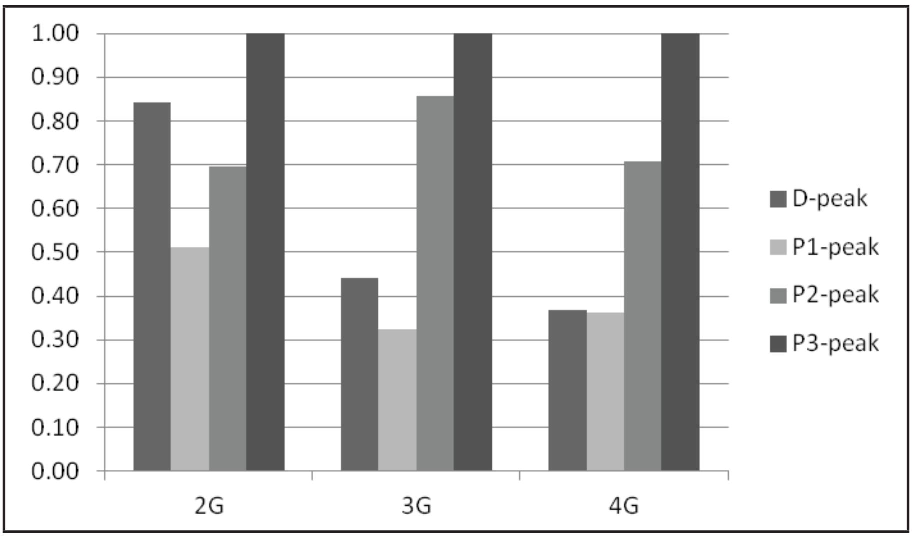



***Figure 9.*** *2G protocol produces higher exposure levels (vertical axis, in mW/m2; averaged across the reception levels)*




In exposure scenarios without intervention, the highest exposure was almost in all cases present at seating place P3, the person using the PC with wireless networking adapter. In 3G and 4G protocols the next highest exposure was obtained at P2 – the person sitting on the back bench next to the PC user (figure 10). In 2G protocol the second highest exposure was at seat D (the driver)

**Figure 10.** *Exposure level ratio of seating places compared to seat P3 (PC user); classified by wireless protocols and averaged across all reception levels; peak readings.*




External antenna intervention produced drastic decrease in RF EMF levels inside the car in case of all wireless network protocols (2G, 3G, 4G) and at all reception quality levels (table 1). The attenuation factor was smaller in case of good reception quality – understandably the wireless adapter antenna transmission power was likewise smaller at the beginning (without intervention).

**Table 1.** *Average intervention effect (dB from power density)*

| | 2G | | 3G | | 4G | |
|---|---|---|---|---|---|---|
| ***Reception*** | **RMS** | **peak** | **RMS** | **peak** | **RMS** | **peak** |
| ***I*** | -26,3 | -25,3 | -23,5 | -23,4 | -17,2 | -16,4 |
| ***II*** | -22,9 | -23,5 | -22,3 | -23,4 | -24,4 | -26,7 |
| ***III*** | -22,9 | -21,6 | -18,3 | -17,6 | -23,5 | -28,1 |
| ***IIII*** | -24,6 | -24,9 | -20,3 | -18,9 | -16,2 | -25,4 |
| ***IIIII*** | -24,1 | -27,1 | -13,3 | -14,6 | -19,8 | -18,6 |
| ***Average*** | -24,2 | -24,5 | -19,5 | -19,6 | -20,2 | -23,0 |

## 4. CONCLUSIONS AND DISCUSSION

In their later paper Hondou et al. (2006) indicated problems with hot spots, where the local exposure level is much higher than average. In our measurements we noticed these hot-spots, but unregularly, not on every seat.

There are certain discrepancies in our measurement results. We tested a special induction plate connector for an external antenna - in these measurements we did not notice similar reduction of microwave power density levels than when the antenna cable was attached to the wireless adapter via a socket. This may be due to the fact, that the induction plate connector is very sensitive to the location, where it is attached to the wireless modem. However since one model of such inductive connector type was measured, no conclusions can yet be made.

In our testing and measurements we used an external antenna on and in the center of the car. Tarusawa et al. (2007) inspected three different antenna types: a trunk-lid antenna, rear-window antenna, and roof antenna. According to their measurements: "The electric-field strengths in the front and back seats are less than 30 V/m when the antenna input is less than 1 Watt as net power. Inside the car, the local peak of the field strength is higher by 2 and 4 dB for the trunk lid and roof antenna, respectively, and approximately 10 dB higher for the rear-window antenna.» (Tarusawa et al., 2007, 1295) This means that in order to minimize the exposure, the antenna should reside at the center of the roof, instead of rear-window.

Generally, our measurements provided both confirmations and clarifications to mathematical calculations and computed models (like Anzaldi et al. (2007) and Ruddle (2007)). Our results show that exposure in driver's seat is occasionally very high, especially with 2G protocols. For this reason we encourage other researchers also to proceed with RF EMF measurements in a motor-car environment.

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# NEW SURFACE-BASED MODELS OF THE HUMAN BODY FOR VERY HIGH RESOLUTION ELECTROMAGNETIC DOSIMETRY

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*ABSTRACT*

*A new, anatomically realistic model of the human body, MAXWEL (MAle fleXible Whole-body modEL) has been developed by EMFcomp, an independent research microenterprise in the UK. The phantom is a surface-based, as opposed to voxel-based, model that allows voxelisation to any desired resolution, to a very detailed 0.1 mm. Therefore, numerical errors due to staircasing of the model are greatly reduced at high resolutions. Advantages of employing the MAXWEL surface-based model are demonstrated in this work by presenting the detailed eye model used in MAXWEL, based on the work of Yoriyaz et al (2005). Small organs such as the eye are poorly represented by traditional human voxel models as the resolution typically used is 2 mm. The surface-based model allows voxelisation at, say, 0.1 mm. The result is a representation of the eye with no obvious loss of the detailed anatomical structure. The MAXWEL model is currently being used in the development of the EMF Directive 2013/35/EU Practical Guide to demonstrate how an incident electromagnetic field is absorbed in small organs like the eye. A Finite-Difference Time-Domain (FDTD) code, produced at EMFcomp and written in FORTRAN, was used to model the coupled, time-dependent Maxwell curl equations. The SAR in the head was calculated from exposure to RF fields. The eye is particularly susceptible to radiofrequency fields as it lacks blood supply to its internal transparent regions (so central regions are prone to hotspots), and has limited capacity for repair. Comparison of the calculated peak localized SAR results, averaged over 10 g of contiguous tissue, with ICNIRP restrictions from exposure to the TETRA handset showed compliance in all exposure configurations studied.*

***Key words:*** *RF, Dosimetry, SAR, Human Phantoms, Modelling*

## 1. INTRODUCTION

Handheld devices used for mobile communication are now widespread and, in recent years, a large number of studies have been conducted to assess the absorption of the electromagnetic fields they produce in the body. However, the assessments, usually involving the calculation of the specific energy absorption rate (SAR) in the head, have generally utilized voxel models of the human head at resolutions of around 2 mm. Whilst this resolution is adequate for representing the anatomical details of the entire human body, models of small organs in the head such as the eye are poor.

The eye has been identified as an organ that is potentially susceptible to damage from exposure to radiofrequency radiation. It lacks a blood supply to its internal, transparent, regions (aqueous humour, lens and vitreous humour). This implies that all significant removal of heat must take place at the periphery, and the central regions are therefore prone to the appearance of hot spots (1). Furthermore, the lens has a limited capacity for repair, and the accumulation of cellular debris can lead to a loss of transparency. Animal experiments (2) have shown the induction of cataracts with acute high level exposure.

The EMF Directive 2013/53/EU (3) states that the SAR in the head should not exceed 10 W kg-1, averaged over a 10 g contiguous mass. This is because a SAR limit of 10 W kg-1 should ensure that the temperature rise in the head does not exceed 38 degrees. This is true if it can be assumed that each 1 W kg-1 of SAR will cause a temperature rise of approximately 0.1 degree. However, it is generally accepted that the heating factor, or temperature rise per unit SAR, is somewhat greater than 0.1 for the eye. Therefore, it is possible that the SAR restriction presented in the EMF Directive might not provide adequate protection for the eye. Questions about how the energy produced by mobile telecommunications devices will be addressed by computing the SAR in a high resolution, detailed model of the eye. Wainwright (4) calculated temperature rises due to radiation from mobile GSM900 and GSM1800 handsets in various tissues. The main object of that study was the temperature rises in the brain. Values were also given for temperature rises in the eye; however, the finite-element mesh was not optimized for that purpose, and these values were not particularly accurate or considered in detail.

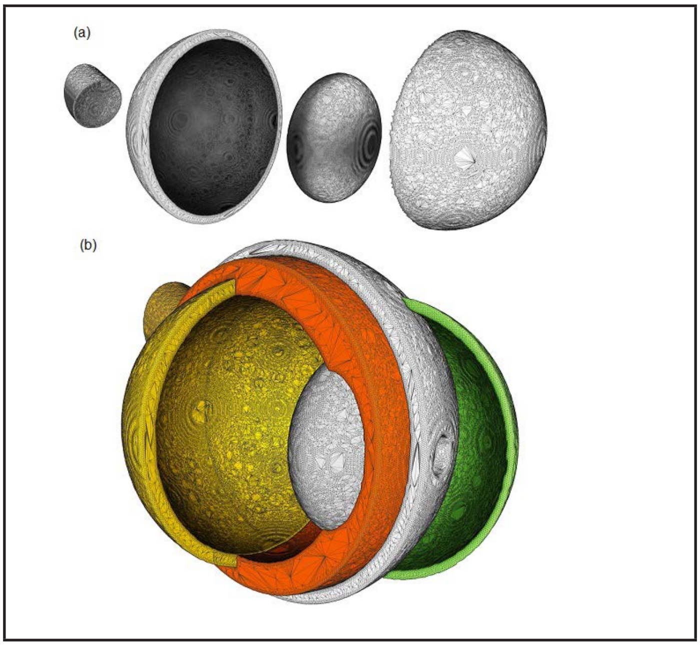
The purpose of this paper is to present the surface based model of the eye in the MAXWEL numerical phantom and to demonstrate the differences in the 10 g localized SAR value calculated over a cube and contiguous region for various frequencies. The new, anatomically realistic hybrid model, MAXWEL (MAle fleXible Whole-body modEL) (5) and the eye is described in Section 2. In Section 3, SAR calculations are presented for exposure to a Terrestrial Trunked Radio System (TETRA) handset. TETRA is used by the UK emergency services and operates at a frequency of around 380 MHz, which is considerably lower than that of public mobile networks. The calculations were performed using the finite-difference time-domain method.

## 2. MODELS

The original high-resolution MRI scans on which MAXWEL is based were of a 23 year old male subject with a height of 1.70 m and mass of 68 kg. These dimensions are very close to the ICRP reference adult male who is 1.76 m tall and has a mass of 73 kg (6). The original MRI slices were 256 x 256 pixels in the axial plane. This resulted in a resolution of approximately 1 mm in the head, neck and arm regions and 2 mm in the rest of the body. Thicknesses for the slices used in the production of the MRI scans were typically 2 mm apart from the arm and leg regions. For these, 4 mm slices in the vertical plane were used. The MRI data were collected in a series of continuous partial body scans. These regions consisted of the head, abdomen and arms, feet, legs and the pelvis area.

Primary segmentation then took place. This involved rescaling the data volumes to 2 mm, segmenting the grey-scale images into different tissue types and arranging the different blocks of data into one continuous model. Manual and automated volume segmentation methods were used to edit the images and successfully segment into the correct tissue type. This was relatively straight forward for tissue voxel intensities that were well defined, but more difficult where they lie within a close range, such as the colon and cortical bone regions. In these instances, seed filling techniques were used. A final segmentation process was then performed using code written in FORTRAN, followed by manual editing to remove any anomalies in the model. The next stage of the process was to import the volume into 3D CAD software and generate surface models of the various tissues. The software utilized NURBS (non-uniform rational B-spline) based tools to create surface based models of the previously voxelized tissue data. Surface-based representations of the tissue types making up the eye can be seen in Figure 1.

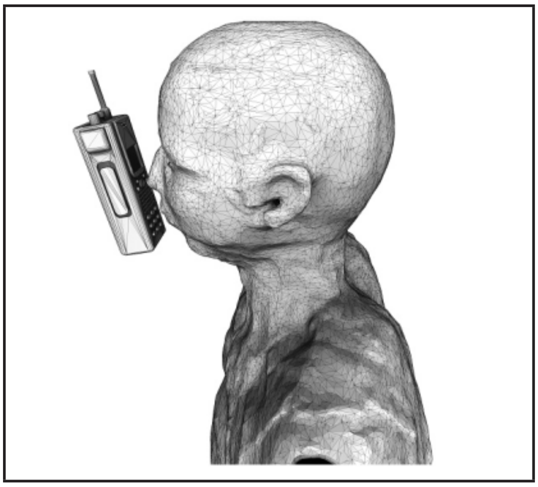
***Figure 1.*** *(a) Selected tissue-types making up the MAXWEL phantom eye, from left to right, optic nerve, retina, lens and cornea (b) assembled cut-away representation of the eye (humour removed for clarity).*




Once this process was complete, the surface based representations of the tissue types could be re-voxelized to a desired resolution using code written in FORTRAN. The end result is the hybrid computational phantom, MAXWEL, displayed in Figure 2 with the representative TETRA handset. Hybrid because the phantom is partly based on an anatomically realistic representation of the human body and partly stylized due to the transformation of this data to a surface based representation of the different tissue types.

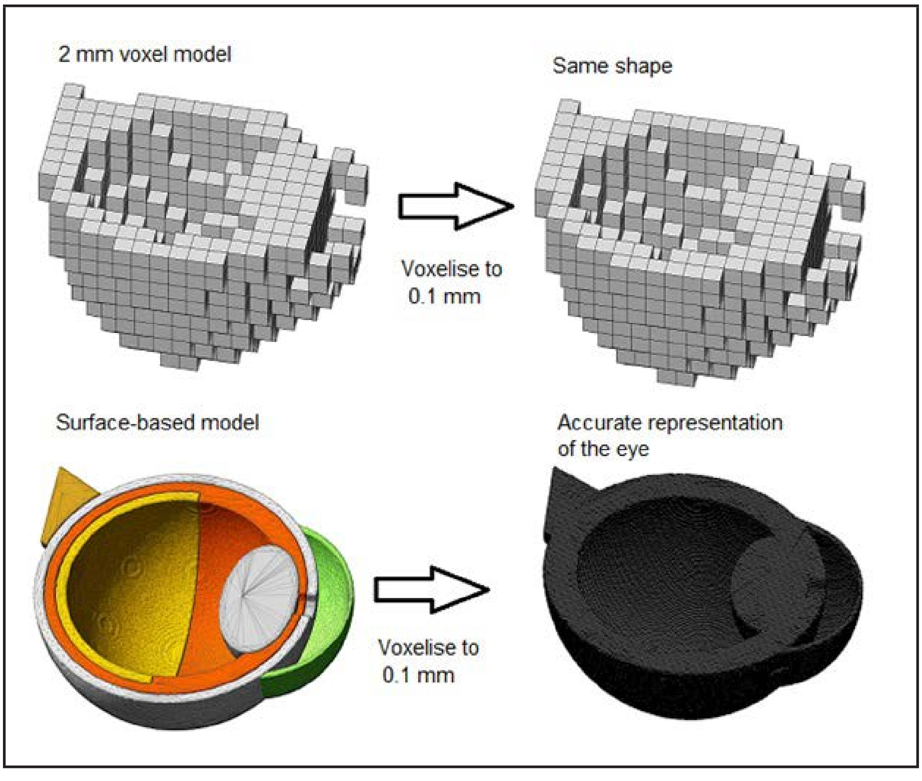
MAXWEL has been scaled to the ICRP 'reference man' dimensions of 1.76 m tall and a mass of 73 kg. The phantom consists of 42 different tissue types. These tissues include cerebrospinal fluid, bile, gall bladder, background air, blood, small intestine, spleen, muscle, breast, liver, thymus, urine, bladder, skin, fat, tendon, nose cartilage, kidney, duodenum, stomach contents, stomach, oesophagus, pancreas, trabecular bone, brain white matter, brain grey matter, spinal cord, lower large intestine, upper large intestine, heart muscle, eye lens, humour, sclera, cortical bone, adrenals, thyroid. Skin in the original segmentation was taken as the outermost 2mm layer and hence overestimates the true extent of the tissue in some regions; however this was corrected by treating the skin as a composite tissue of skin and subcutaneous fat.

***Figure 2.*** *The MAXWEL numerical phantom and TETRA handset model, located in the front (AP) position.*



An advantage of employing the MAXWEL surface-based anatomical model can be demonstrated in Figure 3. This figure displays the model of the eye in the MAXWEL human phantom, based on the Yoriyaz eye model (7). A cutaway view of the surface-based model is shown in the bottom-left image.

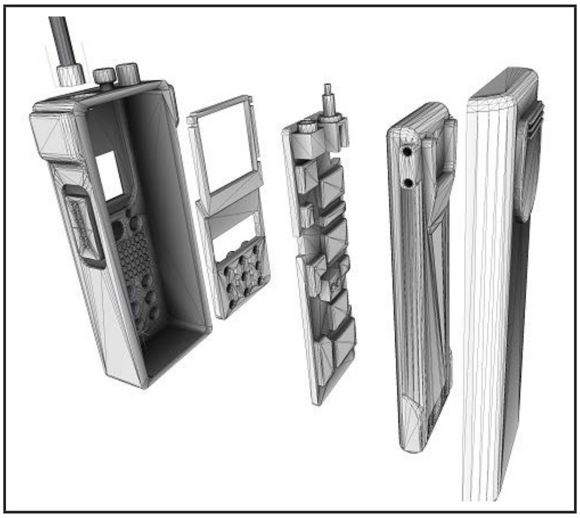
***Figure 3.*** *Cut-away surface-based and voxelised representations of the eye in the MAXWEL phantom. The eye humour has been removed for clarity.*




Voxelised representations of this eye are then shown at 0.1 mm resolution. The use of a fixed, say 2 mm, resolution voxel model limits the accurate representation of small organs in the body like the eye as the resolution of the model can never be higher than 2 mm - regardless of the grid size used to perform a calculation. It can be seen in Figure 3 that there is an obvious loss of the detailed anatomical structure of the eye at this 2 mm resolution when compared to higher resolutions. A surface-based model allows the model to be voxelised at very fine resolutions such as the displayed 0.1 mm, limiting the staircasing of the structure.

A representative model of a TETRA handset has been produced. An exploded view of the model is shown in Figure 4. The dimensions and layout of this representative model are based on commercially available TETRA handsets. The PCB, PCB components, battery and screen assembly are defined as metallic materials. The handset and antenna casings are plastic. The antenna was modeled as a surface-based helical structure, voxelised and imported into the computational domain.

***Figure 4.*** *Exploded view of the generic TETRA handset model comprising of (from left to right) the antenna, front casing, screen, PCB assembly, battery and rear casing.*



### *3. SAR CALCULATIONS*

The specific energy absorption rate is given by:

$$\mathbf{SAR=\sigma E2/\rho} \qquad (1)$$

In equation (1), E is the rms electric field, ρ is the tissue density and σ is the tissue conductivity. The SAR is a specific quantity, i.e. it is the power absorbed per unit mass, and has the units of Watt per kilogram or W kg-1. The whole-body SAR is calculated by summing all of the cells in the calculation and then dividing by the mass of the body. The FDTD method as used in Findlay and Dimbylow (8) has been used to calculate the SAR in the adult MAXWEL phantom. Dielectric properties evaluated by Gabriel (9) have been used for all of the tissue types in the body. A 4-Cole-Cole dispersion model was fitted to the data for each tissue type to parameterize the conductivity and permittivity as a function of frequency. The perfectly matched layer based boundary conditions were used. A Huygens surface was employed in the FDTD code to allow the description of incident fields, to separate the scattered field that is necessary for the boundary conditions from the total field required for the FDTD solution and also to connect the pml layers to the computational domain.

The localized SAR, averaged over a 10 g contiguous region as specified in the EMF Directive, is calculated by again first identifying a cell with the maximum absorption rate in a particular horizontal section of the model. A search is then performed amongst its six neighboring cells touching the faces of the original to find the one with the highest absorption rate. Once this is complete, the powers and masses are summed. A search is performed amongst the corresponding neighbors on its surface to obtain a connected region of cells for which the mass is equal to 10 g and the SAR is calculated for this connected region. This procedure is repeated for each horizontal section, and the maximum SAR value of any connected region chosen.

The handset was placed in front of the face, and then the position was varied in the vertical plane (z axis) downwards from the normal operating position (z=0). The results are shown in Table 1. The maximum 10 g SAR was calculated for a position 6 cm below the normal handset position. For the positions studied, the 10 g SAR values varied between +23% and -37% of this normal position. The handset was moved to the normal position at the side of the head, and again the position was varied, this time in the horizontal plane (x axis) towards the nose. The maximum 10 g SAR value was found when the handset was moved 4 cm from the normal operating position towards the nose. Again, there was considerable variation in the SAR value depending on the position relative to the head.

*Table 1. Peak localized SAR, averaged over a 10 g contiguous region, as the handset position is varied in the vertical/horizontal plane.*

| Position x/z axis (cm) | SAR, Handset to the front, W kg-1 per W | SAR, Handset to the side, W kg-1 per W |
|---|---|---|
| 0 | 2.53 | 2.36 |
| 2 | 2.68 | 2.71 |
| 4 | 2.84 | 3.38 |
| 6 | 3.12 | 3.26 |
| 8 | 2.68 | 2.41 |
| 10 | 1.63 | 1.71 |

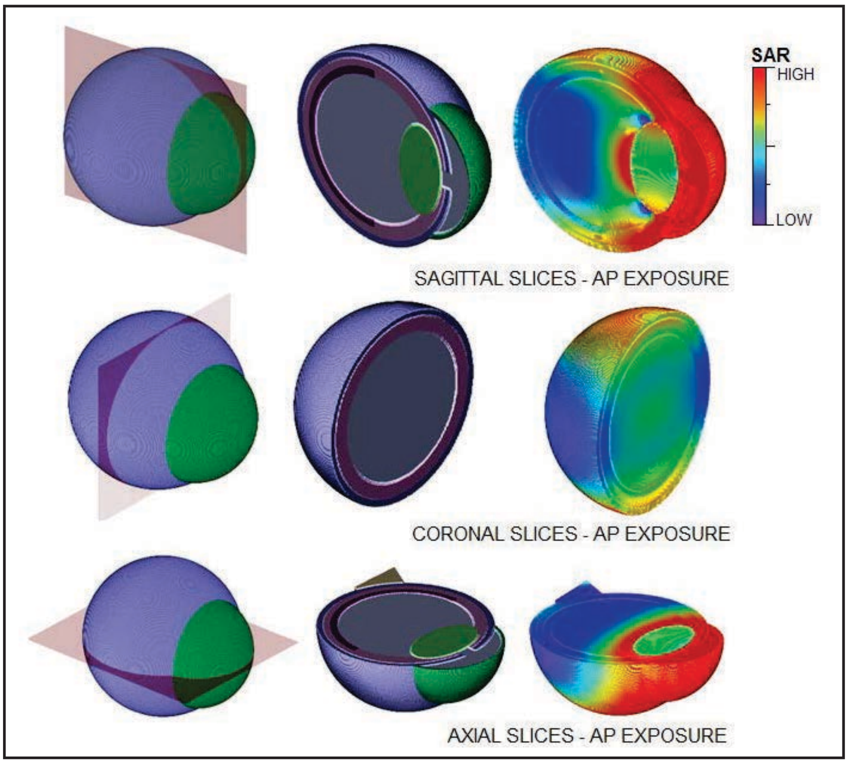
The SAR was also calculated in the eye at the standard 2 mm resolution and high 0.1 mm resolution, to investigate the difference using a high resolution model made. The results are shown in Table 2. The SAR is presented as the maximum localized SAR values averaged over 10 g of the eye and contiguous region surrounding the eye. Although the SAR calculated in the 0.1 mm resolution eye is, on average, 20% higher than that calculated in the 2 mm eye, it is still in compliance with the EMF Directive 2013/35/EU exposure limit values.

*Table 2. Peak localized SAR, averaged over a 10 g contiguous region, for the 2 mm and 0.1 mm resolution eye models. Handset in regular use.*

| Position | SAR (W kg-1 per W) | | % Difference |
|---|---|---|---|
| | *2 mm eye* | *0.1 mm eye* | |
| *Front* | 1.64 | 2.00 | 22 |
| *Left ear* | 0.823 | 1.05 | 28 |
| *Right ear* | 0.775 | 0.961 | 24 |

Figure 5 shows the SAR distribution in the 0.1 mm eye (the images of the eye are shown without surrounding tissues present for clarity). For frontal exposure, the position of the highest SAR tends to occur in the tissues very close to the lens. The lens itself has a relatively lower conductivity and hence SAR. When the head is exposed to the left side, the highest SAR tends to occur in the tissue-types on the left side of the eye, again close to the lens.

***Figure 5.** The SAR distributions in the 0.1 mm eye for frontal (AP) exposure from the TETRA handset. The images of the eye are shown without the surrounding tissues present for clarity.*



## *4. CONCLUSIONS*

A surface-based human model, MAXWEL, has been developed that allows voxelisation to any desired resolution. Therefore, numerical errors due to staircasing of the model are greatly reduced at high resolutions. Advantages of employing the MAXWEL surface-based model are demonstrated in this work by presenting the detailed eye model used in MAXWEL, based on the work of Yoriyaz et al (7). Small organs such as the eye are poorly represented by traditional human voxel models as the resolution typically used is 2 mm. The surface-based model allows voxelisation at, say, 0.1 mm. The result is a representation of the eye with no obvious loss of the detailed anatomical structure.

The SAR in the head was calculated from exposure to RF fields. The eye is particularly susceptible to radiofrequency fields as it lacks blood supply to its internal transparent regions (so central regions are prone to hotspots), and has limited capacity for repair. Comparison of the calculated peak localized SAR results, averaged over 10 g of contiguous tissue, with ICNIRP restrictions from exposure to the TETRA handset showed compliance with the Directive ELVs in all exposure configurations studied.

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# MODELLING HUMAN EXPOSURE TO 1 TO 30 MHZ PLANE-WAVE FIELDS

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*ABSTRACT*

*This paper presents the computed RF exposure metrics for an adult male standing on a ground plane and exposed to a vertical polarized plane-wave over the frequency range 1 to 30 MHz. In this scenario, the person acts as a monopole antenna with resonant absorption at ~λ/4 (free-space wavelength) and the maximum 10g-averaged specific absorption rate (10g-SAR) occurs in the ankle region. Two different voxel models were used for the simulation, "Duke" and "HUGO" and the results were also compared to published data for "Norman", which was used to derive the ICNIRP reference levels. The anatomic differences between the models, particularly in the ankle and foot region, and the total body mass resulted in significant differences in results for SAR averaged over the whole body (WB-SAR), 10g-SAR and limb currents. The results for HUGO were found to be inaccurate for this exposure scenario, largely due to the position of the feet with the toes pointing downwards. The paper also highlights the need to correctly interpret the numerical outputs for commercial EM modelling packages.*

***Key words:*** *Human voxel models, Specific Absorption Rate, SAR, Ankle current, EMF exposure, discretization, HUGO, Duke, Norman, dispersive materials.*

## 1. INTRODUCTION.

Computer simulations using human voxel models play a vital role in electromagnetic field dosimetry by allowing the power absorption, tissue heating and induced currents in the human body, quantities that cannot readily be measured in-vivo, to be determined from quantities that can be measured, namely the incident electric field, magnetic field, total limb current, or the input power to a transmit antenna. For whole-body exposures to incident plane wave fields with frequencies below 50 MHz, worst case whole body absorption is obtained when the person is standing on a conducting ground plane, and exposed to an incident plane wave field having polarization that is parallel to the long axis of the person. In this case, the person acts as a monopole antenna with resonant absorption at ~λ/4 (free-space wavelength), and the maximum 10g-averaged specific absorption rate (10g-SAR) occurs in the ankle region. This scenario is therefor used to determine the relationship between the basic restrictions for SAR (local and whole body averaged) with the limb current and incident plane wave field strength (E-field, H-field or power density), quantities which can be measured in-situ. This paper examines the variability of the exposure metrics obtained from computer simulations of this scenario over the frequency range 1 MHz to 30 MHz due to the human voxel model used. Two readily available voxel models of adult males are used for these simulations: HUGO, which was derived from the visible man project [1], and Duke from IT'IS foundation [2]. The results are also compared to the published values for "Norman" [3], which was the basis of the reference levels given by ICNIRP [4]. The physical characteristics of the voxel models are listed in Table 1. Note that the tissue masses and height of Norman correspond to a 50th percentile European male based on the anatomic data of [5].

***Table 1.*** *Comparison of physical characteristics of the voxel models.*

| *Quantity* | *Norman* | *HUGO* | *Duke* |
|---|---|---|---|
| ***Stature*** | 1.76 m | 1.80 m | 1.74 m |
| ***Mass in-vivo*** | 73 kg | 90.3 kg | 70 kg |
| ***Mass of voxel model*** | n/a | 115.3 kg | 71.8 kg |
| ***Number of tissues*** | 37 | 31 | 77 |
| ***Cross-sectional area of the leg above the ankle (minimum).*** | 35.0 cm2 | 40.7 cm2 | 40.3 cm2 |

## 2. CALCULATION METHOD

Computer Simulations Technology Microwave Studio (CST MWS) [6] Version 2013 was used for all numerical exposure simulations. We used the time domain solver for this work, with a solver accuracy setting of 40 dB. The model consists of an adult male standing on a perfectly conducting ground plane, and exposed to a 2 Vm-1 vertical polarized incident plane wave. The model has perfect matched layer (PML) open boundary conditions and the size of the problem space modelled was 4 m by 4 m by 3.3 m (height). The voxel models were imported with 3 mm resolution and meshed with 5 mm mesh resolution, which yields 80 mesh nodes in the 10g cube used for the local SAR calculation. With this mesh size, the results were found to be convergent to within 2% for WBSAR and 1% for 10g SAR and ankle current. Note that this mesh resolution would be insufficient to obtain current density averaged over a 1 cm2. For both of the human voxel models, it was necessary to partially embed the feet into the ground plane, as the toes on the HUGO model are pointing downwards, and the legs on Duke are very slightly different lengths. The values for the human tissue properties used in both models were from Gabriel [7]. For accuracy, the models were run at each frequency of interest with the exact tissue data. The maximum local SAR averaged over a 10g cube (10g-SAR) was calculated according to IEEE C95.3 standard [8], which uses a cube for the averaging volume, rather arbitrary shape of tissue (contiguous volume) as specified by ICNIRP [4]. The limb current in each leg was calculated from the magnetic field data by integrating the tangential magnetic fields around two curves in a horizontal plane that encircle the left and right ankles at the height corresponding to the 10g SAR maximum. It is important to note that for plane-wave sources, CST MWS references all outputs to an incident peak field level of 1 Vm-1 in free-space. The time-averaged (r.m.s) SAR values which are calculated must therefore be doubled to correspond to 1 Vm-1 r.m.s incident field strength. Further, the incident field level is doubled to 2 Vm-1 when the polarization is perpendicular to a ground plane (electric boundary condition).

## 3. RESULTS

The 10-g SAR distributions for 2 Vm-1 peak incident fields at 15 MHz are shown in Fig 1 for (a) Duke and (b) HUGO. The effect of the pointing down toes in the HUGO model is to shift the region of maximum SAR downwards in the ankle region and the value is reduced by a factor of 4 compared to the Duke model. Fig 2 shows the spatial peak current density in the cross-sections where the 10g-SAR is a maximum. It is apparent that there are significant differences in the anatomy of the models at this region, which yields different current distributions.

***Figure 1.*** *10g-averaged SAR distributions for (a) Duke, and (b) HUGO voxel models when grounded and exposure to a 15 MHz vertically polarized plane wave field of peak amplitude 2 Vm-1.*

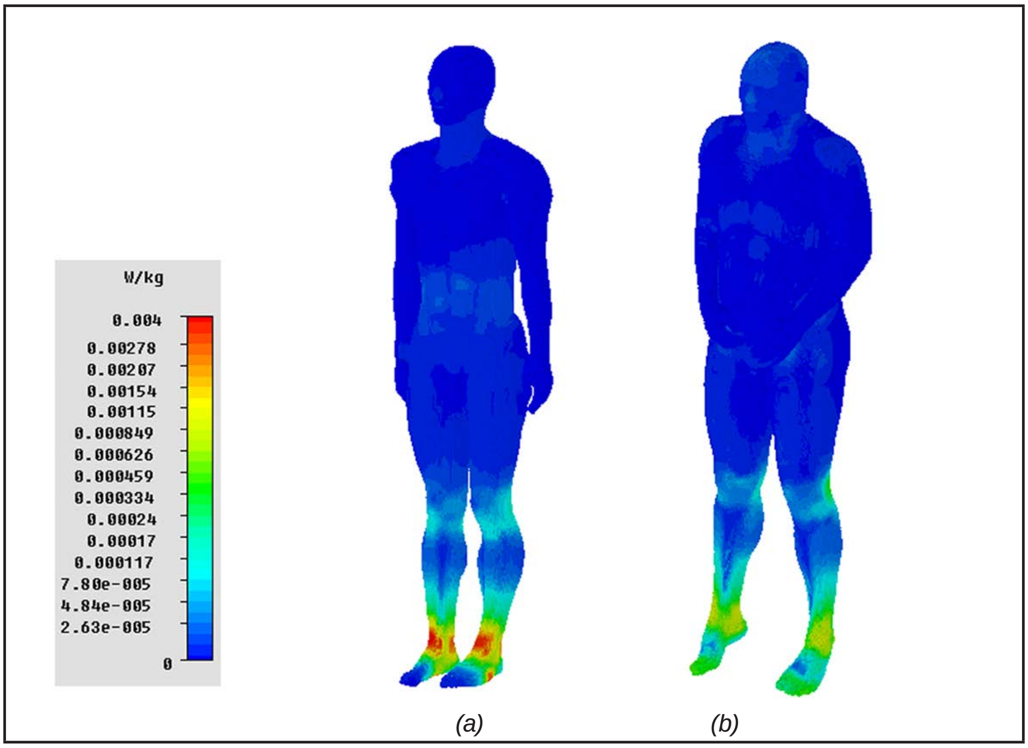

***Figure 2.*** *Plan view showing the spatial peak current density in the ankle for (a) Duke and (b) HUGO for 15 MHz incident field. The cross-sections are at the position of the 10g-SAR maximum.*

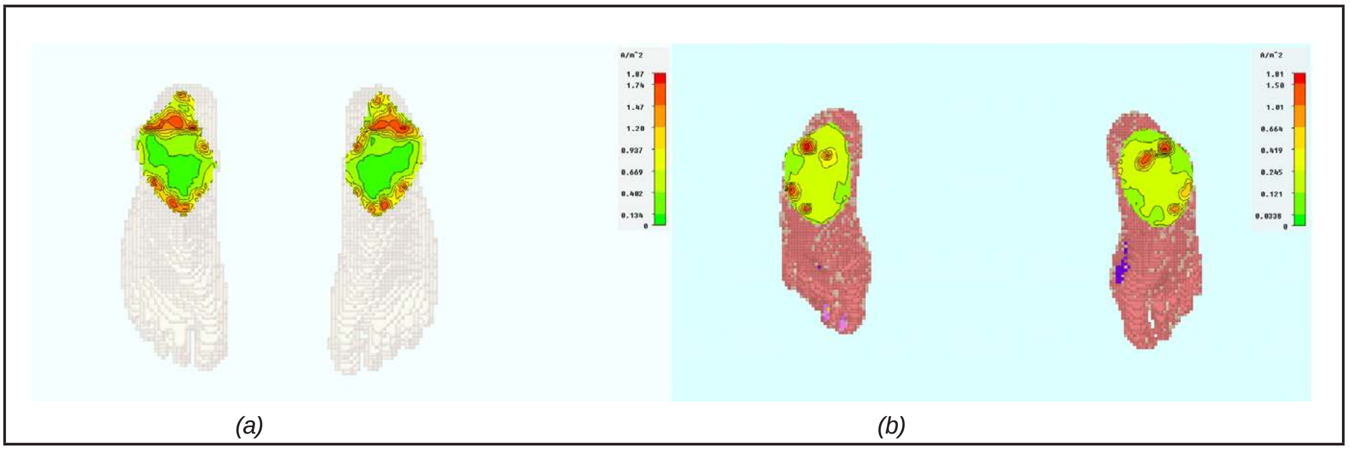

Table 2 gives the computed values of ankle current, 10g averaged SAR and whole body SAR (WBSAR) obtained using the Duke and HUGO models. The results have been normalized to incident field levels corresponding to the ICNIRP occupational reference levels [4] at each frequency, as shown in the table. For comparison, the published results for WBSAR from Norman [3] are also listed. All computed local and WBSAR values were below the basic restriction values. The limb current in Duke exceeds the 0.1 A reference level above 15 MHz, indicating that the limb current is conservative with respect to the basic restrictions at these frequencies. The WBSAR for Norman are approximately 20% higher than the results for Duke. This is because the ankles on Norman are narrower than those on Duke, being 35 cm2 and 40.3 cm2 respectively. Note that the 50th percentile male value is approximately 41cm2 (this has been calculated from data in [9] and makes the assumption that the cross-section of the ankle is circular). The modelled results for the HUGO voxel model have approximate half the limb current of the Duke model and the SAR values are corresponding lower by a factor of 4.

***Table 2.*** *Calculated ankle current and SAR values for HUGO and Duke models, normalised to incident field levels corresponding to the ICNIRP reference levels. The whole-body SAR results for Norman from [3] are also given.*

| *Frequency (MHz)* | *Incident r.m.s field strength (a) (Vm-1)* | *Ankle current r.m.s.(A) mA)* | | *10g10g-SAR (Wkg-1)-(Wkg-1)* | | *Whole body SAR (Wkg-1)* | | |
|---|---|---|---|---|---|---|---|---|
| | | *HUGO* | *Duke* | *HUGO* | *DUKE* | *HUGO (b)* | *Duke* | *Norman* |
| *1(c)* | 610 | 0.037 | 0.116 | 2.63 | 13.16 | 0.092 | 0.267 | 0.097 |
| *5* | 122 | 0.032 | 0.088 | 1.26 | 4.95 | 0.022 | 0.068 | 0.088 |
| *10* | 61 | 0.030 | 0.076 | 1.16 | 4.07 | 0.021 | 0.062 | 0.074 |
| *15* | 61 | 0.043 | 0.099 | 2.26 | 7.33 | 0.040 | 0.116 | 0.141 |
| *20* | 61 | 0.055 | 0.122 | 4.55 | 11.77 | 0.069 | 0.173 | 0.216 |
| *25* | 61 | 0.066 | 0.146 | 4.57 | 13.80 | 0.092 | 0.236 | 0.288 |
| *30* | 61 | 0.076 | 0.164 | 5.30 | 17.09 | 0.129 | 0.288 | 0.337 |
| **ICNIRP Occupational limit [4]** | | **0.1** | **0.1** | **20** | **20** | **0.4** | **0.4** | **0.4** |

*(a). These correspond to the reference levels for occupational exposure from [4],*

*(b) The in-vivo mass (90.3kg) was used for the WBSAR calculation for HUGO, rather than the voxel mass of 115 kg, (c) The results at 1 MHz show some instability if the permittivity values are changed.*

## 4. CONCLUSIONS

The anatomy of the foot and ankle region have a significant effect on the computation of limb current, local SAR and WBSAR for a person standing on a ground plane and exposed to a plane-wave field for frequencies between 1 MHz and 30 MHz. The position of the feet on the HUGO voxel model, in which the toes are pointed downwards, will under-estimate the limb current by a factor of two, and local SAR by a factor of four, when compared to models with feet that are flat on the ground. The WBSAR results from the MRI based voxel model Duke are around 20% lower than the published results for Norman, which provided the basis for the ICNIRP reference levels. This because the ankles on the Norman are quite slender, having a cross-sectional area of 35 cm2 compared with 40.3 cm2 for the Duke model. In this respect Duke is much closer to the 50th percentile adult male value. When using commercial software packages for performing these simulations, it is important to understand the format of the numerical outputs.

## ACKNOWLEDGMENT

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# *SPECIFIC ABSORPTION RATE ASSESSMENT OF VERY-HIGH FREQUENCY RF PORTABLE TRANSMITTERS*

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*ABSTRACT*

*The Specific Absorption Rate (SAR) assessments from portable radio transmitter in different types of phantoms are presented. Normally, such sources (portable radio stations) are used in front of the head or on the belt in transmit mode as compared with mobile phones which are operated at the ear. The portable radio station position, its operating frequency range and output power present new tasks to the assessment of the safety of electromagnetic field (EMF). In this investigation we used the Russian portable transmitter Radiy 301 operating at the very-high frequency (VHF) range. The VHF has the most stringent exposure limits in comparison with other frequencies according to the Russian hygienic standard. Both theoretical (numerical) and experimental dosimetric assessments are performed using a flat phantom and the Specific Anthropomorphic Mannequin (SAM). The research results show different absorption energy values in flat and SAM phantoms for different distances from the portable radio source . The data of the experimental dosimetry are in very good agreement with the numerical simulation results.*

***Key words:*** *specific absorption rate, portable radio transmitter, electromagnetic field dosimetry.*

## *1. INTRODUCTION*

Today there are many different electromagnetic field (EMF) sources. A large part of these sources is the mobile telecommunication equipment which uses radiofrequency electromagnetic energy. Although such EMF sources are located near or against the human body, during the last five to ten years the number of mobile communication devices has increased very fast, especially cellular telephones. This type of EMF source is placed at the ear (left or right) and works in the microwave frequency range (above 450 MHz). However, the cellular phone is not the only type of widely available portable transmitter. In occupational conditions, the personnel use portable radio transmitter for operational connections. This type of EMF source is placed at different locations compared to the cellular phone. The portable transmitters can be operated hand held in front of the face or in the vicinity of the users' body [1, 2]. In the transmit mode, the RF EMF exposure can be higher than basic restriction and reference levels for users [3].

According to Russian and International safety standards, guidelines and recommendations, the exposure limits to the very high frequency (VHF) RF energy are lower than for other bands [4-6]. Therefore, the human exposure to the VHF portable radio transmitters needs to be evaluated.

## *2. METHODS*

In our investigation we used typical portable radio transmitters. The device under test (DUT) was the portable radio transmitter «Radiy-301» manufactured by Izhevkiy Radiozavod (Russia). This model is the recommended portable transmitter for many different services such as Russian Railway, Police, Federal Security Service and others. In our research, the DUT worked in the VHF radiofrequency band (171 MHz) with maximum output power mode (5 W).

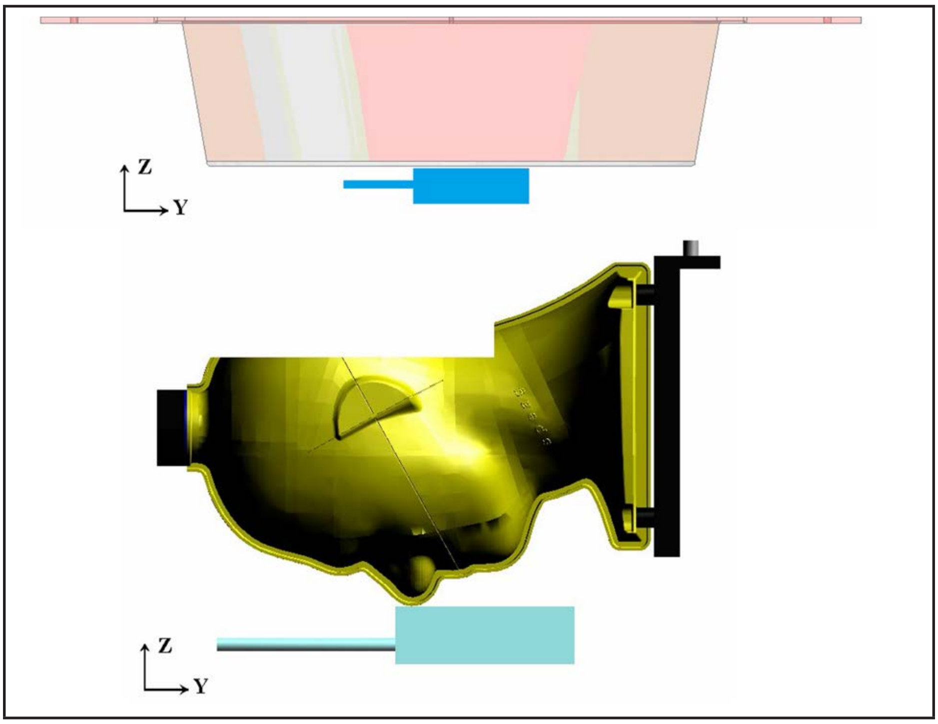
Our investigations included simulation and experimental dosimetry. Dosimetry was carried out by using a homogeneous flat phantom and the Specific Anthropomorphic Mannequin (SAM) head phantom (SPEAG AG, Switzerland). The exposure conditions were the same for both dosimetric approaches and phantoms.

Simulations were based on the Finite-Difference Time-Domain (FDTD) method with the simulation platform SEMCAD X v 14.8 (SPEAG AG, Switzerland). The simulation models consist of more than ninety eight million cells. For fast calculations the NVIDIA TESLA cards was used.

The Specific Absorption Rate (SAR) measurements were carried out using the automatic dosimetric system DASY

52 NEO (SPEAG AG, Switzerland). The DUT was located in a low loss energy holder at the distance of 8 mm from the tissue simulating liquid of phantom. The tissue simulating liquid had the dielectric properties of head tissue at 170 MHz (HSL175, SPEAG AG): εr=52.58; σ=0.80 S/m. The DUT's were located under the phantoms as shown in figure 1.

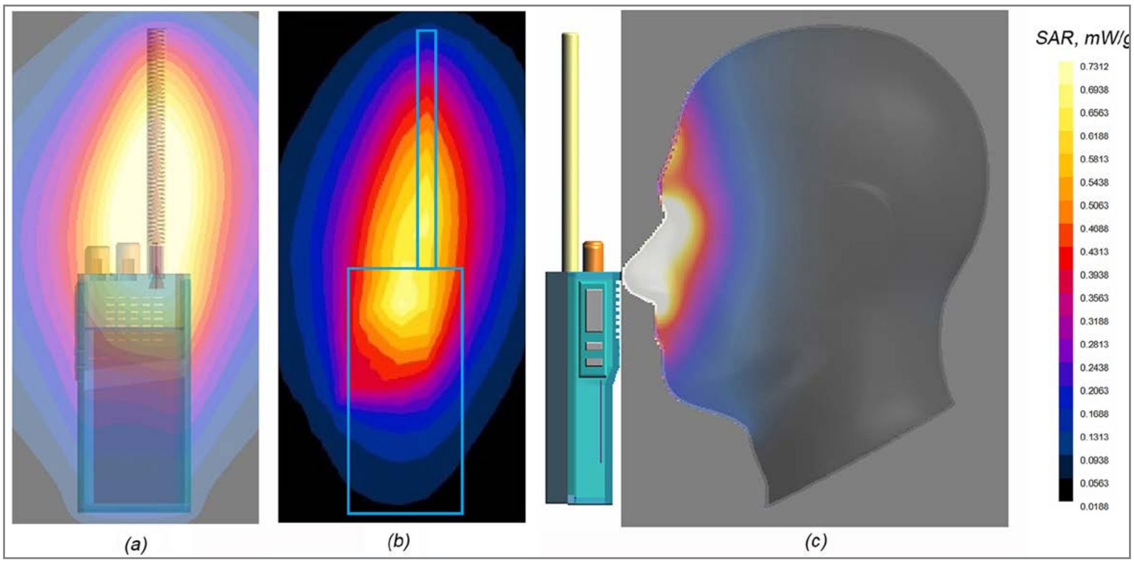
***Figure 1.*** *Phantoms set-up*




### *3. RESULTS*

The simulation and measurement results show the same SAR distributions for the flat and for the SAM phantoms which are depicted in figure 1. The measured and simulated data were collected on surfaces located at 4 mm depth in the phantoms on the side of the transmitter. The attenuation was the same for both phantoms. The calculated peak SAR in the flat phantom was 0.66 mW/g, and the measurements peak SAR was 0.66 mW/g in the same conditions. The calculated peak SAR in the SAM simulation phantom and measured SAR value were 1.69 mW/g and 1.74 mW/g respectively. Overall, the results show higher SAR values for the SAM than for the flat phantom at equal distance from the radio.

***Figure 2.*** *SAR distribution. (a) Simulation in flat phantom. (b) Experimental in flat phantom. (c) Simulation in SAM phantom*

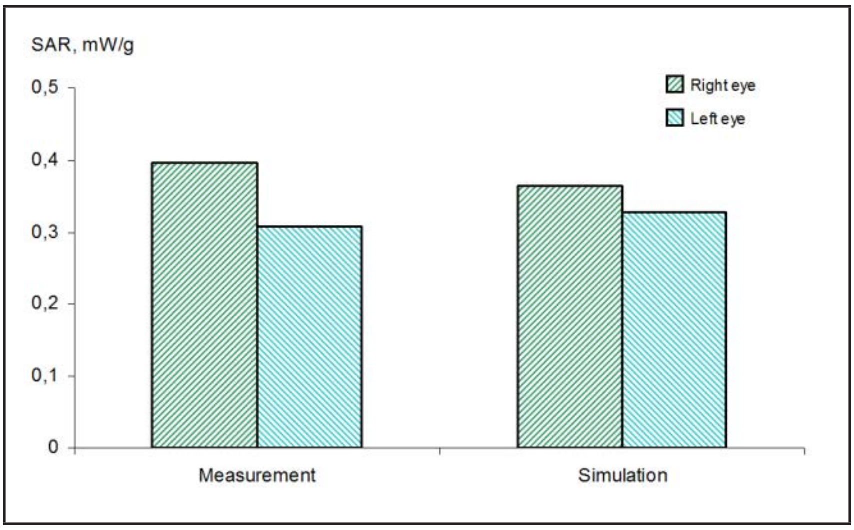


The simulation and measurement results show higher SAR values in the head phantom than in the flat one. The maximum absorption energy is located at the nasal root in the SAM phantom. The point of maximum SAR is in agreement with the simulation results. The deviation was less than 0.5 dB between simulation and experimental results, which shows that the simulation model gives accurate predictive results.

In our investigation we used homogenous phantoms and maximum absorption energy for SAM was located in nose, but the real human head has a heterogeneous structure and the nose has air cavities . Therefore this part is not as important as other critical parts of the head like brain, eyes and other organs.

One of the critical organs of the head is the eye. Therefore in the experimental dosimetry we evaluated the maximum SAR values for the left and right eye, because the antenna of portable transmitter is located in front of the right eye in usual operating condifions. As shown on figure 3, we have different exposure levels for the left and right eye. The simulation results have the same trends. The values of the peak spatial SAR are averaged over 10 g of tissue, a measure of maximum exposure, were the same for simulations and measurements.

***Figure 3.*** *Maximum SAR values for the left and right eye*




The results show higher SAR for such DUT than for mobile phones, home cordless phone and similar personal communication devices. This type of transmitter works in the vicinity of human body and has more stringent reference levels and basic restrictions than other mobile communication devices.

This type of transmitter can be used in two positions (at the head and at the belt) and can't be evaluated according to standards and guidelines established for cell phones.

The exposure of the human head is more intense than that of the trunk, as shown by our measurements. For detailed investigations with this DUT model it is necessary to use an accurate, heterogeneous model of the human head.

The SAR results show that the levels of human body exposure under normal DUT usage are not above the EU limits (Directive 2013/35/EU)[5]. But the measured electric field strength is higher than reference level at the control point for Russian safety standard (SanPiN 2.1.8/2.2.4.1190-03) [4].

Hence excessive use of these portable transmitters in occupational and general public conditions may be potentially harmful to human health. Therefore the operational transmit time of this type of equipment per work shift must be limited as required by the Russian occupational health compliance rules. For this reason, to enforce the Russian occupational hygienic/safety standards, safety controls circuits are necessary to limit the RF transmission time intervals over a person's working day.

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# RADIOFREQUENCY PORTABLE TRANSMITTERS EXPOSURE

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## ABSTRACT

*Several activities, in particular serviceman, require the use of a portable transmitter. These portable transmitters can emit several Watts in the VHF frequency band. These devices are worn near the body and there are questioning on the level of the exposure to the electromagnetic field which they get. This study consists of the numeric and experimental dosimetry of the whole body exposed to a radiofrequency portable transmitter at the frequency 90MHz.*

***Key words:*** *VHF portable transmitter, exposure evaluation, SAR measurements, numerical simulations.*

## 1. INTRODUCTION

Several activities, in particular serviceman, require the use of a portable transmitter. These portable transmitters can emit several Watts in the VHF frequency band. These devices are worn near the body and there are questioning on the level of the exposure to the electromagnetic field which they get. This study consists of the numeric and experimental dosimetry of the whole body exposed to a radiofrequency portable transmitter at the frequency 90MHz.

## 2. METHODS

The model of portable transmitter used in this study is constituted by a metallic parallelepipedic box equipped with an antenna on its top. Its sizes are: 300mm of width, 200mm of height and 100mm of depth. The antenna is a helical monopole. The antenna length is 480mm and its diameter is 22mm for the frequency 90MHz. This transmitter is very similar to the commercial models and it can emit in the 30MHz-90MHz frequency band. It contains a voltage controlled oscillator (VCO), an amplifier, a modulator, a photoreceiver and a battery which feeds all the electronic components. The photoreceiver is connected to an optical fiber bringing a low-frequency modulation. The choice of an optical fiber allows a low electromagnetic disturbance. The output of the photoreceiver is connected to the modulator so as to modulate the output signal of the VCO, which is injected in the input of the amplifier. The output of the amplifier is connected to the input of the antenna, and the radiated power is amplitude modulated at the low-frequency. The portable transmitter is worn in the back of the phantom.

The human phantom is a parallelepipedic box realized in PVC with walls of 2mm of thickness. Its sizes are 1750mm (height) x 400mm (width) x 100mm (depth). It is filled with 70 liters of equivalent liquid. The values of conductivity and permittivity are given by the IEC62209-2 standard: 0.76S/m and 52 respectively, at the frequency 90MHz. The portable transmitter is on contact with the phantom and centered in the width. Its top is located 35cm below the top of the phantom.

The SAR measurement is carried out in the whole body dosimetric assessment system of Supélec [1].The phantom is lying on a PVC and synthetic foam support. The radiofrequency portable transmitter takes place under the phantom (figure 1). The output signal of the dosimetric probe is processed by a specific low noise amplifier followed by a synchronous detection using the signal of low-frequency modulation of the radiated power of the transmitter. This processing increases strongly the SAR measurement sensitivity, i.e. the level of the weakest DAS which it is possible to measure. It is then possible to realize the dosimetry of the portable transmitter with a relatively low emitted power, of the order of 100 mW.

The measurement spatial sampling steps are 29.7 mm (height), 28.5 mm (width) and 10 mm (depth), leading to 8260 measurement spatial points.

This configuration was also simulated numerically by means of the Microwave Studio software from CST.

## 3. RESULTS

The different SAR values are given for a power incident on the antenna access of 1W. The numerical SAR values are about 20% less than the experimental one (table 1). The maximum value of SAR averaged on 10g tissue is about 200mW/kg and the whole body SAR value is about 6.5mW/kg. Figure 1 presents the local SAR distribution in the phantom at a distance of 22mm of the surface. The simulated and the measured distribution are very similar. The maximum local SAR value is located at the foot of the antenna.

***Figure 1.*** *The experimental setup: the transmitter is mounted on the whole body phantom, and both are placed in the dosimetric assessment setup of Supélec.*

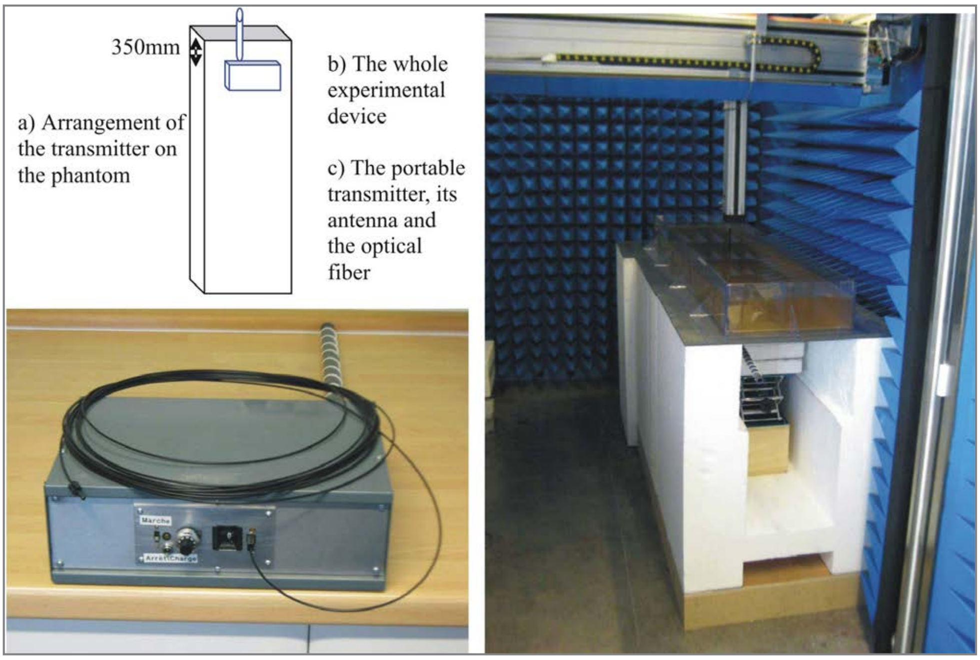


***Figure 2.*** *Distribution of local measured SAR (left) and local simulated SAR (right) at a distance of 22mm of the surface of the phantom. The location in the phantom is in meter and the SAR value is in mW/kg.*

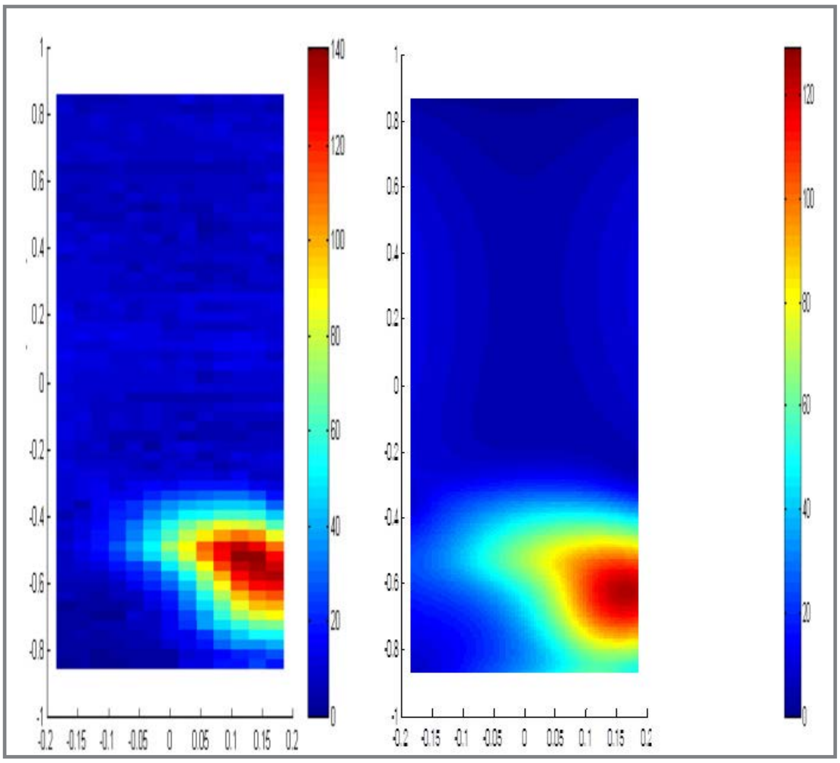

***Table 1.*** *Maximun local SAR, maximum SAR10g and whole body SAR induced by the radiofrequency portable transmitter in the human phantom at 90MHz for 1W incident power on the antenna access.*

| | Maximum local SAR (mW/kg) | Maximum SAR10g (mW/kg) | Whole body SAR (mW/kg) |
|---|---|---|---|
| **Measurements** | 320 | 220 | 7,4 |
| **Simulations** | 290 | 180 | 5,5 |

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# SAR MEASUREMENTS PROBE SENSITIVITY FUNCTION OF THE DIELECTRIC PROPERTIES OF THE TISSUE EQUIVALENT LIQUID

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*ABSTRACT*

*The dielectric properties of the biological tissue equivalent liquid are a cause of error on SAR measurements. Three different parameters are modified by the dielectric properties of the tissue equivalent liquid: 1) the adaptation of the radiating antenna, 2) the coupling between this antenna and the liquid and 3) the sensitivity of the probe in the liquid. This study is devoted to the third aspect for the GSM900 and GSM1800 frequency bands.*

***Key words:*** *SAR measurement, probe sensitivity, dielectric properties, tissue equivalent liquid.*

## 1. INTRODUCTION

The dielectric properties of the biological tissue equivalent liquid are a cause of error on SAR measurements. The effect of this cause of error on the measured SAR value is difficult to predict. Three different parameters depend on the exact value of the dielectric properties of the tissue equivalent liquid: 1) the adaptation of the radiating antenna, 2) the coupling between this antenna and the liquid and 3) the sensitivity of the probe in the liquid. The adaptation of the radiating antenna and the coupling between the radiating antenna and the liquid was already presented [1] [2]. This paper is devoted to the study of the effect of the dielectric properties of the tissue equivalent liquid on the sensitivity of the probe in the liquid which modifies the value of the detected voltage for a given measured electric field.

## 2. METHODS

It is almost impossible to measure the sensitivity of a dosimetric probe with a sufficient precision to be able to evaluate their variations with the electromagnetic properties of the equivalent liquid. Then the sensitivity of the probe is evaluated by means of numerical simulations. The used software is Microwave Studio from CST. The sensitivity is evaluated for two cases, 1)the equivalent liquid with reference values for permittivity and conductivity, and 2)the equivalent liquid with erroneous value for permittivity or conductivity. Then the difference between the erroneous value and reference value of the sensitivity divided by the reference sensitivity gives the normalized variation of the permittivity (NVP). The error coefficient (EC) is then the ratio of the NVP and the relative variation of the electromagnetic parameter which induces the sensitivity variation of the probe.

The variation of the sensitivity is weak, then it is necessary to determine its value with a good accuracy to obtain significant results. Two problems have to be solved. 1)The meshing is related to the wavelength in the equivalent liquid, then a variation of permittivity or conductivity can modify the meshing and the obtained sensitivity. To limit this modification, the variations of the meshing have to be minimized. 2)The EM software uses a finite volume for the calculation, and the electromagnetic wave which propagated in this volume is reflected on the border of the volume, which modifies the electric field at the level of the probe. It is necessary to maximize the direct electric field on the probe in comparison with the reflected fields. For that, the EM waves are radiated by a small dipole located at a small distance from the probe.

## 3. RESULTS

The study is realized at two different frequencies: 900 and 1750MHZ. The dosimetric probes considered here are direct detected probes. The sensitive part of these probes is constituted with three electric dipoles on a dielectric prism. The dipoles are loaded with a schottky diode which detects the radiofrequency electric current induced on the dipole. A transparent dielectric cover is placed around the prism to protect the dipoles. Two different kinds of probe are considered: a probe with a cylindrical cover (n°1) and a probe with a prismatic cover (n°2). Table 1 shows the characteristics of the two probes. The reference values of permittivity and conductivity at 900MHz are respectively 41.5 and 0.97S/m, and 40 and 1.40S/m at 1750MHz [3]. Table 2 presents the EC for electromagnetic properties of the equivalent liquid. The values of these coefficients are very weak: their maximum value is 0.14 for permittivity and 0.074 for conductivity.

## *4. CONCLUSION*

The electromagnetic properties of the equivalent liquid used for SAR measurements, modify the sensitivity of the probe what can induced errors. This study gives the EC on the dielectric permittivity and the conductivity of the equivalent liquid by means of numerical simulations. The values of the EC are very weak, equal or less than 0.14 for permittivity and 0.074 for conductivity. For example, the maximum error on the permittivity and the conductivity of the equivalent liquid is about 10% [3], leading to an error value on the probe sensitivity of 1.4% for permittivity and 0.74% for conductivity which is very weak in comparison with the other causes of error.

***Table 1.*** *Characteristics of the two probes.*

| Probes | n°1 (cylindrical cover) | n°2 (prismatic cover) |
|---|---|---|
| ***Dipoles length (mm)*** | 4 | 4 |
| ***Dipoles width (mm)*** | 0.2 | 0.2 |
| ***Prism side (mm)*** | 5 | 5 |
| ***Prism permittivity*** | 10.6 | 2.7 |
| ***Cover diameter/side (mm)*** | 6 | 6 |
| ***Cover thickness (mm)*** | 0.5 | 0.5 |
| ***Cover permittivity*** | 2.7 | 2.7 |
| ***Diode capacitance (pF)*** | 0.1 | 0.1 |

***Table 1.*** *EC for two different probes at 900 and 1750MHz.*

| Frequency (MHz) | 900 | 1750 |
|---|---|---|
| **Probe n°1 (cylindrical cover)** | | |
| **Permittivity** | **0.043** | **0.14** |
| **conductivity** | **0.012** | **0.0067** |
| **Probe n°2 (prismatic cover)** | | |
| **Permittivity** | **0.035** | **0.023** |
| **conductivity** | **0.015** | **0.074** |

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# REAL TIME DISPLAY OF THE POWER EMITTED BY A MOBILE PHONE BY MEANS OF AN INDIVIDUAL INDICATOR


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## ABSTRACT

*The exposure of the user of a mobile phone is proportional to the power radiated by the phone. The power radiated by a mobile phone depends on the propagation conditions and can be modified at the request of the base station by means of the power control on a large dynamic range which is of 30dB for GSM and of 70dB for UMTS. This study allowed to design and to realize a simple, cheap and light device which displays the level of the power radiated by a mobile phone.*



***Key words:*** *Mobile phone exposure, emitted power, power control.*


## 1. INTRODUCTION

86% of the world population owns a mobile phone in 2011. During its use the phone is placed near the user head. Then the mobile phone is one of the main sources of exposure of the population to the radiofrequency electromagnetic fields. The radiated power of a mobile phone may be modified in function of the propagation conditions at the request of the base station by means of the Power Control function (PWC). The dynamic range of PWC is 30dB for GSM and 70dB for 3G mobile phones. The problem is that the phone user doesn't know what is the value of the emitted power of its mobile phone at a given moment. This paper presents a small portable electronic device which indicates visually the value of the radiated power of a mobile phone for voice communications.

## 2. METHODS

The individual indicator of the power radiated by a mobile phone is constituted by a sensor of electromagnetic field, followed by a power detector, by a circuit of identification of the technology and by a system of display of the power (figure 1). It does not contain any microcontroller nor any digital signal processor. The electromagnetic sensor is an electric dipole loaded with resistances so as to limit the electromagnetic disturbances. The output signal of the sensor is injected at the input of the logarithmic power detector. This stage is followed by a circuit able to identify the GSM technology. The detected technology is indicated with a light-emitting diode (LED). The device memorizes the maximal value of the signal during approximately 100ms to stabilize the display. For GSM technology, the emission takes place in a single time slot (0.577ms) per TDMA frame (4.6ms). Then, in the case of GSM, the display takes into account a factor 1/8 between the value to display and the real display, i.e. a difference of 9dB between the two technologies for the power mean value over peak value ratio. The visualization is assured by a bargraph containing 10 LED assisted by its control circuit.

The device is fed by a battery the voltage of which is 1.5V. The sizes of the power indicator are 4cm x 10cm with a thickness of 1cm. It adapts itself as well to a telephone worn on the right side of the head as on the left side (figure 2).

## 3. RESULTS

The device was tested in GSM900 and GSM1800 with three different phones. The test consists in observing the number of the enlighted LED for the maximum and minimum level of radiated power of the mobile phone. The result is presented in the table 1. At the maximum power level the enlighted LED is the tenth for the 3 phones and the 2 frequency bands. Phones n°1 and 2 are equipped with an internal antenna and the antenna of phone n°3 is a monopole. At the minimum power level the enlighted LED is the sixth, excepted for the phone n°3 and GSM1800 for which the enlighted LED is the fifth. The result depends few on the used phone.

One UMTS phone has been tested. The maximum power level corresponds to the LED n°10 and the first LED is enlighted for a radiated power 55dB lower. The GSM detection works without error even for the weaker power levels.

*4. CONCLUSION*

This device measures the level of the power radiated by a mobile phone. It indicates the used technology. The power level is visualized with a bargraph and the detected technology is indicated with a LED. Its design is very simple and its cost is very low. It is usable with all the mobile phones by offering a low dispersion of its performances. When the propagation conditions are unfavourable, the mobile phone radiates at its maximum power and this indicator informs the user what can allow him to limit its exposure.

***Figure 1.*** *Bock diagram of the power indicator.*

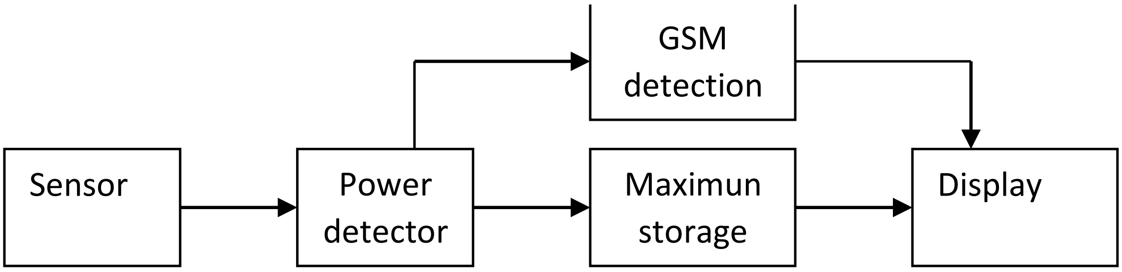


***Figure 2.*** *Photograph of the power indicator mounted on a mobile phone for the two sides of the user head.*

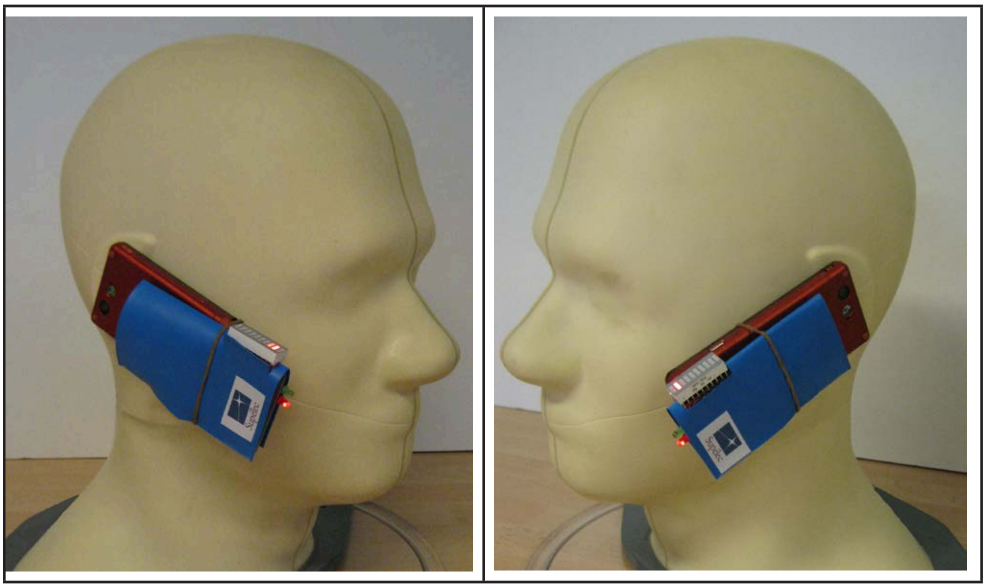

***Table 1.*** *n° of the enlighted LED of the bargraph for three different mobile phones.*

| *Phone n°* | *GSM900 Max.* | *GSM900 Min.* | *GSM1800 Max.* | *GSM 1800 Min.* |
|---|---|---|---|---|
| 1 | 10 | 6 | 10 | 6 |
| 2 | 10 | 6 | 10 | 6 |
| 3 | 10 | 6 | 10 | 5 |

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# GSM MOBILE PHONES EXPOSURE: TURNING ON AND EXTINCTION OF THE PHONE

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*ABSTRACT*

*The mobile phone is the main source of exposure of the population. The exposure level to GSM mobile phone is higher than that to WCDMA mobile phone. The use of a mobile telephone for voice communications can be decomposed into several steps among which in particular the turning on and the extinction of the phone. This study is the characterization of the user exposure to GSM mobile phones during these two steps.*

***Key words:*** *Mobile phone exposure, emitted power, power control.*

## 1. INTRODUCTION

The mobile phone is the main source of exposure of the population to the radio frequencies electromagnetic fields: 86 % of the world population was equipped in 2011, and the antenna of the mobile phone is near the user head. At present, mobile phones use two technologies: GSM and WCDMA. During a communication the base station adjusts the power radiated by the mobile phone in function of the propagation conditions by means of the power control. The dynamic range of the power control is 30dB for GSM and 70dB for WCDMA. Furthermore, for GSM technology, the power emitted by the telephone hands on to its maximal value after each handover. As a consequence, the average power radiated for GSM technology is more important than for WCDMA, as show it several studies [1]. Besides GSM networks are deployed and are doubtless to be used even for a long time in particular in Europe. The exposure to GSM phones is thus an important subject of study.

## 2. METHODS

The use of a mobile telephone for voice communications can be decomposed into several steps among which in particular the turning on and the extinction of the phone. For these two steps the telephone has to indicate its appearance and its disappearance to the network. It results from it an emission for a while with a level of given power. This paper is devoted to the study of the emission of GSM mobile phones during the turning on and the extinction steps for mobile phone with no application software. The measurement of the emission of the GSM mobile phone is performed by means of the SARmeter [2].

The SARmeter consists in a no disturbing sensor, an amplitude receiver and a laptop computer. The sensor is placed on the telephone near the antenna and takes a low part of the emission power. The output radio frequency signal of the sensor is sent to the input of the receiver which delivers at its output the envelope of the signal of the sensor. This output signal is sampled by the micro-computer and recorded. We obtain then the variations of the emitted power in the time, the maximum corresponding to an emission at the maximal power. The SARmeter contains several selective ways which allow it to identify in which frequency band takes place the emission. It contains 4 selective ways among which only 2 are used for a GSM mobile phone in France: the GSM900 band (880MHz-915MHz) and the GSM1800 band (1710-1785MHz). Two different GSM mobile phones corresponding to two different networks (phone 1/network 1 and phone 2/network 2) were used and the tests take place at two different locations (location A and B). Both places are of rural type. They are respectively at 25km and 45km from Paris and the distance between both locations is 20km. The measurement protocol is the following one. The measurement with the SARmeter begins. The PIN code is entered (the emission begins after this action). The turning on emission is visible on the screen of the SARmeter. 15 seconds after the end of this emission the phone is switched off. The turning on emission and the extinction emission are then separated. To characterize both emission steps we estimate the emission duration, the number of TDMA pulses, the average power, the standardized average power, i. e. the average power divided by the maximum power and the frequency band.

## 3. RESULTS

Four different measurement campaigns were realized. Each campaign consists in 12 elementary measurements on one mobile phone (table 1).

The results of the measurement campaigns are showed in the table 2. They are very similar for the campaign 1 and 2 (phone 1, network 1, location A) and they are more different for the campaign 3 and 4. The average number of TDMA pulses goes from 34 to 82 for the turning on step and from 27 to 33 for the extinction step. There is approximately 1 TDMA pulse for 9 frames. The average radiated energy varies from 20 to 84mJ for the turning on step and from 15 to 31mJ for the extinction step. The average radiated power goes from 13 to 24mW for the turning on step and from 12 to 28mW for the extinction step. In a general way the emitted power has a high level, from 51% to 90% of the maximum value. But the average value of this power is relatively low because there are few TDMA pulses on the duration of each step. Each campaign uses a single frequency band: GSM900 for the campaigns 1, 2 and 3 and DCS1800 for campaign 4.

## 4. CONCLUSION

This study allows to obtain the order of magnitude of the characteristics of the exposure to a GSM mobile phone for the turning on and extinction steps. Two different mobile phones, two different networks and two different locations were tested. The exposure is relatively low due to the low number of TDMA pulses required for each step: a mean value of 63 TDMA pulses for the turning on step and 30 for the extinction step. The mean value of the total radiated energy is 52mJ for the turning on step and 26mJ for the extinction step. It results from it a low emitted average power considering the low density of TDMA pulses during these two steps: 19mW for the turning on step and 22mW for the extinction step. These exposures are equivalent to voice calls of 0,3s for the turning on step and 0,14s for the extinction step, at the same power.

***Table 1.*** *The different measurement campaigns.*

| **Campaign** | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **Phone** | 1 | 1 | 2 | 2 |
| **Network** | 1 | 1 | 2 | 2 |
| **Location** | A | A | B | A |

***Table 2.*** *Results for the turning on and extinction steps.*

| **Campaign** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **Turning on step** | | | | |
| **Average duration (frames/s)** | 679/3.1 | 715/3.3 | 288/1.3 | 499/2.3 |
| **Minimal duration (frames/s)** | 650/3.0 | 653/3.0 | 259/1.2 | 243/1.1 |
| **Maximal duration (frames/s)** | 720/3.3 | 914/4.2 | 439/2.0 | 745/3.4 |
| **Average TDMA pulses number** | 80 | 82 | 34 | 58 |
| **Minimal TDMA pulses number** | 77 | 77 | 29 | 29 |
| **Maximal TDMA pulses number** | 85 | 85 | 49 | 89 |
| **Average emission power (stand./mW)** | 0.83/207 | 0.89/222 | 0.51/127 | 0.90/112 |
| **Minimal emission power (stand./mW)** | 0.69/172 | 0.72/180 | 0.15/38 | 0.47/59 |
| **Maximal emission power (stand./mW)** | 0.93/232 | 0.91/227 | 0.79/197 | 0.99/124 |
| **Frequency band** | GSM900 | GSM900 | GSM900 | DCS1800 |
| **Average radiated energy (mJ)** | 76 | 84 | 20 | 30 |
| **Average radiated power (mW)** | 24 | 25 | 15 | 13 |

| Extinction step | | | | |
|---|---|---|---|---|
| Average duration (frames/s) | 240/1.1 | 240/1.1 | 288/1.3 | 279/1.3 |
| Minimal duration (frames/s) | 201/0.9 | 202/0.9 | 257/1.2 | 247/1.1 |
| Maximal duration (frames/s) | 281/1.3 | 291/1.3 | 347/1.6 | 320/1.5 |
| Average TDMA pulses number | 29 | 27 | 33 | 32 |
| Minimal TDMA pulses number | 25 | 25 | 29 | 29 |
| Maximal TDMA pulses number | 33 | 33 | 41 | 33 |
| Average emission power (stand./mW) | 0.85/212 | 0.87/217 | 0.54/135 | 0.65/81 |
| Minimal emission power (stand./mW) | 0.69/172 | 0.68/170 | 0.44/110 | 0.34/42 |
| Maximal emission power (stand./mW) | 0.93/232 | 0.95/237 | 0.73/182 | 0.84/105 |
| Frequency band | GSM900 | GSM900 | GSM900 | DCS1800 |
| Average radiated energy (mJ) | 31 | 29 | 28 | 15 |
| Average radiated power (mW) | 28 | 26 | 21 | 12 |

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# COMPARISON OF METHODS TO DEFINE POWER LINE AND SUBSTATION'S BUSBAR WIRE CAPACITANCES IN ELECTRIC FIELD CALCULATION TASK

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## ABSTRACT

*The aim of this work is to compare the results of capacitances and electric field calculation obtained by different direct formulae, with results obtained by solving a system of potential equations with charges. The results of calculations using these methods on example three-phase wire systems with a horizontal arrangement of phase wires under a 330-kV voltage are presented. It is shown that capacitance calculation error using direct formulae does not exceed 1% in comparison with capacitances obtained by solving a system of potential equations. Accuracy of applying direct formulae to two three-phase wire systems depends on the distance between these systems. Calculation of EF, produced by three-phase systems, using equations with capacitances gives significant differences in comparison with equations with charges, especially under the middle phase wire and in the location between two systems. It is concluded that to conduct more accurate calculations using analytical methods, conductances that define components of displacement currents should be taken into account.*

***Key words:*** *Electric field, capacitance, assessment.*

## 1. INTRODUCTION

It is known that high voltage power objects (power substation) produce low frequency electric and magnetic fields (EMF). Calculation of these fields is a complicated task due to the complexity of the power device geometry and the conductor's arrangements. Therefore, EMF calculations could be performed using three-dimensional numerical modeling or simple analytical methods (at the design stage).

In [1], it an analytical method is developed to assess electric field (EF) levels produced by power substations. This method is based on the provisions of the electromagnetic field theory, applying the image theorem, as well as the calculation of the capacitances of busbar wires using a direct formula.

The aim of the work is to compare the results of capacitance calculations and EF generated by three-phase wire systems under high voltage using different direct formulae [2]–[3], with the results obtained by solving a system of potential equations with charges.

## 2. THEORETICAL MODEL

The resulting value of the EF intensity E at the desired point can be found by summing (1) the x, y, vector components of the intensities Ex and Ey

$$E = \sqrt{\mathrm{Re}\left(\sum \dot{E}x_i\right)^2 + \mathrm{Im}\left(\sum \dot{E}x_i\right)^2 + \mathrm{Re}\left(\sum \dot{E}y_i\right)^2 + \mathrm{Im}\left(\sum \dot{E}y_i\right)^2}\,, \qquad (1)$$

where

$$\dot{E}x_i = \frac{\dot{q}_i}{2\pi\varepsilon}\left(\frac{x \pm d_i}{(x \pm d_i)^2 + (H_i - h)^2} - \frac{x \pm d_i}{(x \pm d_i)^2 + (H_i + h)^2}\right), \qquad (2)$$

$$\dot{E}y_i = \frac{\dot{q}_i}{2\pi\varepsilon}\left(\frac{H_i - h}{(x \pm d_i)^2 + (H_i - h)^2} + \frac{H_i + h}{(x \pm d_i)^2 + (H_i + h)^2}\right), \qquad (3)$$

qi are the charges on the conductors, C/m; x is the distance from the y-axis to the observation point, m; xdi is the distance between the y-axis and the axis of the i-th conductor, m; Hi is the average suspension height of the i-th conductor, m; h is the height of the observation point (plane) above the ground surface, m; ε is the permittivity of air (8.854•10-12 F/m).

The charges qi on the conductors are determined through the voltages Uj and the Maxwell potential coefficients with the system of potential equations

$$\dot{U}_j = \sum_{i=1}^{k} p_j \dot{q}_i \text{ , j = 1, 2..k,} \tag{4}$$

where pii are the self (i = j) and mutual (i ≠ j) potential coefficients

$$p_{ii} = \frac{1}{2\pi\varepsilon} \ln\left(\frac{2H_i}{r_i}\right), \quad p_{ij} = \frac{1}{2\pi\varepsilon} \ln\left(\frac{D'_j}{D_j}\right) \quad ;$$

ri is radius of the i-th conductor, m; Dij is the distance between the i-th and j-th conductor, m; D'ij is the distance between the i-th conductor and the j-th image conductor, m.

Therefore, once system (4) is solved and the charges on each conductor and phase (qA, qB and qC) are known, the EF at a given point using the equation (1), the working (or full) capacitances (i.e., a capacitance to the ground of a phase wire under the presence of other wires) of each phase (CA, CB and CC) using equation (5) [2], and the working capacitance of the three-phase system CS using equation (6) may be calculated as the real part of ratio charges to the capacitances (5).

$$C_A = \mathrm{Re}\left(\frac{\dot{q}_A}{\dot{U}_A}\right), \quad C_B = \mathrm{Re}\left(\frac{\dot{q}_B}{\dot{U}_B}\right), \quad C_C = C_A = \mathrm{Re}\left(\frac{\dot{q}_C}{\dot{U}_C}\right), \tag{5}$$

. (6)

Finally, it possible to replace charges in equation (2) and (3) by multiplication of capacitances and phase voltages, as it was proposed in [1], and use these equations to calculate the resulting value of the EF intensity as follows:

$$C_S = \frac{C_A + C_B + C_C}{3} = \frac{2C_A + C_B}{3}, \tag{7}$$

$$\dot{E}y_i = \frac{C_i \cdot \dot{U}_i}{2\pi\varepsilon}\left(\frac{H_i - h}{(x \pm xd_i)^2 + (H_i - h)^2} + \frac{H_i + h}{(x \pm xd_i)^2 + (H_i + h)^2}\right). \tag{8}$$

It is known that the working capacitance of the middle phase of the three-phase wire system is significantly higher (5-7 %) than the capacitances of the outer phases (under the same geometry of all phases and equal suspension heights). Therefore, different equations are utilized for phase capacitance calculations in [2]. The capacitance of the middle phase (phase B) can be calculated using (9). Equation (10) can be used for calculation of the capacitances of phases A and C. Equations (9)–(10) are derived from the solution of the system of potential equations and determination of the capacitance in general form as the charge to phase voltage ratio.

$$C_B = \frac{2\pi\varepsilon \ln\left[\frac{2H}{r} \cdot \sqrt{1+\left(\frac{2H}{d}\right)^2} \cdot \sqrt{1+\left(\frac{H}{d}\right)^2}\right]}{\ln\left(\frac{2H}{r}\right) \cdot \ln\left[\frac{2H}{r} \cdot \sqrt{1+\left(\frac{H}{d}\right)^2}\right] - 2 \cdot \left[\ln \sqrt{1+\left(\frac{2H}{d}\right)^2}\right]} \tag{9}$$

$$C_A = C_C = \frac{\pi\varepsilon \ln\left[\frac{2H}{r}\cdot\frac{1}{\sqrt{1+\left(\frac{2H}{d}\right)^2}}\cdot\sqrt{1+\left(\frac{H}{d}\right)^2}\right]}{\ln\left[\frac{2H}{r}\cdot\frac{1}{\sqrt{1+\left(\frac{2H}{d}\right)^2}}\right]}\cdot\frac{\ln\left\{\left(\frac{2H}{r}\right)^2\cdot\left[1+\left(\frac{2H}{d}\right)^2\right]^{\frac{3}{2}}\cdot\sqrt{1+\left(\frac{H}{d}\right)^2}\right\}}{\ln\left(\frac{2H}{r}\right)\ln\left[\frac{2H}{r}\cdot\sqrt{1+\left(\frac{H}{d}\right)^2}\right]-2\cdot\left[\ln\sqrt{1+\left(\frac{2H}{d}\right)^2}\right]^2}, \quad (10)$$

where d is the distance between the phases, m; r is the radius of the phase wire, m.

In [2], an approximate equation (11) for the capacitance calculation of wires horizontally arranged in a three-phase system is also presented. The capacitances of each phase (CA, CB, and CC) can be calculated using equation (4) if we assume that CB = (1.05÷1.07)·CA.

$$C_S = \frac{2\pi\varepsilon}{\ln\left[\frac{d\cdot\sqrt[3]{2}}{r}\cdot\frac{1}{\sqrt[3]{\left(1+\left(\frac{d}{2H}\right)^2\right)\cdot\sqrt{1+\left(\frac{d}{H}\right)^2}}}\right]}. \quad (11)$$

In [3], it is suggested to calculate the capacitance of a wire using three equations (12)–(14).

$$C_S = \frac{2\pi\varepsilon}{\ln\left[\frac{2H\cdot d}{r\cdot\sqrt[3]{\left(4H^2+d^2\right)\cdot\sqrt{H^2+d^2}}}\right]}, \quad (12)$$

$$C_S = \frac{2\pi\varepsilon}{\ln\left[\frac{d\cdot\sqrt[3]{2}}{r}\right]}, \quad \text{and} \quad (13)$$

$$C_S = \frac{2\pi\varepsilon}{\ln\left[\frac{D_e}{r}\right]}, \quad (14)$$

where $D_e = \sqrt[3]{d_{AB}\cdot d_{BC}\cdot d_{CA}}$ is the geometric mean distance between the phase wires. The capacitances of each phase is also calculated using equation (4) and assuming that CB = (1.05÷1.07)·CA.

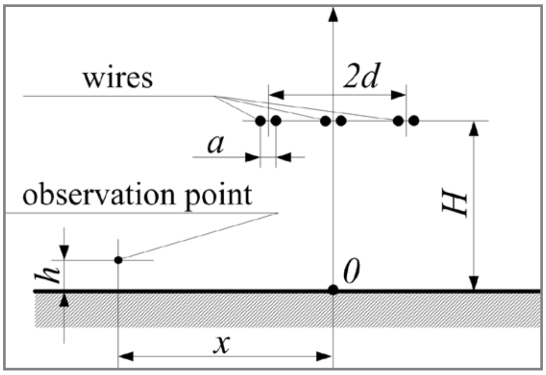
It should be noted that in the case of a bundle phase (r0 is the radius of a single conductor, m; n is the number of sub-conductors in the bundle; and a is the step of phase splitting, m), the phase wires may be substituted in equations (9)–(14), as well as in system (4) when calculating potential coefficients, by an equivalent single conductor with radius.

$$r_{eq} = \sqrt[n]{n\cdot r_0\cdot\left(\frac{a}{2\sin\left(\frac{\pi}{n}\right)}\right)^{n-1}}. \quad (15)$$

## 3. MATERIALS AND METHODS

To compare the capacitance calculation results from solving the system of potential equations (4) and direct formulas (9)–(14), as well as the EF calculation results using charges and capacitances, a three-phase system of wires under 330 kV was chosen. The geometrical parameters of this system are shown in Figure 1. The distance from the lowest phase wire to the ground (H) equalled 10 m. The distance between phases was d=8.5 m. The type of wire was 2xAS 400/51 with spacing a = 40 cm, radius of a single wire, r0 = 0.01375 m, and number of sub-conductors, n = 2. The calculated equivalent radius of the bundle wire was req = 0.074 m. The height of the observation point above the ground surface was 1.8 m.

***Figure 1.*** *Scheme of three-phase wire system (H is the suspension height; h is the height, and x is the distance from the point of observation; d is the distance between the busbar wires; a is the phase spacing)*




## 4. RESULTS AND DISCUSSION

Table 1 presents the results of the capacitance calculation of the three-phase wire system, shown in Figure 1, using the system of potential equations (4) and direct formulas (9)–(14).

***Table 1.*** *Calculated capacitances for horizontal arrangement of phase wires*

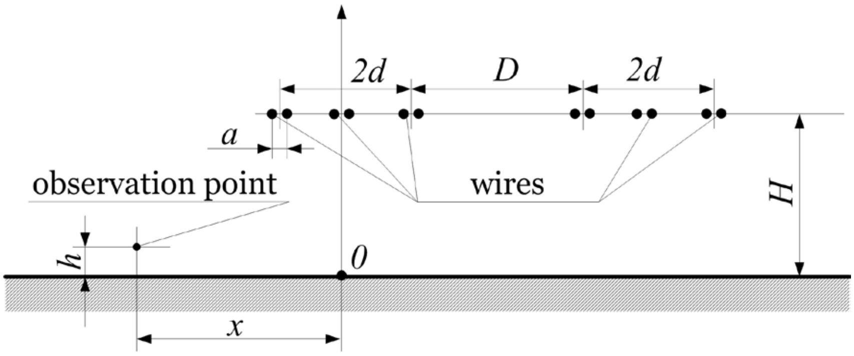
| ***Method for EF intensity calculation*** | **E, kV/m (in % to basic value) at distance x from projection of middle phase wire (B), m** | | | | |
|---|---|---|---|---|---|
| | **0** | **10** | **20** | **40** | **60** |
| Equation (1), (2) and (3) | 3.73 (basic value) | 5.22 (basic value) | 2.18 (basic value) | 0.34 (basic value) | 0.10 (basic value) |
| Equations (1), (7), and (8); capacitances calculated using (5) and (6) | 4.37 (17.15) | 5.34 (2.25) | 2.20 (0.85) | 0.34 (0.72) | 0.10 (0.59) |
| Equations (1), (7), and (8); capacitances calculated using (9), (10), and (6) | 4.36 (16.97) | 5.33 (2.07) | 2.20 (0.67) | 0.34 (0.54) | 0.10 (0.42) |
| Equations (1), (7), and (8); capacitances calculated using (11) and (6) | 4.34 (16.43) | 5.30 (1.53) | 2.19 (0.13) | 0.34 (0.003) | 0.10 (0.11) |

Table 3 presents the capacitance calculation results of two three-phase wire systems (phase sequence is the same in both systems, i.e., “A–B–C” and “A–B–C”), shown in Figure 2, using the system of potential equations (4) under different distances (D) between the systems. Basic values of capacitances are also received from the system of potential equations (4), but it the influence of one of the three-phase wire systems (see the first row in Table 1) has been neglected.

**Table 3.** *Calculated capacitances of one three-phase wire system located at distances D from the other system*

| Distance between the circuits, D, m | Capacitance of phase A CA, pF/m | Difference of capacitance calculation of phase A, % | Capacitance of phase B CB, pF/m | Difference of capacitance calculation of phase B, % | Capacitance of phase C CC, pF/m | Difference of capacitance calculation of phase C, % | Capacitance of three-phase system CS, pF/m | Difference of capacitance calculation of three-phase system, % |
|---|---|---|---|---|---|---|---|---|
| *D = 5 m* | 11.17 | 1.50 | 12.22 | 0.74 | 13.17 | 16.13 | 12.18 | 4.99 |
| *D = 10 m* | 11.22 | 1.06 | 12.19 | 0.49 | 12.15 | 7.14 | 11.85 | 2.15 |
| *D = 20 m* | 11.27 | 0.62 | 12.16 | 0.25 | 11.60 | 2.29 | 11.68 | 0.68 |
| *D = 30 m* | 11.30 | 0.35 | 12.15 | 0.16 | 11.45 | 0.97 | 11.63 | 0.25 |
| *D = 50 m* | 11.32 | 0.18 | 12.13 | 0.06 | 11.37 | 0.26 | 11.61 | 0.08 |
| *D = 100 m* | 11.33 | 0.09 | 12.13 | 0.02 | 11.34 | 0.03 | 11.60 | 0.01 |

**Figure 2.** *Scheme of two three-phase wires system (H is the suspension height; h is the height, and x is the distance from the point of observation; d is the distance between the busbar wires; a is the phase spacing; D is distance between two three-phase systems)*




It can be noted from Table 3 that when we increase the distance between the three-phase wire systems of wires, the difference in capacitance calculation is reduced in comparison with capacitance of one single system, which is due to the decrease in total mutual influence. At distances greater than 30 m, the difference in calculation does not exceed 1%, with the most significant difference being 16%, which occurs in phase C of the first system (and phase A of the second system) when the distance between the systems is the lowest (5 m). Phase C is the nearest wire of the first system to the second system (phase A is the nearest wire of the second system to the first system); therefore, these phase wires are exposed to the most influence. Capacitances of the middle phase almost do not differ from the single system calculation (only 0.74% under D = 5 m).

Tables 4–5 and Figure 3 present the results of the EF intensity calculations using equations with charges and capacitances under different distances (D) between the two three-phase wire systems. The first row values in these tables are received using the system of potential equations (4) applied to two systems. The second row lists the results received through capacitances that are the same on both three-phase systems (the second row in Table 1). The last row in Tables 4–6 presents EF values calculated using capacitances from Table 3.

**Table 4.** *Calculated EF values at distance x from projection of middle phase wire of two three-phase wire systems located at distances D = 10 m*

| Method for EF intensity calculation | E, kV/m (in % to the basic value) at distance x from projection of middle phase wire ("B"), m | | | | |
|---|---|---|---|---|---|
| | -20 | -10 | 0 | 10 | 20 |
| *Equations (1), (2), and (3)* | 2.28 (basic value) | 5.37 (basic value) | 3.61 (basic value) | 3.46 (basic value) | 3.40 (basic value) |
| *Equations (1), (7), and (8); capacitances calculated using (5) and (6) for both circuits* | 2.41 (5.70) | 5.76 (7.26) | 4.28 (18.56) | 2.81 (18.79) | 2.94 (13.6) |
| *Equations (1), (7), and (8); capacitances from Table 3* | 2.37 (3.95) | 5.64 (5.03) | 4.11 (13.85) | 3.21 (7.22) | 3.24 (4.71) |

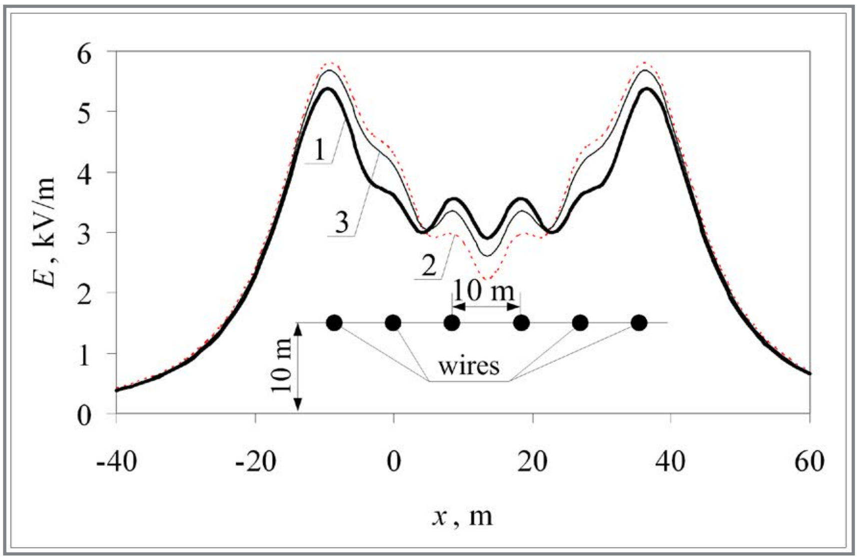
Tables 4–5 and Figure 3 show that, similar to the variation of capacitances (Table 3), EF values decrease when the distance between the systems of wires is increased; the most difference between the results is found under middle phases, due to neglecting components of displacement currents, and in the area located between the two systems, due to significant mutual influence and charge redistribution. Error in EF calculation in these places could reach 19% (D = 10 m).

EF calculation results using capacitances received on the assumption that the first system does not affect the second system, i.e., the capacitances are equaled (row 2 and curve 2 in Figure 3), are less precise in comparison with equations taking into account this influence (row 3 and curve 3 in Figure 3), which is quite apparent at the distances of 10 and 30 m.

***Table 5.*** *Calculated EF values at distance x from projection of middle phase wire of two three-phase wire systems located at distance D = 30 m*

| ***Method for EF intensity calculation*** | **E, kV/m (in % to basic value) at distance x from projection of middle phase wire (B), m** | | | | |
|---|---|---|---|---|---|
| | **-20** | **-10** | **0** | **10** | **20** |
| ***Equations (1), (2), and (3)*** | 2.22 (basic value) | 5.27 (basic value) | 3.70 (basic value) | 4.98 (basic value) | 1.61 (basic value) |
| ***Equations (1), (7), and (8); capacitances calculated using (5) and (6) for both circuits*** | 2.27 (2.25) | 5.46 (3.60) | 4.36 (17.84) | 4.93 (1.00) | 1.39 (13.66) |
| ***Equations (1), (7), and (8); capacitances from Table 3*** | 2.25 (1.35) | 5.42 (2.85) | 4.35 (17.57) | 5.00 (0.40) | 1.42 (11.80) |

***Figure 3.*** *Calculated EF distribution generated by two three-phase wire systems located at distances D = 10 m*




*1 – Equations (1), (2), and (3);*
*2 – Equations (1), (7), and (8); capacitances calculated using (5) and (6) for both circuits;*
*3 – Equations (1), (7), and (8); capacitances from Table 3*

## *5. CONCLUSION*

Based on the capacitance calculation results, it can be concluded that in using direct formulae for capacitances of single phase wires as well as an entire three-phase system with horizontal arrangement, it is possible to receive calculation errors that do not exceed 1% in comparison with capacitances obtained by solving a system of potential equations. Accuracy of applying direct formulae to two three-phase wire systems increases when the distance between these systems is also increased. The greatest discrepancy between the calculation results is found under the distance of 5 m and is equal to 16%.

Based on the EF distribution results, it can be concluded that calculation of EF, produced by three-phase systems using equations with capacitances, gives significant differences in comparison with equations with charges, especially under the middle phase wire (17 %) and in the location between the two systems. This stems from neglecting the imaginary parts of outer phase charges in calculation.

Therefore, these results allow us to recommend these approximated equations with capacitances to use for assessment purposes. To conduct more accurate calculations using analytical methods, conductances that define components of displacement currents should be taken into account.

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# POSSIBILITY TO DECREASING THE 50 HZ ELECTRIC FIELD EXPOSURE WITH DIFFERENT JACKETS

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## ABSTRACT

*The aim of this study was to investigate the possibility of decreasing 50-Hz electric field exposure with different jackets. First, under a 400 kV power line, we made a wooden frame, where we could hang up the jackets. The electric field was 3.2 kV/m (height 1.4 m), near the frame. We tested a summer jacket, a winter jacket, and a vest. We put the sensor of a three-axis commercial EFA-300 meter inside the jackets and measured the field. Using the summer jacket, the electric field was 3.2 kV/m; using the winter jacket, the field was 1.3-1.4 kV/m; and using the vest, the field was 3.4 kV/m. When we had contact from the winter jacket to the ground, the electric field was 2.5 kV/m. In our experiments, the winter jacket barely decreased the electric field exposure inside the jacket, but we tested only some jackets; the situation would be different if we assessed human beings' exposure to electric fields. However, it can be possible to develop new solutions to decrease electric field exposure employing different clothes or textiles.*

**Key words:** *Electric field, jacket, exposure*

## 1. INTRODUCTION

Directive 2013/35/EU on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) was published last year [1]. It includes minimum requirements for the protection of workers from risks to their health and safety arising from exposure to electromagnetic fields at their work sites. The action levels (ALs, workers) of the directive regarding electric fields (50 Hz) are as follows: low ALs 10 kV/m (rms) and high ALs 20 kV/m (rms). [1]

The occupational electric field exposures at 110 substations have been studied earlier in Finland. The maximum occupational exposure was 15.5 kV/m at task 'maintenance of operating device of circuit breaker from service platform,' and the average values of all electric field measurements were 3.6 kV/m [2]. In addition, the disturbances in cardiac pacemakers (PM) or in implantable cardioverter defibrillators in electric and magnetic fields of 400 kV power lines had been studied. The risk of the disturbances is not deemed to be high because only one type out of several tested PMs showed a major disturbance (only in a unipolar electrode configuration) and only in one ICD was there anomalous behavior during the tests. [3, 4]

At Tampere University of Technology (TUT) in a previous study on electric fields near 400 kV transmission lines, it was noticed that the differences in calculations and measurements were caused by vegetation dampening the field. In the earlier study, the measurements of electric fields near spruce trees of different sizes showed that spruce trees dampen electric fields and therefore spruce forests might be a possibility to reduce electric fields from transmission lines [5].

Moreover, in Japan, special clothing that decreases electric field exposure has been developed [6]. However, it is also important to know how much normal work clothes can decrease electric field exposure, and in the future, we will analyze and compare the exposure situations to Directive 2013/35/EU.

The aim of this research was to investigate the possibility of decreasing 50-Hz electric field exposure with different jackets. Furthermore, the aim was to test some normal working jackets under 400 kV power lines.

*2. METHODS*

To test the possibility of decreasing the electric field exposure with different jackets, a wooden frame was built under a 400 kV power line. Then, we used a clothes hanger to suspend the jackets from the frame. To measure electric fields, we used the three-axis commercial EFA-300 meter (Narda Safety Test Solutions GmbH, Eningen U.A., France) (accuracy: 3%, RMS), where the frequency range was 5 Hz–30 kHz. First, we measured the electric filed without a jacket. Figure 1 shows the measurement and testing place (A). In Figure 1, we evaluated electric fields near the frame with the hanger. We also measured electric fields without the hanger and in two places around the frame (place B: 5 m to right from the frame; place C: 5 m behind the frame).

In the tests with jackets, we put the sensor of the EFA-300 meter inside the jackets and measured the electric field. The measurement height was 1.4 m.

***Figure 1.*** *Frame with hanger and electric field meter in measurement location*

Figures 2-4 show the measurements with different jackets (in Figure 2, a summer jacket; in Figure 3, a winter jacket; and in Figure 4, a vest).

***Figure 2.*** *Summer jacket electric field measurement*

***Figure 3.*** *Winter jacket in electric field measurement.*

*Figure 4. Vest in electric field measurement.*

### 3. RESULTS AND DISCUSSION

Table 1 presents the electric field results of the measurements without jackets and with different jackets (summer jacket, winter jacket, vest). The electric field was 3.2 kV/m (height 1.4 m), near the frame. Using the summer jacket, the electric field was 3.2 kV/m; using the winter jacket, the field was 1.3–1.4 kV/m; and using the vest, the field was 3.4 kV/m. When the winter jacket was in contact with the ground, the electric field was 2.5 kV/m.

***Table 1.*** *Electric field results of the measurements with and without different jackets (height 1.4 m)*

| *Measurement location* | *Description of the test* | *Electric field, kV/m* |
|---|---|---|
| **A** | no clothes, wooden frame with hanger (Figure 1) | 3.2 |
| **A** | no clothes, wooden frame without hanger | 3.2 |
| **B** | no clothes, wooden frame without hanger | 4.2 |
| **C** | no clothes, wooden frame without hanger | 3.4 |
| **A** | a summer jacket (Figure 2) | 3.2 |
| **A** | a winter jacket (Figure 3) | 1.3 |
| **A** | a vest (Figure 4) | 3.4 |
| **A** | same winter jacket again | 1.4 |
| **A** | a winter jacket with a contact to the earth | 2.5 |

Table 1 reveals that the winter jacket barely decreased the electric field exposure inside the jacket. However, we tested only some jackets. In addition, the test situation would be different if we analyzed human beings' exposure to electric fields. We tested only jackets without a human being.

The influence of the clothes can be different, for example, in different weather situations. Moreover, when the jacket was in contact with the earth, the decreasing effect was lower than when the jacket was not in contact with the earth. During various tasks, a worker can have a contact to the earth or not. Therefore, the exposure situation can easily change. One possibility is to utilize special clothes that decrease electric field exposure. In any case, it is also important that clothes are electricity safety and user-friendly.

In conclusion, it is possible to say that the workers' jackets and perhaps also other clothes can influence their exposure to electric fields under power lines. In the future, it can be possible to develop new solutions to decrease electric field exposure using different clothes or textiles.

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# PRELIMINARY MEASUREMENTS OF SMART METER ELECTROMAGNETIC FIELD (50-100 KHZ) EMISSIONS IN FINLAND

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*ABSTRACT*

*Smart meters have come to general use in metering electricity. The aim of this paper was to present example measurements of electromagnetic field exposure to smart meters for cable-transmitted (50-100 kHz) signal emissions. The measured magnetic flux densities in various situations at the surface of the meters varied from 0.1–2.2 μT, and the ICNIRP recommended value is 27 μT for those frequencies. The measured values were less than 10% from the recommended values. When usual spectator distance is considered, the ratio is even less, usually less than 1% from the recommended field values. When electric field values are considered, the values ranged from 0.2-2.5 V/m, and compared to the recommended values, they are also less than 3% from the recommended values. Based on our preliminary measurement results, we do not see any specific need to improve the sheltering of the meters from the public or to measure electromagnetic field emissions from all smart meters in the future.*

***Key words:*** *smart meter, electromagnetic fields, exposure*

## 1. INTRODUCTION

The use of smart meters has increased in Europe and also around world. At the same time, the discussion on the possible health effects has been active. Therefore, it has been important to study smart meter electromagnetic field emissions.

In Finland, all electricity companies nowadays use smart meters when measuring customer electricity use. In Finland, smart meters can be divided into two categories: 1) meters using either a radio frequency (800-3000 MHz) aerial signal to masts and 2) meters employing a 50-100 kHz electromagnetic field signal through cables. The exposure to electromagnetic fields is possible only when then smart meter communicates to the HUB station and the reading of the meter occurs.

To evaluate the possible effects of the 50-100 kHz frequencies electromagnetic fields, it is possible to use guidelines of the International Commission on Non-ionizing Radiation Protection (ICNIRP). ICNIRP has published recommended values for the electric and magnetic fields for those frequencies concerning the general public, and the values are 83 V/m for the electric field and 27 μT for magnetic flux density [1].

The aim of this paper was to present example measurements of electromagnetic field exposure to smart meters for cable-transmitted (50-100 kHz) signal emissions. The aim is also to give more details of measurements, which were not in our earlier papers [2,3].

## 2. METHODS

First, we collected possible measurement places and tested different electromagnetic meters. Then, during our measurements, two electricity companies read their smart meters so that we could measure the electromagnetic fields. For us, the companies conducted extra readings of the smart meters.

For magnetic field measurements, we utilized the magnetic field meter MFM 3000 by Combinova, which is a magnetic field instrument with features, such as 1) real-time wideband spectrum analysis in three dimensions, 2) maximum detection in time domain measurements, 3) a frequency range of 40–100 kHz, 4) a dynamic range from 10 nT to 10 mT, with true RMS measurements of both the wideband or any frequency-specific magnetic field, and 5) video recording with RMS values and spectrum (Samsung smart phone type Samsung Galaxy S III). We used an MFM with a separate probe version. We measured electric field values with a single direction Holaday Industry meter 3603 (2-300 kHz and 0.2-2000 V/m), where we measured vectors pointing directly opposite from the smart meter. The measurement distance was either at the surface of the meter or 30 cm directly from the meter (spectator position).

Figures 1 and 2 show the examples of the electric field measurements. Figures 3 and 4 reveal the examples of the magnetic field measurements.

***Figure 1.*** *Example of electric field measurement at surface of meter*

***Figure 2.*** *Example of electric field measurement at 30 cm distance*

***Figure 3.*** *Example of magnetic field measurement at surface of meter*

***Figure 4.*** *Example of magnetic field measurement at 30 cm distance.*

### 3. RESULTS AND DISCUSSION

We did measurements in three places. When we measured at the surface of the smart meters, the magnetic fields were 0.1–2.2 μT, and electric fields were between 0.2-2.5 V/m.

When the measurement distance was 30 cm, the magnetic field was about 0.02 μT, and electric field was approximately 0.22 V/m. When the distance was 50 cm, magnetic field ranged from 0.0002-0.0003 μT.

The ICNIRP recommended value is 27 μT for those smart meters. Our measured magnetic field values (at the surface) were less than 10% from the ICNIRP recommended values. In general, electricity users or workers are not exposed to the fields at the surface. Therefore, the possible exposure is usually less than 1% from the recommended field values. In addition, when we compare the electric field emissions of smart meters to the ICNIRP guidelines, our measurement values are less than 3% from the recommended value.

When we analyze our results, it is important to take into account that we measured fields during the reading of a smart meter. Readings were very short, about 20 s. Thus, the possible exposure time period is also only about 20 s.

In conclusion, it can be stated that there is no specific need to improve the sheltering of the meters from the public or to measure electromagnetic field emissions from all smart meters in the future.

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# EXPOSURE TO RF FIELDS DURING THE REMOTE READINGS OF THE SMART METER IN FINLAND

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## ABSTRACT

*The aim of this paper is to present some example measurements of radiofrequency electromagnetic field exposure detected by smart meters during the remote reading of the smart meter. We made 151 measurements using the Narda EMR-300 with probe T-33C, while the operator of a utility company remotely read the smart meter. He remotely read the smart meters at six sites. In five reading periods, the RF meter was on the surface of the smart meter, and in six reading periods, the distance from the meter was 30 cm. In all situations, the background field did not exceed the detection threshold of the meter. When the distance was*

*30 cm, we took 64 measurements. The average of the values during the reading period of 20 s was 6.2 V/m, and the maximum value was 24.0 V/m. When the RF meter was on the surface of the smart meter, the average was 16.5 V/m, and the maximum value was 51.0 V/m (87 measurements taken). Averaging these values over 6 minute values, as ICNIRP proposes, we obtain, at a distance of 30 cm, an average of 0.52 V/m and a maximum of*

*2.0 V/m. The ICNIRP recommendation values are 39-61 V/m for measured frequencies. The measured values were less than 1-3% from the recommended values.*

***Key words:*** *smart meter, electromagnetic fields, exposure*

## 1. INTRODUCTION

The use of smart meters has been increased around the world. In Finland, these smart meters most often send information or communicate using either a radio frequency (800-3000 MHz) aerial signal to masts or a 50-100 kHz electromagnetic field signal through cables. Communication durations are typically from a few seconds to tens of seconds each time, and these meters do not send information all of the time. The highest sending emissions can be around 1 W for the collector smart meter systems and less for the single-sending smart meters. Collector smart meter systems contain usually around 100 single smart meters, from which the information is transmitted to the collector via a cable system.

The international commission of non-ionizing radiation protection (ICNIRP) (1) has recommended values for public exposure to time-varying electric and magnetic fields (unperturbed rms values) for 800-3000 Hz: electric field strength of 39-61 V/m, magnetic field strength of 0.10-0.16 A/m, and an equivalent plane wave power density of 4-10 W/m2.

The electromagnetic field (EMF) of radio frequency smart meters has been measured in many countries (2), but in Finland, our measurements are the first to the best of our knowledge. The difficulty in these measurements is that during measurement, one must know when the meter is communicating with the nearby mast to be able to receive real values at all; only then can instantaneous values be achieved. Typically, the consumption of electricity is read, for example, once a week or once a month, and the exposure measurements are not easily obtainable without the assistance of a utility company.

Smart meters can be inserted inside or outside in single houses, but in city areas and multi-floor houses, these meters are typically inserted in cellars, where the RF-emitting collectors are also situated. Population and consumers seldom are situated and exposed near RF-emitting equipment; short exposure time combined with brief emission time is typical. Therefore, the probability of significant exposure is low.

The aim of this paper was to present example measurements of radiofrequency electromagnetic field exposure detected by smart meters while remotely reading them.

## 2. METHODS

We made 151 measurements using the Narda EMR-300 with probe T-33C, while the operator of a utility company remotely read the smart meter. He remotely read the same meter from seven to 27 times. In five reading periods, the RF meter was on the surface of the smart meter and in six reading periods, the distance was 30 cm. In both situations, the background field was zero. When the distance was 30 cm, we took 64 measurements. Figure 1 shows an example of the measurements.

The wavelength of these frequencies 800-3000 MHz is less than 30 cm; therefore, in practice, electric field strength values of 30 cm can be used to also evaluate magnetic field strength and power density. Consequently, we did not measure other parameters than electric field strength with the exception of some power density checks that coincided with electric field strength values. However, on the surface of the smart meters, other field strength parameters (magnetic field and power density) cannot be calculated correctly from the electric field strength. Thus, when comparing to the guidelines for the general population, the values measured at 30 cm are more valid than those at the surface of the meter. However, we measured at the surface of the meter because sometimes that was the only distance where it was possible to acquire reliable reading values.

***Figure 1.*** *Example of measurement at distance of 30 cm.*

## 3. RESULTS

Table 1 shows the measured maximum values, average values, standard deviations (SD), and 99th percentiles (95th perc.). We performed measurements at the distances of 0 cm and 30 cm.

***Table 1.*** *Measured results of readings*

| Reading session | n | Distance, cm | Maximum value, V/m | Average value, V/m | SD, V/m | 95th perc., V/m |
|---|---|---|---|---|---|---|
| **1** | 16 | 30 | 24.0 | 8.2 | 6.1 | 18.8 |
| **2** | 14 | 0 | 51.0 | 14.9 | 12.3 | 32.8 |
| **3** | 27 | 0 | 38.0 | 14.5 | 8.4 | 30.7 |
| **4** | 12 | 30 | 5.0 | 3.6 | 0.8 | 4.6 |
| **5** | 9 | 30 | 12.8 | 8.5 | 2.7 | 12.3 |
| **6** | 7 | 30 | 7.8 | 5.9 | 1.5 | 7.7 |
| **7** | 19 | 0 | 38.0 | 22.3 | 7.5 | 34.4 |
| **8** | 15 | 0 | 26.0 | 16.3 | 7.3 | 25.3 |
| **9** | 12 | 0 | 36.0 | 13.9 | 8.9 | 30.0 |
| **10** | 12 | 30 | 7.6 | 5.1 | 1.6 | 7.3 |
| **11** | 8 | 30 | 7.6 | 5.5 | 2.1 | 7.4 |

The average of the values during the reading period of 20 s was 6.2 V/m, and the maximum value was 24.0 V/m. When the RF meter was on the surface of the smart meter, the average was 16.5 V/m, and the maximum value was 51.0 V/m (87 measurements taken).

## *4. DISCUSSION*

When these values are averaged over 6 minute values, as ICNIRP proposes, we obtain, at a distance of 30 cm, an average of 0.52 V/m and a maximum of 2.0 V/m. The ICNIRP recommended value is 39-61 V/m for measured frequencies. The measured values were less than 1-3% from the recommendation. When considering that consumers usually are at the distance of 0.3-1.0 m even when inspecting the meters, the guidelines are clearly not exceeded.

We have to remember, however, that there exist also other radio frequency emissions near smart meters. In Finland, for example, illumination regulators, mobile phones, alarm systems, broadcast antennas, and computer system stations (WLAN, HUB) can emit similar fields. We selected such places where the background field strengths did not interfere with our measurements.

Therefore, we conclude that there is no need to conduct a large, systematic study on the exposure of the field strengths of smart meters. The durations of various electromagnetic field strengths, the randomness of the exposure times, and the size of the field strengths too insignificant to merit further concern.

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# THE DEVELOPMENT OF THE MAXWEL SURFACE-BASED HUMAN MODEL AND CALCULATED INDUCED ELECTRIC FIELDS FROM EXPOSURE TO ELECTRIC AND MAGNETIC FIELDS

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## ABSTRACT

*The development of anatomically realistic models of the human body has mostly concentrated on voxel models. Recently, a limited number of surface-based computational human models have emerged for the application to non-ionizing exposure problems. Surface-based phantoms combine the advantages of stylized and anatomically realistic voxel models. They are flexible, allowing changes to organ position and posture to occur, but they also present accurate models of the human anatomy and can be voxelised to a desired resolution. EMFcomp, an independent research microenterprise that specializes in computational electromagnetics, have developed the male, anatomically realistic surface-based model MAXWEL (MAle fleXible Whole-body modEL). The MAXWEL human model is currently being used in the development of the EMF Directive 2013/35/EU Practical Guide to explain the way in which the human body absorbs electromagnetic fields. This work presents calculations of internal induced electric fields in MAXWEL, from exposure to external low frequency electric and magnetic fields. The maximum 99th percentile induced electric fields have been calculated for fields from 50 Hz to 10 MHz. These calculated electric field values in MAXWEL were compared with values from the male model NORMAN and female model NAOMI. The maximum 99th percentile value for NAOMI, calculated by Dimbylow in bone, was 49.4 mV m-1 per kV m-1 at 50 Hz under grounded conditions. The corresponding value calculated in MAXWEL was 15.7 per kV m-1, considerably lower due to anatomical differences between the male MAXWEL and female NAOMI models.*

***Key words:*** *ELF, Dosimetry, Induced Electric Fields, Human Phantoms, Modelling*

## 1. INTRODUCTION

The European Union (EU) has produced the Directive 2013/35/EU on human exposure to electromagnetic fields to protect against adverse health effects in workers ( 1). Within this Directive, exposure limit values (ELVs) in terms of induced internal electric fields in the body and action levels (ALs) in terms of applied external electric fields are presented. ICNIRP (2) recommends that the 99th percentile value of the electric field (E99), averaged over a contiguous tissue region of 2 x 2 x 2 mm3, is used to determine the induced electric field for comparison with the ELVs. Different values are stated for both the central nervous system (CNS) and the peripheral nerves. However, human dosimetric studies of induced electric fields from exposure to low frequency external electric fields are limited. Dawson et al (3) used a quasi static Finite-Difference Time-Domain (FDTD) method to calculate surface charge densities and interpolate onto a 3.6 mm resolution University of Victoria phantom. These provided source terms for internal dose calculations using the Scalar Potential Finite-Difference (SPFD) method (Dawson et al (4)). Furse and Gandhi (5) used the FDTD method to calculate induced current densities at 10 MHz using 60 Hz conductivities in a 6 mm resolution voxel phantom. They then linearly scaled the values with frequency to obtain current densities at 60 Hz. Dimbylow (6) used a series of nested sub-grids to solve the potential equation and calculate induced current densities in a 2 mm resolution version of the male NORMAN phantom from exposure to electric fields. Dimbylow (7) calculated induced electric fields in the CNS for NORMAN and NAOMI due to electric field exposure and induced electric fields in all tissues for NAOMI at 50 Hz. Dimbylow and Findlay (8) calculated induced current densities in 25 different voxel models at 50 Hz from applied electric fields using the SPFD method, however this study did not extend to the calculation of induced electric fields.

As there are few recent dosimetric studies of induced electric fields from low frequency external electric fields using recently developed anatomically realistic human phantoms, the ICNIRP reference levels and hence Directive ALs for the CNS from exposure to external electric fields were based on calculations using just two anatomically realistic models of the human body, NORMAN and NAOMI, carried out by Dimbylow (7). Furthermore, the Directive ALs for peripheral nerve stimulation, in which any tissue in the body is considered, were based on only one calculated induced electric field value in the female model, NAOMI, also calculated by Dimbylow (7).

The induced electric fields in the body due to an applied external electric field will be different for different human models due to variations in anatomical details. Studies into how these induced electric fields change with different models are important for the production of electromagnetic guidelines that are representative of the entire human population. The objective of this paper is to investigate how the use of a different human model changes the calculated induced electric fields in the body when exposed to an external applied low frequency electric field, by carrying out SPFD calculations using the surface-based MAXWEL male phantom.

The MAXWEL human model is described in the next section. This is followed by a description of the numerical methods used to calculate the induced electric fields. Results for applied electric and magnetic fields are then given and conclusions are presented in the final section.

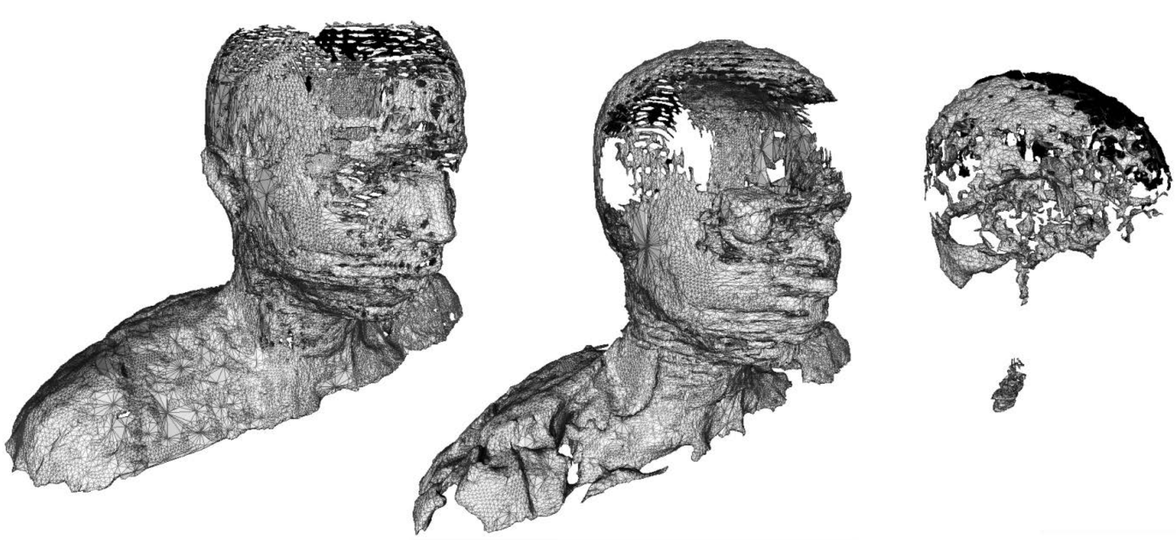
## *2. HUMAN MODEL*

The development of anatomically realistic models of the human body has mostly concentrated on voxel models (see e.g. Dimbylow (6), Furse and Gandhi (5)). Recently, surface-based computational human models have emerged for the application to ionizing and non-ionizing exposure problems. In these models the boundary of each tissue type can be mathematically described by some kind of parameterized surface, which might be as simple as a planar quadrilateral or as sophisticated as a two-dimensional spline. The surface based model can provide a closer geometrical approximation to the interface of adjacent materials by using a non-orthogonal, and sometimes curved, mesh.

Surface based phantoms combine the advantages of stylized and anatomically realistic voxel models. They are flexible, allowing changes to organ position and posture to occur, but they also present accurate models of the human anatomy and can be voxelised to a desired resolution. Examples of surface based models can be found in the literature (e.g. Lee et al (9), Christ et al (10)). The surfaces making up the MAXWEL (MAle fleXible Whole-body modEL) human model tend to be less smoothed than other surface-based models such as the University of Florida adult male (9) as these anatomical details are more important in non-ionizing exposure problems.

The model on which MAXWEL is based originated from whole-body high resolution MRI scans. No information was available about the subject, except that he is a healthy young adult male (no known organic disease), of 23 years with a height of 1.70 m and a mass of 68 kg. The subject was scanned in six regions: ‘head’, ‘thorax’, ‘abdomen’, ‘thighs’, ‘knees’ and ‘feet’. The original MRI data slices were 256 x 256 pixel images in the axial plane. The width of the models shoulders (approximately 44 cm) almost filled the whole image width (230 pixels). Therefore, the horizontal resolution of the data was approximately 2 mm per pixel. The model’s head however was constructed from a separate 1 mm sagittal data volume, to give higher resolution, and rescaled to match the rest of the model.

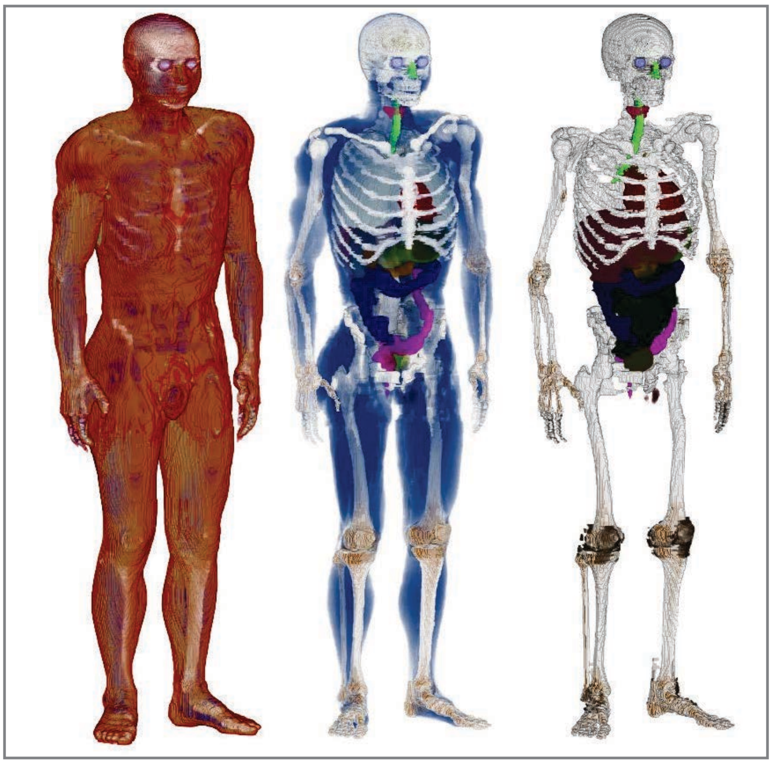
***Figure 1.*** *Surface rendered representations of the subcutaneous fat (left), muscle (centre) and cerebro-spinal fluid (right) tissues in the MAXWEL phantom*



The MRI data was segmented into the various tissue types as follows. Each tissue type was manually defined by assigning specific voxel intensities to organs by filling them individually on each data slice. The segmentation was then checked by using an intersecting orthogonal display that displayed the segmented area in relation to the whole dataset. This was carried out on successive x-y slices throughout the volume. Routines were written in FORTRAN to eliminate background noise and reduce the voxel values outside the body to zero. An automated procedure was also used to pre-process parts of the volume by sequentially loading slices into memory for segmentation of skin, fat and muscle. This was possible as the MRI data values for skin, muscle and fat are often well separated from other tissue types. In this way, a number of intermediate volumes could be generated during the segmentation process. Final post-processing of the entire segmented volume was used to remove these artifacts so that every voxel belongs to one or other of the defined objects in the final volume. This was followed by a check of the resultant volume by a medical anatomical expert.

The phantom consists of 46 different tissue types. These tissues included cerebrospinal fluid, bile, gall bladder, background air, blood, small intestine, spleen, muscle, breast, liver, thymus, urine, bladder, skin, fat, tendon, nose cartilage, kidney, duodenum, stomach contents, stomach, oesophagus, pancreas, trabecular bone, brain white matter, brain grey matter, spinal cord, lower large intestine, upper large intestine, heart muscle, eye lens, humour, sclera, cornea, retina, optic nerve, choroid, cortical bone, adrenals and thyroid. MAXWEL was scaled to 'reference man' (11) dimensions of 1.76 m tall and a mass of 73 kg.

***Figure 2.*** *Volume rendered images of MAXWEL at a resolution of 2 mm.*
*The opacity of certain regions has been varied to enable the internal skeleton and some internal organs to be seen.*



To create a surface-based model of the numerical phantom, the MAXWEL volume was imported, tissue-by-tissue, into 3D CAD software and surface models of the various tissues were generated. The software utilized NURBS (Non-Uniform Rational B-Spline) based tools to create surface-based models of the previously voxelised tissue data. A wire-framed model of the surface is produced by the software, which then can be smoothed and surface rendered. Interpolation or smoothing processes after inserting a volume object can cause the appearance of artifacts in regions where the voxel value of the object can blend with non-segmented surfaces. To minimize these artifacts, resizing by decimation and noise/speckle reduction through median filters was used. A series of programming tools were written in FORTRAN to allow manipulation of surface geometries and the insertion of segmented surface tissue types into the developing model of the human body.

Images of some tissue surface-based representations are shown in Figure 1. In some places it was necessary to rotate the sub-volume slightly as well as rescaling and shifting within the three dimensional space. This was to prevent the overlapping of different tissue types within the model. The final CAD volume is presented as a series of 3D tissue surfaces within a domain. Once the process was complete, the surface-based representations of the tissue types could be re-voxelised to a desired resolution using code, also written in FORTRAN, to reduce the effects of staircasing at the higher resolutions. Volume rendered images of MAXWEL are presented in Figure 2. The opacity has been varied to show the internal structure of the model. In the image on the right the opacity of the skin is high to show the outer surface of the phantom. In the middle image the skin and fat layers have been removed and the muscle layer (blue) has been given a reduced opacity to show the internal tissues and organs. In the image on the left, the muscle layer has been removed to indicate the skeleton, liver, heart and intestines.

An evaluated review of the dielectric properties of all tissue types in MAXWEL was performed by Gabriel et al (1995). A 4-Cole-Cole dispersion model was fitted to the data for each tissue type to parameterize the conductivity and permittivity as a function of frequency.

### *3. NUMERICAL METHODS*

The quasi-static potential equation (12) was solved to calculate the interaction of low frequency fields with the human body. The solution is divided into two parts. First, the coupling between the externally applied field and the human body, defined as a conductor at low frequencies, is calculated to provide the surface charge. This charge is then used as a boundary condition to calculate the internal potential and hence induced fields and current densities in the body.

The outer region must extend sufficiently so the perturbation of the applied field due to the phantom is small at the periphery. However, the resolution of the calculation must be sufficiently fine so as to adequately represent the internal structure of the anatomical model. To do this, a nested grid technique is used. The outermost grid resolution is 32 mm. The field values from this initial run are used to set the outer boundary conditions at a closer boundary for the next iteration at 16 mm resolution. Successive calculations are then performed at 8 mm, 4 mm and finally 2 mm resolution.

***Figure 3.*** *Surface-based representation of part of the MAXWEL phantom with voxelised images of the 16 mm, 8 mm and 2 mm resolution models used in the nested grid calculation technique.*

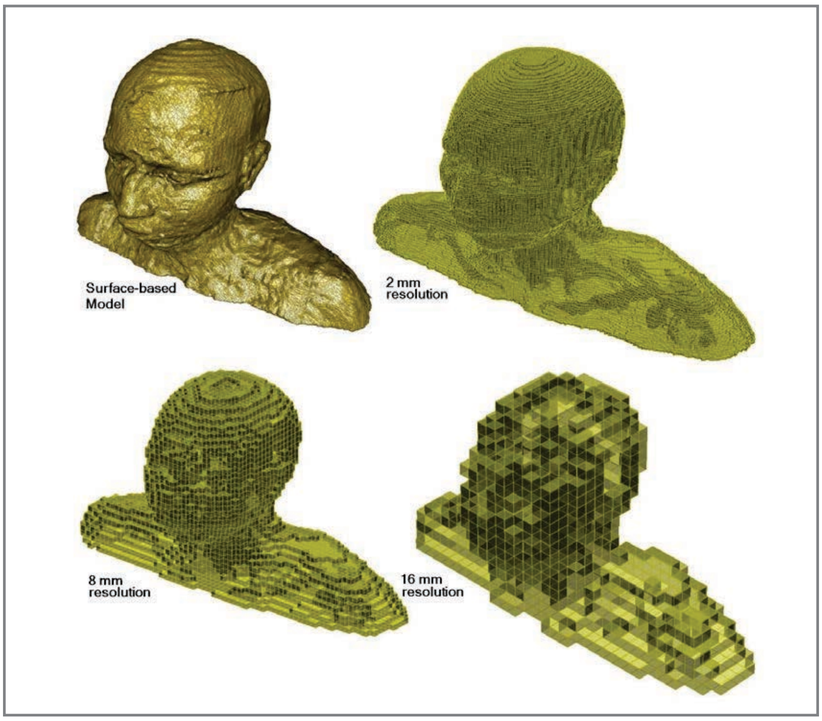



Figure 3 presents the surface rendered representation of MAXWEL along with images of the resized phantom at 16 mm, 8 mm and 2 mm resolutions used in the nested grid calculations. The electrical properties of the composite cells are volume-weighted averages of the non-air voxels. Once the external potential has been calculated, the internal potentials and therefore the induced electric fields are obtained using the external surface charge as a boundary condition. At 10 MHz the quasi-static approximation is approaching the limit of validity and it may be that the calculations are less accurate at this frequency though there are presented here for comparison with the Dimbylow (7) results.

## 4. RESULTS

The maximum 99th percentile electric field values, i.e. the value exceeded in 1% of the voxels of that organ, in the central nervous system of the MAXWEL model were calculated for exposure to an external electric field under grounded and isolated conditions. The highest induced electric field values usually occur in the lower conductivity tissues. The brain and spinal cord have a lower conductivity than the retina, hence, in contrast to the induced current density; it is unusual for the retina to represent the maximum 99th percentile electric field value in the central nervous system. In fact, the highest induced 99th percentile electric field value always occurs in the spinal cord. The values for MAXWEL are 3.49 mV m-1 per kV m-1 for grounded conditions and 1.54 mV m-1 per kV m-1 for isolated conditions. These values are 2% higher and 6% lower than the corresponding values for NORMAN under grounded and isolated conditions respectively.

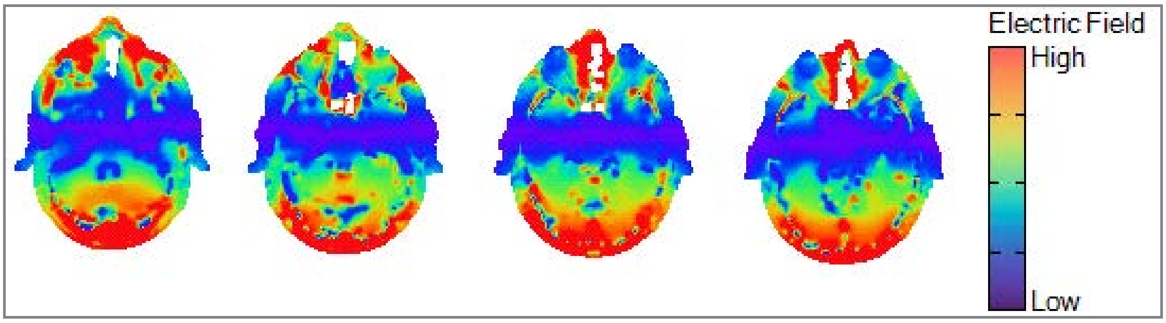
The maximum calculated 99th percentile induced electric field values, as a function of frequency for an applied electric field, were calculated in MAXWEL and compared with NORMAN values. The values for NORMAN were derived from external magnetic flux densities required to generate ICNIRP (13) on induced electric field in Dimbylow (7). The maximum 99th percentile electric field values in MAXWEL under grounded conditions occurred in the spinal cord for all frequencies considered in this work. Agreement with values presented by Dimbylow (7) for NORMAN also compare well. Here, the percentage differences are 2%, 5%, 6%, 15% and 13% for 1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz respectively.

The mean, 99th percentile and maximum induced electric fields at 50 Hz for the different tissue types in MAXWEL were calculated for an applied electric field under grounded conditions. Again, it is not ideal to compare the electric field values for MAXWEL and NAOMI in all tissues due to the differences in male and female anatomy; however the corresponding data for the MALE phantom NORMAN has not been published. Because of these differences, it should not be expected that the induced electric fields in the NAOMI and MAXWEL models are the same or similar for all tissue types. The values calculated for MAXWEL are generally within 30% of the values for NAOMI. Reasonable agreement is seen for the white matter (7% difference) and grey matter (9% difference) in the brain, as well as the retina (10% difference) and muscle (11% difference). However, differences were calculated in other organs. The 99th percentile electric field in fat for NAOMI is 43% higher than in MAXWEL, 55% higher for skin and 59% higher for tendon.

The highest 99th percentile value for NAOMI is important, as it is assumed that the restriction values put forward in the ICNIRP guidelines (2) and EMF Directive (1) for peripheral nerve stimulation are based on this electric field value, which is 49.4 mV m-1 per kV m-1 in bone. The corresponding value in MAXWEL was 15.7 mV m-1 per kV m-1, 68% lower than that calculated in NAOMI. The highest 99th percentile electric field value calculated in NORMAN by Dimbylow at 50 Hz under grounded conditions was also considerably lower than that calculated in NAOMI, 23.3 mV m-1 per kV m-1 in bone.

Figure 4 shows the induced electric fields in each voxel of horizontal slices containing the eyes for an applied LAT magnetic field at 50 Hz. Because the magnetic field in Figure 4 is orientated from side-to-side, the circumferential induction of the induced electric field produces higher values on the front and back of the phantom head, the outermost parts of the region normal to the direction of the applied magnetic field.

***Figure 4.*** *The induced electric field through various axial slices of the MAXWEL head containing the eyes for exposure to a LAT applied magnetic field at a frequency of 50 Hz.*




This can also be seen clearly in Figure 5 (a), which presents the induced electric field in sagittal slices of the MAXWEL phantom. High values occur on the front and back surfaces of the torso with low values in the middle of the body. In contrast to the current density distributions, these high values occur in the low conductivity tissues, the skin and subcutaneous fat, near the surface of the phantom. As has been seen in the previous figures, high values of current density occur when high conductivity tissues combine with enhanced electric field values such as the eye, cerebro-spinal fluid, muscle and the intestines.

*__Figure 5.__ The induced electric field in (a) sagittal slices and (b) coronal slices of the MAXWEL phantom for exposure to a LAT applied magnetic field at a frequency of 50 Hz.*

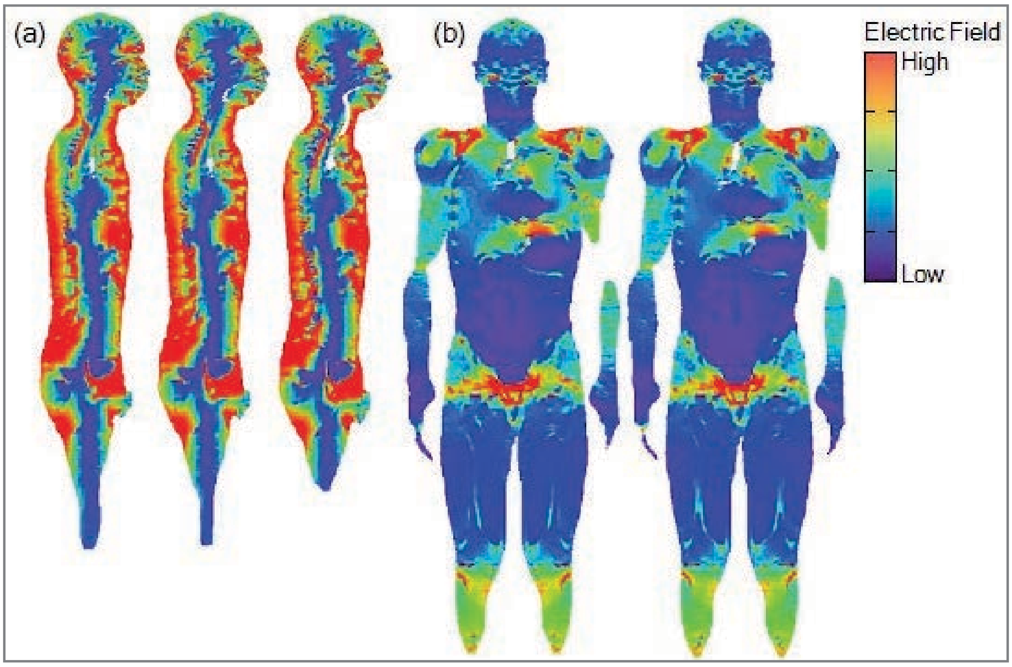
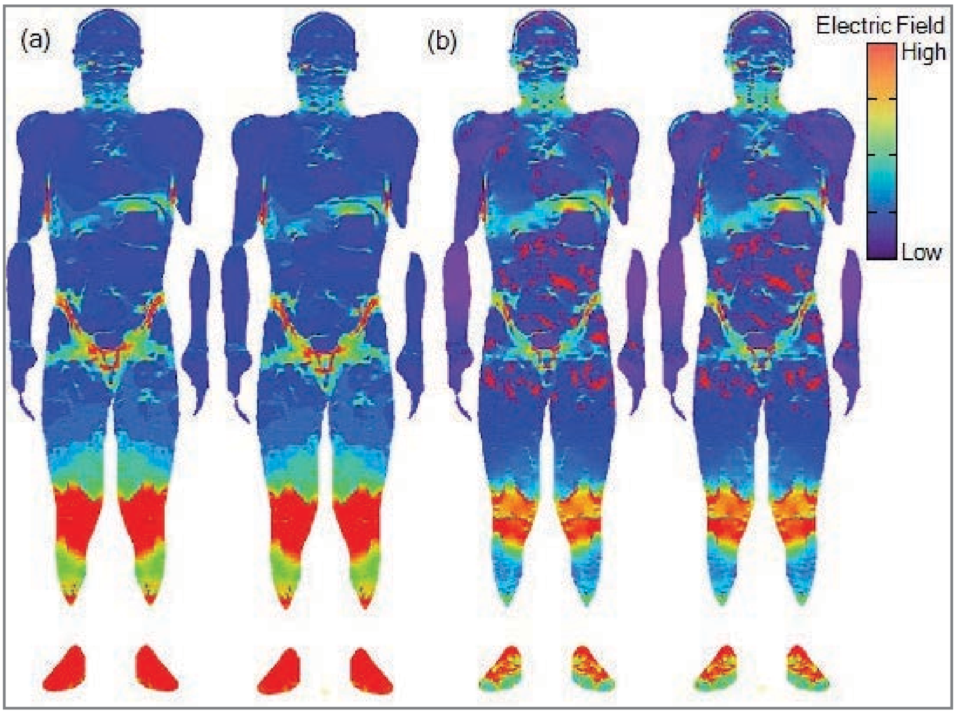



Figure 6 shows the induced electric field in coronal slices of the MAXWEL phantom for exposure to an applied electric field under (a) grounded and (b) isolated conditions at 50 Hz. This figure demonstrates the difference in the induced electric fields in the sections of low cross-sectional area such as the knees and ankles for the grounded and isolated cases.

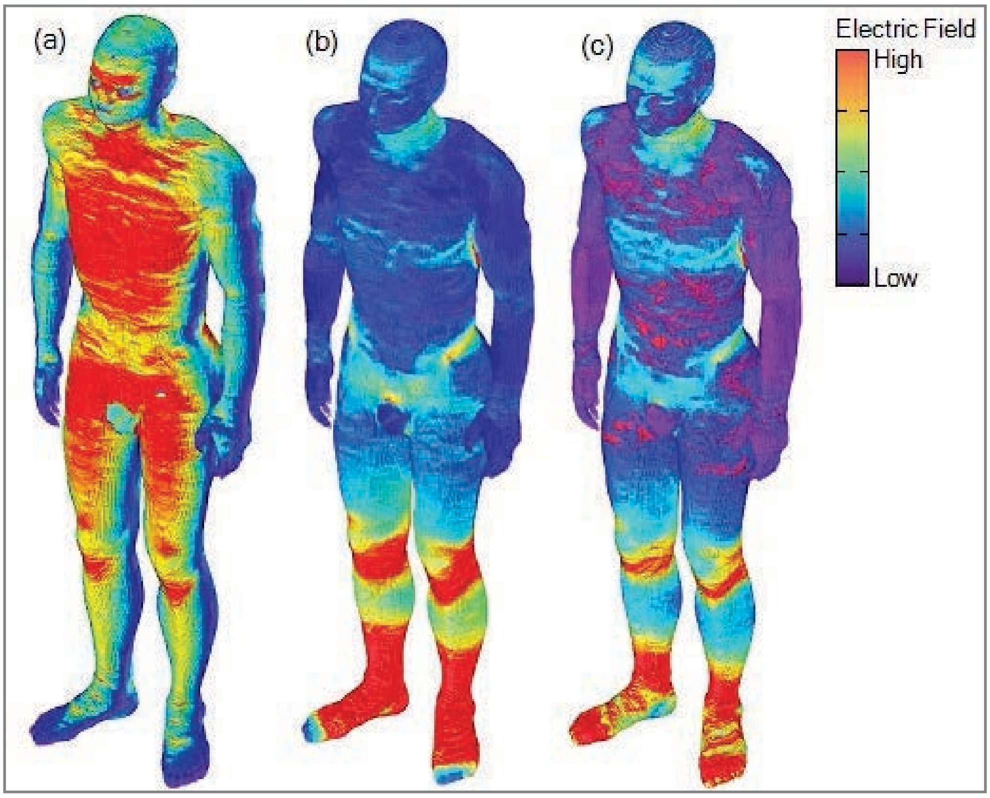
The layer current will increase as one goes down the body to the grounded feet. It will then be further enhanced by narrow cross sections, and so the induced electric field also depends inversely of the cross sectional areas of the section. Therefore, higher electric field values are to be expected in these ankle and knee sections, and also to a lesser extent in the neck. The results are similar to those seen for exposure of grounded humans to electromagnetic fields at higher frequencies (e.g. Findlay and Dimbylow (14)).

*__Figure 6.__ The induced electric field in coronal slices of the MAXWEL phantom for exposure to an applied electric field under (a) grounded and (b) isolated conditions at 50 Hz.*



The higher absorption in the knees and ankles can also be observed in the electric field distributions shown in Figure 7. The joints of the knees and ankles are mainly made up of low conductivity bone and connective tissue with little high conductivity tissue, so there is a further enhancement of the induced electric field. This explains why, for the grounded exposure of MAXWEL to an external electric field, the induced electric field value in bone is so much higher than the corresponding isolated exposure case.

***Figure 7.*** *The induced electric field in the MAXWEL phantom for exposure to (a) a LAT applied magnetic field, (b) an applied electric field under grounded conditions and (c) an applied electric field under isolated conditions, at a frequency of 50 Hz.*




*5. CONCLUSIONS*

Scalar Potential Finite Difference (SPFD) calculations of induced current density and electric field values have been performed in the realistic surface-based model of the human body, MAXWEL, for exposure to external magnetic and electric fields. These calculations have been carried out for exposure at frequencies between 50 Hz and 10 MHz, under isolated and grounded conditions, for various tissue types within the MAXWEL phantom. The values have been compared to authoritative calculations carried out in the NORMAN and NAOMI phantoms by Dimbylow, e.g. Dimbylow (7).

It has been found that the induced currents and fields calculated in MAXWEL generally agree well with those published by Dimbylow for the NORMAN (and NAOMI) models. For example, the maximum 99th percentile induced electric fields in the MAXWEL central nervous system (cns) for exposure to a 50 Hz external magnetic field, AP, LAT and TOP orientations were 29.7, 48.2 and 26.3 mV m-1 per mT respectively. This compares with 30.7 (3% difference), 48.6 (1% difference) and 23.0 (13% difference) for the corresponding values calculated by Dimbylow in the NORMAN phantom. For exposure to external electric fields at 50 Hz, the maximum 99th percentile induced electric field values calculated in the MAXWEL central nervous system were 3.49 (grounded) and 1.54 (isolated) mV m-1 per kV m-1. The corresponding values calculated by Dimbylow for NORMAN were 3.42 (grounded, difference of 2%) and 1.63 (isolated, difference of 6%) mV m-1 per kV m-1.

The highest 99th percentile induced electric field values for NAOMI in all tissues form the basis of the restriction values put forward in the EMF Directive (1) and ICNIRP guidelines (2) and EMF Directive (2013) for peripheral nerve stimulation. There were differences in some of these field values calculated for NAOMI and MAXWEL in non-cns tissues, due to anatomical differences between the male and female models. The maximum electric field value for NAOMI (in bone) was 49.4 mV m-1 per kV m-1 at 50 Hz under grounded conditions. The corresponding value calculated in MAXWEL was 15.7 mV m-1 per kV m-1, 68% lower than that calculated in NAOMI. The highest 99th percentile electric field value calculated in the male phantom, NORMAN, by Dimbylow at 50 Hz under grounded conditions was 23.3 mV m-1 per kV m-1 in bone, also considerably lower than that calculated in NAOMI.

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# ASSESSMENT OF SAR AND PARAMETERS OF MOBILE PHONE MODELS

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*ABSTRACT*

*This study assesses the influence of several models of mobile phones (generic phone 1: quarter-wave monopole mounted on a perfectly conducting box; generic phone 2: quarter-wave monopole mounted on a box consist of perfect electrical conductor, plastic insulator, rubber insulator; resonant dipole antenna, dipole antenna with capacitive loads) and remoteness from human head models on SAR and phone parameters. Specific anthropomorphic mannequin SAM and six layered-sphere phantom models have been used. The 1 g and 10 g peak spatial average SAR were analyzed with commercial software package xFDTD, based on Finite Difference Time Domain Method.*

***Key words:*** *SAR, Mobile phone, SAM, FDTD, Dipole antenna.*

## 1. INTRODUCTION

In recent years with the remarkable progress in mobile communications systems, there has been a growing demand for comprehensive understanding of electromagnetic interactions between handset antennas and nearby human head. The evaluation of the power absorbed in user's head is a key task, both for design and compliance testing of cellular phones, that can be efficiently performed numerically [1]. Several studies have been published showing that numerical dosimetric studies related to the use of mobile phones are sensitive to a multitude of parameters [2-7]. These parameters include: modeling of the device and device parameters [2], position of the device [3], detailed procedures for SAR averaging [4] and boundary conditions [5].

The aim of this paper is to examine influence of distance between the antenna feeding point and human head models on 1) predicted SAR values in computer-based homogeneous and heterogeneous models of the user's head 2) mobile phone electrical parameters and characteristics.

## 2. METHODS AND MODELS

The power deposition in human-head models due to a mobile phone models has been computed by using the finite-difference time-domain (FDTD) method. The 12-field components approach has been used to calculate SAR in the computational cell at 900 MHz.

The all simulations have been accomplished with a commercial FDTD program (XFDTD, Remcom Inc., State College, PA, USA) in the following conditions:

### *a. FDTD mesh*

The uniform mesh FDTD technique has been used to calculate the SAR and input characteristics of the mobile phone models. A cell size of 1mm was used. The FDTD mesh was round with 7 layers absorbing boundary type perfect matched layer. Computations were terminated after steady state was reached.

### *b. Head models*

For this study, two human-head models have been used (see Fig. 1): one was Specific Anthropomorphic Mannequin (SAM) and the other was a heterogeneous spherical model.

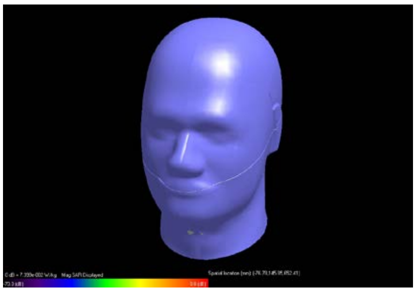
The dielectric properties of the equivalent head tissue used in the SAM at 900 MHz are those defined in [9] and [10] - relative permittivity 41.5, conductivity 0.90 S/m, and mass density 1000 kg/$m^3$, while the dielectric properties of the shell and ear spacer were defined as follows: relative permittivity 3.7, conductivity 0 S/m, and mass density 1000 kg/$m^3$.

A six-layered, lossy dielectric sphere is used to simulate the biological tissues of human head. Identified biological tissues include skin, fat, bone, dura, cerebrospinal fluid (CSF), and brain. The electromagnetic parameters (permittivity and conductivity) of the biological tissues at 900 MHz are shown in Table 1 and taken from [11].

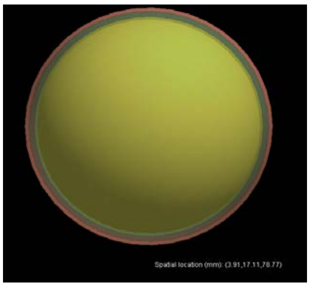
***Table 1.*** *Electromagnetic parameters of heterogeneous spherical model at 900 MHz*

| Biological Tissues | Radius, cm | Relative permittivity | Conductivity, S/m | Mass density $10^3$ kg/$m^3$ |
|---|---|---|---|---|
| ***Skin*** | 9.00 | 40.7 | 0.65 | 1.01 |
| ***Fat*** | 8.90 | 10.0 | 0.17 | 0.92 |
| ***Bone*** | 8.76 | 20.9 | 0.33 | 1.81 |
| ***Dura*** | 8.35 | 40.7 | 0.65 | 1.01 |
| ***CSF*** | 8.30 | 79.1 | 2.14 | 1.01 |
| ***Brain*** | 8.10 | 41.1 | 0.86 | 1.04 |

***Figure 1.*** *Human-head models*



*a) SAM*



*b) Heterogeneous spherical model*

## *c. Mobile phone models*

Four types of mobile phone models were defined, namely, a generic phone 1: quarter-wave monopole mounted on a perfectly conducting box; generic phone 2: quarter-wave monopole mounted on a box consists of perfect electrical conductor, plastic insulator, rubber insulator; resonant dipole antenna, dipole antenna with capacitive loads. The dimensions and electromagnetic parameters of the models are shown in Table 2.

***Table 2.*** *The dimensions and electromagnetic parameters of the phone models*

| *Mobile phone model* | *Antenna, length, diameter* | *Shape, dimensions and electromagnetic parameters* |
|---|---|---|
| **Generic phone 1: quarter -wave monopole mounted and centered on the upper side of a perfectly conducting box** | 78 mm (length);<br>1 mm (diameter) | Perfectly conducting box 42 mm (width) x 102 mm (length) x 21 mm (depth)<br>Material: Perfect Electric Conductor (PEC) |
| **Generic phone 2: quarter-wave monopole mounted and centered on the upper side of a box consist of perfect electrical conductor, plastic insulator, rubber insulator** | 76 mm (length);<br>1 mm (diameter) | Box consist of:<br>Perfect electrical conductor<br>40 mm (width) x 100 mm (length) x 1 mm (depth)<br>was covered symmetrically with a plastic insulator 42 mm (width) x 102 mm (length) x 21 mm (depth) with electromagnetic parameters: relative permittivity 4, conductivity 0.04 S/m |
| **Dipole antenna with capacitive loads** | 119 mm (length)<br>1 mm (diameter) | Perfectly conducting cylinders in the ends of dipole with diameter 12 mm and length 3 mm<br>Material: PEC |
| **Resonant dipole antenna** | 149 mm (length)<br>1 mm (diameter) | Material: PEC |

## *d. Head and phone model alignment*

After importation of the SAM in FDTD mesh, it was rotated 60 degree around y-axis of Cartesian coordinate system and translated so that the longitudinal axis of the mobile phone models aligned with the M-LE (Mouth-Left Ear) line of the SAM. Additional translations of SAM were made to accomplished coincidence between the feeding point of the phone model antenna and the LE point on the SAM surface.

We have been investigated three cases according to distance between feeding point of the phone model antenna and the nearest point of the equivalent head tissue of SAM. They are illustrated in Table 3.

**Table 3.** *Codes for Different Cases*
***A:** Distance between feeding point of the phone model antenna and outer surface of the SAM shell;*
***B:** Distance between feeding point of the phone model antenna and equivalent head tissue of SAM*

| CASE № | Phone model | A | B | Note |
|---|---|---|---|---|
| 1 | *Generic phone 1* | 21 mm | 27 mm | Contact between perfectly conducting box and outer surface of the SAM shell |
| | *Generic phone 2* | 21 mm | 27 mm | Contact between plastic box and outer surface of the SAM shell |
| | *Dipole antenna with capacitive loads* | 4 mm | 10 mm | |
| | *Resonant dipole antenna* | 4 mm | 10 mm | |
| 2 | *Generic phone 1* | 21 mm | 27 mm | Contact between perfectly conducting box and outer surface of the SAM shell |
| | *Generic phone 2* | 21 mm | 27 mm | Contact between plastic box and outer surface of the SAM shell |
| | *Dipole antenna with capacitive loads* | 21 mm | 27 mm | |
| | *Resonant dipole antenna* | 21 mm | 27 mm | |
| 3 | *Generic phone 1* | 24 mm | 30 mm | |
| | *Generic phone 2* | 24 mm | 30 mm | |
| | *Dipole antenna with capacitive loads* | 24 mm | 30 mm | |
| | *Resonant dipole antenna* | 24 mm | 30 mm | |

In order to define the feeding point of phone model antenna positioning with respect to the heterogeneous spherical model, a Cartesian coordinate system attached to the phantom center has been considered. We have been assumed that feeding point of resonant dipole antenna is located 4 mm away from the surface of the spherical heterogeneous head model.

## 3. RESULTS

All results were normalized to net input power level 1W for each mobile phone model.

### *a. Distance between the antenna feeding point and SAM*

The maximum 1-, 10-g, average SAR in whole SAM and SAR average to the mass of one cell obtained for each case from Table 3 are shown in Figs 2 -4.

The results show that SAR values in SAM varied by the distance to antenna feeding point. From the results shown of Fig. 2 (case 1 Table 3) we can see that resonant dipole provokes peak SAR values average to 1-g and 10-g in SAM. The peak SAR average to whole exposed object ($SAR_{WEO}$) value is observe, when dipole antenna with capacitive loads has been used like a source of electromagnetic field (EMF). In Case 1 the capacitive loads distribute additional electric field along dipole length. This field interacts to bigger surface from SAM, and carry out to peak $SAR_{WEO}$.

**Figure 2.** *SAR in SAM for Case 1 from Table 3*

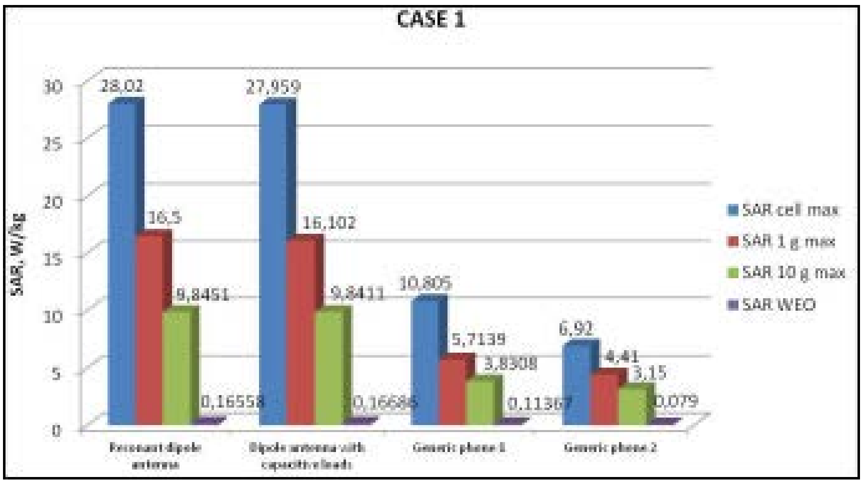
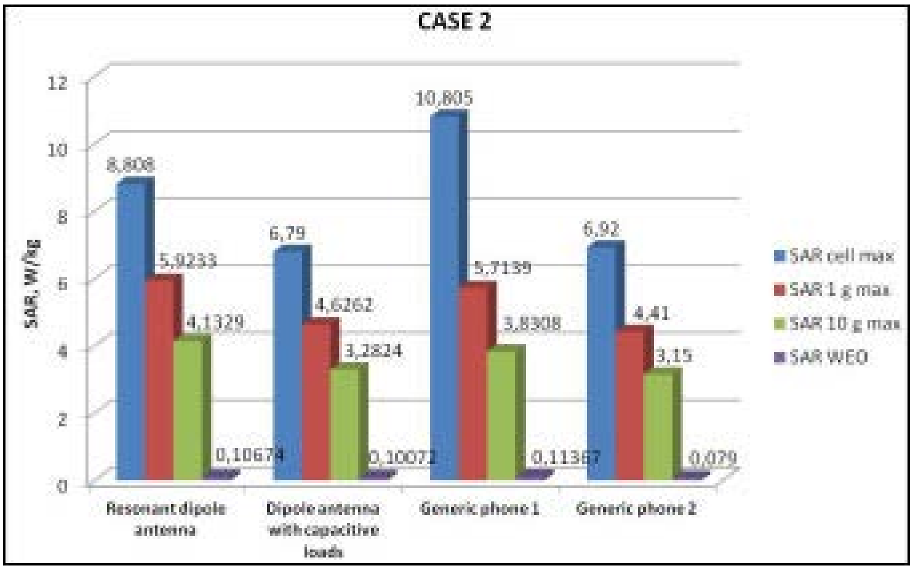


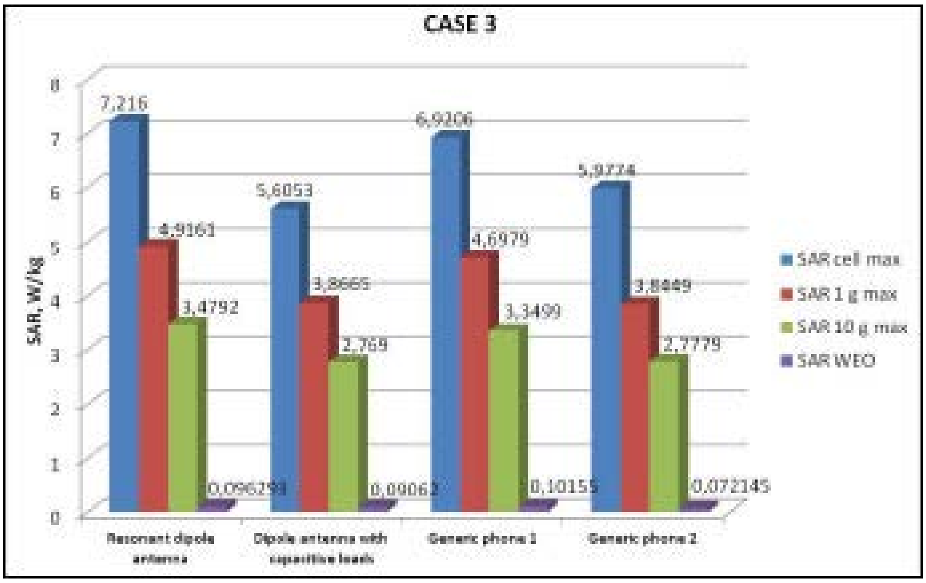
*Figure 3. SAR in SAM for Case 2 from Table 3*




To evaluate the effects of the distance between antenna feeding point and SAM over SAR values we also calculated the SAR distribution for Case 2 in Table 3. In this case the distance is kept constant 21 mm between phone models feeding point and SAM. As we can see from Table 3 the models Generic phone 1 and Generic phone 2 have a contact with SAM surface along line BM. The results presented of Fig. 3 show, that the peak SAR value average to the mass of a cell ($SAR_{cell\ max}$) can be seen when Generic phone 1 is a source of EMF. Compared to the rest mobile phone models, this peak value arise according of two facts: 1) presence of a contact between conductive surface of the metal box and SAM; 2) the smallest distance between tissue equivalent liquid and conductive surface of the source of EMF.

A detailed comparison between the results from resonant dipole and Generic phone 1 (Fig. 3) show that resonant dipole leads to the peak SAR value average to 1 g ($SAR_{1\ g\ max}$). The results show, that the Generic phone 1, have a contact to SAM surface, cause the biggest SAR values in volume much smaller than 1 cm3 with mass 1 g and mass density 1000 kg/m3, namely just in contacting point and in the cells around it. The resonant dipole irradiates bigger area of SAM surface to electromagnetic energy, and that is provoking the peak $SAR_1$ g max. According to 10-g average mass ($SAR_{10\ g\ max}$) we can examine analogous results.

*Figure 4. SAR in SAM for Case 3 from Table 3*




To evaluate influence of the contact between metal box and SAM surface over SAR values, we carried out investigations when the distance between feeding point and SAM is 24 mm (Case 3, Table 3). In this case for all mobile phone models a contact to SAM absent. As can be seen from Fig. 4 the peak SAR values were observe ($SAR_{cell\ max}$, $SAR_{1\ g\ max}$, $SAR_{10\ g\ max}$, $SAR_{WEO}$), when resonant dipole antenna has been a source of EMF .

Compared results presented of Figs. 3 and 4 we can conclude that SARWEO depending of the form, size, distance and orientation of EMF source to the dielectric body.

Presented SAR results in SAM for all investigated distances determinate that resonant dipole ensures the peak SAR values in dielectric body, when the contact between conductive antenna surface and SAM is absent. A contact to conductive structure of the phone model provokes the peak SAR values average to the mass of a cell or to the mass of some cells, which volume is smaller than 1 cm3.

### *b. Electrical parameters and characteristics of mobile phone models. Results of the SAM*

In this section we evaluated the influence of a homogeneous human head model over electrical parameters and characteristics of mobile phone models. The gain patterns in E- and H- plane of the phone models with and without SAM are shown of Figs. 5 and 6, respectively.

***Figure 5.*** *Gain patterns in E- plane of the phone models with and without SAM*

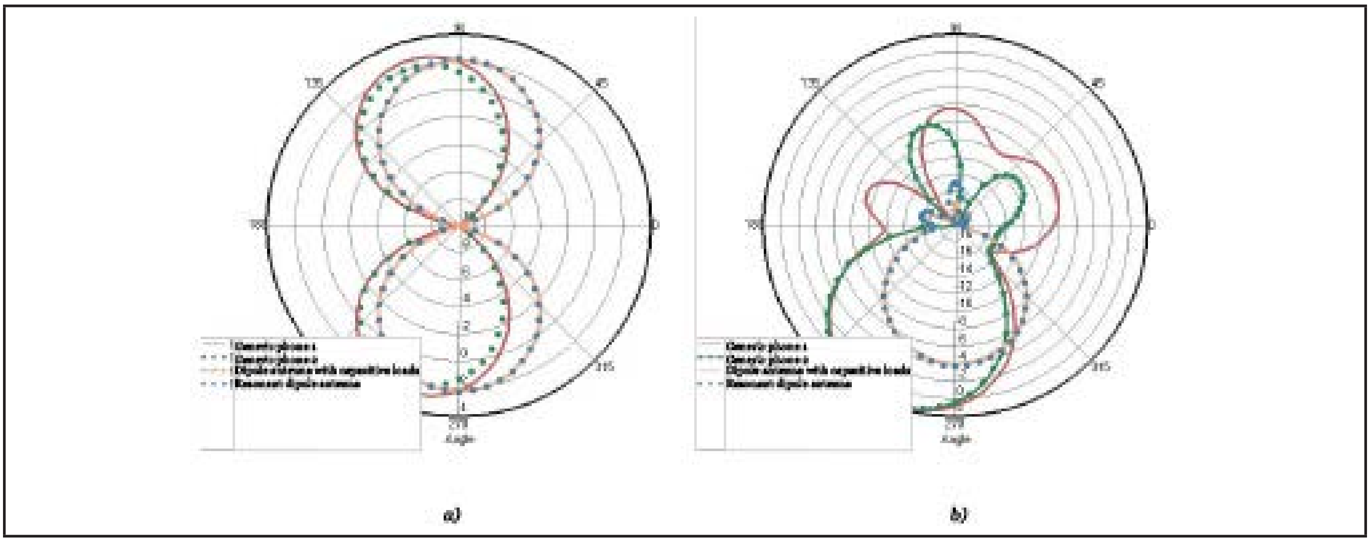
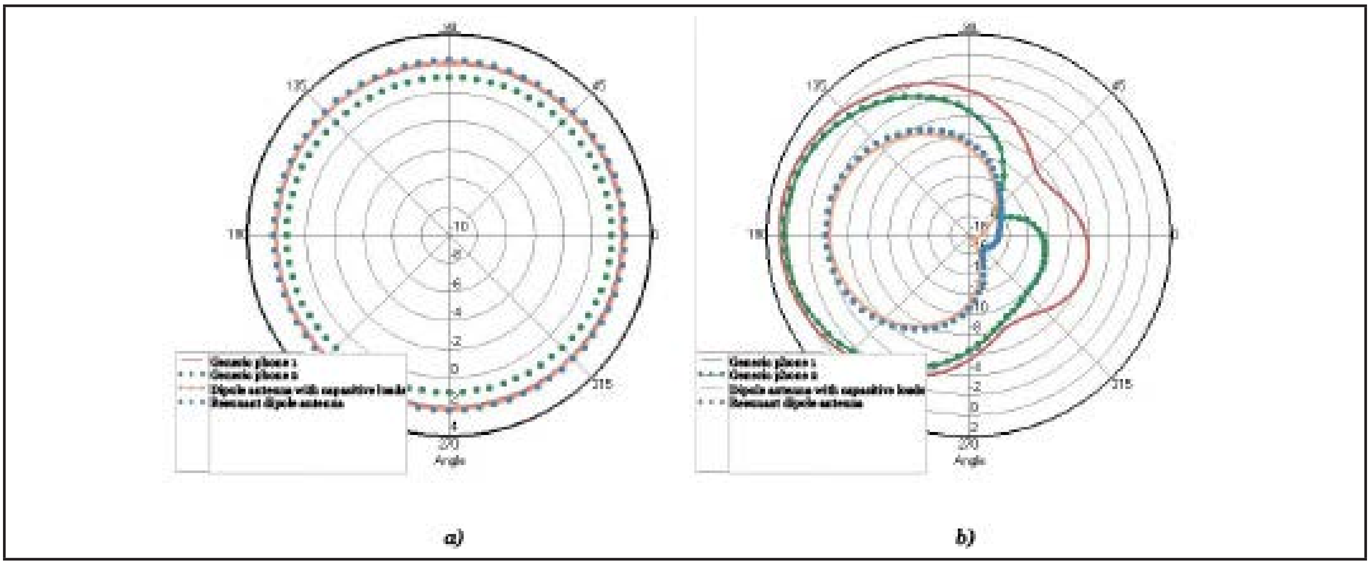



***Figure 6.*** *Gain patterns in H- plane of the phone models with and without SAM*




As can be seen in the Fig. 5 a) gain patterns for Generic phone 1 and Generic phone 2 are slightly asymmetric in the azimuthal plane. According to gain patterns in H-plane in case of free space radiation (Fig. 6 a) we can conclude that all models are omnidirectionaly and have the same gain in far-field in this plane.

In Figs. 5 a) and 6 a) are presented the peak gain values in absence of SAM. The peak gain for resonant dipole and dipole antenna with capacitive loads is 2 dB. This value is smaller than theoretically peak gain of $\lambda/2$ dipole antenna (2.15 dB). The above difference is related to shorter length of investigated models according to 900 MHz, namely 119 mm and 149 mm, respectively for dipole antenna with capacitive loads and resonant dipole.

Results depicted of Fig. 5 a) show, that when the mobile phone is presented like quarter-wave monopole mounted on a perfectly conducting box (Generic phone 1, Table 3) the peak gain of antenna system enhanced (λ3 dB). When the mobile phone is presented in numerical calculation like quarter-wave monopole mounted on a box consist of perfect electrical conductor, plastic insulator, rubber insulator (Generic phone 2, Table 3) the peak gain is reached (λ2 dB), due to dielectric loss in phone body and asymmetric loaded antenna system.

As can be seen of the Figs. 5 b) and 6 b), the far-field patterns for all investigated models are significantly modified by presence of SAM. The results show that the bigger part of the irradiated electromagnetic energy is absorbed in SAM. The gain patterns presented of Figs. 5 b) and 6 b) show, that absorbing energy is bigger (smaller antenna gain toward to SAM) when like a source of EMF are used symmetrical dipoles. The far-field patterns in E- and H- plane for Generic phone 1 and Generic phone 2 are more slightly influenced from SAM.

From Fig. 6 a) we observe the same behavior of the radiation patterns of investigated phone models without SAM. We can see that resonant dipole antenna produces the biggest value of antenna gain that will be provoking the biggest SAR values according to rest mobile phone models. This provides confidence in the ability to approximately assess the electromagnetic interactions between handset antennas and nearby human head using simplified phone model, namely resonant dipole antenna.

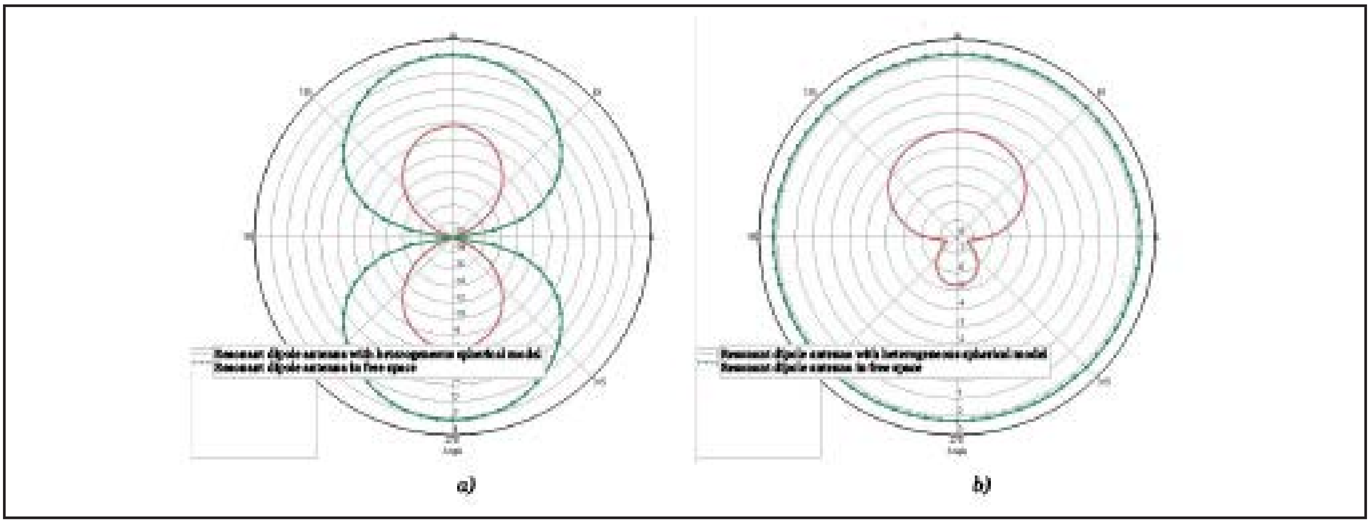
### c. *Electrical parameters and characteristics of mobile phone models. Results of the heterogeneous spherical head model*

Here, we introduce the influence of heterogeneous human-head model over electrical parameters and characteristics of resonant dipole antenna.

The gain patterns of the resonant dipole antenna with and without heterogeneous spherical model are shown of Figs. 7 a) and 7 b). As compared with the free space antenna gain (~2 dB), the peak antenna gain is reduced by ~8 dB toward the spherical head model (Fig. 7 a)). It is observed that, in presence of the heterogeneous head model, the gain pattern of the resonant dipole antenna is significantly distorted and clearly loses its omnidirectionaly in H-plane (Fig. 7 b).

It can also be observed, by comparing Figs. 6 a) and 6 b), Figs. 7 a) and 7 b), that the gain of the resonant dipole antenna is significantly reduced by ~ 16 dB (Fig. 6) in direction of SAM, while in direction of heterogeneous spherical model the gain of the resonant dipole antenna is reduced by ~ 7 dB (Fig. 7). The bigger antenna gain of resonant dipole in presence of heterogeneous model is in consequence of the smaller size than SAM.

***Figure 7.*** *Gain patterns in H- plane of the phone models with and without heterogeneous spherical model*




## 4. CONCLUSION

In this paper, a set of FDTD numerical experiments has been performed in order to investigate the effect of distance between the antenna feeding point and human-head models on predicted SAR values. Furthermore, a detail analysis of influence of human-head model over electrical parameters and characteristics of mobile phone models has been presented.

The obtained results from as support following conclusions:

Generic phone 1, in case of contact between perfectly conducting box and outer surface of the SAM shell, causes the biggest SAR values in volume much smaller than 1 cm3, namely just in contacting point (Fig. 3). Compared to the rest mobile phone models, this peak value arises according of two facts: 1) presence of a contact between conductive surface of the metal box and SAM, and the smallest distance between tissue equivalent liquid and conductive surface of the source of EMF; 2) the biggest value of the antenna gain according to the rest phone models (Fig. 5a)).

Presented SAR results in SAM for investigated distances determinate that resonant dipole provokes the peak SAR values in dielectric body, when the contact between phone model and SAM is absent (Fig. 4).

The SAR depending of the form, size, distance and orientation of EMF source to the dielectric body (Figs. 2-4).

In presence of the homogeneous and heterogeneous head model, the gain pattern of the investigated models of mobile phones (generic phone 1, generic phone 2, resonant dipole antenna and dipole antenna with capacitive loads) is significantly distorted (Figs. 5 b)-7b)) and clearly loses its omnidirectionaly in H-plane (Figs. 6b)-7 b)).

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# IMPROVEMENT OF EXPERIMENTAL SYSTEM FOR TRACKING THE THRESHOLD OF CURRENT PERCEPTION

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## ABSTRACT

*The possible health effects of exposure to electromagnetic fields have been worried. In our previous study about the health effects of contact current, the experimental system which measures the threshold of current perception for Japanese was constructed. In this paper, we have improved the system by reconsidering the instruments and the measurement methods. As a result, the measurement becomes steady, measuring time is shortened, and then the load to the subjects has reduced. In addition, the gender difference and the age difference of the threshold are confirmed by our preliminary experiments.*

***Key words:*** *Radio frequency protection guidelines, Indirect coupling, Indirect effect, Contact current.*

## 1. INTRODUCTION

The health effects of the electromagnetic fields is one of major concerns in the world while the technologies using electronic device are evolving. In Japan, a part of the rf protection guidelines concerning the direct effects to the human body of radio wave is implemented as a technical regulation. The clause of contact currents, which is for an indirect effect of electromagnetic fields (EMFs) involving human contact with the ungrounded metallic objects in the strong field, is included in the rf protection guidelines, based on the experimental results by Chatterjee et al.[1] on the pain and the perception for current stimuli. However, it doesn't become a technical regulation because there are a lot of uncertainties, that is, the measuring instrument and the metrology for the contact current measurement have not been established and the verification experiments for the threshold of current perception have not been done enough to make a consensus. Therefore, we plan the experiments of current perception measurement in many subjects. In this paper, we propose a new, user friendly, safe experiment system for current perception measurement, which an improved version of our previous system[2-5].

The contact current is an electric current that flows to the human body through the contact point when a grounded person touches the ungrounded metallic object put under a strong EMF. The situation in which the contact current is potentially produced is called indirect coupling. For example, it is a situation that the contact current flows to the human body when the person touches an ungrounded bus in the vicinity of the broadcasting antenna.

Indirect effect happens in the frequency up to 10 MHz, the sense of galvanic stimulation is predominant in about 100 kHz or less and thermal sensation is in about 100 kHz or more. Table 1 shows the guidelines of the contact current in these frequency bands established by ICNIRP (international commission on non-ionizing radiation protection)[6].

***Table 1.*** *Guidelines for Contact Currents (ICNIRP 2010)*

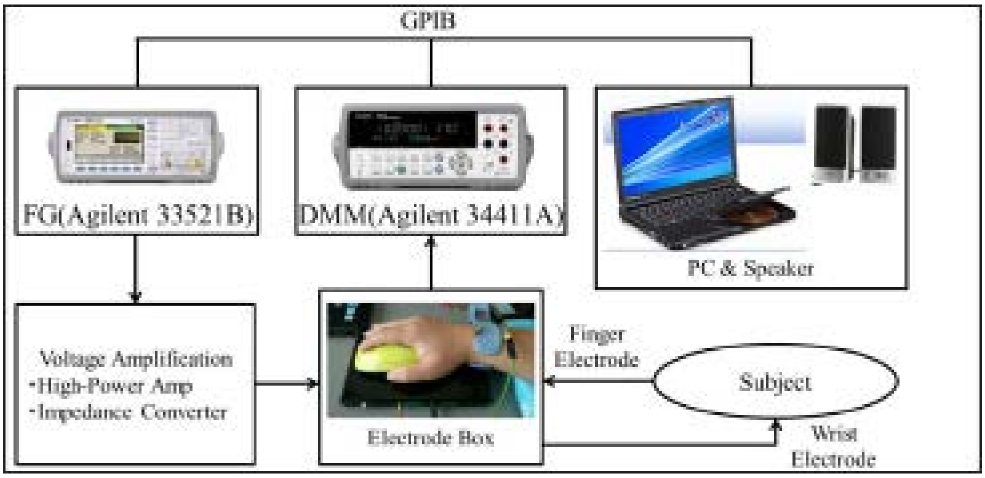
| Exposure characteristcs | Frequency range | Maximum contact current (mA) |
|---|---|---|
| Occupational exposure | Up to 2.5 kHz<br>2.5 ~ 100 kHz<br>100 kHz ~ 10 MHz | 1.0<br>0.4 f kHz<br>40 |
| General public exposure | Up to 2.5 kHz<br>2.5 ~100 kHz<br>100 kHz ~ 10 MHz | 0.5<br>0.2 f kHz<br>20 |

*Note: $f_{kHz}$ is the frequency in kHz*

## 2. EXPERIMENTAL SYSTEM FOR TRACKING THE CURRENT PERCEPTION THRESHOLD

Figure 1 shows the block diagram of the experimental system.

***Figure 1.*** *Block diagram of experimental system*




The equipments in our new system are electrode box of the special order, limb electrode clip for ECG (Fukuda Denshi, TE-43), function generator (FG: Agilent 33521B), digital multimeter (DMM: Agilent 34411A), USB/GPIB interface (Agilent 82357B), power amplifier (Agilent 33502A) for low frequency, rf amplifier (R&K A010K251-4444R) for high frequency, 30 dB attenuator (Agilent 11708A), a homemade impedance converter, PC and speakers. Moreover, to confirm the operation of the program safely and easily, the equivalent circuit of the human body has been developed.

### *a. Electrode Box*

The emergency stop switch and the fuse are equipped in the electrode box directly touched by the subjects. In our previous version, the stimulating electrode for a finger tip was fixed on the flat board. The subject should fix a finger tip on the electrode with a small finger extension. During a long experiment, the subjects became tired, because of keeping their fingers at the same position, and it often disturb the perception experiment. We fixed the stimulation electrode in a mouse shape box so that the subject is able to touch the electrode more naturally.

### *b. Wrist Electrode*

The wrist electrode in a previous version was a velcro belt type that pasted the aluminum tape. Contact pressure and contact area of the electrode are unstable, and then it has often influenced the perception current threshold. A wrist electrode with the limb electrode clip for ECG made the contact pressure and the area stable, and lessened the disturbance of the threshold experimant. Figure 2 shows the electrode box and the wrist electrode.

***Figure 2.*** *Electrode box and wrist electrode*

### *c. Function Generator (FG)*

Agilent 33521B is used as a device that generated the electric current. Because FG is controlled with PC through the USB/GPIB interface, the experimenter need no operation except at the start of experiment. Table 2 shows its main specification.

*Table 2. Specification of Function Generator*

| Model | Agilent 33521B |
|---|---|
| Output | 11 mVpp ~ 10 Vpp into 50 Ω<br>2 mVpp ~ 20 Vpp into open circuit |
| Frequency range | 1 μHz ~ 30 MHz |
| Waveform | Sine, square, ramp, pulse, etc. |
| Interface | GPIB, USB2.0, LAN |
| Other function | Modulation (AM, FM, PM), Burst |

In previous vertion, the relay sound noticed the subjects when the output voltage of FG was changed. It sometimes embarrasses the subject performance. We, therefore, delated the sound, which made the subject readily concentrate on the current perception task.

The electric current duration is controlled by using the burst mode so that beginning and the end of the waveform may become zero.

### d. Digital Multimeter (DMM)

Agilent 34411A is used as a multimeter for the current measurement. Because DMM is controlled with PC as well as FG, the experimenter need not operate it except when the power supply is turned on. Table 3 shows its main specification.

*Table 3. Specification of Digital Multimeter*

| Model | Agilent 34411A |
|---|---|
| Frequency range | 3 Hz ~ 300 kHz (AC voltage)<br>3 Hz ~ 10 kHz (AC current) |
| Maximum reading rate | 500 readings/sec (AC voltage)<br>50000 readings/sec (DC voltage) |
| Interface | GPIB, USB2.0, LAN |
| Other function | Pre-triger, data logging |

The upper limit of the measurement frequency of DMM is 10 kHz and 300 kHz in the current measurement and the voltage measurement, respectively. In our previous study, the current was measured directly in the experiment of 10 kHz or less, and the method of calculating the electric current from voltage drop of the resistance of 10 ohms was used in the experiment above 10 kHz. Therefore, it was necessary to change wiring around DMM on the boundary of 10 kHz. Then, we improve to be able to measure up to 300 kHz without changing wiring by unifying it to the measurement techniques of calculating the current from the voltage drop.

In our previous version, the relay sound was generated when DMM was measured. The new system eliminated the sound using quiet commands.

### e. Power Amplifier for Low Frequency

Agilent 33502A is a power amplifier for low frequency. Table 4 shows its main specification.

*Table 4. Specification of Power Amplifier*

| Model | Agilent 33502A |
|---|---|
| Output | Up to 50 Vpp (+/-25 V)<br>200 mA |
| Frequency range | DC ~ 100 kHz |
| Input impedance | 50 Ω \| 1 MΩ |
| Interface | USB2.0, LAN |

This amplifier is able to output five times of the input voltage. 33502A has two input-output channels, and they can be used with one in two systems. In that case, the experimenters should operate it manually because it cannot control with PC.

## f. RF Amplifier for High Frequency

R&K A010K251-4444R is an amplifier for high frequency. Table 5 shows its main specification.

**Table 5.** *Specification of RF Amplifier*

| Model | R&K A010K251-4444R |
|---|---|
| *Frequency range* | *10 kHz ~ 250 MHz* |
| *Gain* | *+44 dB* |
| *Input impedance* | *50 Ω* |
| *Output power* | *25 W* |

An attenuator is necessary for the input because the gain is very large. The output voltage of 35 V can be obtained with this amplifier for 50 ohms load. Experimenters need operate this amplifier only at the start of the experiments.

## g. Impedance Converter

It is necessary to make impedance matched to inject the rf power in the human body efficiently. The human body impedance is about 1 kilo-ohm in the frequency of 100 kHz or more. We made the impedance converter with the ferrite core and the copper wire for impedance matching in the high frequency experiment. Figure 3 shows the photograph of the impedance converter. The turns ratio is 16:70. The output impedance increases to about 20 times that of the input side.

Figure 4 shows a frequency dependence of the ratio of no load output voltage and input voltage in the impedance converter. It is found that the output voltage increases enough in the frequency of 30 kHz or more.

**Figure 3.**
*Impedance converter*

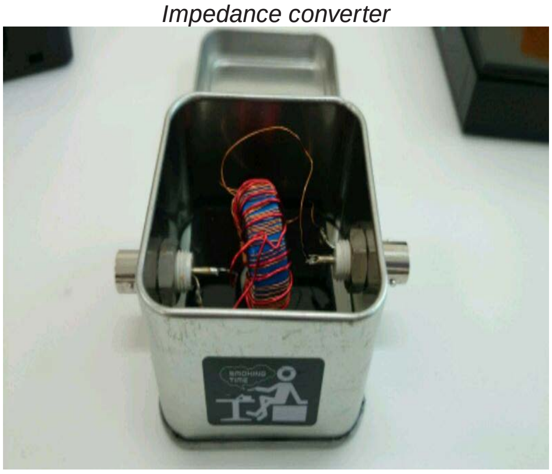
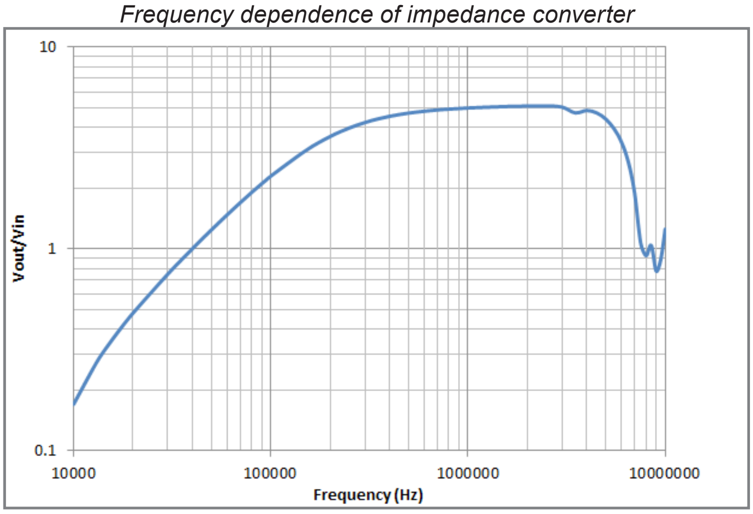


**Figure 4.**
*Frequency dependence of impedance converter*




## h. Equivalent Circuit

We have developed the simple equivalent circuit between the wrist and the tip of a finger of the human body by using the capacitor of 4.7 nF, and resistance of 220 kilo- and 1 kilo-ohm. It is connected instead of the hand at the test of the program. Figure 5 shows the circuit diagram.

**Figure 5.** *Equivalent circuit*

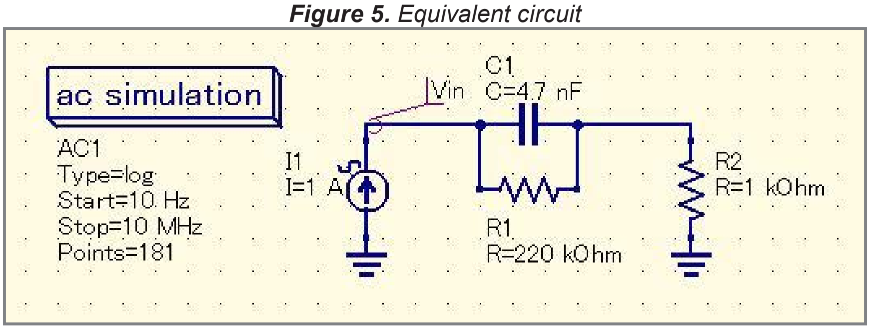
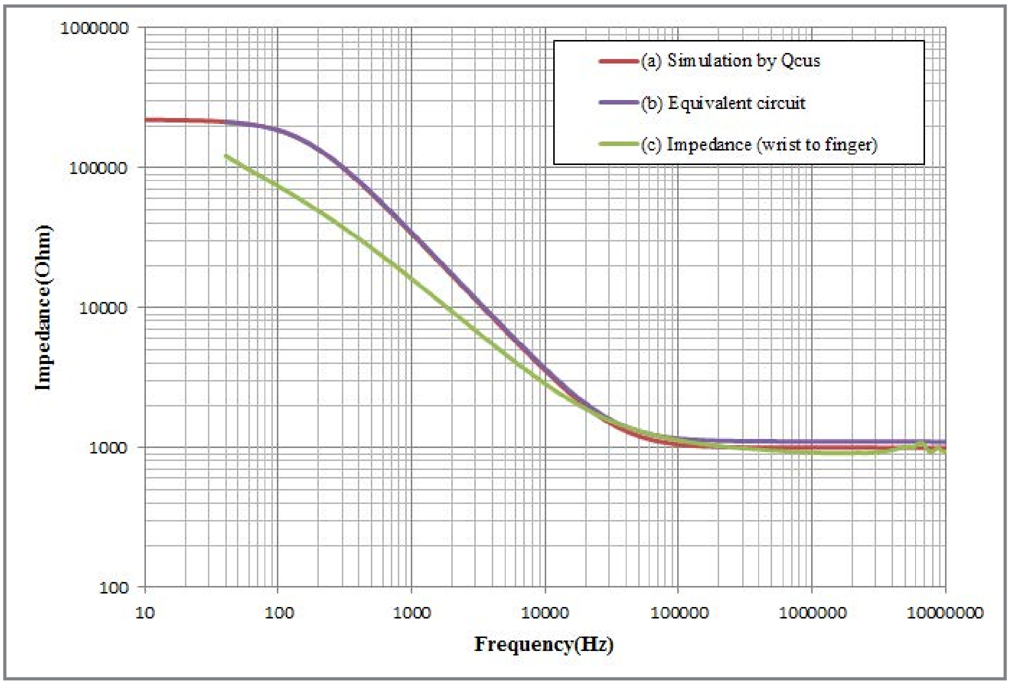


Figure 6 shows the impedance measurements of this circuit. This figure compares the measurement impedance between the wrist and the tip of a finger with the value calculated by circuit simulator Qucs[7].

### 3. MEASUREMENT PROCEDURE

We have tracked the perception current threshold by two methods, method of limits and method of constant stimuli.

***Figure 6.*** *Impedance of equivalent circuit*




### a. Method of Limits

First of all, the method of limits injects electric currents from a subthreshold level into the subject. The subject declares when he/she perceives the electric current while gradually increasing the current intensity at a fixed rate, and the current value at that time is recorded automatically. This procedure is performed three times, and their mean is judged as the measured threshold.

The method of limits tends to be larger than the true threshold because of subjects' adaptation.

### b. Method of Constant Stimuli

We are able to measure the threshold more accurately using the method of constant stimuli.

The electric stimulus of one second duration is presented to the subject ten times, and he/she answers the perception of stimulus in each event. These ten events are one inning. Those results are statistically processed at the end of each inning, and then the current value of which perception is expected at the probability of 50 % is determined to be the threshold by using logistic regression analysis. When the reliable threshold is not determined due to bias of results or the lack of number of data, the inning is added one by one.

In the previous version, we used the threshold voltage obtained by the method of limits at the first trial in the method of constant stimuli, which often forced us to do manyinnings to determine the final threshold. In the present new version, therefore, we used the middle intensity between the upper and lower limit at the first trial in the threshold determination.

At the end of innings, the graph is depicted from all results obtainded as Figure 7. Gnuplot[8] is used for the graph drawing. The plots of the latest inning is classified by color.

## 4. RESULTS OF PRELIMINARY EXPERIMENTS

Preliminary experiments in the frequency range from 50Hz to 300kHz have been performed for 22 subjects. Subject's lineup are each of six men and women in their twenties (M20, F20), and six men and four women from fifties to sixties (M50-60, F50-60). The mean of the current perception threshold of each category is plotted in Figure 8.

According to this figure, the value of F20 is the lowest and the value of M50-60 is highest all over the frequencies. There is a significant difference in most frequencies for the age and the gender.

## 5. CONCLUSION

In this paper, we proposed some improvements in the experimental system for measuring the threshold of human current perception.

The improvement of the electrodes makes the measurements more stable and safe. Unifying amperometries expands the frequency range of the system for the ELF-VLF band. As a result, it can integrate into two kinds of systems for ELF-VLF and LF(-MF) band though three kinds of systems for ELF, VLF and LF(-MF) band were necessary in our previous version. The duration of the experimant is shortened by our refinement of the measurement method.

***Figure 7.*** *Example of results (method of constant stimuli)*

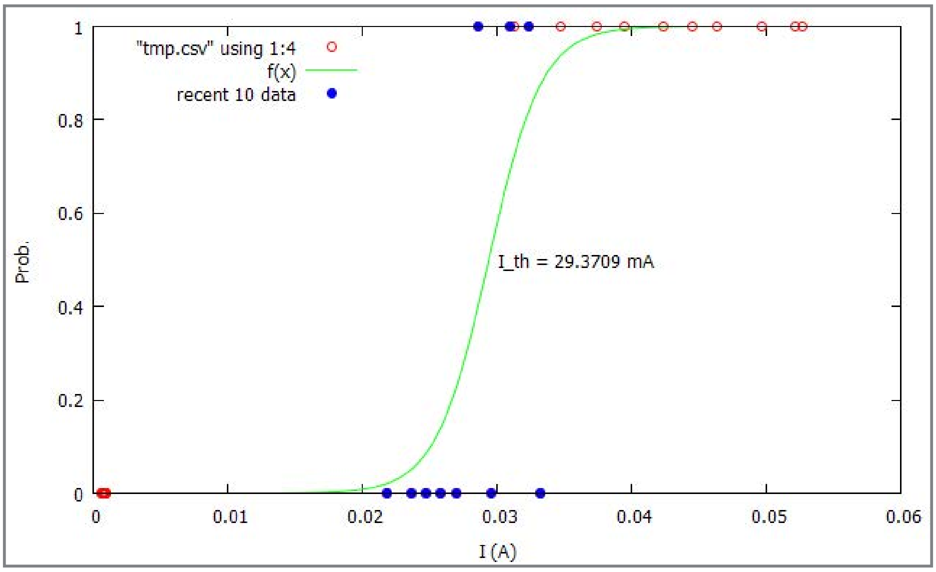
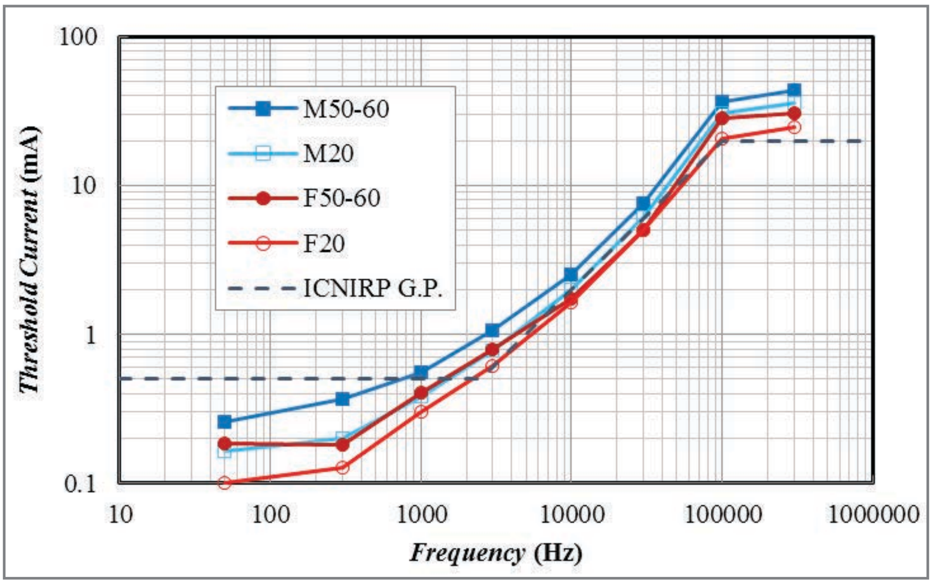



***Figure 8.*** *Frequency dependence of threshold current for perception*



We performed a preliminary experiment by using this new measurement system. Consequently, the gender difference and the age difference in the perception current threshold are confirmed.

The measurement using a lot of subjects is being advanced now, and further improvements of the experimental system are requested to measure them efficiently more safely.


### *ACKNOWLEDGMENT*

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# EMF METERS VALIDATION IN SITU

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_ABSTRACT_

_The electromagnetic (EMF) measurements for labor safety and environment protection purposes are usually done in conditions dramatically different if compare to the laboratory ones. The meters may be damaged during transportation, they may be affected by local environment or their indications may be false understood by a measuring team. It may lead to measuring errors and then to false interpretation of measuring results. In order to create a possibility to check a meter during the measurements several proposals of the meter testers were worked out and introduced to metrological practice. The latest allow a validation of almost any types of meters available on the market. Such a possibility of validation is required from authorized labs by law in Poland. Presented solutions may be of use for metrologists and meters' manufacturers worldwide._

**Key words:** _labor safety, environment protection, EMF quantifying, EMF meters validation._

## 1. NTRODUCTION

Electromagnetic field (EMF) quantifying for labor safety and environment protection purposes is usually done in natural conditions, which are far away from laboratory ones. Thus, apart from sources of measuring errors, typical for the measurements in the near field and complex EM environment [1], the measurements may be affected by possible damages of a meter during transportation or/and by local conditions that may lead to other failures or mistakes that may falsify the measurements results and, as a result, conclusions and recommendations formulated on their ground (for instance: necessity of a radiation system modifications, limitation of a working time or/and procedures, medical investigations, extra payment). It has lead to a necessity of the meter testing (validation) before, during and at the end of the measurements. These were three main reasons to start studies in the field to fulfill the necessity:

***1. Formal.***

Polish protection standards require that any laboratory performing the measurements, and authorized by the Polish Accreditation Center, is able to check a meter (apart from periodic calibration) at the place of measurements. before and after them.

***2. Technical.***

The measurements are often performed in heavy industrial conditions where the meter may be affected e.g.: by chemicals, noises, vibrations or any radiations. Time alternations (modulation) of measured field are usually different than CW field applied, as a rule, for meters calibration. The meter may be damaged as a result of transportation through a traceless. It works in climatic conditions (temperature, pressure, humidity) different to laboratory or/and calibration ones. It may be overloaded that may introduce deformations in its dynamic characteristics, especially in the most sensitive range (without a damage of the meter) and the others.

***3. Human.***

A measuring team is often educated in chemistry, acoustics or ionizing radiation, as the most dominating factors in an industrial environment. Thus the EMF measurement is often a "bay product" of the team that may lead to mistakes or gross errors due to misunderstanding EMF problems. Moreover, even experienced team may be disappointed by low EMF levels near big power sources (e.g.: close to well screened transmitting devices) and quite high EMF intensities near low power devices (e.g.: personal communication devices or domestic appliances).

Poland was one of the first countries where legal measures were introduced in order to protect population against unwanted exposure to EMF. The EMF is not detectible by organoleptic ways and typical EMF meters, applied for the far field measurements, are here useless. As a result there was a necessity to construct specific equipment designated for the field measurements in the near field. The first series of selective E- and H-field meters were designed at the Technical University of Wroclaw. The meters were designated mainly for measurements within-and around BC and TV transmitting centers. Second generation of wideband E-, H- and S-field, type MEH meters, more universal and able to work in much wider frequency range, was designed and widespread through the country and abroad. At the beginning the meters were equipped with probes of sinusoidal pattern; i.e.: flat loop for H-field measurements and dipoles for E and S measurement. Doubts regarded to accuracy and correctness of the measurements in natural conditions have lead to a problem of a necessity to a meter validation in situ at the very beginning, while the first protection standards against unwanted exposure were formulated. Activities in the field of a possibility to construct quite simple, inexpensive and able to work in any conditions device that assure a possibility to check a meter in any conditions were started almost parallel with works devoted to supply EMF meters for work safety and sanitary purposes for national communications, industrial and environmental authorities. In this paper are presented several our solutions and proposals that may be of concern for meters manufacturers, labs and measuring teams. The presentation is done in historic order, starting from our first proposal, devoted only for checking our EMF meters, ending at the most universal ones that make it possible to check any type of meter. The latest were especially important when Polish market was opened for worldwide firms and more and more complex modulations came to use.

## *2. PROPOSALS AND SOLUTIONS*

### *2.1 USMEH-1*

The first solution, shown in figure 1, was a version of a secondary standard and made it possible to check only Polish EMF meters type MEH, equipped with E-field probes with single dipole antennas and H-field probes with single loop antennas presented in the figure. During checking the E-field probe was immersed between plates of a capacitor at the bottom of the compartment in which the probe was placed. A flat loop antenna of the H-field probe during testing was immersed in a pocked in the back side of the device, coupled with a coil, printed at the rear wall. The capacitor and the coil were fed from a 1 MHz generator of a regulated output voltage. The voltage was indicated by a analogue meter. A tested meter work was assumed as correct if full scale indication of the meter, at the most sensitive measuring range, appeared while the tester's indicator shown a half scale division. The possibility of the tester's voltage (EMF intensity) regulation has allowed the tested meter dynamic characteristics checking at the most sensitive range. It has created a possibility to prove if the meter was not overloaded or overheated during measurements that usually leads to the characteristics deformation. A return of the characteristics to its introductory shape, due to overheating, is quite long, while strong overloading leads to a permanent deformation of the characteristics. A tester's output of a regulated DC voltage made it possible to check sensitivity of the meters indicating part. Additional possibility it was a checking of loop antennas (the MEH type antennas were equipped with two loops, applied for different sensitivity ranges).

**Figure 1.** *MEH-type EMF meter validation in ISMEH-1 tester.*

## 2.2 UTEST-3

The first necessity to introduce a modification into the above solution was created by more and more popular applications of omnidirectional probes and wider offer of EMF meters on the marked. This solution, and following ones, is not as accurate and universal as the above one; however, they allow validation of different types of meters and probes, while the previous one was designated only to the MEH-type meters, equipped with sinusoidal probes, testing.

In any of the solution a validation is based upon notification of a meter indications after its calibration (or in a lab before measurements) and then comparing with indications in situ, during and after measurements. Apart from a possibility to check different types of meters and probes the solution, due to several generators working at frequencies between ELF and microwaves, allows the checking at frequencies at which a meter (probe) is to work. Instead of regulated voltage (field intensity) a constant voltage is applied here, with an assumption that the voltage is stable enough for validation purposes. A block diagram of UTEST-3 is shown in figure 2, while its application to a MEH type meter in figure 3. Separate generators fed electrodes for E-field probes validation and loops for H-field probes validation. Generated fields, in this case and in following ones, are of almost linear polarization. With no regard to it there is a possibility to check omnidirectional probes by the way of rotating them within the compartment in which a tested probe is immersed. Indications of the meter, during the rotations, should remind almost constant. Small variations of the indications illustrate deformations of the pattern while larger ones show a possible damage of tested probe.

***Figure 2.*** *Block diagram of UTEST-3*

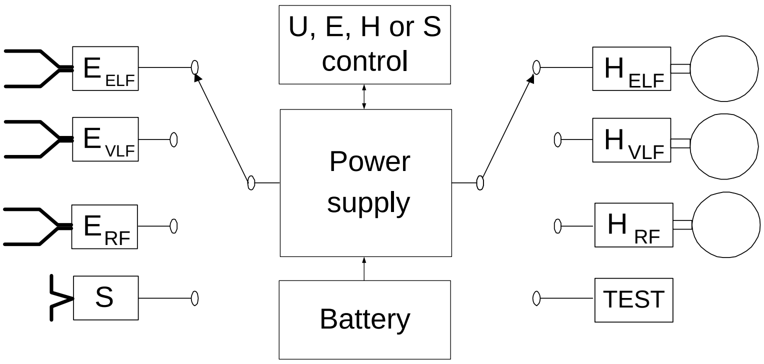


***Figure 3.*** *A MEH-type probe validation*

## 2.3 Examples of other solutions

The UTEST-3 tester allows validation of almost any type of meters and probes and, as a result, may be of use in labs equipped with several types of meters. In the case of smaller labs or institutions, where a single device is applied, there is more convenient to use a tester matched only to the type of the device. In order to satisfy users of different types of meters, different types of testers were proposed. In general these are simplified versions of the UTEST-3, adopted for checking a selected type of meter or probe. Examples of the testers are shown in figures 4 and 5. The first shows a PMM type meter checking using a UTEST-5 device, while the latter shows a UTEST-7 while an EMR and NBM-550 meter type is tested.

***Figure 4.*** *UTEST-5 during a PMM meter testing*

***Figure 5.*** *UTEST-7 with an EMR and NBM meter*

### *2.4 Nonstationary EMF meters testing*

As a rule EMF meters calibration is performed in CW fields. The same approach is applied in any tester, presented above. Then, this way calibrated meters, are used for measuring different time-varying (modulated) fields. Apart from huge errors resulted from such a methodology (suggested way of calibration, designated for standard types of meters, used in alternating fields measurements is presented in [2]) a measuring team may be disappointed, especially while more than one meter is used and any of them shows different indications. The difference may well exceed one order of magnitude and it increases while short, pulsed fields are measured. The worst case here are nonstationary fields, for instance fields in surroundings of rotating radar antenna. In the case suggested way of calibration, specific for any measured source, should be applied. A similar approach is proposed in validation meters during nonstationary EMF measurements.  A block diagram of the device is shown in figure 6 and its application (in laboratory conditions) in figure 7. The test set includes typical, microwave, Gun-diode generator, connected to a horn antenna for a measuring frequency range. The carrier-wave generator, working at frequency around that of the source to be measured, is fed from a pulse generator, which pulse modulation is similar to that of the source. Voltage from the pulse generator is keyed from a square-wave generator which pulse repetition time is proportional to an antenna of the source rotation time and duration of the pulses represents the antenna radiation pattern. An antenna (a meter) under test is placed at chosen (constant) distance away of the horn in the center of its main lobe. It is not rigorously required, but suggested, that the distance exceeds the near field boundary.

The approach makes it possible to validate a meter using signals in the form of train of pulses, similar to that in a measuring point. Unfortunately, contrary to the CW calibration methods, here is necessary to adopt the test set for specific condition of measurements.

Apart from the case of nonstationary EMF measurements the device may be useful during measurements of any field of time-varying amplitude.

***Figure 6.***
*Block diagram of  nonstationary test set*

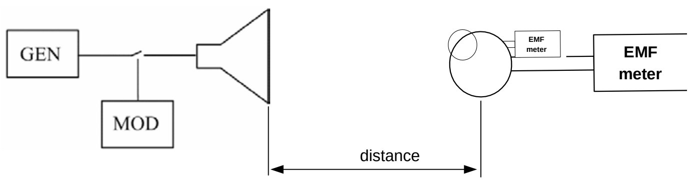


***Figure 7.***
*Checking a probe in nonstationary field*

### *3.  FINAL COMMENTS*

EMF surveying is usually performed in complex EM environment, in different meteorological conditions, in heavy industrial environment in a factory or a transmitting center, or similar place. These conditions may affect measuring team and measuring equipment used by the team. With no regard from obligatory, periodic calibration any device, exploited in these conditions, may be damaged; thus, a possibility of it's checking during the measurements is of primary importance. The authors, cooperating with Laboratory of EMF Measurements and Standards at the University, that is an accredited lab - authorized for meters calibration, have had many possibilities to see strange defected or damaged meters, brought for the calibration. Apart from newly bought meters' imperfections (as partly discussed in [3]) one of the most typical damage is inactivity of one of three sensors in omnidirectional probes (due to overloading or vibrations). Such a probe will work; however, its pattern became toroidal instead of omnidirectional. In other cases of damages of mechanical nature or due to so called "cold soldering" in a probe or in an indicating part circuitry a meter may work; however, its indications are usually false. Similar case was found in a meter with optic data transmission due to inappropriate voltage of a battery feeding its probe. When and where these damages appeared in the meters and how many measurements were performed using them is impossible to say. However, what was accuracy of these measurements reminds a rhetoric question – to remind: usually, on the basis of the measurements results are taken legal decisions devoted to necessary exposure limitation or similar. This authors' experience shows once more an advantage of the meters validation possibility.

Presented designs of meters' testers were designated mainly for labor safety or environment protection inspections, which usually perform the measurements outside a lab. With no regard to it a tester may be helpful in any laboratory involved in bioelectromagnetics, or even in electromagnetic compatibility, where EMF meters are applied. In the latter cases a checking of a meter may confirm correctness of an exposure system and assumed or estimated exposure conditions.

Similar solutions of meters testers were still not presented in the literature or available on the market. Any presented device is an original proposals that were designed at the Technical University of Wroclaw. However, the presentation is not of commercial character. The authors would like only to present advantages of a possibility to check meters in situ and possible solutions of devices for this purpose. This way the presentation is addressed as for people performing measurements (advantages of the approach) as for representatives of industry (necessity and a possibility to follow offered meters by testing devices).


## *ACKNOWLEDGMENT*

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# NUMERICAL MODEL OF HUMAN HOMOGENOUS HEAD WITH METALLIC GLASSES APPLIED IN BLUETOOTH APPLICATION

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ABSTRACT

*This paper presents investigation on human homogenous head model with spectacle frame to electromagnetic field from Bluetooth receiver placed inside the ear. Microstrip antenna working in ISM 2.4 GHz has been used. Proposed antenna size is 25x35x1,5mm is simulated on low cost FR4 substrate (εr=4.4, tanδ=0.035) and has VSWR=1.15 at bandwidth 4%. Three different settings of antenna regarding to head model with glasses has been studied in this paper. Results show that the shape of glasses and antenna rotation has remarkable impact to SAR value and distribution inside the human head model which in selected aspects might lead to increase antenna gain.*

***Key words:*** *SAR, human head model, microstrip antenna, glasses.*

## 1. INTRODUCTION

Development in telecommunication systems became natural in these days. Undoubtedly continuous research on improvement mobile phone antenna properties by creating more compact, multiband, low profile and durable lead to use more sophisticated methods of design. Recently, many novelty applications must keep up with the current trends, which force designers and researcher to create new good looking equipment and be eligible to fulfill electromagnetic requirements. Many antennas used in near wireless telecommunications such us: cordless headphones or Bluetooth wireless receiver has been studied [1-2] in the past. Those devices usually are in surrounding of the human head. It is obvious fact that part of the electromagnetic field radiated by the antenna is absorbed into the human body. The quantity of absorbed energy is evaluated as SAR coefficient.

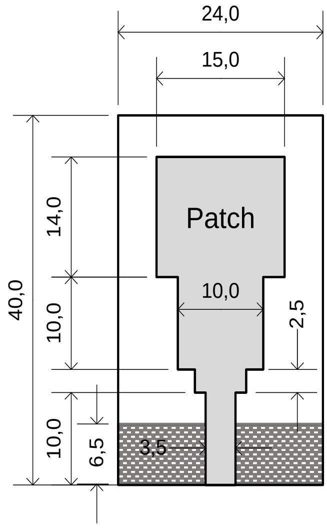
$$SAR = \rho E2/\sigma \qquad (1)$$

Where ρ is tissue density, E is rms value of electric field and σ is tissue conductivity. In order to measure SAR value it is not possible to measure it in vivo due to the fact of interaction with body interior, however nowadays exist techniques which can assess SAR value inside the human model. Mainly used method of estimation SAR inside biological organism is creating simulation of electromagnetic field (EMF) by means of sophisticated software, likewise phantoms bodies and external EMF probes are applied, however that method is more expensive. In this paper, a numerical analysis has been carried out through CST Microwave Studio. SAR distribution and coupling of EMF within the liquid head model are calculated for three different types of glasses with antenna rotation. Previous investigation of mobile phone working in GSM900 and GSM1800 proved that metallic glasses placed one the head model had significant impact to SAR value inside the human head model where changes of SAR value achieved up to 67% as regards simulation without glasses [3]. The VSWR of reference antenna is less than 1.2 for ISM 2.4GHz band. This research is aimed to study the interaction between Bluetooth headsets and human head with glasses, and also inspecting the effect of the headset position on the head and antenna performance. Investigation proved that placing of the glasses has considerable impact on SAR value.

## 2. MODEL USED IN SIMULATION

### a. Antenna Model

*Figure 1. Front view of used antenna in simulation.*




Antenna is the key of physical layer for each wireless device. Proposed antenna is based on [4], however it size has been optimized for simulation purposes. Dimensions of obtained antenna are shown in Fig. 1. The proposed patch antenna on the top side is formed by 50Ω feed line with two microstrip transformators and radiating patch. Spotted grey field is a ground, placed on the bottom side of the low cost FR4 substrate with 1,57 high ($\varepsilon r$=4.4, tanδ=0.035), thickness of the used PEC layer was set to 0,8mm. The size of the antenna is 24x40mm. Modification has been applied to reduce size of the antenna and find the best match to 50Ω. Antenna gain is 2.46 dBi with omnidirectional radiation pattern.

### b. Human head model.

Human homogenous head model is simple sphere with added electrical parameters in accordance with the data provided by CST human brain properties, showed in the table below.

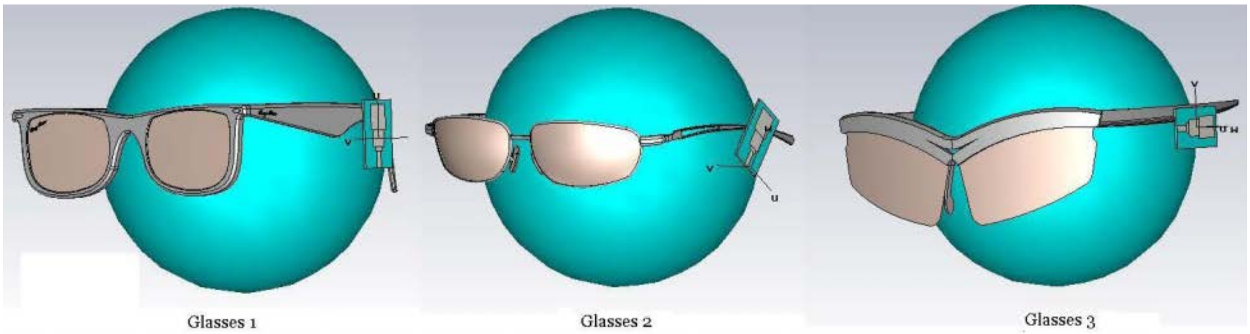
*Table 1. Electric parameters of human head used in simulation*

| Epsilon | Heat capacity [kJ/K/kg] | Thermal conductivity [W/k/m] | Density [kg/m3] | Electric conductivity [S/m] |
|---|---|---|---|---|
| 40 | 3600 | 0.51 | 1046 | 0.9 |

## 3. SIMULATION SCENARIOS AND RESULTS

Headset used in simulation in simple antenna fed by waveguide port. In order to placement antenna in the headset housing, authors proposed three different angle (Glasses 1 – 0 degrees, Glasses 2 – 45 degrees Glasses 3 – 90 degrees) setting of the antenna regarding to the head with glasses which are shown in Fig. 2.

*Figure 2. Three different type of glasses with three setting of the antenna*



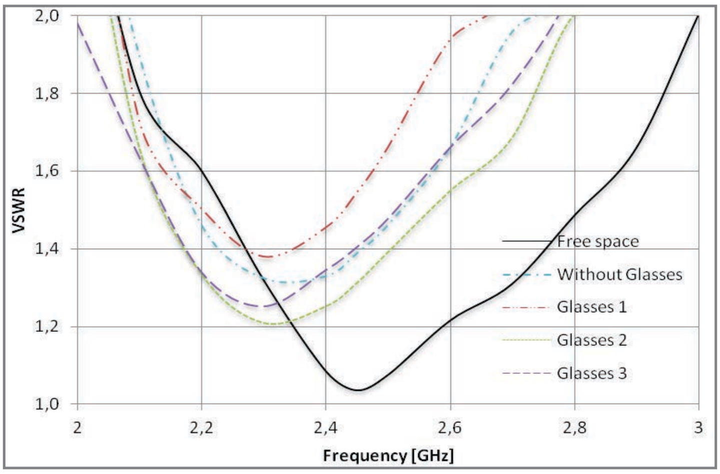

In normal exploitation setting, headset is placed inside the ear hence constant distance between human model and patch antenna was set to 20mm. For both, Glasses 1 and Glasses 3 distance between antenna and arm glasses is constant equal 6mm, respectively. Only Glasses 2 has 8mm distance since arm shape is fillet in order to head model.

## 4. RESULTS AND ANALYSIS

### c. Circuit parameters

All simulations in the paper are performed by using CST Microwave Studio 2013. The Voltage Stand Wave Ratios are presented on Fig. 3.

**Figure 3.** *VSWR of the antenna for free space and glasses (0 degree)*




Four results of VSWR for model with glasses and without are in good agreement in order to each other, however in comparison to free space curve results have slightly deteriorated. Antenna mach for glasses was shifted to lower frequencies. At VSWR less than 1,8 all curves contains in ISM 2.4GHz band. Power reflected achieves at most 8%, consequently model antenna in surrounding of the head and glasses have still good circuit parameters.

### d. SAR results

To achieve accurate numerical results, authors defined three positions for three different angular positions of the headset in installation: 0◦, 45◦ and 90◦. For SAR calculation is preferred FDTD method computation of electric field components due to its accuracy and simplicity. In this paper, spatial SAR [5] values were measured based on the IEEE standard-1529. Antenna input power is set to 0.0025W (second Bluetooth headset class) as the maximum radiation power. All results are not exceeding 1.6W/kg (1g tissue) and 2W/kg [6-7] for 10g tissue averaging as regards IEEE C95.1-2005. Maximum obtained results is 0,68 W/kg. Tab. 2 is included results of numerical SAR measurements regarding three types of averaging. It can be seen that maximum SAR were obtained for point method without averaging [8]. In addition, antenna radiation pattern was dramatically changed, many side lobes has been appeared, metallic glasses became shield for radiating patch, as a consequence in selected cases antenna gain go up to 5.7 dBi.

**Table 2.** *SAR obtained results*

| | | SAR Averaging [W/kg] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 G | | | 10 G | | | Point | | |
| | | Freqency [MHz] | | | Freqency [MHz] | | | Freqency [MHz] | | |
| Angle | Type | 2400 | 2440 | 2490 | 2400 | 2440 | 2490 | 2400 | 2440 | 2490 |
| 0 | Glasses 1 | 0,41 | 0,39 | 0,37 | 0,23 | 0,22 | 0,21 | 0,60 | 0,58 | 0,55 |
| 0 | Glasses 2 | 0,48 | 0,46 | 0,44 | 0,28 | 0,27 | 0,26 | 0,70 | 0,68 | 0,66 |
| 0 | Glasses 3 | 0,36 | 0,35 | 0,33 | 0,20 | 0,20 | 0,19 | 0,48 | 0,46 | 0,43 |
| 45 | Glasses 1 | 0,17 | 0,17 | 0,17 | 0,11 | 0,11 | 0,11 | 0,25 | 0,24 | 0,23 |
| 45 | Glasses 2 | 0,48 | 0,46 | 0,43 | 0,26 | 0,25 | 0,24 | 0,67 | 0,65 | 0,62 |
| 45 | Glasses 3 | 0,36 | 0,34 | 0,32 | 0,20 | 0,19 | 0,18 | 0,46 | 0,44 | 0,41 |
| 90 | Glasses 1 | 0,31 | 0,29 | 0,27 | 0,17 | 0,16 | 0,15 | 0,47 | 0,44 | 0,41 |
| 90 | Glasses 2 | 0,40 | 0,37 | 0,34 | 0,20 | 0,19 | 0,18 | 0,58 | 0,55 | 0,51 |
| 90 | Glasses 3 | 0,25 | 0,24 | 0,24 | 0,12 | 0,12 | 0,11 | 0,35 | 0,34 | 0,33 |

To measure dissimilarity to SAR results with and without glasses Table 3 presents the relative changes in order to results without glasses. It can be seen that for both, SAR10g and SAR1g relative changes are proportional, however, for each type of glasses presented results are not cohesive, since for 45 degree, each type of glasses achieve scattered values, namely for Glasses 1 -2,9dB (95% - twice decreased), for Glasses 3 1,5 dB (more than 40% increase) and Glasses 3 0,2 dB (5% decrease), As a consequence, it suggest that glasses with fillet arms provide shielding of the human head model. In addition, for both setting 0 and 90 degree can be observe the relative smallest change regarding to 45 declination, thereby proposed antenna are more susceptible and unpredictable to angular changes, since for each type of glasses we achieved different incoherent results.

***Table 3.*** *Relative changes in dB regarding to model without glasses*

| | | SAR Averaging | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 G | | | 10 G | | | Point | | |
| Angle | Type | 2400 | 2440 | 2490 | 2400 | 2440 | 2490 | 2400 | 2440 | 2490 |
| 0 | Glasses 1 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,9 | 0,9 | 1,0 |
| 0 | Glasses 2 | 1,0 | 1,0 | 1,0 | 1,1 | 1,1 | 1,2 | 1,5 | 1,6 | 1,7 |
| 0 | Glasses 3 | -0,2 | -0,2 | -0,2 | -0,4 | -0,2 | -0,2 | -0,1 | -0,1 | -0,2 |
| 45 | Glasses 1 | -2,9 | -2,8 | -2,5 | -2,5 | -2,3 | -2,2 | -2,3 | -2,2 | -2,0 |
| 45 | Glasses 2 | 1,5 | 1,5 | 1,5 | 1,2 | 1,2 | 1,3 | 2,1 | 2,2 | 2,2 |
| 45 | Glasses 3 | 0,2 | 0,2 | 0,2 | 0,0 | 0,0 | 0,0 | 0,4 | 0,5 | 0,5 |
| 90 | Glasses 1 | 1,0 | 1,1 | 1,2 | 1,1 | 1,2 | 1,4 | 0,3 | 0,4 | 0,4 |
| 90 | Glasses 2 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| 90 | Glasses 3 | 1,1 | 1,0 | 1,0 | 0,7 | 0,7 | 0,8 | 0,9 | 0,9 | 1,0 |

***Figure 4.*** *Minimum (a) and maximum(b) SAR1G for second glasses type*

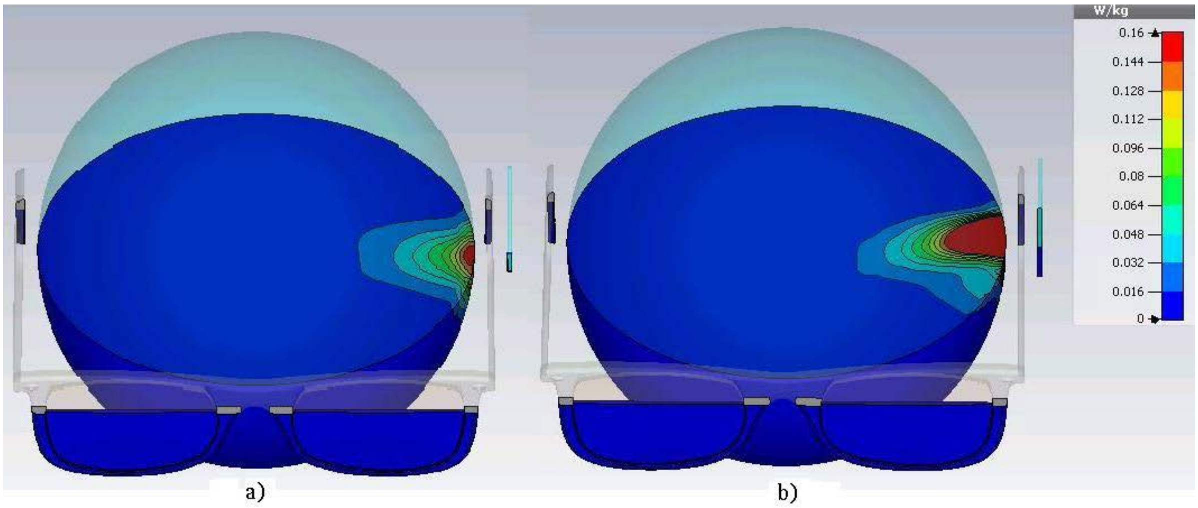



Fig. 4. shows three dimensional SAR1g results for both, maximum (0 degree antenna declination) and minimum (45 degree antenna declination), respectively. Both results are scaled to minimum obtained SAR value to show dissimilarity SAR distribution inside human head model.

## 5. CONCLUSION

In this paper the interaction between Bluetooth headset and human head model with glasses was investigated. A patch antenna was designed and homogeneous head model was used. Authors took simplified model up, since investigation focused on simulation with and without glasses, hence more significant are SAR relative changes rather than absolute value, which always depend on transmitter type and power. Three angular positions of the antenna placed in the ear were defined for three different modern glasses. Microstrip patch antenna was chosen to investigate the effect of the mobile headset working in ISM 2.4GHz on human head with metallic glasses. CST Microwave Studio was used with FDTD method for authors numerical studies. Finally, the results of VSWR and SAR were obtained in order to human head model with and without glasses. According to the results, metallic spectacle frame have not relevant impact to VSWR regards to model without glasses however slightly deteriorated regarding free space outcomes. Additionally, remarkable results were obtained for each type of glasses with angular changes, hence that scenario is more likely as user have latitude in placing headset into the ear. In addition, Bluetooth manufacturers are embedding antenna in different configuration. Thereby selected shape of glasses can shield or expose human head model to EMF in Bluetooth application. SAR value analyses emphasizing the problem of wearing glasses during using Bluetooth devices, however presented results are calculated only for three different glasses types and in different configuration, results might change.

*ACKNOWLEDGMENT*

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# REAL-TIME SIGNAL ANALYSIS FOR POWER VERSUS TIME EVOLUTION ASSESSMENT OF MOBILE PHONE RADIATION IN THE CALLING INITIATION PERIOD OF THE GSM VERSUS UMTS COMMUNICATIONS

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*ABSTRACT*

*Emitted power in the reactive near field of mobile phones transmitting in either the GSM and in the UMTS communication standards is followed during the first 20 seconds of a call. By using a real-time signal analyzer and a miniature E-field probe, significant differences were observed between the two generations of communication technologies. Not only the time- but also the frequency- variation of the communication power has to be considered for a proper dosimetric approach when one focuses on head exposure while using handsets. The main differences between the 2nd and the 3rd generation of communication standards are presented from a signals' perspective analysis and also from the statistics of exposure perspective, taking into consideration the incident field level and not the specific absorption rate (therefore a non-standardized approach is proposed).*

***Key words:*** *GSM, UMTS, mobile phone, near field, human exposure.*

## 1. INTRODUCTION

In the guidelines for limiting human exposure to electromagnetic fields available from many years now [1], for the radiofrequency (RF) region of the spectrum (100 kHz - 10 GHz), the indicated quantity to be directly connected to the safe exposure is the specific energy absorption rate (SAR) in the tissue. The values provided for SAR limits (basic restrictions) are established so as to prevent whole-body heat stress and excessive localized tissue heating but they are neglecting the non-thermal effects of RF exposure. Practically, SAR is expressed as the power dissipated in the unit mass of irradiated tissue (W/kg). Standardized instrumentation and methodology are provided for SAR determination in the head and body for the mobile phones radiation [2] – [4], however they are mainly devoted to the compliance testing of the handsets, while the phones' functioning is forced at the highest emitted power - which is not a realistic approach. With these standardized measurement procedures a lot of ambiguities/gaps are yet encountered: 1. an unrealistic human model is used for SAR measurement/computation; 2. the manufacturers' measurements of SAR assume a homogenous human model which does not account for absorbed «hot spots»; 3. the measurements are made at undefined distances from the head/body; 4. SAR measures absorption over 1 gram of tissue (or 10 grams in Europe, respectively) but this may miss the hot spots during spatial averaging; 5. one does not take into account the pulsed nature of the phone's signals so the average power can remain low whereas the individual bursts are high.

The insufficiency of SAR usage as the unique protective indicator of human health was first signaled in 2001 by the TCO certification development group [5]. In that Swedish standardized approach, the authors added the telephone communication power (TCP) to SAR, to offer protection to the public. The complementary quantity TCP (expressed in W) represents the maximum power the phone can use for communication. A good telephone is not necessarily one with a low SAR value but one that uses a large part of its power for communication and very little power is lost by the absorption of electromagnetic field in the user's head. The higher the TCP value, the greater the signal strength that reaches the base station; this allows a decrease of the power of the telephone transmitter and consequently a reduced exposure level of the user. In this manner, both SAR and TCP values are important elements in characterizing the emission characteristics of a handset. Moreover, the investigations of TCO development group revealed that there are clear differences in TCP values between different phone models and frequency bands, even for the same SAR value. So they prepared the TCP requirements on the basis of those findings. Later on, by unknown reasons, the use of TCP besides SAR, as a tandem indicator of humans' safety, disappeared from any standardized approach. During the next years SAR alone continued to be the only indicator of RF radiation safety. In 2013 the American Academy of Pediatrics clearly stated in an official letter [6] that "the current metric of RF exposure available to consumers, the Specific Absorption Rate, is not an accurate predictor of actual exposure". In the same year, the technical problems of SAR usage were argued in [7], in which the authors stated that all existing methods of SAR estimation, especially those based upon tissue conductivity and internal electric field, have serious deficiencies. Also, they said that the only method to estimate SAR without large error is by measuring temperature increases within biological tissue. However environmental field strength is usually negligible and thus cannot be measured.

Another weakness of present RF exposure metrics is disregarding of the signal characteristics. In the period 2008-2013, scientific evidence has been accumulated in favor of differences between biological effects due to signals belonging to different generation of mobile communication technologies. Therefore, the simple energetic approach wasn't able to cope this. The first report proving that different network technologies caused mobile devices to generate completely different emission levels came by the publication of a 12-country study [8] and afterwards by a separate experiment authored by the French telecom industry [9]. Both works indicated that when carriers shifted from second generation (2G) to third generation (3G) of communication standards, phones operating in 3G networks used less power much of the time and their users experienced lower exposures. In 2011 another study [10] showed that 2G networks using Global System for Mobile Communications (GSM) technology conducted to an exposure of 30-300 times higher than 3G networks with Wideband Code Division Multiple Access (WCDMA) technology. The same year, a presentation at a conference [11] indicated that from the perspective of average power at the head level, it is safer to use 3G technology – namely Universal Mobile Telecommunications System (UMTS), instead of GSM or Long Term Evolution (LTE) – which is the 4th generation, 4G. 3G handsets emit radiation which is orders of magnitude smaller than 2G or 4G. A study from 2012 [12] reported that 4G -LTE antenna designs produced average emission rates 2- 60 times greater than 2G and 3G designs.

Therefore evidence is collected that SAR is not always a proper metrics of RF exposure and that different emission technologies used for mobile communications conduct to different biological effects, independent on the SAR technical specification present in the booklet of the handset model. Starting from these aspects and continuing some previous original work of ours [13], [14], present work aimed to follow the evolution of the emitted power of the electromagnetic near field of mobile phones operating under 2G and 3G mobile communication technologies during the first 20 seconds of an initiated call in frequency and in time domains.

## *2. MATERIALS AND METHODS*

GSM technology (2G) phones have a radiated mean power always situated in the upper end of the dynamic range of 30 dB, typically in the upper 5 dB, the communication channel is 200 kHz wide, the separation is implemented with time division multiple access (TDMA) and frequency hopping may be used. WCDMA technology (3G) phones use a fast power control at a rate of 1500Hz compared to GSM (2G) where the power control varies at a rate of 16.6 Hz [8] and 3G channel is 5 MHz wide. 3G mobile networks operate in a different way than 2G networks: when a call is made on 2G, a line is held open for the user's conversation throughout the duration of the call. With 3G networks, the data sent across them is divided in little 'data packets' which are reassembled in the correct order at the receiving end. This encoding means more data sent and more efficient communication. Moreover, 3G handsets can be in contact with more than one base station at a time. 3G mobile phones are low powered and automatically reduce it to the lowest possible power needed to maintain a quality connection.

In present experiment, by using a FSWR 30 real-time signal and spectrum analyzer (by Rohde&Schwarz, Germany) connected to a miniatural electric (E) field probe model Scan EM-EC model CTM030 (Credence Technologies, Inc., USA) – see Fig. 1, we aimed at analyzing the power versus frequency and power versus time, comparatively for the radiated power of 2G versus 3G phones.

***Figure 1.*** *Experimental set-up with the E-field probe inspecting the phones and the real-time signal analyzer during 3G-phones' scan*

A set of 11 handset models able to transmit, each other, in either GSM or in UMTS standards (setting available), were used for the measurement of the E-field strength measurement in the proximity of the device. The experiment took place in a laboratory in a fixed position. Each device was connected successively to one of the three Romanian mobile operators - Orange, Vodafone and Cosmote, by inserting corresponding SIM cards and was measured by the E-field probe during calling. A total of 60 experimental situations were considered for the radiated power measurement - 30 cases for GSM and 30 cases for UMTS connection. During calling, the recipient phone didn't answer, so that the forwarder phone was forced to ring continuously for about 20 seconds. In this period, continuous/multiple sweeps of the near field level were captured from the real-time spectrum analyzer. Each measurement case was repeated 8 times and average results were considered further on. The miniature electric E-field sensor stood on a tripod at distances between 2-5 mm from the phones' surface in a fixed position, while the measurement was remotely controlled by a code developed specially for this purpose(Python application). The software also collected and processed the data, offering the results in the form of power levels emitted in the investigated uplink band.

Even if in the near-field case, we presumed that the power density is still a function of the squared E-field strength. This assumption was considered fairly suitable because: a) it is physically impossible to measure both field components simultaneously and in the same point in space just near the phone; b) the position of the E-field sensor was exactly the same throughout all 8 measurement repetitions made in one single experimental case.

The settings of the analyzer controlled by the software were chosen according to the specificities of 2G or 3G communication standards to allow an accurate, realistic field level measurement. Most important settings are the resolution bandwidth (RBW) and the sweep time (SWT). For 2G scans RBW=100 kHz, SWT=228 μsec, while for 3G scans RBW=1 MHz, SWT=80 μsec.

Measurements were of the type channel-power and power versus time respectively. Real-time capabilities of the FSWR instrument enabled time-evolution characterizations by means of spectrograms, persistence spectrums and power versus time representations. Repeated scans were used for descriptive statistics processing that followed the time-evolution of emitted power near to the phone. Dependencies on mobile phone model, communication technology and mobile operator were also investigated.

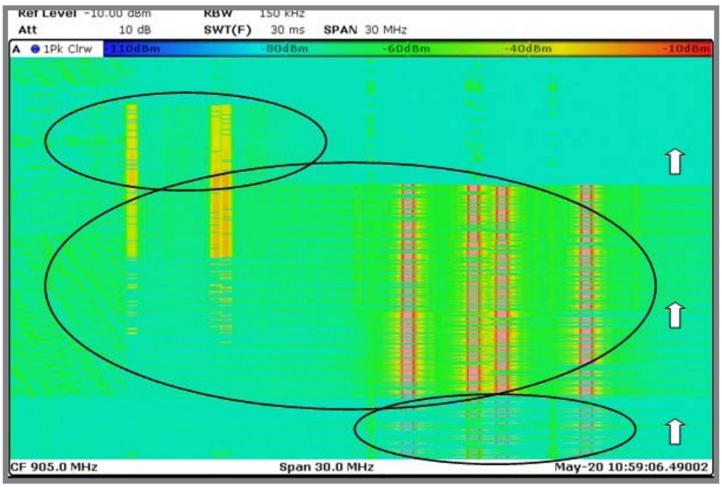
### 3. RESULTS AND DISCUSSIONS

Net differences were obtained between 2G and 3G technologies following the evolution of radiated power in frequency and in time, conducting to the idea that additional care should be taken in dosimetric studies.

#### *a. 2G technology signal analysis:*

Fig. 2 shows the spectrogram of the signal emitted in the uplink band by a GSM mobile phone during the first 12 seconds of the call. The initiation of the call is observed at the bottom of the figure, where 4 channels are observable while the hops are short and not very intense. Then, after approximate 4-5 seconds, the signals become stronger and the hops are very evident on the 4 frequencies. Later on, another 3 channels become occupied, at lower frequencies, but the signals are less intense. Therefore, an evolution with 3 steps during the calling period is obvious, fact we have previous reported in [12] and [13] by using a swept-spectrum analyzer. This is a general behavior of 2G communication. In Fig. 3 the persistence spectrum of such a call is observed, so as the presence of multi-channel hopping is very clear. The presence of short signals in a wide band is specific only to GSM technology.

***Figure 2.*** *Spectrogram of the first 12 seconds of the GSM signal of the phone.*



In Fig. 4 the spectrogram clearly show the temporal slots of 4.67 ms long peesent in GSM standard and the hops that take place here on 4 frequencies during calling. The markers used for the analysis correspond to the next frequencies and moments: M1: 908.633 MHz; t=-20.08msec; M2: 913.576MHz; t=-24.8msec; M3:906.11MHz; t=-29.44msec; M4: 909.007MHz; t=-33.92msec. This happens with 2G phones' signals while the user keeps the handset near the head and is calling.

Fig. 5 shows a snapshot of 26 ms long during the calling period where one notes the power versus time behavior of the temporal slots in GSM. Fig. 6 presents a much longer frame of power distribution - 20 s long, the frame starting from the moment when the phone began calling. At the beginning, during a 2.6 s period, the signal power is highly variable, afterwards the power stabilizes but varies as the adaptive power control mechanisms evolves. Well defined steps of power adjustment in the temporal slot are observable, with modifications in the points where the markers were established: M1: -2.63 dBm; 2.43 sec; M2: -2.65 dBm; 4.63 sec; M3:-6.23 dBm, 8.05 sec; M4: -5.79 dBm; 12 sec; M5: -8.29 dBm; 13.44 sec.

***Figure 3.*** *Persistence spectrum of GSM radiated power near the phone while calling*

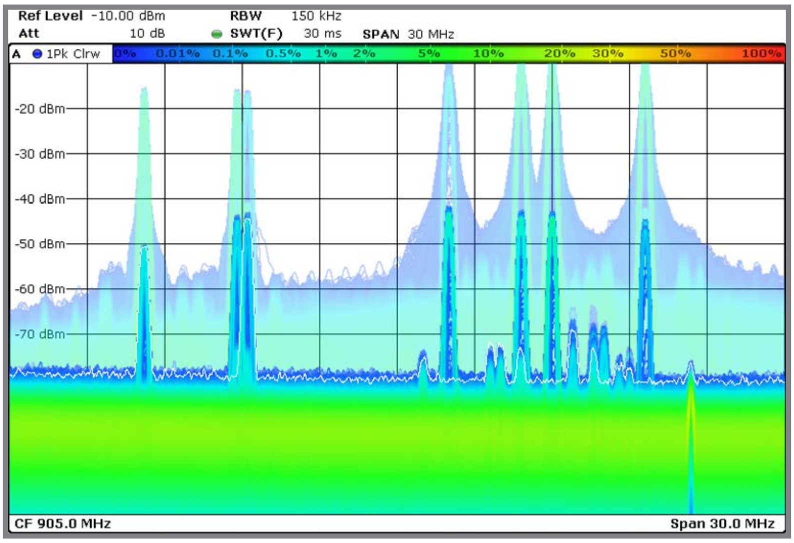



***Figure 4.*** *Spectrogram showing the frequency hopping on four frequencies in GSM and the temporal slots of 4.67 msec long*

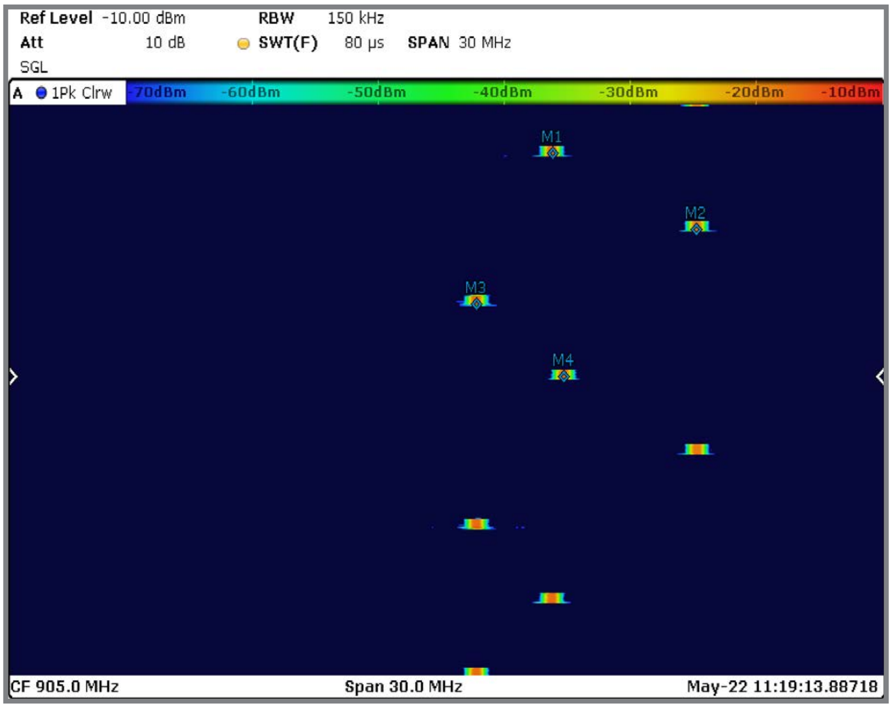


*Figure 5. Temporal slots during calling of a 2G phone*

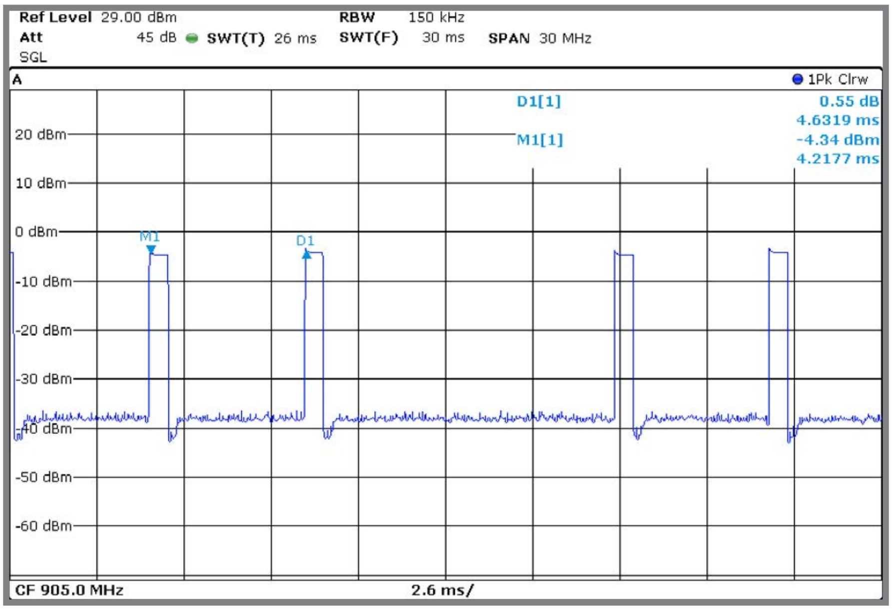
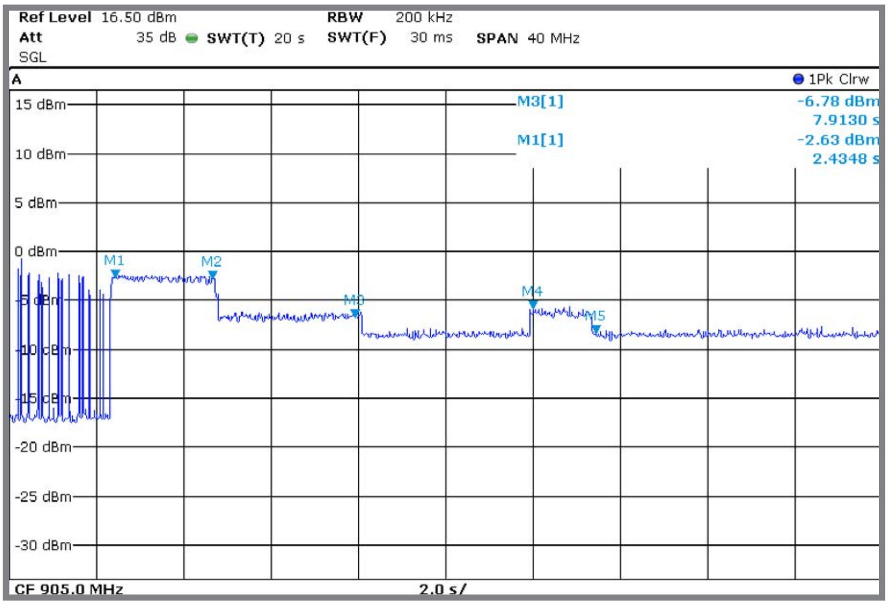



*Figure 6. Power versus time representation in a GSM temporal slot showing the adaptive power control mechanism during a frame of 20 seconds starting from the initiation of the call.*




### *b. 3G technology signal analysis:*

A persistence spectrum is presented in Fig. 7 for 3G phones' radiation in their immediate proximity. In this figure two 5 MHz wide channels are visible in the band: one belonging to the forwarder phone (right side) and the other one to the recipient phone (left side). Curiously, sometimes the amplitude of the signal emitted by the recipient phone while called may exceed the signal emitted by the calling phone (present case), even if the recipient phone was meters away from the E-field sensor, while the forwarder was in the millimeter distance from the probe. During the whole period of 20 sec of calling, the amplitude of the channel belonging to the calling phone was changing much less than for 2G emitting case and the channel remained fix in the band. Sometimes the channel can be changed by handover, but generally this is a less frequent behavior. These are significant differences between 2G and 3G radiated field.

In Fig. 8 the power evolution in time was captured for the first 15 s from call initiation in a 3G network, near the phone. A RBW of 200 kHz (maximum available for FSWR signal analyzer) was used to capture the signal variations from the whole channel bandwidth of 5 MHz. The graphics demonstrates the amplitude variation limits during the call.

### *c. 2G versus 3G technology – statistical results of emitted power:*

By comparison over all our measurements, the average power emitted by 2G phones was between 10 times up to 175 times higher than the one of 3G phones. For Cosmote network operator, the ratio of power (RP) emitted by 2G phone to the powers emitted by 3G phone (5 tested handests) was: RP=9.4 - 81; for Orange (4 tested phones) RP=11.5 - 47.7; for Vodafone (3 tested phones) RP=54 - 174.3. The ratio of the coefficient of variation, RCV, between average powers of 2G and 3G phones was: for Cosmote network RCV=4.5 - 11.4, for Orange RCV=3.2 - 4.7, for Vodafone RCV=2.2 si 3.9

In Fig. 9 boxplots of the relative field strength distribution during calling period of 20 seconds is represented comparatively for the 11 models of phones emitting in GSM (Fig. 9a) and for the same phones emitting in UMTS network respectively (Fig. 9b). The cases are for Cosmote network operator. On the abscissa of the boxplots it is represented the normalized E-field strength, while the denominator was chosen as the maximum reached E-field strength during the call, therefore no comparsion is to be made between the values on the abscissas of Fig. 9a and 9b.

***Figure 7.*** *Channels of two phones communicating in UMTS network*

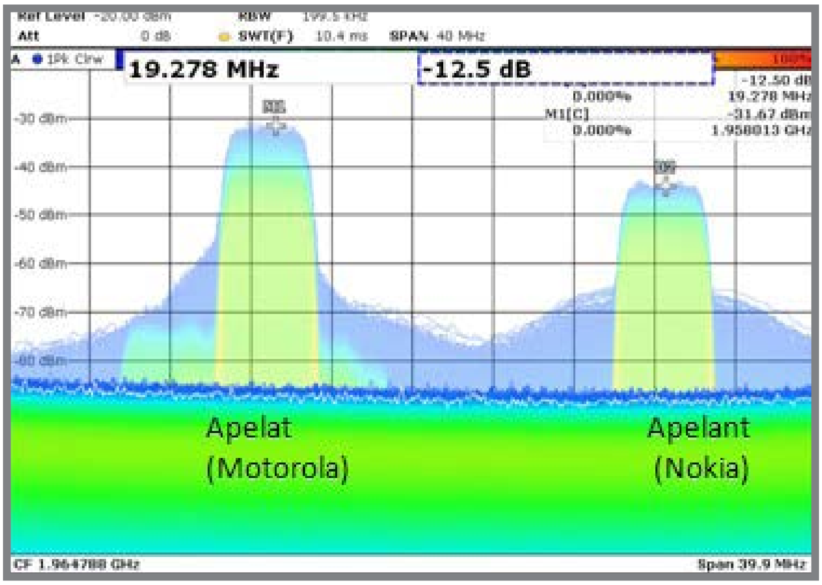



***Figure 8.*** *Power versus time evolution in the near field of a 3G phone channel during the first 15 sec from starting the call*

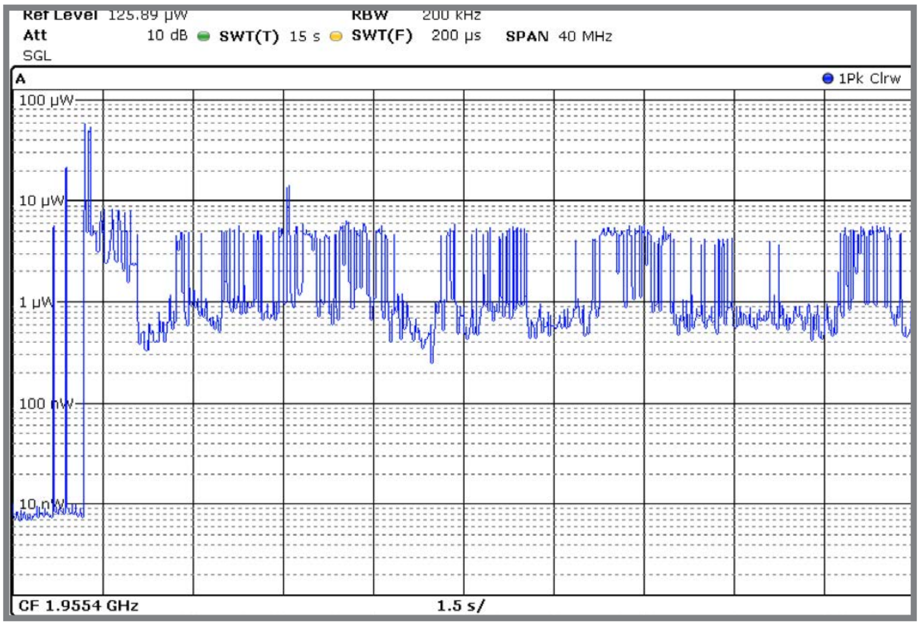
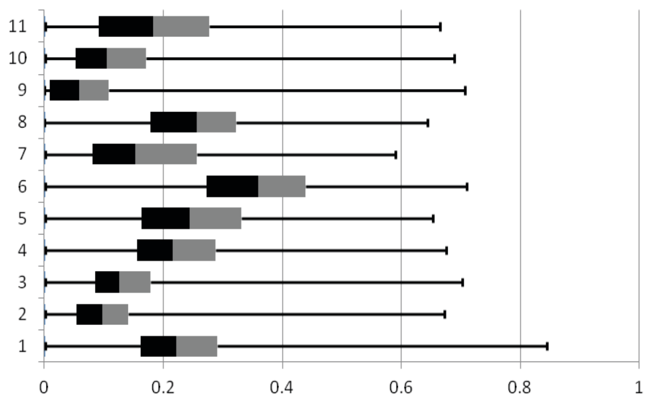
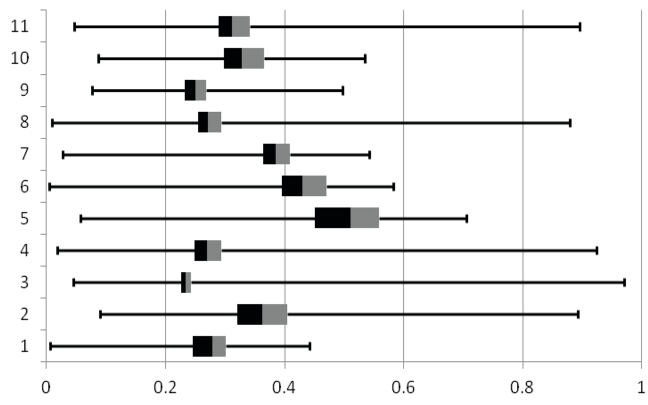


***Figure 9.*** *Boxplots of normalized E-field strength emitted by 11 models of mobile phones emitting in 2G (a) and in 3G (b) standard of mobile communications*




Descriptive statistics provided the probability density functions (PDF) and the shape descriptors of these functions, kurtosis and skewness, were also analyzed over the 11 phone models. Kurtosis is a measure of the relative concentration (flatness or peakedness) of data values in the center versus in the tails of a distribution when compared with the normal distribution (kurtosis = 3). Kurtosis of the 2G phones' radiation indicated a more flatter distribution than of the 3G. The most peacked distribution appeared at 3G phones connected to Orange network, while the flattest distribution appeared for all 2G network-connected phones' radiation and had similar values. Skewness characterizes the degree of asymmetry of the distribution around its mean. Positive skewness indicates a distribution with an asymmetric tail extending toward more positive values and negative skewness indicates a distribution with an asymmetric tail extending toward more negative values. In case of 2G phones, all PDF of emitted power had a positive skewness, while for 3G phones negative skewness was encountered in half of the cases. This analysis proves once more the complete different behavior of incident signals of GSM versus UMTS signals upon user's head with consequences unable to be completely described purely energetic.

## *4. CONCLUSIONS*

By measuring the emitted E-field strength in the reactive near-field of mobile phones connected in 2G and 3G networks, making use of a real-time signal and spectrum analyzer, we were able to show considerable differences regarding power evolution in frequency and in time in the place where usually the head of the user is positioned. The field was monitored over 20 seconds from the beginning of the call, while the receiver didn't answer. The results may have an important impact upon the correction needed in RF metrics used today in dosimetry, which relies only on SAR determination.

The 2G communication standard show that during calling multiple channels are present in the emitted field while hops in the temporal slots are allowed on 3-4 frequencies in the first 5-6 seconds from the call initiation. In this period the radiated power increases constantly. Afterwards other 2-3 channels become active while the power decreases. During the calling period 2G phones follow a specific evolution of signal, which depends on the operator and in a lesser extent upon the phone model. For 3G phones, only one channel is generally present during calling but it may change by handover. The power is highly variable just in the first 2.5 seconds from the call initiation, afterwards becoming more constant. No dependence of time evolution of the signal upon operator or upon phone model was observed. A specificity of 3G phones is that both forwarder and receiver handsets radiate power during the calling period. This phenomenon is never encountered in the 2G communication standard, where in the uplink band just the calling phone's signals are present. The average power emitted by 3G phones is considerable lower than the one emitted by 2G phones, and it is more constant in time.


## *ACKNOWLEDGMENT*

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# MEASUREMENTS OF MAGNETIC FIELDS AND CONTACT CURRENTS PRODUCED BY DOMESTIC INDUCTION HOBS

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ABSTRACT

*Domestic induction heating (IH) cookers have became increasingly popular because of their specific features such as safety, cleanliness, quick heating, and high efficiency. It is well known that magnetic fields at 10 kHz to 100 kHz are used for operating these devices. At the same time, electric potentials are induced on a metallic pan on the top panel due to capacitive coupling between the pan and heating coils, resulting in flowing contact currents through a human body when the human touches the pan. In the present paper, both leakage magnetic fields and contact currents produced by three IH cookers were measured with pans of various sizes. We found that larger pans reduced the leakage fields, but increased the contact currents.*

**Key words:** *induction heating cooker, intermediate frequency, leakage B-fields, contact currents*

## 1. INTRODUCTION

Domestic induction heating (IH) cookers became increasingly popular because of their specific features such as safety, cleanliness, quick heating, and high efficiency. It is well known that magnetic fields at 10 kHz to 100 kHz are used for operating these devices. From an engineering viewpoint, electric fields and currents are induced in a human body using an IH cooker by the time-varying magnetic fields and can stimulate nervous system tissues in the body. With regard to the effects of magnetic fields on human beings, attention has been widely paid to induced electric fields and current densities in humans by such magnetic fields, with some numerical investigations having been conducted(1, 2). At the same time, a contact current flows through a human when the human touches a metallic portion of a pan on an IH cooktop in operation. However, few investigations considering the contact current have been reported.

In the present paper, both leakage magnetic fields and contact currents produced by an IH cooker are measured with varying the size of various pans. In addition, calculations of induced electric fields in a numerical human body by both exposures are demonstrated based on the measurements.

## 2. MEASUREMENT PROCEDURES

### a. B-field measurements

An instrument for measuring magnetic fields with a power frequency ranging up to 100 kHz was newly developed. Air-core coils with a cylindrical shape and dimensions of 10 mm diameter and 10 mm length, which is small enough to ensure fine spatial resolution, was made in our laboratory to sense time-varying magnetic fields. To amplify micro-order voltage from the air-core coils, an amplification device coving the frequency range from 40 Hz to 100 kHz was used. The waveform of the output signal from the instrument can be observed by a digital oscilloscope and an FFT analyzer. In measuring leakage magnetic fields, the air-core coils were placed on the edge of the IH cooker.

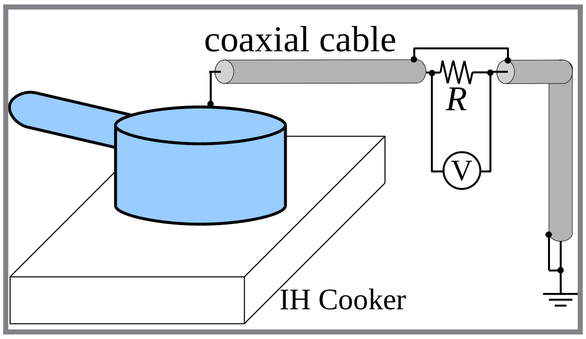
### b. Contact current measurements

In a preliminary study, it was confirmed that a capacitive current due to earth capacity of a human can be ignored, which means that contact currents flow through a human as conductive current. As illustrated in Figure 1, a resistance was connected between the metal portion of a pan and the ground. Contact current can be estimated by measuring a voltage across the resistance. The resistance should be sufficiently smaller than the capacitive impedance between the pan and heating coils of the IH cooker because the capacitive current flowing from the pan to the ground can appear. Here, a 1 kΩ-resistance was used. The voltage across the resistance can be exchanged to the current by the resistance value and can be observed by a digital oscilloscope and a FFT analyzer in a similar way to the measurement of magnetic fields.

### c. *IH cookers and size of pan*

Three IH cookers (IH-A, IH-B, and IH-C) that were produced by different companies were used for measuring. All IH cookers used in the study used 200 V source and 2 kW output per coil. A total number of 16 metallic pans including saucepans, frying pans, and kettles were used for measuring both B-fields and contact currents. The diameter of the bases of the pans ranged from 140 to 240 mm, corresponding to area of 130-480cm$^2$. The volume of each pan was filled to approximately 70% with water and is placed on the center of the heating coils. The IH cookers were operated under maximum output power during the measurements.

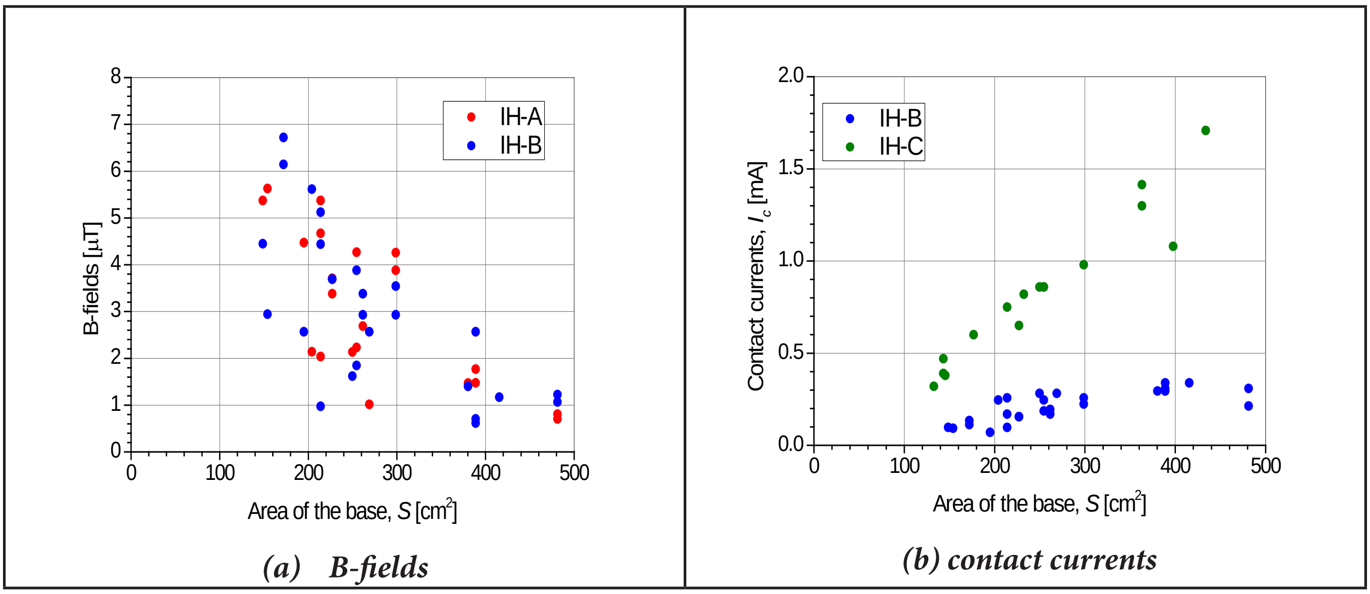
***Figure 1.*** *Measurements of contact currents*




## 3. RESULTS

It was found from the preliminary measurements that the frequency components from heating coils of the IH cookers used in the study were around 20 kHz for fundamental frequency and its harmonics. Figure 2 shows the measurement results at the fundamental frequency of the B-fields and contact currents against the different base size of the pans for the three IH cookers. It is found that the leakage B-fields decrease with the larger area of the base as expected. In contrast, the contact currents increase in proportion to the area of the base since the capacitance between the pan and the heating coil increase as the capacitive impedance decreases. In addition, the contact current value depends largely on the IH cookers, with the current values for IH-C being 3-4 times larger than those for IH-B.

***Figure 2.*** *Measurement results of B-fields and contact currents*



## *4. CONCLUSION*

In the present paper, both leakage magnetic fields and contact currents produced by IH cookers were measured with pans of various sizes. Results show that larger pan sizes reduced the leakage fields, but increased the contact currents. In the future, calculations of induced electric fields in a human body using a numerical human model for both exposures to B-fields and contact currents should be investigated.

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# IEEE EMF EXPOSURE AND ASSESSMENT STANDARDS ACTIVITIES

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ABSTRACT

*IEEE standards are developed with oversight of the IEEE Standards Association to ensure due process openness, balance of interests and transparency at every level. The IEEE International Committee on Electromagnetic Safety (ICES) develops standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz. Technical Committee (TC) 95 develops standards based on established adverse effects and include safety margins for human exposure to electric, magnetic and electromagnetic fields, including induced currents from such fields; TC34 deals with methods for the assessment of human exposure to such fields, and develops compliance standards for products that emit electromagnetic energy. The IEEE C95.1 standards development process is further governed by principles of balance of concerns over safe exposure and attainment of levels of restrictiveness that are based on the best available science and engineering. The subcommittee that developed IEEE C95.1-2005 had an extremely wide range of participation by 125 members from 25 countries with expertise in engineering, biology, medicine, measurements, and safety programs. In terms of stakeholders, the committee consists of members of the government, military, academia, industry, and general public. In this presentation, activities of the two ICES Technical Committees will be updated.*

***Key words:*** *exposure standards, assessment standards, established adverse effects, safety, compliance.*

## 1. INTRODUCTION

The scope of IEEE-SA Standards Coordinating Committee 39 (International Committee on Electromagnetic Safety, ICES) is "Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards of exposure of humans, volatile materials, and explosive devices to such energy. Such standards will be based on established effects and will include safety levels for human exposure to electric, magnetic and electromagnetic fields, including induced currents from such fields, methods for the assessment of human exposure to such fields, standards for products that emit electromagnetic energy by design or as a by-product of their operation, and environmental limits." Currently, there are two technical committees (TC) under ICES. TC95 is responsible for the development of exposure standards and TC34 for product assessment standards. TC95 has five subcommittees: SC1 (Techniques, Procedures, Instrumentation, and Computation); SC2 (Terminology, Units of Measurements, and Hazard Communication); SC3 (Safety Levels with Respect to Human Exposure, 0 Hz to 3 kHz); SC4 (Safety Levels with Respect to Human Exposure, 3 kHz to 300 GHz); and SC5 (Safety Levels with Respect to Electro-Explosive Devices). TC34 has two subcommittees; SC1 (SAR Evaluation – Measurement Techniques); and SC2 (SAR Evaluation – Numerical Techniques). In this presentation, standard development activities of the two TCs will be updated.

## 2. IEEE PROCESS

IEEE standards are developed through an open consensus process with oversight by the IEEE Standards Association under the principles of transparency and due process to allow for challenging and testing of all viewpoints. The IEEE standards development process is further governed by principles of balance, representation across the social spectrum of concerns over safe exposure, and attainment of levels of restrictiveness that are based on the best available science and engineering and, as such, are scientifically defensible. All approved meeting minutes are posted on the committee website (http://www.ices-emfsafety.org/). Balloting for approval of draft standards is held at the Subcommittee and Sponsor levels. Both levels, 75% of ballots must be returned with at least a 75% approval to reach consensus. All negative comments and their resolutions must be recirculated to ensure all views are considered. For examples, C95.6-2002 had 90% approval, C95.1-2005 96%, and C95.1-2345 (2014) 98%.

The committee that developed IEEE C95.1-2005 had 125 members from 25 countries, with a wide range of participation by experts in engineering, biology, medicine, measurements, and safety programs. In terms of stakeholders, the committee consists of members of the government, military, academia, industry, and general public. Contributions from a large number of experts with diverse backgrounds and from various stakeholders ensure standards are developed to be scientifically correct and practical to implement. IEEE standards are living standards with a 10 year life cycle. Before their expiration dates all standards must be reaffirmed, revised or withdrawn. Table 1 shows the expiration dates of the standards to be discussed below.

***Table 1.*** *Expiration dates of current IEEE ICES standards*

| Number | Year | Expiration Date | Approval Date |
|---|---|---|---|
| 1460 | 1996 | 12/31/2018 | 12/10/1996 |
| 1528 | 2013 | 12/31/2023 | 06/14/2013 |
| C95.1 | 2005 | 12/31/2018 | 10/03/2005 |
| C95.1a | 2010 | 02/02/2020 | 02/02/2010 |
| C95.1-2345 | 2014 | 12/31/2024 | 05/16/2014 |
| C95.2 | 1999 | 12/31/2018 | 09/16/1999 |
| C95.3 | 2002 | 12/31/2018 | 12/11/2002 |
| C95.3.1 | 2010 | 03/25/2020 | 03/25/2010 |
| C95.4 | 2002 | 12/31/2018 | 11/11/2002 |
| C95.6 | 2002 | 12/31/2018 | 09/12/2002 |
| C95.7 | 2014 | 12/31/2024 | 06/13/2014 |

## 3. TC95 STANDARDS

### *SC1: Measurements & Calculations*

Table 2 shows all current and draft standards that have been developed by the ICES. SC1 has three active standards: 1) 1460-1996 "Guide for the Measurement of Quasi-Static Magnetic and Electric Fields," which was reaffirmed in 2002 and listed active but the content has been incorporated into C95.3.1-2010; 2) C95.3-2002 "IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz–300 GHz;" and 3) C95.3.1-2010 "IEEE Recommended Practice for Measurements and Computations of Electric, Magnetic, and Electromagnetic Fields with Respect to Human Exposure to such fields, 0 Hz to 100 kHz." Currently, SC1 is working to combine the two standards into a single standard covering the 0 – 300 GHz frequency band (Draft Recommended Practice for Measurements and Computations of Electric, Magnetic and Electro-magnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 300 GHz).

### *SC2: Warning Signs/Hazard Communication*

SC2 has two active standards: 1) C95.2-1999 "IEEE Standard for Radio Frequency Energy and Current Flow Symbols," which was reaffirmed in 2005. The content of this standard is stable and a revision is not expected in the near future. 2) C95.7-2014 "Recommended Practice for Radio Frequency Safety Programs - 3 kHz to 300 GHz" is a companion standard on implementing a RF safety program to comply with the exposure standard C95.1-2005, which was first published as C95.7-2005 and is revised in 2014.

### *SC3: Exposure Limits for 0-3 kHz*

This subcommittee was organized in 1991, with 75 members from 11 countries. This subcommittee developed C95.6-2002 "IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz" with exposure limits derived to minimize effects associated with electrostimulation. The standard was reaffirmed in 2007. Now SC3 is working jointly with SC4 to combine the low frequency standard C95.6 with the high frequency standard C95.1.

### *SC4: Exposure Limits for 3 kHz-300 GHz*

This subcommittee has the longest history in developing RF exposure standard. Its predecessor published the first RF exposure limits in 1966 as USAS C95.1-1966. The most current version is C95.1-2005 “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency electromagnetic Fields, 3 kHz to 300 GHz.” In July 2009, IEEE and the NATO Standardization Agency signed an agreement to develop a standard to replace NATO STANAG 2345 MED (EDITION 3) – “Evaluation and Control of Personnel Exposure to Radio Frequency Fields – 3 kHz to 300 GHz.” SC3 and SC4 worked jointly to combine C95.6-2002 and C95.1-2005 and published C95.1-2345-2014 “IEEE Standard for Military Workplaces—Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.”

During the revision process, the subcommittees found terminology associated with different predominant interaction mechanisms above (heating) and below 100 kHz (electrstimulation) was one of the challenges in combining the two standards. This is important since appropriate safety factors must be defined that result in adequate safety margins for protection against hazards and adverse health effects. Several terms have been changed to address these differences and to make the meaning of each term more logical and obvious. Table 3 lists the changes of the terminology. The only changes in the exposure limits are those for contact current at radio frequencies (Table 7 in C95.1-2345-2014). Table 4 has the numerical values of the exposure limits. A special exposure zone (Zone 2) with relaxed limits restricted to selected experts has been established in the NATO standard to enable multinational interoperability. Currently SC3 and SC4 continue combining C95.6-2002 and C95.1-2005 into one IEEE standard. Figure 1 shows the unrestricted and restricted environments as defined by the C95.7-2014 RF safety program standard. Review of literature published after 2003 will be the main immediate activity of the subcommittees.

### *SC5: Electro-Explosive Devices*

SC5 has one standard, C95.4-2002 “IEEE Recommended Practice for Determining Safe Distances from Radio Frequency Transmitting Antennas When Using Electric Blasting Caps During Explosive Operations.” This standard was reaffirmed in 2008. SC5, after several dormant years, will resume its activity to harmonize the standard with other international standards.

****Free C95.1 standards: Under the sponsorship of US Air Force, Army, and Navy, several IEEE C95 standards are available at no cost through the “IEEE Get Program (http://standards.ieee.org/about/get/index.html).***

**Table 2.** *IEEE International Committee on Electromagnetic Safety standards*

| *Technical Committee* | *Subcommittees* | *Standards* | *Titles* |
|---|---|---|---|
| TC95 | SC1 (Techniques, Procedures, Instrumentation and Computation) | C95.3-2002 | Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz to 300 GHz (Reaffirmed 2008) |
| | | C95.3.1-2010 | Recommended Practice for Measurements and Computation of Electric, Magnetic and Electromagnetic Fields With Respect to Human Exposure to Such Fields, 0 Hz – 100 kHz. |
| | | 1460-1996 | IEEE Guide for the Measurement of Quasi-Static Magnetic and Electric Fields (Reaffirmed 2002, 2008, incorporated into C95.3.1-2010) |
| | | PC95.3-00X: | Draft Recommended Practice for Measurements and Computations of Electric, Magnetic and Electro-magnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 300 GHz |
| TC95 | SC2 (Terminology, Units of Measurement and Hazard Communication) | C95.2-1999 | IEEE Standard for Radio Frequency Energy and Current Flow Symbols (Reaffirmed 2005) |
| | | C95.7-2014 | Recommended Practice for Radio Frequency Safety Programs - 3 kHz to 300 GHz |
| TC95 | SC3 (Safety Levels with Respect to Human Exposure, 0-3 kHz) | C95.6-2002: | IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz (Reaffirmed 2007) |
| TC95 | SC4 (Safety Levels with Respect to Human Exposure, 3 kHz-300 GHz) | C95.1-2005 | IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency electromagnetic Fields, 3 kHz to 300 GHz |

| | | | |
|---|---|---|---|
| | | C95.1a-2010 | Amendment 1: Specifies Ceiling Limits for Induced and Contact Current, Clarifies Distinctions between Localized Exposure and Spatial Peak Power Density |
| TC95 | SC3/4 | C95.1-2345 -2014 | IEEE Standard for Military Workplaces—Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz |
| | | PC95.1-201X | Draft Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic and Electromagnetic Fields, 0 Hz to 300 GHz (Revision—incorporates C95.1-2005 and C95.6-2002) |
| TC95 | SC5 (Safety Levels with Respect to Electro-Explosive Devices) | C95.4-2002 | IEEE Recommended Practice for Determining Safe Distances From Radio Frequency Transmitting Antennas When Using Electric Blasting Caps During Explosive Operations (Reaffirmed 2008) |
| TC34 | SC1 (SAR Evaluation - Measurement Techniques) | 1528-2013 | Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques (similar to IEC 62209-1) |
| TC34 | SC2 (SAR Evaluation – Numerical Techniques) | IEC/IEEE P62704-1 | Draft Standard for Determining the Peak Spatial Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz – 6 GHz: General Requirements for using the Finite Difference Time Domain (FDTD) Method for SAR Calculations. |
| | | IEC/IEEE P62704-2 | Draft Standard for Determining the Peak Spatial Average Specific absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz – 6 GHz: Specific Requirements for Finite Difference Time Domain (FDTD) Modeling of Vehicle Mounted Antenna Configurations. |
| | | IEC/IEEE P62704-3 | Draft Standard for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz: Specific Requirements for Finite Difference Time Domain (FDTD) Modeling of Mobile Phones/Personal Wireless Devices. |
| | | IEC/IEEE 62704-4 | Draft Standard for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz: General Requirements for using the Finite-element Method (FEM) for SAR Calculations and Specific Requirements for Modeling Vehicle-mounted Antennas and Personal Wireless Devices. |

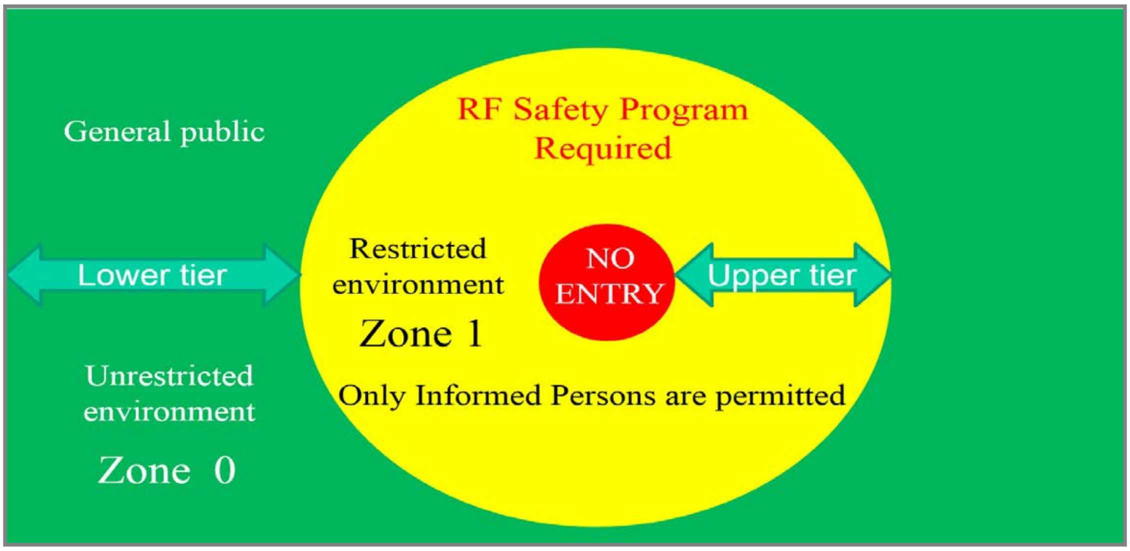
***Table 3.*** *C95.1 terminology changes*

| C95.1-2005 | C95.1-2345-2014 | Remarks |
|---|---|---|
| RF radiation | RF exposure | Avoid confusion with ionizing radiation |
| safety limits | exposure limits | Exposure limits with large safety margins |
| action level | unrestricted environments | Avoids the term “uncontrolled” environment |
| persons in controlled environments | | |
| | restricted environments | Under RF safety program C95.7-2014, there is a restricted environment. |
| Informed persons including the general public are permitted to enter, with exposure not to exceed the upper tier. | | |
| Basic Restriction | Dosimetric Reference Limit (DRL) | Recommended limits relative to dosimetric thresholds for established adverse health effects that incorporate appropriate safety factors. |
| Maximum permissible exposure (MPE) | Exposure Reference Level (ERL) | ERLs are sometimes called reference levels, derived limits, permissible exposure limits, maximum permissible exposure values, or investigation levels. |

***Table 4.*** *Exposure limits for induced and contact current (mA) for continuous sinusoidal waveforms in C95.1-2345-2014*

| | Zone 0 (unrestricted environments) | | | Zone 1 (restricted environments) | | | Zone 2 (restricted experts only—REO) |
|---|---|---|---|---|---|---|---|
| **Frequency** | **100 kHz-3 MHz** | **3 MHz-30 MHz** | **30 MHz-110 MHz** | **100 kHz-3 MHz** | **3 MHz-30 MHz** | **30 MHz-110 MHz** | **100 kHz-110 MHz** |
| **Induced, each foot** | 45 | 45 | 45 | 100 | 100 | 100 | 100 |
| **Contact, grasp[a]** | — | — | — | 100 | $100(f/3)^{0.3}$ | 200 | 250 |
| **Contact, touch** | 16.7 | $16.7(f/3)^{0.3}$ | 33.4 | 50 | $50(f/3)^{0.3}$ | 100 | — |

***Figure 1.*** *Green area (Zone 0) depicts the unrestricted environment for the general public. Yellow area (Zone 1) is restricted environment where only informed persons are permitted to enter. The boundaries between the two environments and for no entry area are determined by the RF safety program.*




## *4. TC34 STANDARDS*

### SC1: Experimental methods

In 1997, SC1 was organized to develop a standard for the measurement of SAR in the head of the user of mobile telephones held next to the ear. The standard was first published in 2003 and a revision "Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques" was published in 2013. This standard is technically similar to IEC 62209-1 [1], which is important in standards harmonization.

### SC2: Numerical methods

As shown in Table 2, four draft standards are being developed by the SC2 and IEC TC106 project teams. The first is on general requirements for using the Finite Difference Time Domain (FDTD) method. The second is application of the FDTD method for the assessment of SAR associated with vehicle mounted antennas, the third is the application of the FDTD method for determining the SAR associated with mobile phones. All three draft standards are at the voting stage of both IEEE and IEC processes. After approval, the three standards will be published as dual logo IEC/IEEE standards. A fourth project, "General Requirements for using the Finite-element Method," is still in the drafting stage.

## 5. CONCLUSION

Both human exposure limits and exposure assessment standards have been developed by the IEEE International Committee on Electromagnetic Safety. C95.6 and C95.1 standards protect against established adverse health effects and include safety margins for human exposure. A standard developed for NATO application was published in 2014. Work combine C95.6-2002 and C95.1-2005 into a single standard for frequencies between 0 Hz and 300 GHz is ongoing. ICES continues to critically review the relevant scientific information while updating its standards. ICES considers harmonization with ICNIRP guidelines [2, 3] and the European Union Worker Directive [4] important, with an ultimate goal of internationally-harmonized EMF exposure criteria.


## ACKNOWLEDGMENT

Materials are adapted from IEEE International Committee of Electromagnetic Safety standards and committee discussions. The author is responsible for the presented content, which is the author's own personal opinion, and not a position of IEEE, IEEE-Standard Association or ICES TC95. Thanks to Ron Petersen for editing the manuscript.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# THE ROLE OF COMPUTATIONAL DOSIMETRY IN THE ASSESSMENT OF COMPLIANCE WITH THE EMF DIRECTIVE 2013/35/EU

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*ABSTRACT*

*EMFcomp are currently preparing the EMF Directive 2013/35/EU Practical Guide, with Public Health England in the UK, for the European Commission. The Practical Guide is intended to facilitate the implementation of the EMF Directive in EU Member States. The purpose of this paper is to outline the computational aspects of the EMF Directive Practical Guide and describe how computational modeling can provide useful tools to demonstrate compliance with the Directive. Numerical simulations to calculate the Directive's exposure limit values (ELVs) are usually required when the action levels (ALs) are exceeded and no mitigation measures are available, for example, when a worker is very close to an electromagnetic field source. Numerical dosimetry provides several useful tools for analyzing near-field conditions. Calculations can take into account the non-uniform nature of the field, and the influence of factors such as the distance from the source, part of the body exposure etc on the way in which the field is absorbed. In these scenarios, simulations can be utilized to calculate dose quantities for direct comparison with the Directive ELVs. In general, calculations are applied in the field of electromagnetic dosimetry to assess electric/magnetic field strength, or more commonly to evaluate the interaction of between an external electromagnetic field and an exposed subject. Numerical dosimetry can be used to directly calculate the Directive ELV quantities such as the induced electric field (up to 10 MHz) and SAR (from 100 kHz to 10 GHz) from an electromagnetic field source. These ELV dosimetric quantities are directly linked to the adverse health effects outlined in the Directive.*

***Key words:*** *Dosimetry, SAR, human phantoms, modelling, EMF Directive 2013/35/EU*

## 1. INTRODUCTION

In 2013, the European Union (EU) produced a Directive 2013/35/EU concerned with the minimum health and safety requirements for risks arising from exposure to electromagnetic fields (1). It is a requirement for all EU member states to implement the Directive by July 2016. EMFcomp are currently preparing the EMF Directive 2013/35/EU Practical Guide, with Public Health England in the UK, for the European Commission. The Practical Guide is intended to facilitate the implementation of the EMF Directive in EU Member States.

The Directive 2013/35/EU includes exposure limit values (ELVs) and action levels (ALs) to protect workers against adverse health effects. The ELVs are limits on exposure to electromagnetic fields based directly on established biological effects and biological considerations. The ALs are levels provided for measurement or calculation purposes to determine whether the ELVs are likely to be exceeded. For a particular exposure scenario, measured or calculated field strengths can be compared to the appropriate ALs. Compliance with the AL will ensure compliance with the relevant ELV. Non-compliance with the AL does not necessarily mean non-compliance with the corresponding ELV. However, in this situation it is necessary to test compliance with the relevant ELV to determine whether additional protection measures are required.

Different adverse health effects are produced from exposure to electromagnetic fields at different frequencies. Because of this, ELVs are provided for non-thermal effects (0-10 MHz) in Annex II of the Directive and thermal effects (100 kHz-300 GHz) in Annex III of the Directive. In the intermediate frequency range (100 kHz-10 MHz) both thermal and non-thermal ELVs need to be considered. The ELVs are defined in terms of the internal dose quantities SAR and induced electric fields. These internal quantities are very difficult to measure within the body. They can only be assessed accurately using the numerical calculations. Annex II and III of the Directive provide the ALs in terms of external field quantities as a means to allow measurements and analytical calculations to be used in compliance assessments.

The Directive identifies when numerical calculations in electromagnetic field occupational risk assessment are required. It states in item 1 of Article 4: 'In carrying out the obligations laid down in Articles 6(3) and 9(1) of Directive 89/391/EEC, the employer shall assess all risks for workers arising from electromagnetic fields at the workplace and, if necessary, measure or calculate the levels of electromagnetic fields to which workers are exposed.' Additionally, The Directive states in item 4 of Article 4: 'If compliance with the ELVs cannot be reliably determined on the basis of readily accessible information, the assessment of the exposure shall be carried out on the basis of measurements or calculations. In such a case, the assessment shall take into account uncertainties concerning the measurements or calculations, such as numerical errors, source modeling, phantom geometry and the electrical properties of tissues and materials, determined in accordance with relevant good practice.' The purpose of this paper is to outline the computational aspects of the EMF Directive practical guide and describe how computational modeling can provide useful tools to demonstrate compliance with the Directive.

## 2. DOSIMETRY METHODS

### a. Experimental Dosimetry

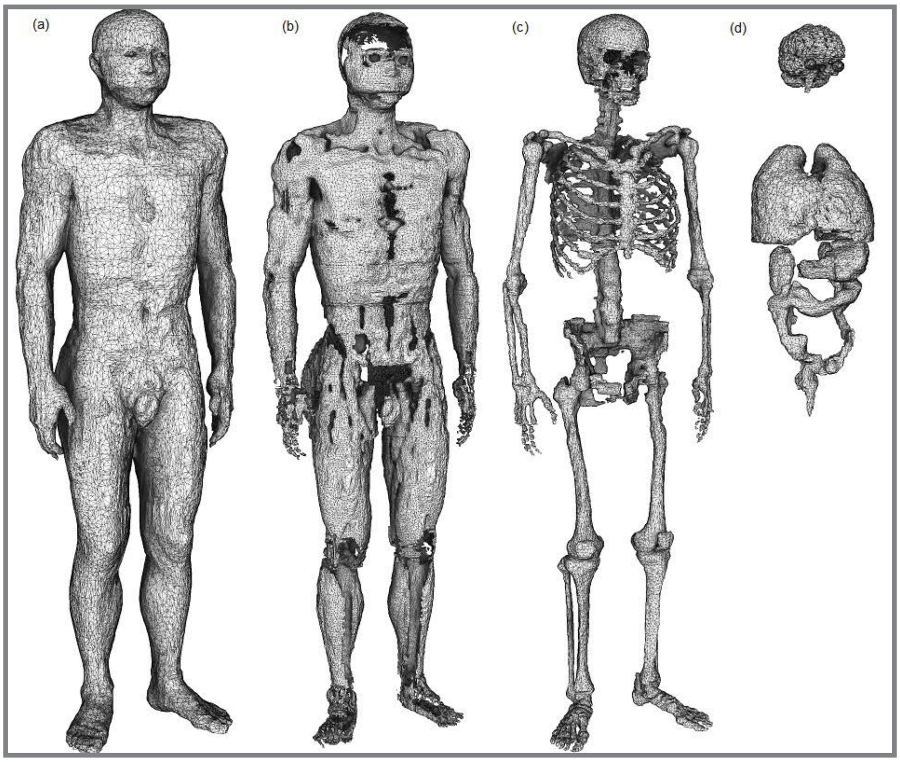
Experimental dosimetry uses measurements and homogeneous, experimental phantoms to assess to dose within humans from exposure to electromagnetic fields. It is routinely used to determine the SAR within the head during the use of mobile phones. The human phantoms used tend to be plastic shells filled with a biological equivalent material that can simulate the dielectric properties of a particular tissue-type for a given frequency.

In conjunction with small electric field probes or temperature meters, the phantoms give an indication of SAR within a human. However, the accuracy of the results produced through utilization of these phantoms and measurement methods tend to be poor, as they are not representative of the heterogeneous nature of the human body and measurement probes frequently affect the SAR value measured due to coupling effects. Therefore, the use of experimental dosimetry is generally confined to the validation of computational dosimetry results. Measurements are also used in the assessment of compliance with the EMF Directive through comparison with the action levels.

### b. Analytical Dosimetry

Analytical Dosimetry is the use of continuous, analytical solutions to solve an exposure problem mathematically. Analytical solutions can solve the Maxwell equations for a particular exposure situation, utilizing the dielectric properties of the exposed material and the electromagnetic field source. However, analytical solutions are limited to the solution of simple exposure scenarios, generally when the exposed material is a simple shape (ellipsoid, sphere, cylinder or cube), is made up of one material – hence has one conductivity, permittivity etc. and is located in free space or over an infinite, perfectly conducting ground plane. Therefore, similar to experimental dosimetry, it tends to be used to validate results produced by computational dosimetric methods for simple test cases.

***Figure 1.*** *An example of a heterogeneous model of the human body used in computational dosimetry, the MAXWEL male phantom, developed by EMFcomp. Displayed are the (a) skin, (b) muscle, (c) bone and (d) selected internal tissue types.*



### c. Computational Dosimetry

Computational dosimetry, that is the use of discrete numerical methods, is used to solve the Maxwell equations for complex exposure configurations involving anatomically realistic human computer models made up of many tissue types when exposed to a variety of electromagnetic field sources. Computational dosimetry is often used to assess dosimetric quantities, i.e. the induced electric fields and SAR within workers, for comparison with the Directive's exposure limit values. The most commonly used numerical methods used in the field of electromagnetics are the finite-difference time-domain (FDTD), finite-difference frequency-domain (FDFD), finite-element (FE), scalar-potential finite-difference (SPFD) and method of moments (MoM).

Certain numerical methods are more suitable for a particular frequency range. In the low frequency range, techniques such as the SPFD and MoM methods are applicable and utilize the quasi-static approximation, relevant when the dimensions of the exposed objects are small when compared with the wavelength of the incident field. This approximation allows the separate solution of the electric and magnetic field exposure problem and is applicable from 1 Hz up to a few hundred kilohertz. For radiofrequency field applications, the FDTD method is the most suitable method. It calculates the internal electric fields and hence SAR in individual cells making up the human body for a particular cell for a particular frequency. Because high resolution human body models are made up of millions of cells, powerful workstations tend to be required for accurate assessment.

The human models are usually based on CAT or MRI based imaging data, segmented into a number of discrete tissue types. Each tissue type is assigned frequency dependent dielectric properties based on experimental evaluation. An example of a human model is the phantom used in the Practical Guide to the Directive, the MAXWEL (MAle fleXible Whole-body modEL) human phantom (2), shown in Figure 1. MAXWEL was developed by EMFcomp and designed to be representative of an adult male. It was based on high resolution MRI scans of a male subject and has been segmented into 46 different tissue types, rescaled to the dimension of the ICRP standard reference man.

## 3. COMPLIANCE ASSESSMENT

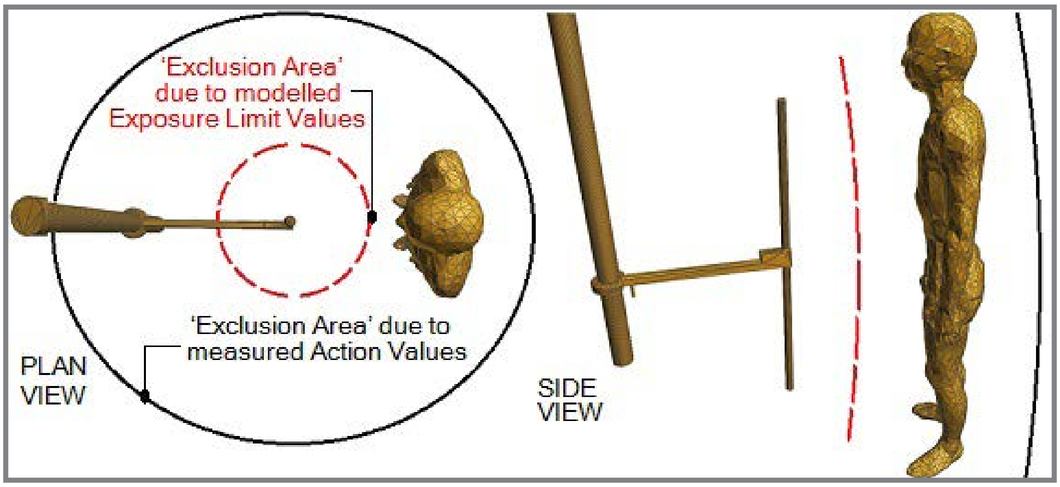
It is important to identify situations when assessing compliance with the Directive 2013/35/EU using computational methods is required. If the field strength values are relatively low in the vicinity of a device producing electromagnetic fields, a small number of measurements are sufficient to demonstrate compliance with the Directive's action levels. However, if the action values stated in the Directive are exceeded and mitigation measure are either difficult or not possible, there exists a need to assess the exposure limit value quantities (induced electric fields, SAR) using computational methods.

Computational dosimetry in the assessment of compliance with the Directive is particularly applicable for:

- **Low frequency fields**

At low frequencies, particularly below 1 kHz, the Directive action levels represent a very conservative approximation of the exposure limit values. The result is a number of situations where field measurement values are significantly above the allowed action value, yet when the induced electric fields in the body are calculated using computational methods, compliance with the Directive's ELVs is comfortably achieved. This can be demonstrated by the determination of an 'exclusion area' in which the worker is not permitted to enter, due to non-compliance with the EMF Directive restrictions (Figure 2).

***Figure 2.*** *Plan and side views of the MAXWEL model and calculated exclusion areas due to (i) induced electric fields in the body and (ii) measured magnetic flux densities in the vicinity of a Demagnetizer device.*



An exclusion region for an antenna has been defined; based on the measure values of electric field strength and comparison with the Directive action levels. Another, less restrictive exclusion region has also been defined based on the internal SAR (in watts per kilogram) induced in the human model and comparison with Directive exposure limit values.

It can be seen that the exclusion area based on computed ELV quantities allows the worker to occupy a region much closer to the device that is being operated.

- **Radiofrequency fields**

For radiofrequency fields, when the field source is very close to the human body and the potential for coupling between the electromagnetic device and human tissue exists. Computational dosimetry is a useful method that can accurately analyse near-field exposure situations, taking into consideration the heterogeneous nature of the human body and the influence of field source parameters (e.g. region of the body exposed, extent of the coupling between field source and body, influence of field source – body separation distance etc.).

The Directive states that, for low frequency exposure, 'in the case of a very localised source within a distance of a few centimetres from the body, the induced electric field shall be determined dosimetrically, case by case'. Similarly, for radiofrequency fields the Directive advises that 'in the case of a very localised source within a distance of a few centimetres from the body, compliance with ELVs shall be determined dosimetrically, case by case'.

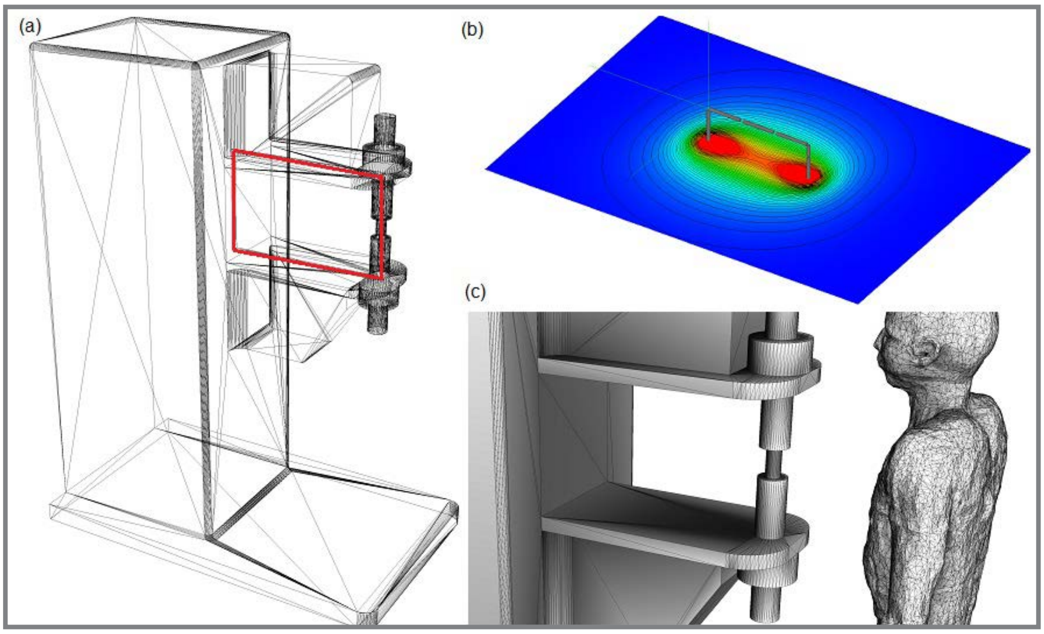
### *a. Low Frequency Example (Pedestal Welding Machine)*

Pedestal welding machines are used to spot weld prepared metal panels together. For this particular example, the operating frequency was 50 Hz. The field source is modeled as a current loop, shown in Figure 3 in red with a width of 45 cm and a depth of 30 cm.

Experimental results were obtained for the magnetic field around the device, and an equivalent source model was produced based on these results to generated magnetic vector potentials for each cell in the computational domain.

The human model was then imported into the computational domain and the SPFD method used to calculate the induced electric fields in the body. The human model was positioned so that the chest was approximately 15 cm away from the welding electrode.

***Figure 3.*** *(a) Wire-framed model of the pedestal welding machine showing the current loop in red, (b) the magnetic fields calculated from the loop and (c) the positioning of the machine and human model within the computational domain.*

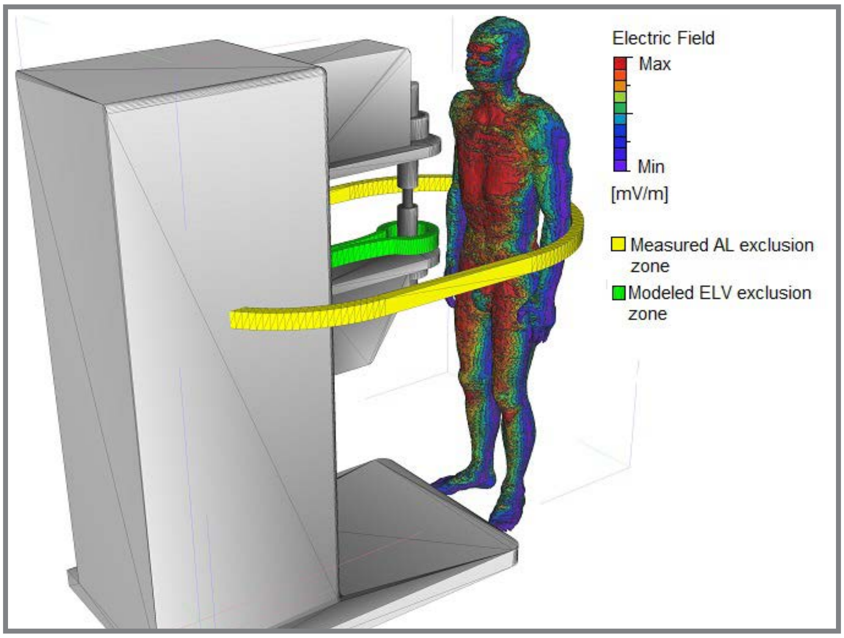



The distribution of the induced electric field in the body from exposure to the pedestal welding machine is shown in Figure 4. The color map is a rainbow spectrum, with the highest values in red and the lowest values in violet. The values have been normalized to the highest field value calculated. The color map was then stretched to enhance the lower part of the spectrum.

High values of induced electric field are seen in regions close to the welding machine, in the lower conductivity tissues such as bone, fat and tendon, and in regions determined by the shape of the body. These regions include areas where sharp corners exist such as the underarm region, fingers and the groin area.

The exclusion zones based on comparisons of the induced electric field with the Directive ELVs and of the magnetic flux density with the ALs. As described previously, the exclusion zone based on calculated ELVs is significantly smaller than that based on measured ALs. case'.

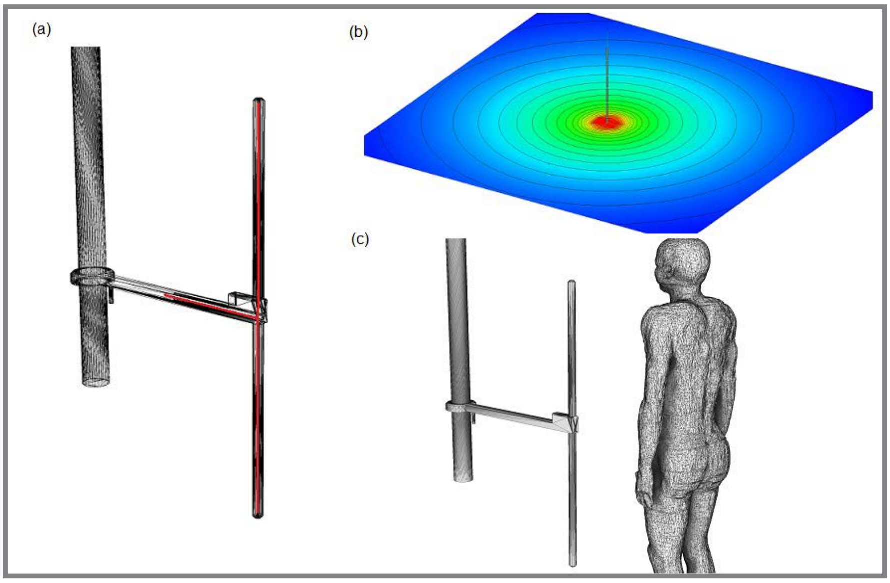
***Figure 4.*** *The distribution of induced electric fields in the human model from exposure to the 50 Hz welding machine. Also shown is the calculated exclusion zones from comparison of the modeled induced electric fields to the ELVs (green) and measured magnetic flux densities to the ALs (yellow).*




## *b. Radiofrequency Example (Antenna)*

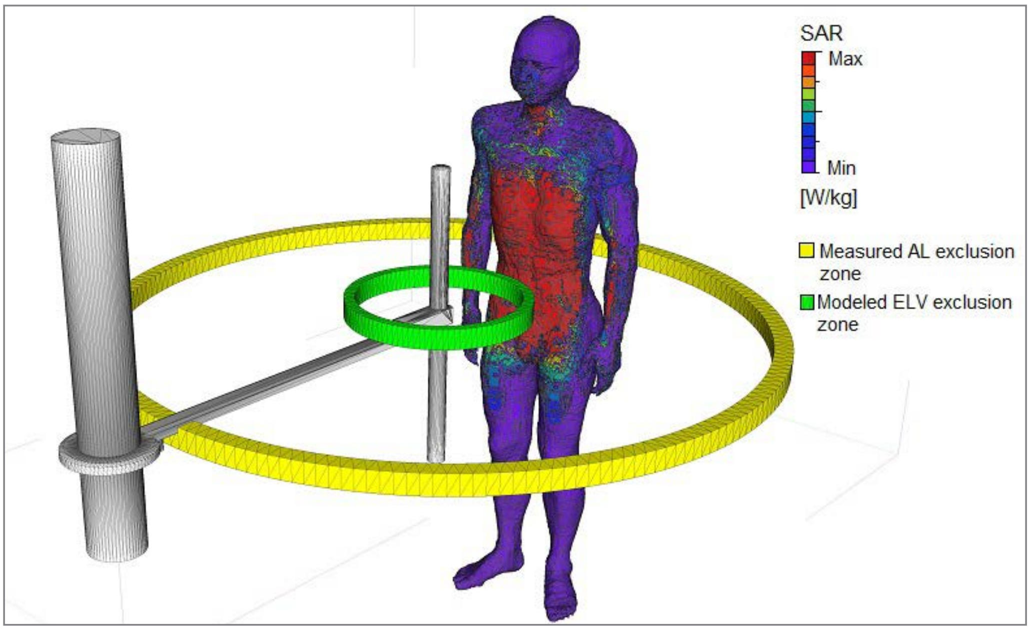
Dipole antennas are used in communication applications to send and receive signals. The antenna in this example is omni-directional, and operates at a frequency of 400 MHz. A computational approach is taken to assess the absorption in a worker from exposure to the radiofrequency field produced by this device.

***Figure 5.*** *(a) Wire-framed model of the antenna showing the dipole in red, (b) the electric fields calculated from the dipole and (c) the positioning of the antenna and human model within the computational domain.*




The FDTD method is used to calculate the SAR in the body for this example. A model of the dipole is created FDTD computational domain, and output from this antenna was validated by comparison of electric field strength values generated using a different numerical method (method of moments). SAR was calculated in the MAXWEL human model at different antenna-body separation distances.

***Figure 6.*** *The distribution of the SAR in the human model from exposure to the dipole. Also shown is the calculated exclusion zones from comparison of the modeled SAR to the ELVs (green) and measured magnetic flux densities to the ALs (yellow).*




The distribution of the SAR is shown in Figure 6. It can be seen that the field absorption is relatively localized to the torso region. In this situation, the peak localized SAR value, averaged over a 10 g contiguous region as specified in the Directive, is the relevant dose quantity to be compared against the ELVs.

The exclusion zones based on comparisons of the induced electric field with the Directive ELVs and of the magnetic flux density with the ALs are again shown. Similar to the low frequency example, the exclusion zone based on calculated ELVs is significantly smaller than that based on measured ALs.

## *4. SUMMARY*

Computational modeling can be an extremely useful and versatile tool in demonstrating compliance with the EMF Directive 2013/35/EU. Numerical simulations to calculate the Directive's Exposure Limit Values (ELVs) are usually required when the Action Levels (ALs) are exceeded and no mitigation measures are available, for example, when a worker is very close to an electromagnetic field source.

Calculations can take into account the non-uniform nature of the field, and the influence of factors such as the distance from the source, part of the body exposure etc on the way in which the field is absorbed. In these scenarios, simulations can be utilized to calculate dose quantities for direct comparison with the Directive ELVs.

In many exposure situations, calculation of the induced electric fields and SAR values, coupled with comparisons with the Directive's ELVs, results in an exclusion zone around a device that is considerably less restrictive when compared with a similar exclusion zone derived from measurements and comparisons with ALs.

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# HEALTH SURVEILLANCE ACCORDING TO THE NEW EU DIRECTIVE 2013/35/EU: POSSIBLE CRITERIA

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## ABSTRACT

*In a discussion on possible criteria for health surveillance (HS) of workers exposed to electromagnetic fields (EMF) it should be stated beforehand that the new EMF Directive 2013/35/EU specifically refers to the protection from the risks associated with known direct biophysical and indirect effects caused by EMF (0 – 300 GHz), while does not address to suggested long-term effects. HS of EMF exposed workers should be performed based on the results of the risk assessment, but until now no international guidelines or authoritative documents on criteria to be applied are available. A further specific problem is HS of workers "at particular risk", as: a) no shared comprehensive definition of these workers is currently available, and b) an adherence to the ELVs of the Directive 2013/35/UE do not necessarily provide an adequate protection workers at particular risk and e.g. interference problems, especially with pacemakers, may occur at lower levels. As a conclusion, at present the problem concerning the HS of workers exposed to EMF is that sound scientific data, especially on groups at higher risk, are largely insufficient, and do not give an adequate support to the occupational physician to face the problem; accordingly, no consensus exists regarding adequate procedures to be applied*

**Key words:** *Directive 2013/35/EU, health surveillance, exposed workers, workers "at particular risk"*

## 1. INTRODUCTION

The new EU Directive 2013/35/EU provides specific measures for the protection of workers from "the health and safety risks related to exposure to static electric, magnetic and time-varying electric, magnetic and electromagnetic fields with frequencies up to 300 GHz (EMF)" during work (Art. 2). One of the measures is implementation of an "appropriate health surveillance" (HS).

The problem here is that HS of EMF exposed workers is a problem still open in occupational medicine. In fact, while guidelines exist on various other aspects, until now no authoritative guidelines/documents are available on this topic.

An open discussion among occupational physicians and the other involved occupational professionals on the scope and main criteria for the definition and implementation of HS of EMFs exposed workers should be highly suitable. Here some criteria are presented and discussed.

## 2. METHOD

In a discussion on possible criteria for health surveillance (HS) of workers exposed to electromagnetic fields (EMF) it should be observed that the present EMF Directive 2013/35/EU specifically refers to the protection from the risks associated with known direct biophysical and indirect effects caused by EMF (0 – 300 GHz), while does not address to suggested long-term effects since scientific evidence of a causal relationship is considered not conclusive.

Taking into account this premise, the objective of health surveillance according to the Directive 2013/35/EU is the prevention, or the early diagnosis, of any adverse health effect in workers associated to occupational exposure to EMF.

## 3. DISCUSSION

An extensive body of research is available on possible effects of EMFs: thousands of scientific studies have been performed, and several hundreds of scientific papers have been published: just to give an idea, in the "EMF Portal", a web-based information platform collecting scientific information regarding the effects of electromagnetic fields on humans and on interaction with biological systems or body aids implemented by the Clinic of Occupational Medicine of Aachen University 19.608 scientific publications are collected (http://www.emf-portal.de/_index.php?l=e, last accessed: July 2, 2014). It is evidently impossible to discuss in details literature, but authoritative reviews as the Environmental Health Criteria of the World Health Organization (WHO) and several other, are available (1-5).

In very general terms, possible adverse health effects related to EMF exposure can be classified in short- and long-term. The former can be further classified as direct biophysical effects including thermal and non-thermal effects, and indirect effects including contact currents, interference, and others. Long-term effects entail several different suspected effects, such as cancer, neurodegenerative diseases, and others (4, 5).

As anticipated, the new European Directive 2013/35/EU specifically refers to the protection from the risks associated with known short-term effects only.

As a consequence, specific objectives of HS performed according to this directive should be considered:

1) The prevention of any thermal and non-thermal established effect, such as the stimulation of muscles, nerves, sensory organs (including temporary annoyance or effects on cognition), and limb currents;

2) The health and safety of workers that can be considered "at particular risk," such as workers with active or passive implanted medical devices (cardiac pacemakers, insulin pumps, cochlear implants, etc.) and pregnant workers; nevertheless, a shared comprehensive definition of the workers, and conditions, that should be considered "at particular risk" is admittedly lacking (1-5).

Medical examinations for HS should be performed based on the results of the completed risk assessment according to the EU Directive 2013/35. Clinical evaluation should be mainly based on the collection of anamnestic data, including clinical symptoms, and on a comprehensive physical examination, while specific laboratory tests are currently not considered required, except on an individual clinical basis.

Furthermore, appropriate medical examinations, or individual health surveillance, must be provided in cases where undesired or unexpected health effects presumably related to EMF are reported by workers, or in any event where an acute overexposure, i.e., an exposure above the Exposure Limit Values (ELVs), is detected. The investigation procedure depends on how well the exposure situation is known, and on the symptoms and signs presented from the subject. The more usual clinical symptoms in case of overexposure to radiofrequency fields are acute skin or eye reactions, but symptoms to the nervous system (both CNS and/or PNS) are also possible depending on the EMF frequency range, level, etc. (6). Accordingly, HS should usually include an accurate overall clinical evaluation (dermatological, ophthalmological, neurological); specialist(s) consultation and appropriate laboratory tests should also be considered on an individual clinical basis.

Regarding subjects who can be considered "at particular risk," the number among active workers is progressively increasing. The more sophisticated technology can, at least in some cases, be vulnerable to adverse effects of the external EMF fields. A relevant aspect to be considered here is the fact that an adherence to the ELVs of the Directive 2013/35/UE should provide an adequate protection with regards to the established adverse health effects, but not necessarily in workers at particular risk, e.g., interference problems, especially with pacemakers, may occur at lower levels (7,8). Procedures for health risk assessment in workers with implanted medical devices are available (9-11). Regarding pregnant workers, the overall evidence for developmental effects and reproductive effects is currently considered inadequate (1-5), but the problem related to concern, and consequently, anxiety, should be taken into account; in such cases, adequate measures, including moving the concerned worker or granting a leave of absence, can be adopted under Directive 92/85/EEC "on the introduction of measures to encourage improvements in the safety and health at work of pregnant workers."

## 4. CONCLUSIONS

In conclusion, the problem presently concerning the health surveillance of workers exposed to electromagnetic fields (EMF) is that sound scientific data, especially on groups at higher risk, are insufficient and do not give adequate support to occupational physicians to face the problem; accordingly, no consensus exists regarding adequate implementation procedures. The development of shared criteria for health surveillance of EMF exposed workers, medical examinations in case of overexposures, and the definition, approach, and management of the problem of "workers at particular risk" is an evident and urgent need in this field.

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# ELECTROMAGNETIC FIELDS HYGIENIC REGULATION IN RUSSIA. WAYS OF INTERNATIONAL HARMONIZATION

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*ABSTRACT*

*Electromagnetic field (EMF) hygienic standardization in Russia is based on the results of hygienic, clinical-physiological, epidemiological and experimental studies. Hygienic norms are developed for discrete frequency ranges. In Russia there are hygienic norms of occupational exposure for hypo-geomagnetic conditions, static and 50 Hz electric and magnetic fields, radiofrequency EMF (from 10 kHz to 300 GHz, and for special EMF case (ultra broadband pulses). General public hygienic standards are developed for static electric field, power frequency electric and magnetic fields and radiofrequency EMF (from 30 kHz to 300 GHz) and for spe¬cial case: mobile communication systems. General public hygienic norms are applied not only to general public but also to staffs exposed by EMF at work places but not connected with EMF equipment maintanance and exploration.*

*Today new norms for frequencies from 3 Hz up to 30 kHz are developed, as well as attempt of near zone EMF adequate evaluation (for >300 MHz frequency range) principles are in development.*

*The main discrepancy of Russian and international EMF hydienic standardization approaches are in concepts of "cumulative" or "acute" factor effects, correspondingly. Hence EMF hygienic norms in RF are time dependent, comprising a principle "protection by time". Some new approaches are suggested.*

***Key words:*** *electromagnetic field, hygienic standardization, different approaches, international harmonization.*

The problem of occupational and general public electromagnetic safety is increasing urgency in connection with increasing environment electromagnetic pollution and increase in this connection health risks. Main sources of electromagnetic fields (EMF) traditionally are the equipment power- and radio transmission objects, radar and navigation systems. Last years the essential contribution into electromagnetic environment is brought with personal computers and mass media, mobile telecommunication systems especially. Environmental EMF exposure in private life may be commensurable with occupational today. The most actual are the questions of EMF effects of combined with another environmental factors exposure.

Hygienic EMF standards in former USSR and Russian Federation now are developed, as a rule, on the basis of hygienic, clinical and physiological, experimental, and last years epidemiological studies as well as scientific publications in peer reviewed journals. Hygienic researches are carried out on purpose to definite the time-level EMF exposure parameters in real conditions; clinical and physiological - are directed to reveal health state and physiological functions unfavorable changes; epidemiological – to analyze the remote consequences of factor exposure; experimental - to study the features and character of EMF biological effects. The main bases of EMF norms setting are the experimental data of EMF exposure hazard effects threshold determination. Experimental studies play the leading role in hygienic norms substantiation, taking into account the results of experiment, from animals to human transfer criterion and hygienic safety factor (different for different frequency ranges and emission modes).

According Russian concept electromagnetic field of power, broadcasting, television objects, mobile radio communication systems (Wi-Fi including), etc. are health risk factor. In case of occupational exposure EMF are purposeful risk factor; in case of other workers (occupationally unconnected with EMF sources maintenance) and general public exposure EMF are enforces risk factor; and in case of EMF emitters (mobile phones, laptops, Bluetooth, etc.) use EMF are voluntary risk factor.

Critical organs and systems of radio-frequency range EMF exposure have been determined: nervous, cardiovascular, blood system, reproductive function; nervous-endocrine systems interrelation was determined (as hypothalamus-hypophysis-adrenal glands bark axis), first criteria of immune system changes are revealed, etc.

There are the data of cataractogenic effect under 80-100 mW/cm2 acute RF EMF esposure .

Occupational exposure chronic EMF effects include:

- Asthenic syndrome (initial phase of disease) – patient complaints: headache, high fatigability, irritability, occasional heart pains. Autonomic changes vagotonic type usually (hypotension, bradicardia, etc).
- Asthenovegetative syndrome (neurocirculatory dystonia hypertensive type (in moderate and expressed stages of disease) – besides deepening of asthenical manifestations there are vegetative disorders connected with vegetative nervous system sympathetic part tone prevalence by way of vascular instability with hypertensive and vasoconstrictive reactions
- Hypothalamic syndrome, with paroxysmal states in form of sympatho-adrenal crisis. In time of crisis there are the possibility of paroxysmal ciliary arrhythmia and ventricular premature beats. Hyperexcitability, emotional instability. Signs of early atherosclerosis, coronary heart disease (ischemia), essential hypertention

EMF occupational exposure may be risk factor of possible long-term effects:

- Early atherosclerosis;
- Coronary heart disease;
- Essential hypertention;
- Cancer (leukemia, brain tumors);
- Congenital malformations;
- Neurodegenerative diseses (Alzheimer's dementia, Parkinson's disease, ALS).

Hygienic norms (standards) in Russia concept is based on the need to exclude adverse health effect of present and future generations. The principle of EMF chronic exposure adverse effect threshold definition is basis for hygienic norms in the Russian Federation. Hence, Russian EMF hygienic ocupational norms are time dependent, comprising a principle "protection by time". According to it, hygienic norms are developed for discrete frequency ranges and conditions. In Russia there are hygienic norms of occupational exposure for hypo-geomagnetic conditions, static electric and magnetic fields, 50 Hz EMF and radiofrequency EMF (from 10 kHz to 300 GHz, and for special EMF case (ultra broadband pulses) [1-4] (see table 1). General public hygienic standards are developed for hypo-geomagnetic conditions, static electric field, power frequency (50 Hz) electric and magnetic fields and radiofrequency EMF (from 30 kHz to 300 GHz) [2,3,5,6] and for special case: mobile communication systems [7].

***Table 1.*** *EMF occupational exposure hygienic norms in the Russian Federation*

| Frequency range | Electric field strength | Magnetic field strength; magnetic flux density | Equivalent plane wave power density, seq. | Power exposition |
|---|---|---|---|---|
| **Static field** | 20–60 kV/m 9.0–1.0 h per work shift depending on time | 10–30 mT (local to limb exp. 15–50 mT) depending on time | - | - |
| **50 Hz** | 5–25 kV/m depending on time | 0.1–2.0 mT (local to limb exp. 0.8–6.4 mT) depending on time | - | - |
| **≥10 - 30 kHz** | 500 V/m (max. 1000 V/m) depending on time | 50.0 A/m (max. 100 A/m) depending on time | - | - |
| **≥0,03-3,0 MHz** | 50.0 V/m (max. 500 V/m) depending on time | 5.0 A/m (max.50 A/m) depending on time | - | 20000 (V/m)² ·h; 200 (A/m)² ·h |
| **≥3-30 MHz** | 29.6 V/m (max. 300 V/m) depending on time | - | - | 7000 (V/m)² ·h |
| **≥30-50 MHz** | 10.0 V/m (max. 80 V/m) depending on time | 0.3 A/м (max. 3.0 A/м) depending on time | - | 800 (V/m)² ·h; 0.72 (A/m)² ·h |
| **≥50-300 MHz** | 10.0 V/m (max. 80 V/m) depending on time | - | - | 800 (V/m)² ·h |
| **≥0.3 - 300 GHz** | - | - | 25,0 μW/cm² ; max. 1000 μW/cm² | 200 (μW/cm²)·h |

RF is only country that has hygienic standards of hypo-geomagnetic environment - decreased terrestrial magnetic field. This decreased magnetic field levels are: in shielding premises in radio-technical, radio- electronic, aircraft industries; in civil and military radio communication and radar units; in underground constructions (archives, bins, mining camps, subway premises); in reinforced concrete buildings; and in civil and military land, water and air transport, etc. The maximum permissible level of geomagnetic field intensity attenuation when working in hypo-geomagnetic conditions to 2 hours per shift is set to 4, and for all work day - to 2 [3].

International EMF safety standards are based on peer reviewed scientific publications data. Until 2013 the main criteria of standardization were: "basic restrictions" and «reference levels» for different EMF frequency ranges [8]. "Basic restrictions" are based directly on established health effects and biological considerations (current density or specific absorption rate (SAR) in different frequency ranges). These reference levels (ICNIRP) or maximum permissible exposure levels (IEEE) correspond to basic restrictions under worst case exposure conditions for one or more of the following physical quantities: electric field strength (E), magnetic field strength (H), magnetic flux density (B), power density (S), limb current (I ), contact current (I ) and, for pulsed fields, specific energy absorption (SA). Part of measurement values were the same as in RF: electric field strength, magnetic field strength, equivalent plane wave power density.

New EU Directive [9] introduces some new definitions and criteria of EMF hazard effects and safety:

- «Exposure limit values (ELVs)» as values established on the basis of biophysical and biological considerations, in particular on the basis of scientifically well-established short-term and acute direct effects, i.e. thermal effects and electrical stimulation of tissues;
- «Health effects ELVs» as ELVs above which workers might be subject to adverse health effects, such as thermal heating or stimulation of nerve and muscle tissue;
- «Sensory effects ELVs» as ELVs above which workers might be subject to transient disturbed sensory perceptions and minor changes in brain functions;
- «Action levels (ALs)» as operational levels established for the purpose of simplifying the process of demonstrating the compliance with relevant ELVs or, where appropriate, to take relevant protection or prevention measures specified in this Directive.

As a whole, principles and criteria of EMF health risk assessment and management in Russian Federation and International are similar. EMF control principles and methods on workplaces and in places of general public residing, basically, also sufficiently correspond. Nevertheless, because of differences in approaches to EMF hygienic rating significant differences between permissible levels are found out. The main difference is EMF cumulative effects concept (in Russia) and acute effects concept (in international). Comparison of Russian and International EMF hygienic norms is presented in table 2.

***Table 2.*** *EMF general public exposure hygienic norms: RF and International*

| Frequency range | Russian Federation, permissible levels | | | COUNCIL RECOMMENDATION 1999/519/ EC | | |
|---|---|---|---|---|---|---|
| | Electric field strength | Magnetic field strength; magnetic flux density | Equivalent plane wave power density, seq. | Electric field strength | Magnetic field strength; magnetic flux density | Equivalent plane wave power density, seq. |
| Static field | 15 kV/m | - | - | - | 400 mT | - |
| 50 Hz | 0.5 kV/m; max. 20 kV/m | 5 μT (max. 100 μT) | - | 5 kV/m (max.20 kV/m) | 0.5 mT (max.5.0 mT) recautionary principles | - |
| 20-22 kHz | 500 V/m | 4 A/m | - | 87 V/m | 5 A/m | |
| 30-300 kHz | 25 V/m | - | - | 87 V/m | 5-0,73/f A/m | |
| 0.3-3.0 MHz | 15 V/m | - | - | 87-87/f V/m | 0,73/f A/m | - |
| 3-30 MHz | 10 V/m | - | - | 87/f - 28 V/m | 0.73/f-0.0037 | - |
| 30-300 MHz | 3 V/m* | - | - | 28 V/m | 0.0037 A/m | 20 W/m² (0.2 mW/m²) |
| 0.3-300 GHz | - | - | 10 μW/cm² 25 μW/cm²** | 1.375f – 61 V/m | 0.0037f – 0.16 A/m | f/200-1.0 mW/m² |

** Except for means broadcasting and TV (frequency ranges 48.5-108; 174-230 MHz);*
*** For cases of rotating or scanning modes of antenna functioning.*

General public hygienic standards in Russia include the same as occupational standards principles of EMF safety. EU Council Recommendation 1999 /519/EC [10] saved previously entered for occupational exposure according Directive 2004/40/EC [9] definitions “basic restrictions” and “reference levels”. The Russian general public permissible levels are stricter than International, except for special norms for inductive oven EMF emission. Serious disadvantage of domestic standards is its lack on EMF magnetic component, which is now regarded as human health risk factor.

The WHO/International Agency for Research on Cancer (IARC) in 2002 has classified extremely low frequency magnetic field as possibly carcinogenic to humans (Group 2B) (childhood leukemia) [11]; in 2011 IARC has classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B), based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use [12]. Reports of possible association of mobile phone EMF and possible thyriod gland cancer risk elevation were published in 2013 March.

**There are 3 principles of EMF safety:**

- **Protection by time.** It is applied when there is no opportunity to reduce EMF intensity up to all day (or all working day) maximal permissible levels. It is realized in hygienic norms both for occupational exposure, as well as general public exposure.

- **Protection by distance.** In case of occupational exposure it consists in deducing staff of raised EMF levels zone. In case of general public exposure it is realized by the maximal removal of population places of residing (constant stay) from EMF source. In particular, for general public PF electric field protection, are organized sanitary-protective zones.

- **Protection by protective means.** Protective means are collective and individual. As collective protective means for occupational conditions the devices limiting EMF levels at workplaces (shielding) are used. To individual protection from PF EF apply screening clothes.

The main differences between occupational and general public EMF exposure hygienic norms together with norms of mobile phone EMF between the Russian Federation and the western countries are connected with basic differences in approaches to standardization: application of various criteria of effects evaluation (acute exposure effects as main criteria, «continuous» standardization, “basic restriction”, “reference levels”, SAR from one side and chronic exposure effects as main criteria, cumulative effects, power density, power exposure from another).

One of the main problems today is the EMF threshold permissible values international harmonization. The main complexity is represented with distinction in approaches to hygienic standardization. Possible way of occupational and general public EMF exposure hygienic norms harmonization can be preservation of hygienic norms which used in the Russian Federation already (for discrete frequency ranges and modes of EMF generation). For frequency ranges (or EMF components), and also modes of generation which are absent in the Russian hygienic norms, as temporary the recommendations offered as international can be accepted.

Russian EMF occupational and general public exposure new hygienic norms for 3 Hz – <30 kHz frequency range are developed (see table 3-5) but not official published yet. In this document EMF standardized parameters are corrected RMS values of electric (Ew) and magnetic (Hw) fields. RMS-weighted values of electric or magnetic fields can be determined by direct measurement or frequency analysis using.

For direct measurements RMS corrected values of electric and magnetic field decade bands 3 - <30 Hz, 30 - <300 Hz, 300 - <3000 Hz, 3 - <30 kHz should be used measurement means with defined frequency characteristics and meter errors. Under using the frequency analysis should be measured RMS value of electric and magnetic field levels for certain discrete frequency components in decade bands: 3 - <30 Hz, 30 - <300 Hz, 300 - <3000 Hz, 3 - <30 kHz, and then to calculate RMS corrected E and H values by special formulas.

***Table 3.*** *Occupational exposure maximum permissible levels RMS-weighted values of electric field strength in 3 Hz – <30 kHz frequency range (draft)*

| *Frequency range, f* | *Maximal permissible level, Ew, kV/m* | |
|---|---|---|
| | *Exposure more than 2 h* | *Exposure up to 2 h* |
| 3 - <30 Hz | 5 | 10 |
| 30 - <300 Hz* | 2,75 | 5,5 |
| 300 - <3000 Hz | 0,6 | 1,2 |
| 3 -<30 kHz** | 0,5 | 1,0 |

*- 50 Hz sinusoidal electrical field permissible levels are excluded from this table and relevant according table 1.

** - in this frequency range RMS corrected value of E coincides with mean-square value, measured by means of linear frequency response

***Table 4.*** *Occupational exposure maximum permissible levels RMS-weighted values of magnetic field strength in 3 Hz – <30 kHz frequency range (draft)*

| *Frequency range, f* | *Maximal permissible level, Hw, A/m* | |
|---|---|---|
| | *Exposure more than 2 h* | *Exposure up to 2 h* |
| 3 - <30 Hz | 200 | 1000 |
| 30 - <300 Hz* | 55 | 270 |
| 300 - <3000 Hz | 12 | 25 |
| 3 -<30 kHz** | 10 | 25 |

**- 50 Hz sinusoidal magnetic field permissible levels are excluded from this table and relevant according table 1.*

*** - in this frequency range RMS corrected value of H coincides with mean-square value, measured by means of linear frequency response*

***Table 5.*** *General public exposure maximum permissible levels RMS-weighted values of electric and magnetic field strength in 3 Hz – <30 kHz frequency range (draft)*

| *Frequency range, f* | *Maximal permissible level* | |
|---|---|---|
| | *Ew, kV/m* | *Hw, A/m* |
| 3 - <30 Hz | 500 | 20 |
| 30 - <300 Hz* | 250 | 3 |
| 300 - <3000 Hz | 100 | 2 |
| 3 -<30 kHz** | 50 | 1 |

**- 50 Hz sinusoidal electric and magnetic field (generated by external sources) permissible levels are excluded from this table and relevant according table 2.*

*** - in this frequency range RMS corrected value of E and H coincides with mean-square value, measured by means of linear frequency response*

Strong restriction in EMF hygienic norms improvement taking into account Russian and International criteria is EMF dose concept. Russian approach based in EMF cumulative effects including does not take into account the correction factors that are depend on radiation level. This parameter named “power exposition” is not completely adequate to “dose” definition, but takes into account possible effects of radiofrequency EMF energy storage. More close to dose concept may be approach that include specific absorption rate (SAR) for radiation levels evaluation in the near field. Russian approach is based in radiofrequency EMF physical characteristics, and SAR approach bases on the electric field strength and dielectric characteristics of human body.

Consequently the electromagnetic safety problem has some different aspects. One of them is continuation of medical and biological studies of EMF different frequency ranges and emission modes human health risks assessment, magnetic field component and new technical devices especially. The another future prospect of electromagnetic safety insurance (in Russian Federation especially) is dosimetry development in account the international experience, as well as dose and threshold permissible values interrelationships search, that must be substantiated by medical and biological studies data. New complex methods of electric and magnetic EMF components as well as SAR levels measurement and evaluation must be developed.

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# THE COGNITIVE SIDE OF ELECTROMAGNETIC HYPERSENSITIVITY

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ABSTRACT

*No satisfying working definition of electromagnetic hypersensitivity (EHS) has ever been proposed, leaving anyone willing to investigate this condition with assertions from alleged sufferers as the only inclusion criterion for participants in his study. The deeply subjective nature of this criterion undoubtedly impedes the scientific understanding of EHS. This paper thus examines the genesis of symptoms attribution to EMF exposure among forty people claiming to suffer from EHS. The data consists of semi-structured interviews conducted with them in person, in various areas of France, over one year between 2012 and 2013. They were analyzed following an ethnographic approach. We observed that in every subject, the attribution of symptoms to EMF exposure results from an identical, seven stages cognitive process through which its obviousness is progressively forged. Nothing in this process appears specific to any set of symptoms, provided they are disturbing and resilient enough. We therefore argue that EHS should less be regarded as a disease in its own right, than as a mental structure making it possible to cope with such symptoms (which might be labeled as medically unexplained).*

***Key words:*** *electromagnetic hypersensitivity, EHS, idiopathic environmental illness attributed to electromagnetic fields, IEI-EMF, medically unexplained symptoms, MUPS, cognitive processes, contested illnesses, medical sociology*

## 1. INTRODUCTION

The question of electromagnetic hypersensitivity (EHS) has imposed itself as an essential dimension of the global questioning of EMF possible effects on human health. A growing number of investigations have been devoted to it during the last 20 years, yet it hardly seems better understood. Notably, it still awaits to be associated with a concrete physiopathological mechanism. Our starting hypothesis is that this situation results mainly from an impossibility to formulate an objective definition of EHS, that is to say, to identify a criterion or an empirical test which would allow to diagnose reliably this condition. Let's verify this by taking a quick glance at the most recent literature.

Starting from the clinical point of view, it appears there is no standard picture of EHS. The symptoms attributed to EMF, either in daily life or in experimental contexts, are both extremely various and non specific. The most commonly reported are fatigue, headaches, cognitive difficulties, memory losses, insomnia, cutaneous rashes, and pain in numerous locations [1]. They are not associated with any obvious clinical signs or biological markers, as far as immunologic, hematological, respiratory, nervous and genetic abnormalities have been investigated [2]. Some studies have documented an association between EHS and pathological personality traits like anxiety, depression, somatization and stress [3]. However such psychiatric correlates are common among medically unexplained symptoms suffers in general, and might be regarded as their cause as well as their consequence [4]. Thus EHS is not characterized by a specific clinical picture that would allow to diagnose it in a medical setting. Provocation trials have not proved more successful in providing an empirical criterion to define EHS. When compared to the control groups, the allegedly sensitive subjects do not present more or different symptoms, nor do they appear more able to discriminate between sham and real exposures – provided the tests are conducted in proper double-blind conditions [5]. Conversely, their reactions are significantly correlated with the information they are provided about their exposure [6], and all the more adverse that this information is alarmist [7]. Therefore, provocation trials cannot be considered as a reliable diagnostic tool for EHS, their sensitivity and their specificity being both very low. Eventually, the few randomized trials of therapies that have been conducted have not provided any other lead regarding the fundamental basis of EHS: among the different specific treatments which have been tested, notably cognitive-behavioral therapy, none have been observed to exert significantly stronger effects than placebo treatments [8].

No satisfying way to define and to diagnose EHS has thus been identified – the consequence being that when investigating this condition, researchers are compelled to rely solely on self-declaration from the potential subjects. Indeed, the authors of a recent review have established that in every published study on EHS, the claim to be hypersensitive to EMF was the only inclusion criterion to be employed [9]. Admittedly, various exclusion criteria were also used, such as the absence of any disorder susceptible to account for the subjects' symptoms, or the delay between their exposure and the onset of their symptoms. But their basis remains fundamentally subjective, therefore flimsy and somewhat unconvincing. In this paper we will check whether this problem can be addressed by inquiring the subjective claims themselves. What can we learn about EHS by studying, in a cognitive perspective, how certain individuals come to regard themselves as hypersensitive to EMF?

## 2. METHODS

To answer this question, we implemented an ethnographic approach, which principle is to interrogate directly the subjects on their life stories and personal experiences, before looking for regularities in their discourses and social properties. This procedure is very common in sociology. The data were collected in various areas of France over a period of one year between 2012 and 2013.

Two inclusion criteria were employed to select the subjects: the claim to suffer from EHS, evidently, and the adjustment of one's lifestyle in corresponding ways (e.g., getting rid of one's electronic devices, shielding one's home from EMF, avoid places deemed exposed, etc.). This second criterion aimed at ensuring they were genuinely convinced of their condition. However, it never proved necessary to resort to it: we never encountered anyone who would have deserved to be described as only verbally sensitive.

The subjects were recruited by means of a small ad sent on several mailing lists of EMF-sensitive people, direct requests during self-aid groups (SAG) meetings, and through the word of mouth in personal networks. EHS sufferers turned out to be too numerous to be all questioned (on June 2014 slightly more than 1 000 were registered with the largest French SAG). Predictably enough they also appeared impossible to sample randomly, as there is no exhaustive list of them. Thus we have not used a conventional statistical approach, but rather the incremental process to which sociologists usually resort to in such situations: results are considered valid when they prove robust to the inclusion of additional subjects into the study, who are chosen so as to maximize the diversity of a few relevant characteristics. We reached that point relatively quickly, with forty interviews. The criteria we monitored to ensure the diversity of our "sample" were the following (unless stated otherwise, they characterize the subjects at the moment they were interviewed):

1. Degree of sensitivity, reflected by the scope of the related changes in the subjects' lifestyles: 17 subjects had chosen to quit their job and/or left their home, the remaining having kept both.
2. Ancientness of the symptoms attribution to EMF: 7 subjects were regarding themselves as EHS sufferers for one year or less, 33 for more than one year.
3. Place of residence: 20 subjects were living in city centers, 8 in the suburbs, and 12 in the countryside.
4. Conjugal status: 21 subjects were living with a partner at the first onset of their symptoms, the remaining 19 being alone.
5. Gender: 11 subjects are male and 29 are female.
6. Age: 16 subjects were aged less than 50 years, 24 were aged 50 years ore more.

This approach has the significant drawback that is does not allow to control for the risk that certain categories of potential subjects are wrongly excluded from the study, because of unforeseen biases in the recruitment procedure. It is worth noting, however, in the case of this study, that the additional inclusion of 18 subjects suffering from another environmental hypersensitivity (namely, multiple chemical sensitivity) did not modify the results in any way. This must be seen as a serious indication of their sturdiness.

The interviews were conducted in person, always in venues of the subjects' choice (mostly their homes), to create a climate of trust and avoid them being stressed by the confrontation with an unknown environment. The method of semi-structured interviews was used: firstly, the subjects were presented with a very broad interrogation ("how did things happen for you?") and allowed to answer freely for as long as they wished. Then specific questions were asked following a detailed interview guide – theses questions regarding their symptoms, their ways of coping with them, how they came to attribute them to EMF exposure, their perceived effects on their social relationships, and some of their general social characteristics. The advantages of this method are the minimization of suggestion from the investigator, and the production of very detailed information on the subjects' mental representations and on their reasoning process, at the expense of being time-consuming (the interviews lasted 2h20 on average). Here are a few examples of the questions that were asked:

- ***"Can you describe precisely what you feel when you're exposed?"***
- ***"What convinced you that EMF were responsible for your symptoms? Do you ever doubt it?"***
- ***"How do you distinguish between the symptoms triggered by EMF exposure, and those resulting from other causes?"***

All interviews were recorded, and transcribed for analysis. The subjects' discourses invariably present as strongly structured narratives, predictably enough given that the production of such narratives has been observed to be an essential part of the coping process with disease [10], and more generally with every major biographical disruptions (the most investigated example of which being religious conversion [11]). The challenge is therefore to reconstitute the original course of the events from these semi-conscious reconstructions that are illness narratives, even so they might differ significantly in the case of medically unexplained symptoms [12]. Our method was to proceed to systematic comparisons between the subjects' stories to identify a first set of regularities, to organize these regularities into a coherent process, before checking the latter for consistency with each of these stories.

## 3. RESULTS

The claim to be hypersensitive to EMF is the outcome of a seven stages cognitive trajectory.

1. Annoying or incapacitating symptoms appear and develop until they become unmanageable. This might happen either progressively (on the course of several years) or suddenly (within a few weeks) but always results in a biographical disruption (mostly an unexpected inability to fulfill one's professional and/or domestic duties) which reveals the symptoms' abnormality.

2. The subject seeks treatment for his ailment beside general practitioners, medical specialists or alternative therapists – most of the time beside them all, because none of the treatments he is offered proves durably effective. Thus he fails to restore the normality of his situation. The length of this stage varies greatly also. It comes to an end when...

3. The subject happens to learn about EHS, either in a radio show, in a newspaper article (usually from the local or militant press), or during a talk with friends or relatives – but very rarely on the Internet. He is presented with the testimony of an alleged EHS sufferer in which he recognizes himself ("what he was telling, that was me, that was what I was living"). This moment is experienced as a true revelation, which arouses a vertiginous questioning ("what if EHS is what I am suffering from?")

4. The subject then start to collect information on EHS compulsively, on the Internet first, then beside patient groups and small but active associations campaigning against wireless communications. This information typically concerns the other sufferers' symptoms and the devices to which they attribute them. Their analysis arouses contrasting feelings, fluctuating between relief (having at last identified the disease one suffers from: "I'm not crazy, it's not all in my head") and fear (in anticipation of the multiple constraints associated with this condition: "how am I going to live?"). This stage is short but extremely intense, the subjects tending to devote all their available time to their investigation ("I needed to know"). It also proves emotionally taxing.

5. The conviction that the subject is hypersensitive to EMF appears unconsciously in his mind, taking the paradoxical form of a conscious and violent rejection of this diagnostic ("I don't want this illness, it's too bad!").

6. The subject goes into an active verification procedure, conducting small experiments to appraise the responsibility of EMF exposure in his health state. These experiments take two forms: therapeutic ("do I fell better when I take shelter from EMF exposure?") and metrological ("can I identify a source of exposure when my symptoms occur?"). Their realization implies the acquisition of a technical knowledge, regarding which devices emit EMF (initially the only transmitters most subjects know of are cell phones and masts, and WiFi routers), how to detect them (notably with EMF sensors), and how to shield oneself from them. Remarkably, these experiments are conducted in such ways they cannot fail. For instance, the subjects do not admit any threshold in their sensitivity: every exposure they manage to identify, however weak or short, is regarded as a plausible cause of their symptoms. What they really seek to demonstrate is the independence of their conviction from their will ("I was really skeptic but I was forced to believe").

7. The subject's conviction is accepted and reaches the conscious level. Now regarding himself as an EHS sufferer, he starts adapting his lifestyle – and rewriting his personal story to make it coherent with his new belief system (that is, producing an illness narrative).

Becoming hypersensitive to EMF amounts to producing the obviousness of the association between one's symptoms and one's electromagnetic environment. This requires the latter to be made perceptible, by means of a cognitive work that is always long and complex. What makes this work even more necessary is the absence, in France, of any doctor who diagnoses EHS among his patients on a regular basis (as seems the case in the USA [13]). What makes it easier is the increasing awareness, among the general population, of the controversy surrounding the health effects of EMF and the existence of EHS. Be that as it may, this cognitive work tends to be evacuated from the narratives given afterward by those people claiming to suffer from EHS. Thus we recommend the greatest circumspection in the analysis of their testimonies.

More decisively, the cognitive process we have described as leading to this claim functions with absolutely any set of symptoms, provided they are disturbing and resilient enough. This might well be the explanation of the confusing diversity of symptoms reported by observational studies, and of the elusiveness of EHS in experimental settings. As a consequence, electromagnetic hypersensitivity should less be regarded as a disease in its own right, than as a mental structure making it possible to cope with lasting and crippling symptoms (which might be labeled as medically unexplained).


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# IRON STATUS IN WHEAT SEEDLINGS IN RESPONSE TO STATIC AND ELECTROMAGNETIC FIELDS

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## ABSTRACT

*Iron is an essential constituent of plant redox system. Moreover, since it is the most abundant ferromagnetic element, is considered to have crucial roles in perception of magnetic field (MF) by the plants and their responses to it. The present study was undertaken in order to evaluate such a hypothesis in wheat seedlings. The seeds of wheat (Triticum aestivum L.) were imbibed in water and then were treated with static magnetic (SMF, 30 mT) and electromagnetic fields (EMF, 10 kHz) for 4 days, each 5 hours. The contents of ferritin (the most iron containing macromolecules), iron, calcium, and Fe-bound proteins, as well as radical scavenging capacity of seedlings were measured. In comparison with the control group, treatment with EMF and SMF significantly decreased the content of ferritin (12% and 26%, respectively) and Fe-bound proteins (7% and 43%, respectively), but increased (125% and 113%, respectively) iron content of seedlings. Exposure to SMF also significantly reduced the radical scavenging capacity and calcium content of seedlings, while EMF did not alter this capacity but increased calcium content, compared to the control group. The results suggest that MFs alter redox status of wheat seedlings by changes in the quantity of ferritin, iron and calcium.*

**Key words:** *electromagnetic field, ferritin, iron, static magnetic field, Triticum aestivum*

## 1. INTRODUCTION

Increasing Static magnetic fields (SMF) and electromagnetic fields (EMF) are widely distributed in the environment, and their effects are interesting with the burgeoning development of technology. In the past, physiological investigations were pursued in a somewhat unsystematic manner and no biological advantage of any magnetoresponse was immediately obvious. As a result, most studies remain largely on a phenomenological level and are generally characterized by a lack of mechanistic insight, despite the fact that physics provides several theories that serve as paradigms for magnetoreception (1). Commonly 3 types of magnetoreception are discussed in biology: the radical-pair mechanism, the ion cyclotron resonance mechanism and ferrimagnetism (2). Ferrimagnetic resonance model is one of the most plausible mechanisms for bio-effects of magnetic fields, however, this model has not been tested experimentally in plant cells. Ferritin is a metalloprotein composed of 24 sub-units, whose stored bulk of iron is known to be as hydrous ferric oxide crystallites of various sizes up to 12 nm in diameter. The function of ferritin in plants is storage of iron for short or long periods to protect the cell against the toxic effects of free iron, thus serving as a primary antioxidant. Iron from ferritin may serve as a preliminary pool for the building up of iron-containing proteins. Iron is an essential element for all forms of life and its limitation of oxidizing to ferric form has a profound impact on the productivity of organisms (3).

Some reports have shown that the adverse bio-effects of the magnetic fields are usually mediated by oxidative stress, possibly due to either the direct production of reactive oxygen species via the Fenton reaction or by an increase of their longevity due to a reduction in the level of antioxidant enzymes (4). Oxidative stress also brings about changes in enzyme activity, gene expression, and the release of calcium from intracellular storage sites (4). Numerous investigators have reported that some low or extremely low MF modify the rate of ion transport across the plasma membrane or otherwise affect membrane lipid/protein dynamics. In addition to effects on the relative open and closed times for channels, EMF would contribute an oscillating component to the electrical potential of the membrane that would alter the diffusion gradient for ions across the membrane (5). Calcium ions are of major ones which regulate diverse cellular processes in plants as a ubiquitous internal second messenger, conveying signals received at the cell surface to the inside of the cell through spatial and temporal concentration changes that are decoded by an array of Ca2+ sensors including Ca2+-ATPase pumps and certain ion channels e.g., Ca2+/H+ antiporters (2).

General effects attributable to magnetic fields have been usually reported in animal models (6). Literatures of this kind are rare on plant systems. Such studies may help us to elucidate the mechanism(s) of the responses of plants to magnetic field (MF). Previous studies have shown the alteration of radical scavenging capacity of plant cells after exposure to MF, suggesting that MF excretes its effects, at least in part, via change of reactive oxygen species pool (7). The present study was undertaken in order to compare the effects of a static magnetic field (SMF, 30 mT) and electromagnetic field (EMF, 10 kHz) on the ferritin, calcium, iron, and Fe-bound protein contents, as well as radical scavenging capacity of wheat seedlings.

## *2. METHODS*

Wheat seeds (Triticum aestivum L. cv. Kavir) of uniform size and shape were surface sterilized by subsequent washing with detergent, sodium hypochlorite (containing 5% active chlorine), EtOH (70%), and rinsed three times with double distilled water. They were imbibed in distilled water and were allowed to germinate between two moistened layers of filter paper in containers horizontally exposed to the magnetic fields, in the same direction of MFs (Fig. 1).

They were treated with EMF (10 kHz) and SMF (30 mT) for 4 days, each 5 h. The duration of exposure and the intensity of MFs were decided based on previous studies and regarding the fact that static magnetic field of 30 mT is the minimum level of MF used in magnetic therapy equipment and high-frequency inductive power distribution, which is routinely used in industry of electricity, produces electromagnetic fields of 10 kHz (8-9).

Exposure to EMF was performed by a locally designed electromagnetic wave generator able to generate different wave shapes including sinusoidal, triangular, and quadratic. The system could generate EMF in range of 0.1 Hz -10 kHz with a continuous fine control in stable conditions and maximum consuming power of 9 W. It was consisted of two vertical coils each 28 turns of 0.3 mm copper wire turned around a quadratic frame of 48 × 34 cm. One coil was oriented in vertical plane (XOZ) with pointing vector in horizontal direction (antiparallel with the gravity), while the other one was oriented in horizontal plane (XOY) with pointing vector in vertical direction (perpendicular with the gravity). Impedance of each coil was 8 Ω. The calibration of the system was performed at different frequencies. The maximum consumption power was 32 W which was controlled by an analogue power control system capable of providing different power selections. The samples were exposed to a quadratic EMF of 10 kHz, power of 8.3 W, with average electric and magnetic components as 307± 5 KV/m and 650 ± 20 mA/m, respectively.

Exposure to SMF was performed by a locally designed MF generator. The electrical power was provided using a 220 V AC power supply equipped with variable transformer as well as a single-phase full-wave rectifier. Calibration of the system as well as tests for the accuracy and uniformity of the SMF were performed by a teslameter (13610.93, PHYWE, Gottingen, Germany), and also was calculated with Complete Technology for 3D EM Simulation software as explained elsewhere (9).

Wheat seedlings (uniform in weight, 2 g) were selected and were extracted by the methods described by Lukac et al. with few modifications (10). In brief, the seedlings were homogenized on ice in extraction buffer (10 mM sodium phosphate buffer, 100 mM sodium chloride, 2% polyvinylpyrolidone, and 1 mM phenylmethanesulfonyl fluoride, pH 7.2), using mortar and pestle. The slurry was centrifuged at 15,000 ×g for 10 min at 4 °C. Magnesium chloride was slowly added to the supernatant at a final concentration of 0.7% (w/v), followed by 10 min incubation on ice and then centrifugation at 26,000 ×g for 5 min at 4 °C. Adding MgCl2 (1%, w/v) was repeated and after an incubation at 4 °C (1 h), sodium citrate (2%, w/v) was added. The samples were incubated again for 20 min on ice prior to centrifugation at 26,000 ×g for 50 min at 4 °C. The pellet was re-suspended in sodium phosphate buffer (10 mM, pH 7.2) and centrifuged at 10,000 ×g for 15 min. The supernatant was stored at -20 °C until used for further analysis.

For quantification of ferritin by ELISA sandwich method, an ELISA kit (PT-T4, Pishtazteb Zaman Diagnostics, Tehran, Iran) was used. Fifty micro liters of the extracts or standard were added to the plates whose well were pre coated with anti-ferritin antibody and ferritin content was determined according to the result of complexes formed during the antigen-antibody reaction. The absorbance was detected at 450 nm using an ELISA plate reader (Anthos 2020, Biochrom, Cambridge, UK).

The ratio of Fe-bound proteins content to total protein content was estimated using the method described by Bejjani et al. (11). The protein and Fe (protein bound Fe) were estimated spectrophotometrically at λ= 280 and 420 nm, respectively by spectrophotometer (Cintra 6, GBC, Dandenong, Australia).

The content of iron and calcium of the wheat seedlings was measured by atomic absorption spectrometer (AA-670, Shimadzu, Kyoto, Japan) after acid digestion of sample ash (7).

The radical scavenging capacity (RSC) of the cells was assessed using DPPH (1, 1-diphenyl-2-picrylhydrazyl) at 517 nm.The RSC as an inhibitor of the DPPH free radical in percent was calculated as follows (12):

$$RSC_{DPPH} (\%) = (A_{blank} - As_{ample})/A^{blank} \times 100$$

All of the experiments were carried out with at least three samples. Data were expressed as the mean values ±

standard deviation (SD). Statistical analysis was performed using SPSS 16.0 (SPSS, Chicago, IL, USA) and the significance of differences between treatments was evaluated using LSD test at level of $p \leq 0.05$.

## *3. RESULTS*

Treatment of wheat seedlings with EMF and SMF remarkably decreased their ferritin content (12% and 26%, respectively) in comparison with those of the control plants (Fig. 1).

The ratio of Fe-bound protein of wheat seedlings to total protein content in treatment with EMF and SMF was significantly lower than that of the control ones (7% and 43%, respectively; Fig. 2).

The content of iron in EMF and SMF-treated plants was significantly higher than that of non-treated plants (125% and 113%, respectively; Table 1). Different from Fe, alteration of Ca content of seedlings in response to SMF and EMF were not identical. Treatment with EMF significantly increased calcium content of wheat seedlings (168%), but SMF decreased it (35%), in comparison with the control group (Table 1).

Treatment of wheat seedlings with EMF did not change their radical scavenging capacity, however, exposure to SMF decreased it (15%), compared to the control group (Fig. 3).

## *4. DISCUSSION*

When considering the effects of magnetic fields at the molecular scale, the iron cage protein ferritin is an obvious candidate, because it has the highest net magnetic moment of all proteins (13-14).

Despite a wealth of information on ferritin biochemistry and expression in plants, the main function of this iron-storage protein in the response of plants to MF is largely unknown. Exposure of wheat seedlings to EMF and SMF in the present study significantly reduced their ferritin contents. Coincident with ferritin, the ratio of iron bound proteins to total protein contents remarkably decreased in MF-treated plants, compared to the control ones. Iron content of MF-treated seedlings however was higher than those of the control group. It is noteworthy however, that besides ferritin, there are abundant vacuoles in plant cells that enable them to sequester and detoxify excess iron inside (15). Ayala-Vela et al. (16) found no relationship between ferritin transcriptional levels and ferritin protein contents with iron content of different cultivars of common beans. Previous studies have shown that 30 mT SMF can increase the concentration of free radicals and cause an inconsistency in the capacity of plant cells in scavenging of free radicals (4,8). Decrease of RSC of wheat seedlings by SMF may be related to increase of iron content and decrease of ferritin and iron bound proteins.

It has been shown that MF influences ion uptake capacity of the plant cells. Exposure to EMF increased calcium contents of wheat seedlings. Betti et al. (17) reported that EMF enhanced the transportation of Ca2+ across the cell membrane of pollen of Citrus clementina Hort. ex Tan. It has been showed changes in Ca2+-concentrations in Arabidopsis thaliana, induced by combinations of magnetic and electromagnetic fields that match Ca2+ ion cyclotron resonance conditions (2). Calcium content of SMF-treated wheat seedlings significantly was lower than those of the controls. Li and his coworkers (18) observed decreasing cytosolic free calcium concentration, in human vascular smooth muscle cells after exposure to SMF. Using plant plasma membrane vesicles, Koch et al. (19) showed that suitable combinations of static and time varying magnetic fields directly interact with the calcium channel proteins in cell membrane. The results suggest that exposure of wheat seedlings to SMF and EMF influence on redox status of plant cells via changes in the quantity of ferritin and alteration of iron and calcium balance.

***Figure 1.*** *The effects of EMF and SMF treatments on the ferritin content of wheat seedlings. Data are means obtained from three samples ± SD. Different letters indicate significant differences at p ≤ 0.05 according to LSD.*

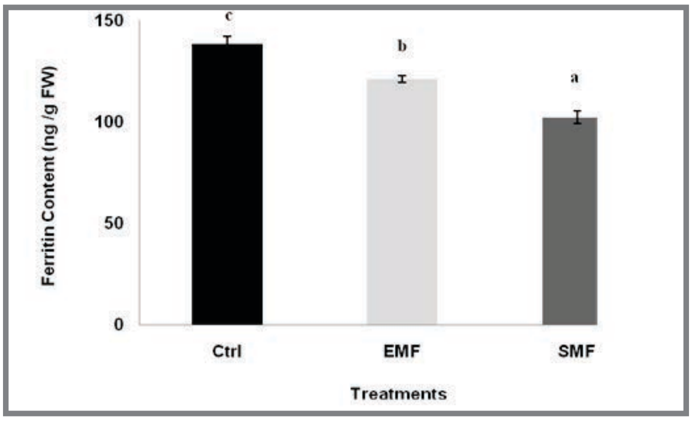

***Figure 2.*** *The effects of EMF and SMF treatments on the ratio of Fe-bound to total protein content of wheat seedlings. Data are means obtained from three independent repetitions, each at least with three samples ± SD. Different letters indicate significant differences at p ≤ 0.05 according to LSD.*

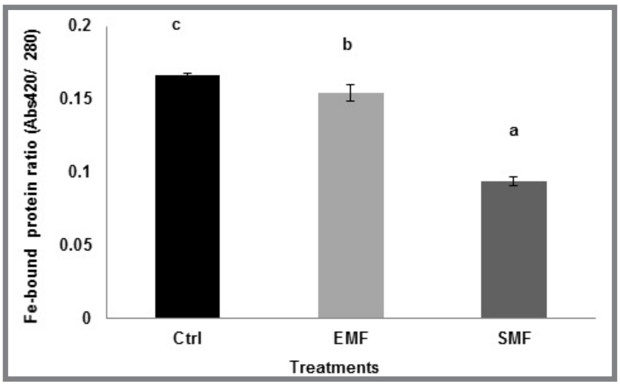


***Figure 3.*** *Radical scavenging capacity (RSC) of wheat seedlings before and after exposure to EMF and SMF. Data are means obtained from three independent repetitions, each at least with ten samples ± SD. Different letters indicate significant differences at p ≤ 0.05 according to LSD*

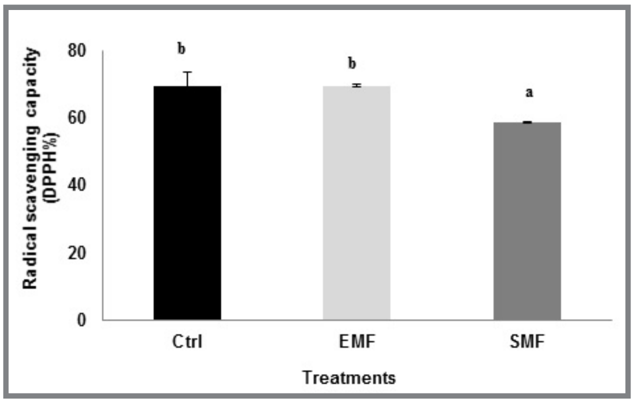


***Table 1.*** *Iron and calcium contents (µg /g FW) of wheat seedlings after treatment with EMF and SMF. Data are means obtained from three independent repetitions, each at least with three samples ± SD.*

| Elements | Ctrl | EMF | SMF |
|---|---|---|---|
| Ca | 7.73 ± 0.33 b* | 13.06 ± 0.39 c | 4.99 ± 1.13 a |
| Fe | 0.76 ± 0.04 a | 0.95 ± 0.04 b | 0.86 ± 0.01 b |

** In each column, different letters indicate significant differences at p ≤ 0.05 according to LSD.*

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# NEUROEFFECTS CUMULATION OF REPEATED NONTHERMAL INTENSITY ELECTROMAGNETIC EXPOSURES

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*ABSTRACT*

*The article presents the results of its own long-standing studies, that complete the literature about the possibility for accumulation of biological effects of nonthermal intensity EMF. Shown, that this phenomen can occur when repeating these influences exposures: short (1 – 6 hours), long (month) and chronic (years). Experiments on animals and employee surveys respective productions showed the dependence of cumulation from: general duration of exposure, the character of the presentation of individual exposures, exposure regime and functional status bioobject. This complex dependence explains the various character of the final CNS reactions (from normal to borderline manifestations) under irradiated microwave nonthermal EMF levels with similar energy and amplitude- frequency characteristics*

**Key words:** *cumulation, CNS, reaction , VHF EMF, low level of energy, repeated exposure, animals, experiment, a survey of working.*

## 1. INTRODUCTION:

It is known that the repetition of the short-term influence of any modality can raise their biological significance by cumulation of bioeffects. Practical interest is the study of such repetitions with various total exposure (hours, months, years). Repetition of short exposures for hour is a handy teaching technique in practice, scientific study of the ways of forming a cumulation. Study of long-term and chronic effects of physical factors important to the contemporary tasks of medical practice (hygiene, physiotherapy). All these three aspects in relation to EMF, is reflected in the literature [1-7]. A special place is occupied by the chronic exposure of EMF in conditions of production. Many authors shown leading value changes in neurological field of health working in conditions of chronic exposure to EMF [4-7]. Despite the large amount of literature on the subject, changing production conditions require additional research, focusing attention on new parameters and length of service. . Years of research have allowed in one article to consider the development of central nervous system (CNS) reactions to the cumulation of microvave EMF similar parameters and conditions of irradiation at different total exposure (day, month, yeas). It is defines the novelty and practical importance of the work.

## 2. METODIC

Studies cited in the article is sourced in rabbits, rats, and in a survey of working in conditions of EMF. Impact factors were EMF VHF range (1-1.5 GHz) in continuous (CR) or pulse (PR) regime of non-thermal intensity (≤ 300 mkVt/cm^2 in CR or pulse). The reaction of the CNS on such short microvave EMF exposure, also experimental camera and EMF generators, previously described [8]. Each series was performed on 10 or more animals and experiments with EMF exposure accompanied by appropriate controls with false turning on the generators. An attention should be paid to the results of a survey of people in contact with EMF in conditions of production activity. The accumulated material as a result of survey - into 4 statistically significant groups of length service : from 1 to 5 years, from 6 to 15 years , from 16 do 25, from 26 to 35 years. Main indicators in experiments on animals were EEG and motor activity. Clinical and electrophysiological examination of workings included: neurological monitoring, REG, EEG, EGR researches.

All the compared versions of microwave exposure of the used methods of statistical evaluation of (Studenty and $\chi 2$ test, in accordance with the accuracy of distribution figures) using a computer program «Statistics» (Russia).

## 3. RESULTS

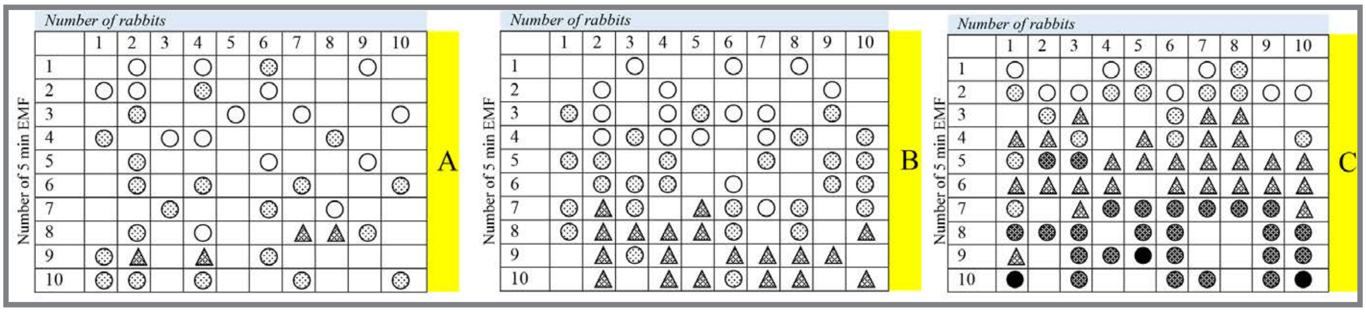
The results of our experiments confirm in the literature about biger effect of microvave irradiation for fractional (than with continuous expense) of cumulation bioeffects. A continuous 30 min 1 GHz radiation (CR or PR , ≤ 300 mkVt/cm^2) is the head of a rabbit called in EEG changes that did not differ significantly from the corresponding 5 min of exposure. The same EMF radiation, but against a 5 min batches with random intervals of 5 ÷ 15 min caused by the cumulative impact of changes. More it could be observed when a modulated EMF (compared to the CR) and the defective functioning of the CNS, as shown in Figure 1. A and B - the results obtained in the healthy adult rabbits using «non-artefacts» electrode in experiments with 1 GHz EMF exposure, 300mkVt/ sm2 in constant or pulse (100 Hz) regime. Distinguishes their speed and character alterations in EEG, which affects the end result. The essence of cumulation is included: the 1-4 effects of EEG reaction takes place only in the first 5 min after switching off and is to increase the number of spindle-like fluctuations in the alpha range; next (3-7 use EMF )-these same changes are observed during 5 min exposures; next ( 8-10 presentation of the factors) cause changes of another kind (increased teta- activity), of indicating increased biological significance of impacts. The emergence of more significant changes were received with the same EMF , but on the background of defective functioning of the CNS (Figure 1 c). On the background of the postoperative stress (over 30 min after the implant in the bone «non-artefacts» electrodes) major changes in the alpha range of EEG on 5 min irradiation observed already the first two 5min EMF . Theta was dominant in the third to sixth 5 min exposure; during the seventh-tenth 5 min EMF irradiation appears and dominated the stress activity in the form of high-amplitude slow and sharp waves. A day after the irradiation parameters of the EEG is not different from control values.

A similar result was obtained in experiments on rats. As shown in table 1, 6 hours of continuous exposure to 1.5 GHz EMF in pulse regime (pulse characteristics: duration-0.4 msec, frequency – 1000 Hz, 300 mkVt/cm^2) does not lead to a significant change in motor activity over 6 hours (summary) observation, compared to the fractional irradiation. It is important to note that the exposure EMF in phase of motor activity has led to its increase, and the effects EMF in phase motor rest is reduced. The most significant result was obtained when exposed to be a phase motor rest activity (reliable result was every hour and had the same orientation ,table 1). The result of same irradiation for 1 month is shown in Figure 2. From 6 days, significantly ($P < 0.05$) reduced the number of movements of rats in the exposed group compared to the control. Up to 20 days of exposure, this difference is gradually increasing, reflecting the manifestation of cumulation. But, then, the result is close to the control values with some sporadic manifestations of reliable differences, which may be a sign of adaptation.

Exposure to rats and rabbits of EMF similar parameters for 30 minutes every day during a month without being bound to a particular background has resulted in slower development of cumulation. Only with 14 days of exposure, observed the emergence of signs of disadaptation and neurotic manifestations.

The results of the survey working in conditions of EMF coincide with those of other authors [4-6]. Most of the data are kept in the research objective «picture» vegeto-vascular dystonia varying degrees of symptoms from prolonged EMF irradiation with 1 MW/cm^2. Our research is distinguished by dynamic monitoring of changes of length of service. In the first five of the most characteristic is the appearance of vegetative-vascular dystonia syndrome in hypertensive type-75%. Further develops the syndrome of vegetative-vascular dystonia with mixed type (60% with a length of 6-15 years and 70.8% 16-25 years ‘ service). With a length of 26 to 35 of years developing hypertension (67 %).

***Fig. 1.*** *The dynamics of EEG changes in rabbits in experiments with fractional 50 min MICROWAVE irradiation.*




*Note:*

*A-continuous mode 1 GHz MICROWAVE EMF with AEP 300 µw/cm^2, against the backdrop of the physiological norm, and «non-artefact» of the electrodes;*
*B - In the same MICROWAVE EMF, but the pulse (square wave 100 Hz, 300 µW/sm^2);*
*C – same as, but against the backdrop of the defective functioning of the CENTRAL NERVOUS SYSTEM;*
*- the increase in the number of spindle-like oscillations in alpha and beta1-band EEG only during or after irradiation respectively;*
*- increased Theta activity;*
*- complexes of high-amplitude slow and sharp waves;*
*- epileptic activity*

***Table 1.*** *Results of experiments on rats with continuous and fractional MICROWAVE irradiation*

| Time of observation | Change the direction and amount of movement relative to the background (100 per cent) under MICROWAVE irradiation: | | | | |
|---|---|---|---|---|---|
| | continuously | | fractional | | |
| | K (n-12) | EMF (n-12) | K (n-10) | EMF - in phase MA ( n-10) | EMF - in phase MR (n-10) |
| 1 h | + 38.4 | +30.1 | + 48.4 | + 40.3 | -30.7 |
| 2 h | + 51.8 | + 17.2 | +62.2 | + 72.4 | - 49.3 |
| 3 h | + 69.2 | + 91.3 | +29.7 | + 16.8 | - 43.5 |
| 4 h | -31.8 | -58.2 | - 38.3 | + 2.4 | - 24.0 |
| 5 h | - 2.1 | +19.4 | - 22.1 | -13.1 | - 38.1 |
| 6 h | -24.1 | - 11.3 | +14.8 | + 7.4 | -29.9 |
| total | + 101.4 | +88.1 | +95.7 | + 126.2* | - 215.5** |

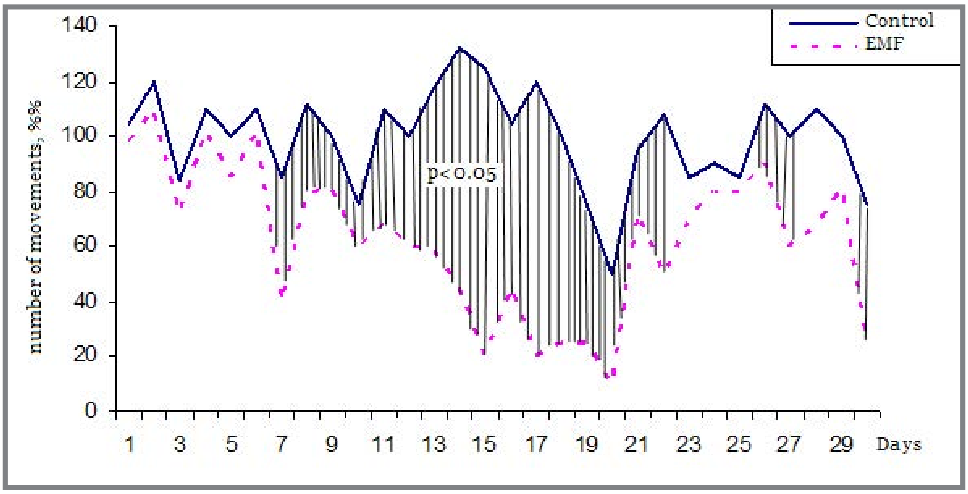
*The note to table 1:*

*k-control, YES-motor activity, DP- motor rest (less than 5 movements per min);*

*+,-increase, decrease in the number of movements;*

**, * * p 0.05, p < < 0.001, respectively, by the criterion of χ2, relative to the control. motor rest movement*

***Fig. 2*** *Dynamics of motor activity of rats in experiment in during 30 days exposure EMF in phase motor rest (average values by rats groups (n-12) in percents relative background (100%); mistakes – 4-12%%; p<0.05).*

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# DIFFERENTIAL RESPONSE OF MONO- AND DICOT PLANT SEEDS TO MAGNETIZED WATER


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## ABSTRACT

*The changes which occur in the structure of liquid water under the effect of an external magnetic field are important in various applications, e.g., water treatment, biological processes, and biotechnology. Due to bipolar characteristics of water molecules and the fact that approximately 70% of live cells are composed of water, application of magnetized water on biological systems may help to clarify the routs through which external magnetic fields affect living organism. Water also is an evitable material for germination of plant seeds. In the present study the effects of magnetized water on germination of Cicer arietinum, Brassica napus, Linum usitatissimum, and Oryza sativa were investigated. The water was magnetized by a 110 mT MF.*

*The results indicated that magnetized water treatment significantly increased the percentage and rate of germination of all tested seeds except for Cicer arietinum for which germination was retarded by magnetized water, compared to those corresponding controls. Further studies are required to clarify whether such a differential response is of relevance for the structure of cell walls of seed coats and differences in their composition or is related to the effect of magnetized water on amylase activity.*



***Keywords:** Cell wall, magnetized water, static magnetic field*


## 1. INTRODUCTION

Increasing amount of literature is available on the effect of magnetic fields (MF) on germination of plant seeds, growth and development of their seedlings, as well as precocious flowering and increased fruit set (1–3). The exact mechanism(s) of these effects however, have not been elucidated yet (4).

Water is the most common and important material in nature. Moreover, water is the most abundant compound in living cells and has a crucial role in their metabolism. The growth and development of human beings, animals and plants need plenty of water, therefore both our lives and work, as well as agriculture and industry, cannot depart from water at all.

Magnetization of water, exposure to a magnetic field, denotes changes in optical thermodynamical, and mechanical properties of water. The mechanism(s) of magnetization and its features are not clear yet (5).

Dielectric constant, viscosity, surface tension force, the solidifying, boiling point, and electrical conductivity are of the main properties which are expected to be changed in magnetized water (MW).

Because of its bipolar nature, water acts as universal solvent. Activity of enzymes critically depends upon an increase of water content in the solvents (6).

Influences of magnetic field on microscopic structures and macroscopic properties of water were studied by Pang and Deng (5). They found that MF enhanced the clustering structure of hydrogen- bonded chains and polarization features of water. Toledo et al. compared the results of experimental measurement and theoretical calculations of viscosity, enthalpies and surface tension of water after MF treatment (7). They found that the external MF influences the hydrogen bond networks.

The beneficial effects of magnetically treated irrigation water have also been reported on germination percentages of seeds (8).

In the present study the effects of magnetized water on germination of certain di- and monocotyledons i.e., Cicer arietinum, Brassica napus, Linum usitatissimum, , and Oryza sativa were investigated.

## 2. METHODS

The seeds of rice (Oryza sativa L. cv. Hashemi) as a monocotyledonous plant and of chick pea (Cicer arietinum), canola (Brassica napus), and flaxseed (Linum usitatissimum) as samples of dicotyledonous plants were selected. The seeds of uniform in size and shape, were surface sterilized by subsequent washing with detergent, sodium hypochlorite (containing 5% active chlorine), and 70% EtOH followed by rinsing three times with double distilled water.

After surface sterilization, the seeds were soaked in water and were allowed to germinate between two moisten Watman filter paper in Petri dishes. The seeds were irrigated either with deionized water tap (control group) or with magnetic water for 4 days. For magnetization of water, it was pumped through a device composed of several permanent magnets providing a 110 mT magnetic field. The pumps were on for 10 minutes and then the magnetized water was added to Petri dishes.

Germination percentage (GP) and germination mean time (GMT) were monitored for 4 days as well, in both groups, by following equations:

$$\textit{GP (Percentage of germinated seeds after 4 days)} = \textit{(germinated seeds/total tested seeds)} \times 100$$

$$\textit{Germination mean time; } GMT = \Sigma\,(n_i t_i)/\Sigma(n_i)$$

Where ti is the number of days from the beginning of the experiment and ni is the number of germinated seeds.

## 3. RESULTS AND DISCUSSION

Germination percentage of chick pea seeds significantly decreased by magnetized water, compared to the treatment group. Percent of germination of other tested dicotyledonous seed, Brassica napus and Linum usitatissimum however higher in those groups which were irrigated with was magnetized water (Figs. 1 and 2).

Similarly, percentage of germination of Oryza sativa increased by magnetized water (Figs 1 and 2). Other than (Cicer arietinum) which showed a retarded germination under MW, germination mean time of all tested seeds was shorter in MW-treated seeds, compared to the corresponding control groups (Fig. 3).

Different from the reports of Belyavskaya (9). on significant induction of cell metabolism and mitosis meristematic cells in pea, germination of chick pea reduced by MW. However, stimulatory effect of magnetic water on germination of rice, canola, and flaxseed may be due to the increase in endogenous promoters (e.g., gibberellic acid, protein, etc.) biosynthesis. Similar reports can be found in available literature on promoting effects of MW on germination of certain seeds (1). Mohammadalikhani et al. showed that germination of maize seeds and further growth of their seedlings increased, while the germination mean time reduced by MW (10).

Hozayn et al. suggested that there may be resonance-like phenomena which increase the internal energy of the seed (11). Considering possible effect of MF and magnetized water on ossilation of ferromagnetic ions containing proteins (e.g., ferritin), Vaezzadeh et al. suggested that oscillation of such molecules exerts its energy, then damps and finally locates in the field direction (12). The relaxed energy increased the internal temperature (i.e., the effective temperature of the magnetic spin system of plant) so that it is situated in a proper temperature for germination and growing. Further studies are required to clarify whether the differential responses of different seeds to MW is of relevance for the structure of cell walls and the composition of their coats or is originated from the sensitivity of involved enzymes (such as amylase) to MW. The content and the influence of MW on growth regulators which contribute in seed germination, i.e., gibberellic acid and brassinolids should not be overlooked as well.

***Figure1.*** *Effect of magnetized water (MW) on germination of Cicer arietinum, Brassica napus, Linum usitatissimum, and Oryza sativa seeds*

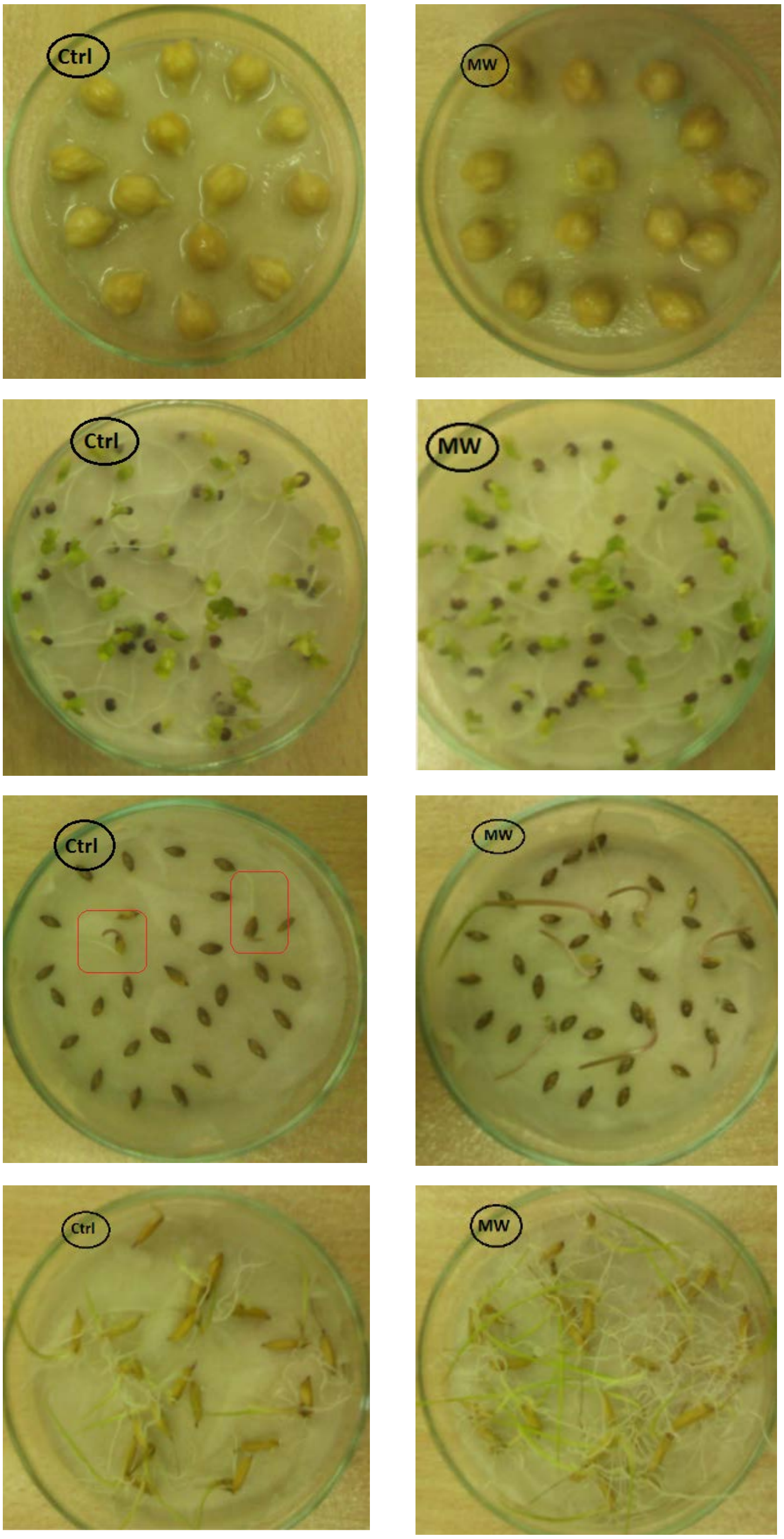


***Figure 2.*** *Comparison of seed germination with or without treatment with magnetized water*

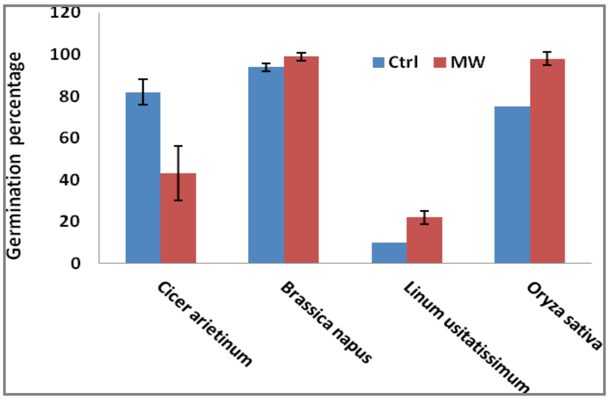
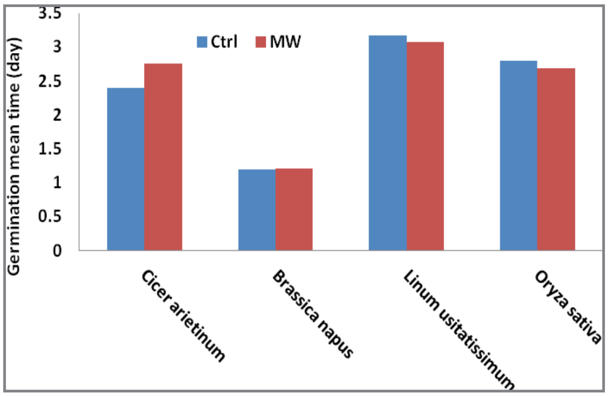



***Figure 3.*** *Comparison of mean time of germination of magnetized water-irrigated seeds of chickpea, canola, flaxseed, and rice with those corresponding control groups*

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# INVESTIGATION ON THE EFFECT OF STATIC MAGNETIC FIELD ON CANCER AND NORMAL CELL LINES

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*ABSTRACT*

*There is considerable evidence demonstrating that moderate intensity of static magnetic field (SMFs) is capable of inducing a number of biological systems. In this study we have investigated the effects of static magnetic fields (SMF) on the viability of in the human cervical cancer (HeLa) cell line and Fibroblast cells as cancer and cell lines. The cells were cultured in DMEM medium containing 10% fetal bovine serum (FBS) than Cells have treated with several time and intensity of magnetic field. The cytotoxicity and cell Death percent in treated cells was mediated by MTT assay for mitochondrial dehydrogenase activity. The magnetic field ability on induce cell death or inhibit biochemical function and living cells was reported as cell death percent. The results showed that the increase of magnetic field intensity and the time that cells were exposed to this treatment caused to rising of cell death percent in HeLa cell compare to Fibroblast group. The data described in the present study suggest a modulation by SMFs on cell death in different cells. Cell type and time of exposure have been found to be significant factors for the effects produced. Thus the modulation of the cell death process by SMFs could be used to improve new therapeutic approaches for cancer cells.*

***Key words:*** *Human cervical cancer (HeLa) cell line, Static Magnetic Field, Fibroblast cells, Viability percent*

## *1. INTRODUCTION*

Living organisms are always exposed to the geomagnetic field of around 20–70μT that exists over the Earth and which is associated in the orientation and migration of certain animal species.(1) The sensitivity of the organisms to weak electromagnetic fields (EMF) has been defined elsewhere(2, 3), mostly in respect to the dependence of bio effects on the largeness or the frequency of fields. The quick progress of electrical and electromagnetic devices in industry, medical as well as in domestic life has intended that human beings are more exposed than ever to an extensive range of electromagnetic fields (EMF) of different intensities(4). The frequency of exposure to EMFs has increased with advances in science and technology, such as nuclear magnetic resonance (NMR) spectroscopy, magnetic resonance imaging (MRI) diagnosis, and passenger transport systems that are based on magnetic levitation(5). This has led to a rising attention in the study of the biological effects of EMF and probable influence on human health. In an attempt to describe the biological effects of SMFs, it is useful to categorize them as weak (<1 mT), moderate (1 mT to 1 T), strong (1–5 T), and ultra-strong (>5 T). Recent progress of biological science and technology can help us understand EMF effects more obviously. Three variables are mainly relevant in the study of these probable effects: cell type and EMF intensity and duration of exposure.

The interest in the variation biological effects of non-ionizing electromagnetic fields (EMFs) on the whole organism, as well as on cellular systems, has considerably increased in recent years in consideration of their probable health risk for humans (6). Several studies have shown that MF has an influence on a large variety of cellular functions; nevertheless the its exact mechanism(s) still is not clear (7). Few studies exist on the effects of static magnetic fields (SMFs) on living cells and tissues, compared with low-frequency magnetic fields. Most of these studies dealt with the potentially genotoxic or oncogenic effects especially those that have a relationship with clinical applications of static magnetic field. Part of these studies focused on this basic idea that SMF play a critical role in activating and/or alternating the molecular mechanisms in eukaryotic cells (8). Many experiments were recently performed to study the interaction between organisms and MFs (9, 10). Converging data indicate that the primary site of action of magnetic fields is the plasma membrane (3, 11). The influence exerted by MFs (static or oscillating) on the plasma membrane has been described at different levels on: the plasma membrane surface (12), the distribution of membrane proteins and membrane receptors (13), cell-cell and cell-matrix junctions (14), cell membrane sugar residues (15, 16) and the trans-membrane fluxes of different ions, especially calcium (17); In turn these perturbations influence the apoptotic rate, cellular and cytoskeleton shape (9, 16).

There is considerable evidence demonstrating that moderate intensity of static magnetic field (SMFs) is capable of inducing a number of biological systems. In this study we have investigated the effects of static magnetic fields (SMF) on the viability percent of the human cervical cancer (HeLa) cell line and Fibroblast cells as cancer and cell lines.

## 2. METHODS

***Cell culture:*** Human cervical cancer (HeLa) cell line and fibroblast (mesenchymal) cells were purchase from National Cell Bank of Iran (NCBI) and cultured at 37ºC, 5% CO2 in DMEM medium supplemented with 10% fetal bovine serum, 100 U/mL of penicillin and 100 µg/mL of streptomycin. The cells were grown until 70–80% confluent. Confluent cells were passaged and plated at 1:2 or 1:3 dilutions every 3–4 days using 0.25% trypsin and 1mM EDTA (Invitrogen LT, Merelbeke, Belgium) medium was changed every other day. The cells were frozen in DMEM with 93% FBS and 7% DMSO (MERCK, Darmstadt, Germany) in liquid nitrogen.

***Magnetic field application:*** Exposure to MF was performed using a locally designed SMF generator (Figure 1). The electrical power was provided using a power supply working in range of 0-50 V and 0-20 A with a maximum power of 1 kW. Using three different sensors the controller system was able to control the temperature, humidity and CO2 level. The accuracy of the teslameter was ± 0.1 % for MF and the range of measurements was 3 µT–30 mT. With respect to this research, 0, 5, 10, 20, and 30 mT were the optimized intensity (18). Three flasks were placed at the center of the incubator (10 cm distance from the center in each side) within solenoid generating a homogenous magnetic field, in each exposure. The duration of exposures was 24, 48, 72 and 96 h. Before each exposure, the MF intensity was set to appropriate intensity using a teslameter (18-21).

***MTT assay:*** Cell suspensions were seeded into a 96-well-plate and incubated for 24 h (10,000 HeLa and 4000 Fibroblast per well). Cells were allowed to reach exponential growth. After removing the medium, 100 µL medium containing compounds at different were added into the each well. Different intensity of SMF (0, 5, 10, 20, and 30 mT) and duration of exposure (24, 48, 72 and 96 h) were tested in five replicate wells. After 24, 48, 72 and 96 h cells were incubated with 10 µL of 5 mg/ml 3-(4, 5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT), which was dissolved in 90 µL of medium for 4 h. Cells that were live, cleaved the yellow tetrazolium salt to aninsoluble precipitate (formazan). As our knowledge, decrease in the percentage of living cells is correlated with the amount of formazan precipitate crystals. Then discarded the supernant, kept the formazan precipitate and added 100 µL DMSO into the wells. The absorbance of specimen was measured at 460 nm with BioTek ELx808 microplate reader. Cell death results were showed as percentages of control group.

***Statistical analysis:*** Data were presented as mean±SD (standard deviation) and were analyzed using One-way repeated measure analysis of variance (ANOVA) followed by Tukey's post hoc test. If $p<0.05$ results were judged to be significant. Dose–response curves for determining IC50 values were draw by applying a graphical fitting method with graphpad prisme 5.

## 3. RESULTS

Evaluation of Viability percent: Increasing of intensity and time of SMF-exposure exhibited a marked decrease in viability percent in HeLa cells compare with fibroblast cells. Figures 2 showed the obtained mean viability percent of HeLa and fibroblast cells after exposure to different intensities of SMF and exposure times. The results exhibited that by increasing the intensity as well as time the viability percent decreased. However this decrease is less obvious in fibroblast group as HeLa group and this difference is significant in all intensity and different exposure times.

Evaluation of The half maximal inhibitory concentration (IC50): The intensity of SMF required for a 50% inhibition of cell growth (IC50) was obtained by extrapolation from an inhibition curve. In the presence of SMF, the respective IC50 values of fibroblast cells were 35.54 ± 8.51, 17.5 ± 3.485, 7.24 ± 1.825 and 3.287 ± 0.645 mT at 24, 48, 72 and 96 h; the IC50 values of Hela cells were 20.63 ±4.335, 9.985 ± 2.705 , 6.176 ± 1.463 and 2.857 ± 0.62 mT at 24, 48, 72 and 96 h. The IC50 value to SMF was greater for fibroblast cells than for HeLa cells, suggesting that HeLa cells are sensitivite to SMF.

## 4. DISCUSSION

Static and time varying magnetic fields are widely distributed in the environment, and their effects are interesting with the burgeoning development of technology. Organisms including human beings are exposed daily to magnetic fields (MFs) generated by home /environmental sources. This increases the concern about the possible risk of functional disorders in biological systems; however some reports suggested the therapeutic role for magnetic fields in clinical applications. Epidemiological and biological studies have been carried out with the duel aim of establishing whether any correlation exists between MFs and increased disease risk. There is substantial evidence indicating that static magnetic fields (SMFs) of intensity (from 1 mT to 1T) are capable of influencing a number of biological systems. These studies have shown that magnetic field (MF) exerts influence on a large variety of cellular functions; nevertheless the exact mechanism(s) of it is yet to be understood (18).

Based on the previous reports, a general mechanism for the action of moderate intensity SMFs on biological systems would be by virtue of their effect on the molecular structure of excitable membranes, an effect sufficient to modify the function of embedded ion-specific channels, (9, 11, 22). The SMF may decrease the concentration of calcium ion through influencing either the function of Ca2+-ATPase or modifying the function of Ca2+ binding protein and the contiguous ion specific channels (23). This hypothesis would explain practically all of the bioeffects attributed to these fields, including the modulation of apoptosis, proliferation and cell viability, and is testable using several different neurophysiological techniques (11). Other possible effects of SMFs leading to perturbation of the apoptotic rate , such as alteration of the gene pattern expression (9, 16, 24, 25) or increment of oxygen free radicals cannot be excluded. It is well-known that free radicals are mediators of apoptosis and through it alters proliferation rate and viability (24, 26). Interestingly, the concentration of free radicals in transformed cells and tissues is higher than in their normal counterparts. In addition, concentration of free radicals has been described as increasing in different conditions of exposure, from SMF to pulsed MF to EMF (24). Probably, magnetic field exposure affects iron homeostasis in certain cells, leading to an increase in free iron in the cytoplasm and nucleus, which in turn leads to an increase in hydroxyl radicals, via the catalytic reaction of the Fenton reaction, which damages DNA, lipids, and proteins (26). Damage to lipids (lipid peroxidation) in the cellular membrane in turn leads to an increase in calcium leakage from internal storage sites in the cell (26).

It is generally accepted that static magnetic fields are unable to transfer energy to cells in sufficient amounts to break chemical bonds and thus to damage DNA directly. For this reason, SMF is not considered to be direct genotoxic agents. Their contribution to cancer development might be exerted by inducing secondary currents in the body, by altering certain cellular processes, such as free radicals production and activity, by modulating certain enzyme activities, by enhancing cellular proliferation, by perturbation of the cell cycle, or by other indirect mechanisms (27).

***Figure 1.*** *Photograph showing the apparatus used to generate static magnetic field (a) the whole body of the system (b) the incubator within solenoid.*

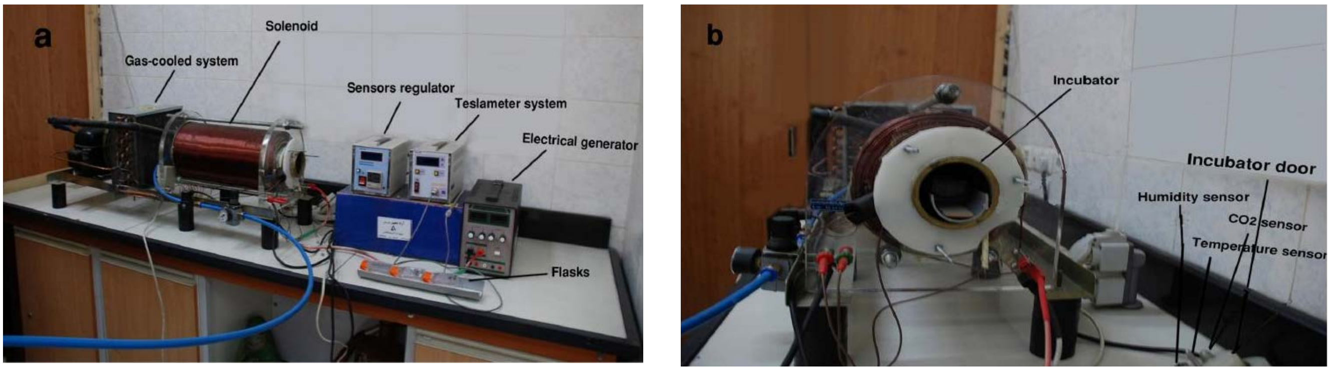
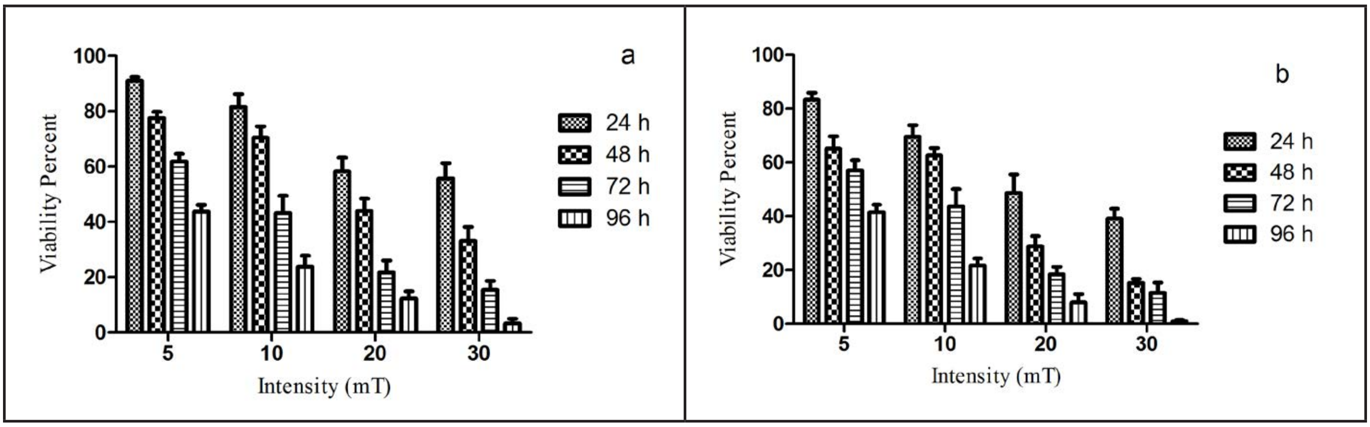



***Figure 2.*** *The mean viability percent of fibroblast (a) and HeLa cells (b) after exposure to different intensities (5, 10, 20 and 30 mT) and exposure times (24, 48, 72 and 96h) of SMF and control group. Data are means ± SD, n=3.*



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# STATIC MAGNETIC FIELDS INCREASE THE EFFECT OF GAMMA RAY ON CELL CYCLE PROGRESSION IN HELA


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## ABSTRACT

*The effects of Gamma radiation and static magnetic fields (SMF) on cell cycle in the human cervical cancer (HeLa) cell line were investigated. The cells were cultured in α-MEM containing 10% fetal bovine serum (FBS). The proper subculture was then divided into four groups: control, SMF exposed (6 and 15mT for 12hours), Gamma ray exposed (2 and 4 gray), and double exposed (SMF and Gamma ray). The cells were fixed 12, 24 and 48 hours following the starting of the treatments to measure the cell cycle phase distribution using flow cytometery.*

*The data obtained showed that cell cycle phase distribution changed in treatment groups compared to controls. Percentage of cells in G2/M phase in the exposed group with 2 and 4Gy Gamma ray compared to controls showed an increase about 16 and 31 percent, respectively. Also, double treated group showed an increase about 25 and 28 percent for 2 Gy radiated cells before treatment with 6 and 15 mT. Similarly, an increase up to 48 percent was seen in 4 Gy radiated cells with 6 and 15 mT. These changes in percent of populations were dependent on doses of Gamma ray and intensity of SMF. These findings suggest that SMF increase the effects of genotoxic agents such as free radicals through enhancing their life span. They can exaggerate the damages created in DNA. The cells heal the repairable DNA damages by arresting the cells in the G2/M phase.*



***Key words:*** *Static magnetic field, MTT assay, Flow cytometry, G2/M phase*


## 1. INTRODUCTION

There is long scientific history on the biological effects of ionizing radiation (IR). A part of IR is electromagnetic radiation that has sufficient energy to remove electrons from atoms. In the presence of oxygen, ionizing radiation leads to formation of reactive oxygen species (ROS), such as superoxide anion, hydrogen peroxide, hydroxyl radical, and singlet oxygen. The hydroxyl radical is thought to be the most important ROS with respect to DNA damage–mediated clonogenic cell death. Although ROS influence the cell cycle progression, apoptosis and chemical toxicity (1-4). Ionizing radiation altered cell cycle and induces apoptosis in p53 mutant E6.1 Jurkat cells and cell population in G2-phase enhanced upon increasing the amount of gamma-ray doses (5).

Mankind exposure to magnetic fields (MFs) has increased with rapid advances in science and technology, such as magnetic resonance imaging (MRI) diagnosis, nuclear magnetic resonance (NMR) spectroscopy power lines, electric appliances at homes and offices, and passenger transport systems that are based on magnetic levitation (6). This increases the concern about the possible risk of functional disorders in biological systems; however, some reports suggested the therapeutic role for magnetic fields in clinical applications (7, 8). Therefore, it has become necessary to scientifically elucidate the influence of MFs on the body. In recent years several studies have suggested possible negative bio-effects of magnetic fields (9, 10). There is substantial evidence indicating that static magnetic fields (SMFs) of intensity (from 1mT to 1 T) are capable of influencing a number of biological systems. The harmful effects of MFs on different cell lines and/or biological organisms had been intensively investigated during the last decades (11, 12). Interest in the interaction of MFs with living has been triggered primarily from epidemiology studies, in which researchers have reported weak associations between MF exposure and a variety of cancers (13). Other studies have been shown that, SMF influence the cell viability, cell cycle progression and apoptosis. Tavasoli et al in 2009 showed that SMF induced apoptosis in bone marrow stem cells of rat (14). In 2013 Javani et al investigate effect of SMF on the viability and proliferation rate of rat bone marrow stem cells, and their studies revealed SMF reduce viability and proliferation rates in exposed cell (15). In another study in 2010 Sabet Sarvestani et al was founded SMF aggravated the effects of ionizing radiation on cell cycle progression in bone marrow stem cells (16). Despite the numerous studies mechanism of presumptive effects remain unknown, but one of the most recognized hypotheses the mechanism of presumptive effects is radical pair's mechanism in which MF, influences the kinetics of chemical reactions with radical pair intermediates. It can lead to increasing the activity, concentration, and lifetime of free radicals (17, 18).

We applied both treatments of gamma radiation and SMF. We aimed to investigate whether a static magnetic field enhances effects of gamma radiation on cell cycle progression.

## 2. METHODS

### 1.1. Cell culture

HeLa Cells was obtained from Iran's Pasteur Institute (Iran, Tehran). The cells were cultured in αMEM medium containing 10% fetal bovine serum (FBS), 150UI/ml penicillin, 50 mg/ml streptomycin and kept at 37 C◦ in a humidified 5% CO2 atmosphere. The cell medium was changed every 2 days.

### 1.2. Gamma irradiation

Cells were seeded into T25 flasks and were allowed to grow until 70–80% confluence of the surface area of flask (in exponential growth phase) and irradiated in the Radiotherapy Department of Imam Hospital at room temperature, Co -60 gamma-ray source (Source Canada, Theratron780 E). Cells were irradiated with 0, 2 and 4 Gy at a dose rate of 1 Gy/min at room temperature (20°C), at a distance of 0/8 m from the source. After irradiation, parts of the samples were placed in a 37 °C incubator with 5% CO2 and other were transferred to the magnetic field.

### 1.3. Magnetic field exposer

Immediately after treatment with gamma irradiation, cells were exposed to SMF of 6 and 15 mT for 12 h continuously. Magnetic field that used in this study was locally planned SMF generator. The electrical power was provided using a power supply effective in variety of 0–50 V and 0–20 A with a maximum power of 1 kW. This system was consisted of a 40-cm-long solenoid (1800 loops of 2.5 mm covered copper wire) equipped with an incorporated incubator within the solenoid (a copper container with 40 cm length and 8 cm diameter). Via three different sensors, the controller system was able to control the temperature, humidity, and CO2 pressure. Heat was proficiently removed by a gas cooled system using tetrafluoroethane. Circulation system consisted of a condenser, refrigerator engine in addition to a heat-exchanging pipes network of copper with 8-mm width which turned around both inner and outer sides of solenoid. This system was deliberate to create SMF in range of 0.5 μT to 90 mT with steady situation. An electronic board was used to stabilize the system so that we constantly got a homogeneous SMF within the exposure unit. Calibration of the system and tests for the exactness and homogeny of the MFs were performed with a teslameter (13610.93, PHYWE, Gottingen, Germany) with a probe type of Hall Sound. The accuracy of the teslameter was ±0.1% for MF, and the range of measurements was 3 μT–30 mT. Presence of any pulsation in the efferent current was tested by an oscilloscope (40 MHz, model 8040, Leader, Japan). The predefined SMF of 4, 7, and 15mT was generated by passing 1, 2, and 4 Ampere DC current according to calibration data. Temperature was regularly checked before and after all field and control exposures. Three flasks were placed at the center of the incubator (10 cm distance from the center in each side) within solenoid with a homogenous magnetic field, in each exposure. The time of exposures was 12 h continuously. Previous to each exposure, the MF intensity was set to an suitable intensity (6 and 15 mT) using a teslameter (15).

### 1.4.Flow cytometric analysis

Treatment cells and control cells were centrifuged at1200 rpm for 5 min at room temperature. The supernatant (culture medium and FBS) was decanted. The cells were suspended in phosphate-buffered saline (PBS) and re-centrifuged at1200 rpm for 5 min at room temperature. The supernatant was decanted and the cells gently re-suspended in 0.5 ml PBS. Then, the cells were fixed by adding 4.5 ml cold ethanol (70%). Fixed cells were left at

4 °C for 24 h before further analysis. After 24h, fixed cells were again centrifuged as above, washed once and re-centrifuged with cold PBS. Centrifuged cells were re-suspended in staining solution containing 0.5 ml PBS,10 ml of 10 mg/ml ribonucleaseA, 1 ml triton-x-100 and 10 ml of 1mg/ml propidium iodide stock solution, and incubated at 37 °C for 30 min. Flow cytometric measurements were performed using a LSRII flow Cytometer (Becton–Dickinson).

### 1.5 Gating and cell cycle analysis

For each measurement, data from 10,000 single cell events were collected. An important principle of flow cytometry data analysis is to selectively visualize the cells of interest while eliminating results from unwanted particles e.g.

dead cells and debris. This procedure is called gating. Cells have traditionally been gated according to physical characteristics. For instance, subcellular debris and clumps can be distinguished from single cells by size, estimated by forward scatter. Also, dead cells have lower forward scatter and higher side scatter than living cells. Cell doublets and aggregates were gated out using a two parameter dot plot of FL2-Area versus FL2-Width (16) (Fig. 1). Thus single cells isolated from other particles and histogram chart were plotted for the single cells using Flow software. Finally cell cycle phases were separated in different areas and were analyzed using Flow software.

## 3. RESULTS

It was observed that the static magnetic field (6 and 15 mT) alone changed the cell population in the different phase of cell cycle. As it is obvious from Table 1, the arrested cell population in G2/M phase is enhanced from 18 percentage in control to 24, 30 percentage in 6 and 15 mT respectively and cell population in G0/G1 phase proportionally decreased in comparison with control. As shown in Table 1, the effect of gamma irradiation on cell populations of various phases of cell cycle was much stronger than the static magnetic field. Twelve hours after starting treatment with gamma-ray, cell population of G2/M phase showed a significant increase compared to control group and cell population of G0/G1 phase showed a significant increase compared to control group. These changes were dependent on the dose of gamma radiation. Also, when cells were exposed with both SMF and gamma-ray, SMF aggravated the effect of ionizing radiation, significantly. So that 4 Gy increased percentage of G2/M cells from 18% to 45% compared with control cells, but 4 Gy and 15 mT SMF increased percentage of G2/M cells from 18% to 54% in 12 after treatment (table 1). Furthermore, increasing the time after treatments up to 24 h and 48 h causes an increase in the population of G2-arrested cells in all treatment groups, thus, the existing cell population in G1 phase decreases. Maximum percentage of G2/M cells was observed in 24h after treatment (table 2 and 3).

***Fig. 1.*** *Gating, dot plot obtained from flow cytometry (A), single cells were separated from unwanted particles (B), unwanted particles were eliminated from plot (C), histogram of cell cycle phase regions (D)*

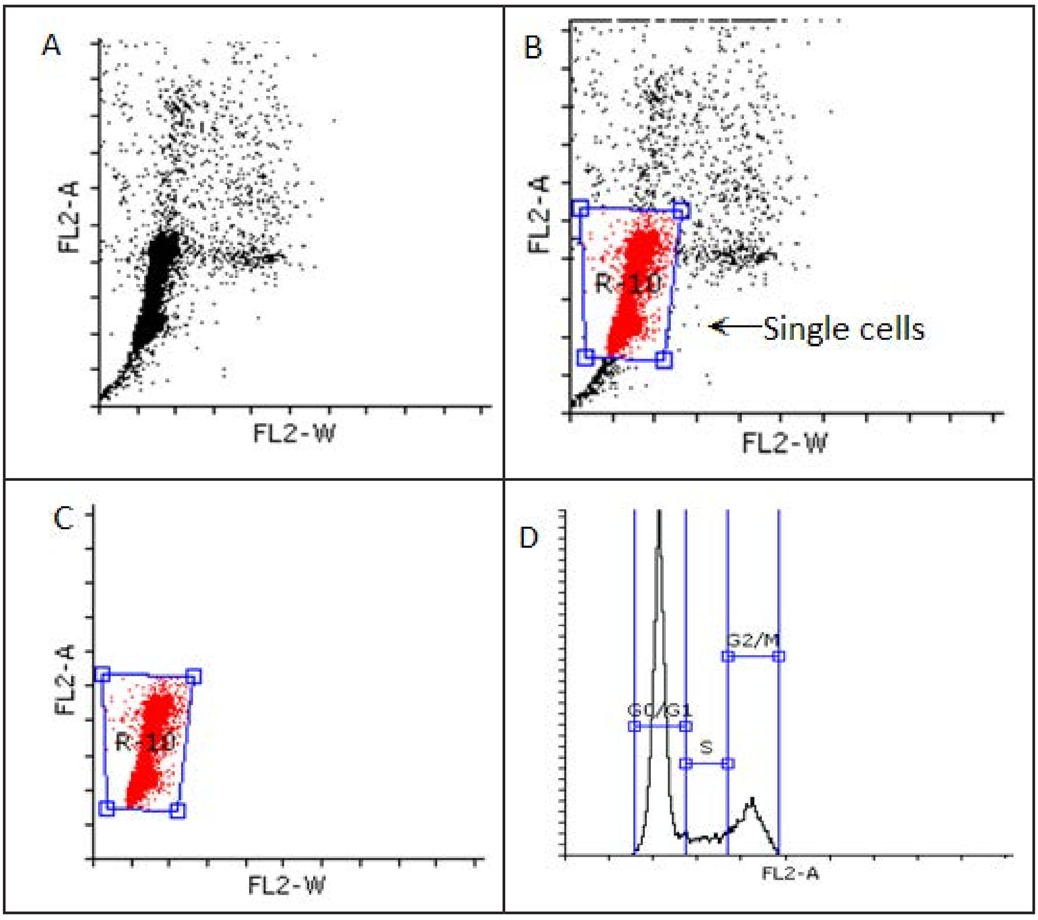

***Table 1.*** *Cell cycle phases of HeLa cells 12 hours after treatment with 2 and 4 Gy of gamma radiation and 6 and 15 mT SMF*

| *Treatments* | *G0/G1* | *S* | *G2/M* |
|---|---|---|---|
| **Control** | 23/1 ± 72/71 | 05/1 ±64/9 | 94/1±32/18 |
| **6mT** | 76/1±74/64 | 11/2±30/9 | 43/1±72/24 |
| **15mT** | 15/1±97/61 | 56/1±17/9 | 25/2±97/29 |
| **2Gy** | 84/1±73/57 | 45/2±12/9 | 30/2±15/33 |
| **4Gy** | 68/1±85/43 | 78/1±58/10 | 35/1±57/45 |
| **2Gy_6mT** | 56/1±35/50 | 88/1±49/11 | 68/1±16/38 |
| **2Gy_15mT** | 63/1±39/46 | 44/2±29/11 | 11/2±32/42 |
| **4Gy_6mT** | 79/1±29/37 | 61/1±26/11 | 68/1±39/51 |
| **4Gy_15mT** | 97/1±71/34 | 87/1±78/10 | 65/1±52/54 |

***Table 2.*** *Cell cycle phases of HeLa cells 24 hours after treatment with 2 and 4 Gy of gamma radiation and 6 and 15 mT SMF*

| *Treatments* | *G0/G1* | *S* | *G2/M* |
|---|---|---|---|
| **Control** | 23/1 ± 72/71 | 05/1 ±64/9 | 94/1±32/18 |
| **6mT** | 76/1±74/64 | 11/2±30/9 | 43/1±72/24 |
| **15mT** | 15/1±97/61 | 56/1±17/9 | 25/2±97/29 |
| **2Gy** | 84/1±73/57 | 45/2±12/9 | 30/2±15/33 |
| **4Gy** | 68/1±85/43 | 78/1±58/10 | 35/1±57/45 |
| **2Gy_6mT** | 63/1±75/45 | 26/2±54/10 | 14/1±71/41 |
| **2Gy_15mT** | 46/1±33/46 | 22/2±26/10 | 74/1±41/43 |
| **4Gy_6mT** | 37/1±94/34 | 85/1±60/11 | 62/1±46/53 |
| **4Gy_15mT** | 78/1±33/32 | 06/2±20/11 | 65/1±47/56 |

***Table 3.*** *Cell cycle phases of HeLa cells 48 hours after treatment with 2 and 4 Gy of gamma radiation and 6 and 15 mT SMF*

| *Treatments* | *G0/G1* | *S* | *G2/M* |
|---|---|---|---|
| **Control** | 23/1 ± 72/71 | 05/1 ±64/9 | 94/1±32/18 |
| **6mT** | 22/2±14/64 | 78/1±73/9 | 56/1±13/23 |
| **15mT** | 53/1±64/62 | 25/2±98/9 | 38/1±18/27 |
| **2Gy** | 52/1±81/55 | 23/2±69/9 | 51/1±46/34 |
| **4Gy** | 82/1±08/44 | 76/1±51/10 | 68/1±23/45 |
| **2Gy_6mT** | 48/1±04/54 | 13/2±72/10 | 84/1±24/37 |
| **2Gy_15mT** | 83/1±55/47 | 58/1±31/10 | 79/1±04/42 |
| **4Gy_6mT** | 39/1±74/37 | 65/1±56/10 | 46/1±48/51 |
| **4Gy_15mT** | 77/1±38/34 | 02/2±06/11 | 39/1±61/54 |

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# STATIC MAGNETIC FIELD AND HIGH NATURAL RADIOACTIVITY ON THE GENE EXPRESSION AN ACTIVITYOF CATALASE IN VICIA FABA

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## ABSTRACT

*The effects of static magnetic field (SMF) and high natural radioactivity on the gene expression, the activity of catalase and Content of chlorophyll in Vica faba were investigated. Soil samples with high natural radioactivity were collected from Ramsar in north of Iran where the annual radiation absorbed dose from background radiation is higher than 20 mSv/year. The specific activity of the radionuclides of 232Th, 236Ra, and 40K was measured using gamma spectrometry. The seeds were planted either in the soil with high natural radioactivity or in the control soils and then were exposed to SMF of 30 mT for 8 days; 8 h/day. Levels of expression of catalase gene and the activity of catalase and the content of chlorophyll were evaluated. The results demonstrated significant differences in the expression of catalase gene in SMF and HR-treated plants, compared to the controls. SMF and HR influenced on catalase activity and content of chlorophyll. The results suggested that response of Vica faba plants to SMF and HR may be mediated by modification of reactive oxygen species (ROS).*

***Key words:*** *Static magnetic field, high natural radioactivity, Vicia faba, catalase, ROS*

## 1. INTRODUCTION

Ionizing radiation is known to have general effects on plant growth and development, ranging from stimulatory effects at very low doses, to the pronounced decreases in reproductive fitness and yield at high radiation levels (1). When ionizing radiation is absorbed in biological materials, there is a possibility that it will act directly on critical targets in the cell. The radiation may interact with other atoms or molecules in the cell, particularly with water, to produce free radicals which can diffuse far enough to reach and damage different important components. This indirects effect of irradiation is important in plant cells, the cytoplasm of which contains about 80% water (2). Generation of free radicals, particularly H2O2 had been proposed to be part of the signaling cascades that leaded to protection from stresses (3). Cytological study of certain crop plants growing under exposure to different radiation levels have shown dose-dependent genome destabilization and high frequency of chromosome aberrations (4). It has been shown that static magnetic fields (SMF) can cause an inconsistency in the function of antioxidant enzymes in plant cells; thereby lead to oxidative stress (5). SMF in conjunction with other physical disturbing factors e.g., radioactive radiations or chemical signaling agents e.g., salicylic acid, showed considerable effects on the balance between ROS and anti-oxidant system (6). Chlorophyll is the most important assimilatory pigment involved directly in the conversion of solar energy into chemical energy at the molecular level, thus chlorophyll content is an indicator of plant health and productivity. Chloroplasts have paramagnetic properties which means that magnetic field of magnetic moments of atoms in them are affected by SMF and oriented downwards the field direction (7). Moreover, SMF has an effect over photochemical activity, for example, the rate of CO2 uptake in radish was reduced following exposure to SMF (8).

Present study was undertaken in order to evaluate the effects of SMF on the activity/expression level of catalase as the major H2O2 scavenging enzyme and total chlorophyll content in broad bean plants cultivated in the soils with high natural radiations.

## 2. METHODS

Six soil samples with high natural radioactivity (HR) were collected from Ramsar, located in north Iran. The specific activity of the radionuclides 232Th, 226Ra and 40K in the soil samples was measured by gamma spectrometer equipped with a high purity germanium semiconductor (Canberra GC4020) and the soil sample with the highest natural radioactivity was selected. The soil was silt-loam, with electrical conductivity 3.5 , pH 7.2, and the specific activity of 226Ra, 232Th, and 40K of it was 9830±124, 22.8±4.1, and 654±49.1 Bq/kg, respectively. Control soil samples similar to Ramsar soils just in terms of minerals, texture, EC, and pH were collected from experimental field of Tarbiat Modares University in Tehran.

### *Magnetic field exposure*

Seeds of broad bean (Vicia faba L.) were prepared from Seed and Plant Improvement Institute, Golestan-Iran. The seeds were surface sterilized by subsequent washes with detergent, sodium hypochlorite (containing 5% active chlorine), and ethanol 70%. The seeds were then rinsed three times with distilled water and were sown in 500 gr plastic pots in four groups. The first group of the seeds was sown in the control soil (without radiation) and also was kept far enough from the MF-producing apparatus to avoid any potential exposure to the MF. In addition, other electric appliances and laboratory facilities were turned off so that the control samples were only exposed to the local natural MF (47±5μT, according to The Geophysics Institute of Tehran University). The second group of the seeds were sown in the soils with HR but again was kept far from MF. The third groups was cultivated in the control soils but were exposed to SMF. The fourth group was cultivated in HR and also exposed to SMF. The pots were irrigated every day with either tap water or ½ Hoagland nutrient solutions. Treatment with SMF (30 mT) was started from the day of sowing until day 8, each day 8 h. Description of the SMF-generating apparatus, and the tests which were conducted for accuracy and homogeneity of the field have been described previously (9). At the end of treatment period, the seedlings were harvested. The plants were washed; their roots and shoots were separated, wiped, and frozen in liquid N2 and kept at -80 ºC until used for biochemical and molecular analysis. Root was placed inside the soils with high natural radioactivity and therefore the probability of getting involved in biological response is higher.

### *Biochemical procedure*

Frozen samples (200 mg fresh weight) were homogenized in 3 mL Na-phosphate buffer, followed by centrifugation at 12,000 ×g for 10 min. All operations were performed at 4 ºC. Activity of catalase (CAT) was measured in a reaction mixture consisted of 25 mM Na-phosphate buffer (pH 6.8), 10 mM H2O2 and diluted enzyme extract (supernatant) in a total volume of 1 ml. The decomposition of H2O2 was followed by the decline in absorbance at 240 nm by spectrophotometer (GBC, Cintra 6, and Australia), and the CAT activity was expressed based on change in absorbance against protein content (Hajnorouzi et al., 2011). Protein contents were determined by the method of Bradford using bovine serum albumin (BSA) as a standard (10). The total chlorophyll content was measured at 652 nm with 95% ethanol colorimetry and calculated (11).

### *Molecular procedure*

Semi-quantitative RT-PCR technique was used for detection of relative expression level of CAT using Actin as an internal control. Total RNA was isolated from samples by RNXTM+ (CinnaGen Inc.) reagent according to the manufacturer's instruction, in presence of chloroform, isopropanol and ethanol 70%. The concentration and purity of RNA were determined by Agarose gel electrophoresis. First strand cDNA was synthesized from 3 μg of total RNA using 1 μL oligo-(dT)18 primer (MWG-Biotech AG) and 0.5 μL RNase inhibitor (Fermentas), at 70 ºC for 10 min. The mixture was then quickly cooled on ice to allow annealing of the primer and RNA. In a separate microtube, other components of reverse transcription (RT), i.e., 1 μL dNTPs, 0.5 μL RNase inhibitor, 1 μL reverse transcriptase (Revert AidTM M-MuLV, Fermentas), and 4 μL 109 RT buffer were mixed together and then were added to the former mixture. RT reaction was accomplished at 42 ºC for 2 h.

The experiment was structured following a completely randomized design arranged in a 2 × 2 factorial with three replications. For all variables, analysis of variance was performed to test the differences between HR and SMF treatments and their interactions. When analysis of variance showed significant treatment effects, Duncan's multiple range test was applied to compare the means at $P<0.05$.

## *3. RESULTS*

Figure 1 shows the activity of CAT in different parts of Vicia faba plants cultivated in different soils and treated with or without SMF. Activity of CAT in the roots of those plants treated with SMF either in the control soil or in HR soil was significantly higher than that of the control group (Fig. 1). Similarly, CAT activity of shoots of SMF-treated plants in control soils also was significantly higher than that of the control one (174%). In the shoots of the plants of HR and HR+SMF groups however, CAT activity respectively decreased to 56% and 45% of the control (Fig. 1).

Relative expression of CAT gene increased in roots of all SMF- HR- or SMF+HR treatments (142%, 128%, and 120% of the control, respectively) (Fig. 2). Relative expression of CAT gene in shoots of treated plants also were significantly higher than that of the control plants (Fig. 2).

The content of chlorophyll in plants of each three treated groups was increased significantly to that of the control plants. (Fig 3).

***Figure 1.*** *Effect of static magnetic field (SMF) and high natural radiations (HR) on the activity of catalase in Vicia faba*

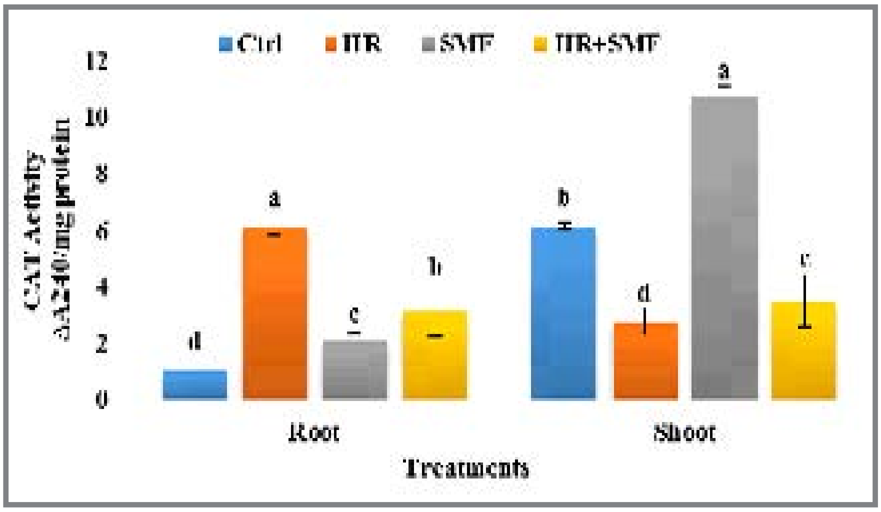



***Figure 2.*** *Effect of static magnetic field (SMF) and high natural radiations (HR) on catalase gene expression in Vicia faba*

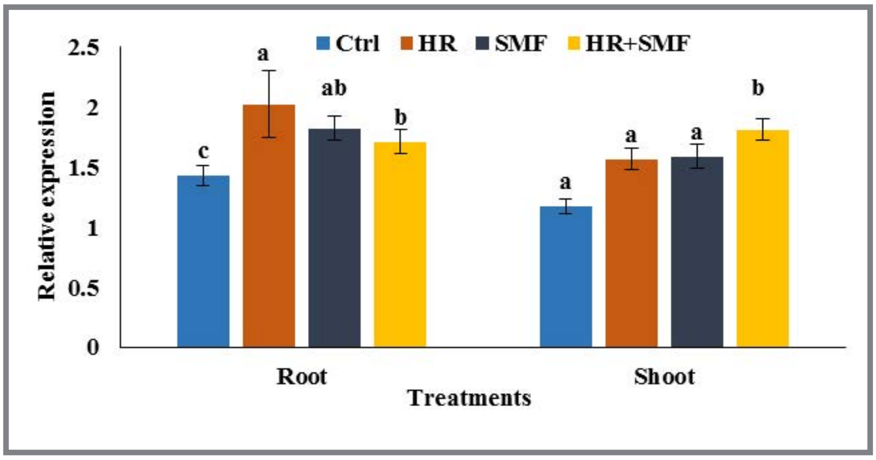
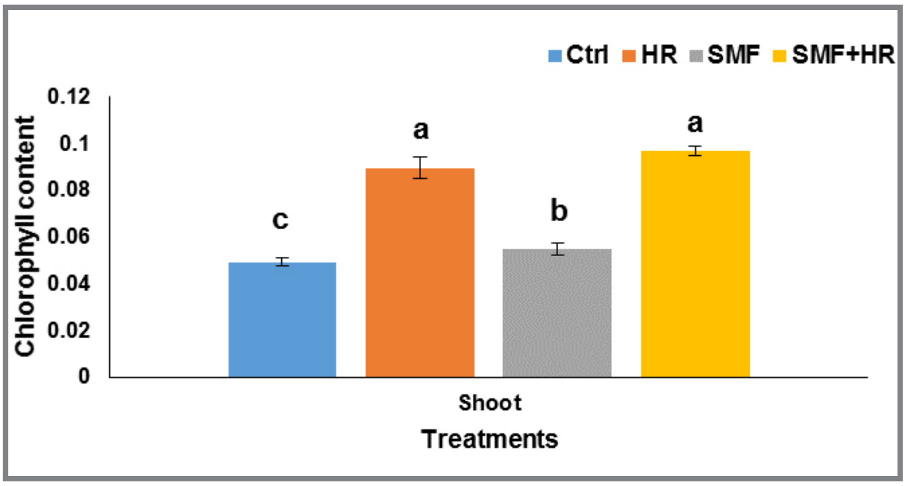



***Figure 3.*** *Effect of static magnetic field (SMF) and high natural radiations (HR) on chlorophyll content in Vicia faba*




In conclusion, SMF in presence of ionized radiation come from soils with high natural radioactivity changed content and life time of H2O2, increased CAT gene expression and activity (12). Moreover, SMF has the ability to change water properties, thus magnetized water increased the plant chlorophyll content. Recent studies have shown that Static magnetic fields at the range of 10-100 mT increased photosynthetic pigments significantly (13).

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# GERMAN RESEARCH ON EXPOSURE AND BIOLOGICAL EFFECTS OF TETRA RADIOFREQUENCY SIGNALS

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## ABSTRACT

*The exposure of users by the handheld radio communication devices of police forces and other security services using the TETRA-standard (Terrestrial Trunked Radio) was numerically modelled for various scenarios. Typical use of TETRA radio terminals in the German digital radio network for security services did not result in an exposure in excess of current limits. An experimental study on the effects of TETRA-signals emitted from mobile devices on the central nervous system has been performed in 32 healthy young male volunteers. Slight significant effects have been found in sleep and waking EEG, predominantly concerning the powerspectra of the ß-band. These slight changes were not subjectively perceived and their health relevance is not known. No important exposure effect on brain activity during sleep was observed for the macrostructure of sleep, sleep quality and the subjectively perceived sleep efficiency. Slow brain potentials, elicited by visual and acoustic cues, were affected in only one of several cognition tests. Vigilance, attention, reaction times, working memory and the well-being during the day were not affected. The volunteers did not report any annoying perceptions and symptoms. Altogether, mobile devices of the police broadcast do not seem to pose any health relevant risk to young male users. Further studies in females and elderly are planned.*

**Key words:** *occupational exposure, radiofrequency, TETRA, brain, cognition, sleep, EEG,*

## 1. INTRODUCTION

In Germany, a nationwide uniform radio network for security authorities and organisations based on the TETRA standard (terrestrial trunked radio) is currently being set up. For the users (e.g. police, fire brigade, rescue service, civil protection, and civil defense) the new radio network will lead to a change of their occupational exposure to electromagnetic fields. In two studies funded by the German Federal Agency for Digital Radio of Security Authorities and commissioned by the Federal Office for Radiation Protection the exposure and biological effects caused by handheld TETRA-devices were investigated.

## 2. EXPOSURE BY TETRA-DEVICES USED IN GERMANY

In the first study, the absorption of the radiation emitted by a TETRA-device in the human body was investigated. The study was based on the devices actually used by German security services. These are handheld radio terminals with and without hands-free speaking systems as well as built-in units in cars with external vehicle antennas.

Various scenarios cover the typical daily use as well as realistic worst-case operation. They include exposure of the head (different phone positions) and the torso (phone near the chest or worn on the belt). Scenarios were included to cover exposure from radio terminals in cars.

The specific absorption rate (SAR) inside the human body was calculated using numerical methods. For this purpose, simulation models of two handheld radio terminals were developed. For the mobile radio terminals in cars, a realistic model of a vehicle antenna was created. Two high-resolution simulation models of the human body were used. For sensitive organs (e.g. the eye), the temperature increase due to the absorbed radiation energy was calculated.

The radio terminals can be operated in different modes. The Trunked Mode Operation (TMO), using the base stations of the radio network, can be considered typical. For this operation, there is currently no multi-timeslot allocation used and the time averaged transmitting power equals 0,25 W. Under these conditions, the German occupational exposure limit (10 W/kg), as well as the limit recommended by ICNIRP (International Commission on Non-Ionizing Radiation Protection) for general public exposure (2 W/kg) is met for all considered scenarios.

In Direct Mode Operation (DMO), multi-timeslot allocation is possible. In this case, the average transmitting power increases to 1 W. For all considered scenarios in this operation mode, the German occupational exposure limit (10 W/kg) is still met.

The mobile radio terminals in cars can be operated in direct mode with a comparatively high transmitting power of up to 10 W. Exposure of a person directly beside a car close to an external vehicle antenna is within the given exposure limits.

The maximum temperature rise in tissue due to the absorbed radiation energy in TMO-mode is 0,25 K, which is below the 1 K temperature rise the ICNIRP guidelines are based on. This temperature rise is limited to the surface of the skin, namely on the pinna (typical phone use) and the tip of the nose (walkie-talkie scenario). Highest temperature increase in the eyes was found using the handheld radio terminals in front of the face, with a value of 0,075 K.

Overall it can be concluded, that the use of TETRA radio terminals in the German BOS digital radio network does not result in an exposure in excess of current limits.

## 3. *INFLUENCE OF TETRA RADIOFREQUENCY SIGNALS EMITTED FROM HANDHELD DEVICES ON BRAIN FUNCTION, COGNITION AND SLEEP IN HEALTHY SUBJECTS*

The second study was a double-blind cross-over volunteer study investigating acute biological effects of radiofrequency electromagnetic fields (RF-EMF) emitted by TETRA handheld devices on the central nervous system. Possible effects on the sleeping brain as well as on the waking brain in resting state and under cognitive demand were studied. Sleep was used as a model for brain activity without conscious control in which exogenous factors are eliminated to a large extent. Thirty-two healthy young males (18 – 30 years) were included.

Human studies investigating possible RF-EMF effects in comparison to sham exposure have to be performed double-blind. Since perception of skin warming resulting from exposure would compromise the blinding, a pilot study was performed with 15 male subjects (age 23 – 36). In this pilot study, the same exposure signals as in the main study were applied: a pulse modulated 385 MHz signal. In a randomized, double-blind cross-over design three exposure conditions (sham, of 1,5 W/kg and 6 W/kg) were investigated. The antenna with a foam cushioning and a textile cover was fixed at the left ear.

In the pilot study skin temperature was measured. Additionally subjective perception of warming was assessed. The measurements revealed a temperature rise proportional to the supplied RF power with an average temperature increase of 0.8 °C following an exposure level at 6 W/kg. However, subjects were not able to distinguish between exposure conditions.

The screening of eligible subjects comprised a questionnaire-based review of inclusion and exclusion criteria as well as ambulatory sleep recordings and a medical examination. An adaptation night was followed by nine study nights (three for each exposure condition) separated by a two weeks interval. At study nights subjects were exposed at the left side of the head for 30 min prior to sleep and afterwards for the duration of the whole night (8 hours). Sleep architecture, sleep spindle parameters and power spectra of the sleep EEG were analysed.

The week succeeding the adaptation night subjects underwent a test session to become familiar with the test procedures. Daytime assessment comprised the level of tonic alertness measured by the pupillographic sleepiness test (PST), the alpha-attenuation test (AAT) and the resting state waking EEG with eyes closed. Phasic alertness was tested by several visually and acoustically evoked potentials with and without behavioural measures. Additionally effects on selective attention, divided attention, vigilance and working memory were investigated. Alternating to study nights daytime assessments were performed every second week, also with three test sessions per exposure condition. Prior to testing subjects were exposed for 30 min followed by tests with parallel EEG registration for a duration of approximately 2 hours. To avoid time of day effects, all tests were performed in the afternoon.

Pre and post every study night and daytime testing participants filled in self-rating scales on mood and symptoms: visual analogue scales, Positive and Negative Affect Schedule, State-Trait-Anxiety Inventory and the Giessen Subjective Complaints List. Additionally four questions related to a possible thermal perception at the head were included.

Data analysis followed a conservative approach. Analyses of exposure effects were based on robust means calculated individually on the basis of the three nights/days with the same exposure condition. Depending on the results for normal distribution exposure effects were analysed by a parametric (mixed linear models) or a non-parametric (Friedman test) analysis of variance for dependent measures with the factor “exposure”. In case of significant results (tested with $p < 0.05$) a posteriori tests for pairwise differences between exposure conditions were performed.

No important exposure effect on brain activity during sleep was observed for the macrostructure of sleep. There were also no systematic variations of sleep spindle parameters with exposure. Power spectra of NREM sleep may vary with exposure. Effects seem to be more pronounced with increasing duration of exposure. Most of the observed differences, however, do not reflect a “dose-response” relationship.

While the PST and the AAT did not reveal any evidence for an exposure effect on the tonic level of central nervous alertness, powerspectra based on 0.25 Hz frequency bins yielded more statistically significant results than expected by chance. These slight physiological variations, however, are typically not reflected in parameters of phasic alertness (exception: Contingent Negative Variation where results indicate a more efficient information processing under exposure). With one exception (reduced variance of the reaction time in the vigilance task), no exposure related differences were observed for the three attention components: vigilance, selective and divided attention. Results concerning the working memory were inconsistent. A pre-post exposure comparison of mood and symptoms did not reveal any variation in relation to exposure. Results of thermal perception in the main study confirmed those of the pilot study.

So far, results refer to the group level. Analyses at the individual level, which are possible based on multiple assessments per exposure condition and person are still pending. Given that brain activity during wake and sleep varies with age and gender, it is open whether these results, which were observed for young healthy males, can be transferred to elderly subjects and to women. Therefore, further investigations in these populations are planned.

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# RADIOFREQUENCY RADIATION INDUCED IMPAIRMENT OF SPERMATOGENESIS, DNA DAMAGE AND OXIDATIVE STRESS IN MICE

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*ABSTRACT*

*Reports on exposure to radiofrequency radiation (RFR) and its correlation to decreasing fecundity and infertility in man are inconclusive. Sperms are vulnerable to oxidative stress due to abundant substrates availability for free radical attack and the lack of cytoplasmic space to accommodate antioxidant enzymes. Therefore, the present study investigates RFR from conventional mobile phone induced impairment of spermatogenesis, DNA damage and oxidative stress in male reproductive organs of mice. Total sperm count, sperm head abnormality, assessment of genotoxicity by comet assay, tissue index, and histopathological changes were evaluated. Further, ultrastructural changes in sperm morphology by scanning electron microscopy have been identified. Our results show that RFR induce profound effect on testicular architecture, enzymatic activity and sperm quality in mice. Epididymal sperm analysis revealed significant decrease in sperm count and increased sperm head abnormalities. Biochemical assessment of Superoxide dismutase (SOD), glutathione (GSH) and lipid peroxidation (LPO) showed that the exposure lead to oxidative imbalance in mice testis significantly. Significant DNA damage in sperms was observed. Furthermore, a disorganization of seminiferous tubules and interruption in sperm cycle in testicular tissue of mice was observed. Scanning electron microscope analysis revealed some specific sperm abnormalities among the exposed groups.*

**Key words:** *Radiofrequency radiation; mobile phone; Oxidative stress; Comet assay; Sperm; testis.*

## 1. INTRODUCTION

Human exposures to Radiofrequency radiations (RFR) can occur through various personal devices (such as mobile telephones, cordless phones), occupational sources (such as high-powered pulsed radars) and environmental sources (such as mobile-phone base stations and broadcast antennas). For workers, most exposure to RFR comes from near-field sources, whereas the general population receives the highest exposure from transmitters close to the body, such as handheld devices like mobile phones [1]. Widespread use of mobile phones, has led to the growing concern about their biological implications on mankind. To address this issue, WHO started the International Electromagnetic fields Project in 1996 for critically analysing RFR induced possible adversities to humans.

Subsequently, International Agency for research on Cancer (IARC) classified cell phone radiation (RFR) as a possible human carcinogen (2011) and strongly recommended the use of pragmatic measures to reduce exposure to brain, such as hands-free devices and Bluetooth [1]. However it's noteworthy that such approach might leave other body parts more exposed.

The male reproductive system is one of the most sensitive targets to radiations [2]. A number of recent studies have revealed a possible association between mobile phone use and male infertility. However contradictory results leading to inconclusive findings create scope for further studies in this area of research. Most of the epidemiological studies in human subjects have found that RFR exposure leads to a variety of undesired outcomes such as low sperm count, aberrant sperm and apoptosis, hence sperm cells are most vulnerable [3, 4,5]. Moreover, animal studies show that RFR exposure for different duration and over a range of different frequencies resulted in decreased sperm count, increased frequency of altered sperms and apoptotic cells [6,7, 8,9,10].

An observational study on men attending infertility clinic in Hungary showed significant reduction in sperm count related to cell phone handling. A total of 231 men were followed for a period of 13-month, and results showed that high users had 30% lowered sperm count than non-users [3]. Another study performed on semen samples, exposed to RFR for 60 min at 1.46 W/kg SAR showed the significant decrease in sperm viability and increased ROS production in human spermatozoa [5] suggesting that RFR can be a plausible etiology for growing incidences of male infertility. In contrast, other studies negate any such effect on testis and sperm [11,12]. Despite of growing evidences from human studies, till date no study has explored the exposure duration dependent effect on testis and sperm vitality of experimental animals. Hence, it is of paramount interest to conduct studies with more practical approach to produce real time data for extrapolation and interrelation which could be beneficial in policy formulation.

It is hypothesized that duration of RFR exposure affects male germ cells through ROS dependent mechanism and alterations in sperm morphology are the implication of the same. Hence in the present study, the impact of RFR mediated oxidative damage to cellular macromolecules like lipid and DNA, impact on cellular antioxidants and pro-oxidants after different exposure durations at the end of one spermatogenic cycle in mice testis was evaluated.

## *2. METHODS*

**Animals:** The research work has Institutional Ethics Committee approval. A total of 48 male swiss albino mice, weighing about 20-30g, age 6 - 8 weeks, were procured from Pasteur institute, Shillong (India), and provided with food pellets and water ad libitum throughout the study period.

**RFR exposure:** Animals were exposed to RFR from a GSM (900/1800MHz) mobile phone with SAR 1.14 W/kg on call mode for different time durations for 35 days. To address the concern that any effects of the mobile phone could be due to heat emitted rather than to RF-EMR alone, the phone in silenced mode was tied below the lid of 4”×2”×1” plastic cage at distance of 4.5–22.3 cm from mice. Animals were free to move about in the cage during the exposure period.

**Experimental Design:** The animals were divided into four groups: Group I (control) remain unexposed to RFR whereas animals of Group II , III and IV were exposed for a total of 4hr, 6hr and 8hr /day given twice daily once in the morning and once in the evening continuously for 35 days.

**Tissue Index:** Weight of the animals and male reproductive tissue i.e. testis, epididymis and vas deferns were recored at the end of 35days. Tissue Index was calculated as:

$$\textbf{Tissue Index} = \frac{\textbf{Weight of organ (g)}}{\textbf{Weight of animal (g)}} \times 100$$

Total sperm count & Sperm head abnormality assay: Animals were sacrificed by cervical dislocation after 35 days of radiation exposure and sperm samples were collected from the both cauda epididymis in 1ml normal saline and sperm counted was taken with a haemocytometer. For sperm head abnormality assessment, a smear was prepared on a clean slide, air-dried, fixed in absolute methanol and stained in 2% eosin Y. One thousand sperms per animal were scored according to the criteria described by Wyrobek and Bruce [13]. Mean % abnormal sperm value is calculated as shown below:

$$\textbf{Abnormal Sperms(\%)} = \frac{\textbf{Total number of aberrant sperm head studied}}{\textbf{Total number of sperm head studied}} \times 100$$

**Biochemical parameters:** Lipid peroxidation (LPO) in testis was measured as thiobarbituric acid-reacting substance (TBARS) by the method of Rehman [14]. Tissue Homogenate (10%) was prepared in normal saline followed by centrifugation at 3000 rpm for 10 mins, 1 ml of the supernatant was incubated at 37ºC for 2hrs. Then, 1ml Trichloroacetic acid (10%) was added and centrifuged at 2000 rpm for 5 mins (4ºC). To 1ml of this supernatant, an equal volume of Thiobarbituric acid (0.67%) was added and mixed thoroughly followed by incubation in boiling water bath for 10min. The samples were then cooled, diluted and O.D was recorded at 535nm on Genesys-20 spectrophotometer (Thermo Scientific, USA). Results were expressed as µmol TBARS/g testis.

Estimation of reduced glutathione (GSH) was done using 5,5’-dithiobis-2-nitrobenzoic acid (DTNB) method [15]. Testis was homogenized in 0.02M EDTA, followed by dilution with ice cold water and addition of 50% Trichlorocetic acid (1ml). Then, it was centrifuged at 6000rpm for 15mins followed by addition of 2ml Tris buffer (0.4 M; pH-8.9) and 100µl DTNB (0.01M). Absorbance was measured at 412nm and results were expressed as µMol/g tissue.

The method described by Marklund and Marklund [16] was used to perform superoxide dismutase (SOD) activity assay. 100µl of testis homogenate (10%) prepared in normal saline was added to 2.9 ml Tris-HCl buffer (0.4 M; pH-8.5) followed by addition of 25 µl of Pyragallol (25mM in 10mM HCl). Absorbance was taken at 420nm and results were expressed as Units/ml.

**Comet assay:** Alkaline comet assay was carried out to study RFR induced DNA breaks in sperm following the method of Singh et al. [17] with modifications of Tice et al. [18]. Each Sample at the concentration of 2x 104 cells/ml was mixed with 1% LMPA and 85 µl of the mixture was spread on frosted slides pre-coated with 1% NMA which was followed by the coating with 90 µl LMPA (0.5 %) on ice pack. Slides were kept at 4ºC for 1 hr in cold lysis buffer (consisted of 2.5M NaCl, 100mM Na2EDTA,10mM Trizma base, 1% TritonX100 and 10% DMSO; pH 10). Then, the slides were immersed in the electrophoresis buffer (300mM NaOH: 1mM Na2EDTA at pH 13.5) for 20 min at 4ºC followed by electrophoretic run at 4ºC at constant Voltage (24V; 300mA). Slides were then neutralized with 0.4M Tris buffer (pH7.5) for 5 min and rinsed in distilled water. EtBr (20µgm/L) was added to stain the DNA and scoring was done on software-Komet 5.5 (Kinetic imaging, UK) attached to a fluorescence microscope (Leica, Germany). Images of 50 cells per slide for each animal were analyzed. Cells were divided in 5 comet classes depending upon the Tail DNA content: class1 (<5%), class2 (5-20%), class3 (20-40%), class4 (40-90%) and class5 (>90%) (Fig.6). Percentage of cells in each class was calculated along with the fold change in comet parameters as compared to control group.

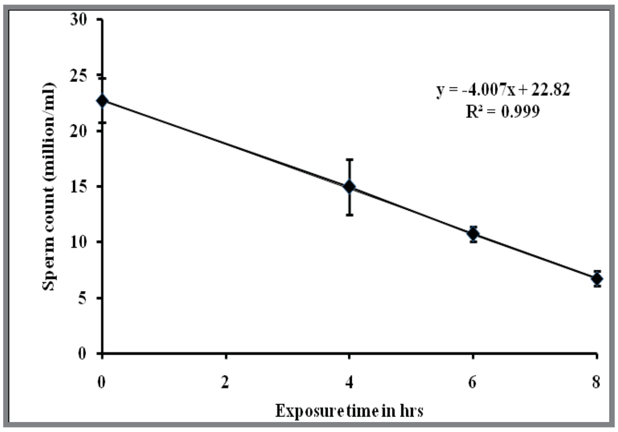
**Statistical evaluation:** One-way analysis of variance (ANOVA) was used to analyze the difference of mean among the groups. Tukey-Post hoc analysis was performed for multiple comparisons among the treatment groups. To compare the percentage cells in various comet classes among the experimental groups, two way ANOVA was performed followed by Bonferroni post hoc test.

## 3. RESULTS

***3.1. Tissue index:*** No significant difference was found among the control and exposed group.

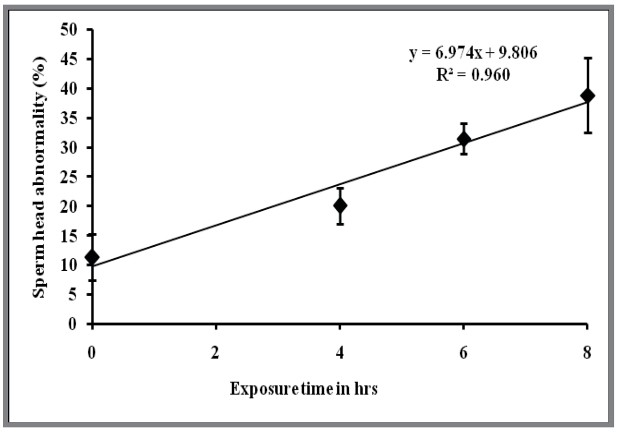
***3.2. Sperm parameters:*** Statistically significant increase in sperm head abnormalities (P<0.001) and subsequent decrease in total sperm count (P<0.001) was observed after 35days of RFR exposure. A duration dependent decline (R2 =0.999) in sperm count and increase in sperm head abnormality (R2=0.960) was observed (Fig.1 & 2). In all the RFR exposed groups, 4hr exposure (15±4.96; P<0.05), 6 hr exposure (10.75±1.39; P<0.001) and 8 hr exposure (6.75±1.39; P<0.001) the sperm count was lower as compared to the control group: 22.75±3.96 9 (Fig.1). The percent abnormality in sperm heads in control, 4hr exposed, 6hr exposed and 8hr exposed groups was 11.40±3.89, 20.17±3.04 (P<0.05), 31.53±2.56 (P<0.001) and 38.90±6.36 (P<0.001) respectively (Fig.2).

***Fig.1.** Graph showing regression line and correlation coefficient (R2) of epididymal sperm count in mice after 35 days of RFR exposure at different exposure duration*




*Mean±SD; N=4*

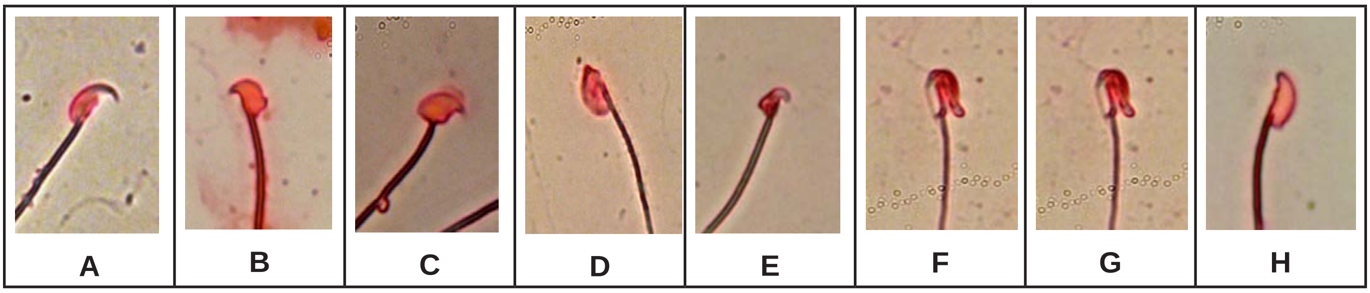
***Fig.2.** Graph showing regression line and correlation coefficient (R2) of aberrant head morphology (%) in epidimal sperms of mice after 35 days of RFR exposure at different exposure duration*




*Mean±SD; N=4*

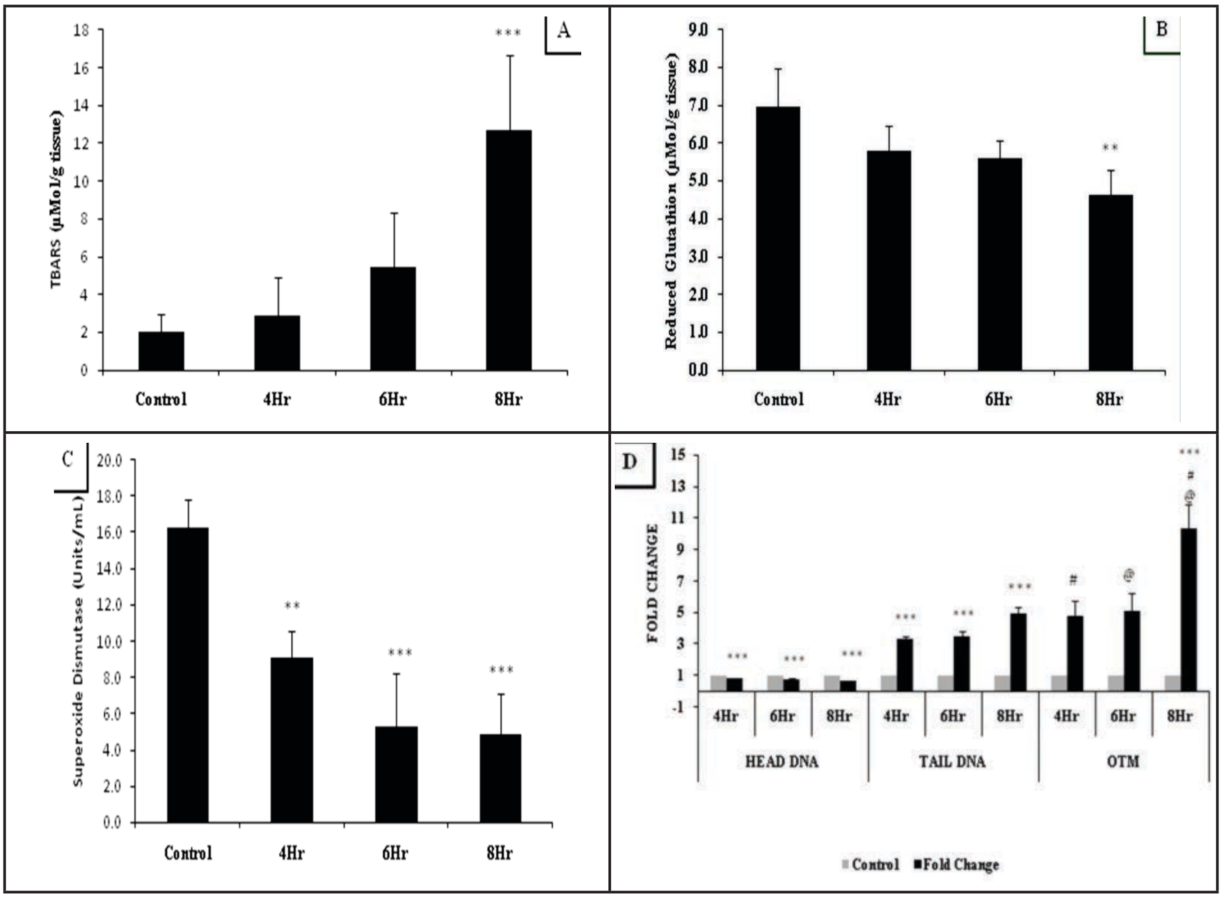
The results confirm the RFR potential to reduce epididymal sperm count which may be due to impairment of spermatogenesis in testis of exposed animals. Various sperm head abnormalities observed in exposed animals are shown in Fig. 3.

***Fig.3.** Photomicrograph of epididymal sperms of normal and RFR exposed mice. In panel A-is seen the typical normal mouse sperm ; panel B-H – Aberrant head morphologies, B-triangular sperm; C-incorrect head and neck attachment; D- Hookless; E- Hooked; F – amorphous ; G – club shaped and H- Banana shaped.*



***3.3. Oxidative damage:*** RFR exposure for 8hr daily for 35 days led to a significant increase in the TBARS level in testes (12.69±3.9591µMol/g ; P<0.001) as compared to the control group (2.06±0.91µMol/g). However, 4 and 6hr exposure could not induce statistically significant increase in TBARS levels in testicular tissue of mice (Fig.4A).

***Fig.4.*** *Graph showing levels of TBARS in testis (A), Testicular concentration of reduced Glutathione (B), Superoxide dismutase activity in testis (C). Each bar represents mean ± SD (n = 4) where as Graph D represents the fold change in comet parameters i.e. Head DNA, Tail DNA and Olive tail moment in RFR exposed groups as compared to control. Values are mean± SD. Significantly different from control: * = P<0.05; ** = P < 0.01. *** = P < 0.001, # and @ represents significance difference in mean among the groups at p<0.05 .*




***3.4. Antioxidant strength:*** A significant drop in GSH content in testis of 8hr exposed group (4.62±0.67 µMol/g, P<0.01) was recorded in comparison to control (6.96 ±1.00 µMol/g) (Fig.4B). SOD activity was found to be significantly lowered in all three exposed groups (4hr: 9.07 ±1.52 U/ml, 6hr: 5.30 ±2.92 U/ml, 8hr: 4.851±2.259 U/ml, P<0.001 for all) than control group (16.29±1.52 U/ml)(Fig.4C).

***3.5. DNA Damage:*** To ascertain oxidative DNA damage to male germ cells, fold change in comet Head DNA, Tail DNA and Olive Tail moment (OTM) was calculated in sperm cells of mice (Fig.4.D). RFR exposures led to significant decrease in head DNA and increase in tail DNA and OTM. Fold decrease in Head DNA for 4, 6 and 8 hr exposure time was found to be 0.81, 0.79 and0.68 respectively whereas 3.5 fold increase in 4 and 6 hr group, and 4.9 fold increase in 8 hr exposed group tail DNA was observed (Fig.4D). For OTM, 10 fold increase was found in 8hr exposed group (p<0.001). The exposure time dependent effect in fold change of comet head DNA (R2 =0.965), Tail DNA (R2=0.959) and OTM (R2=0.884) was found.

Quantitative analysis of cells with respect to tail DNA, revealed the significantly decreased proportion of cells with <5% damage in all exposed groups (P<0.001) than control in sperm cells (Fig.5). There were approximately 0% cells with >20 % DNA damage in control (Fig.5). Consequently, proportion of cells with 40-90 % damaged DNA were significantly higher in 6 hr exposed and 8hr exposed groups in sperm (P<0.05 and P<0.01 respectively). These results are suggestive of the RFR potential of DNA oxidation through ROS generation.

***Fig.5.*** *Graph representing percentage of cells in each comet classes for sperm cells. Based on Tail DNA: class1(<5%), class2 (5-20%), class3 (20-40%), class4 (40-90%) and class5 (>90%) (mean±SD; N=3). Statistical test: Two way ANOVA; post hoc – Bonferroni test. Significantly different from control: # = P<0.05; $ = P < 0.01. @ = P < 0.001.*

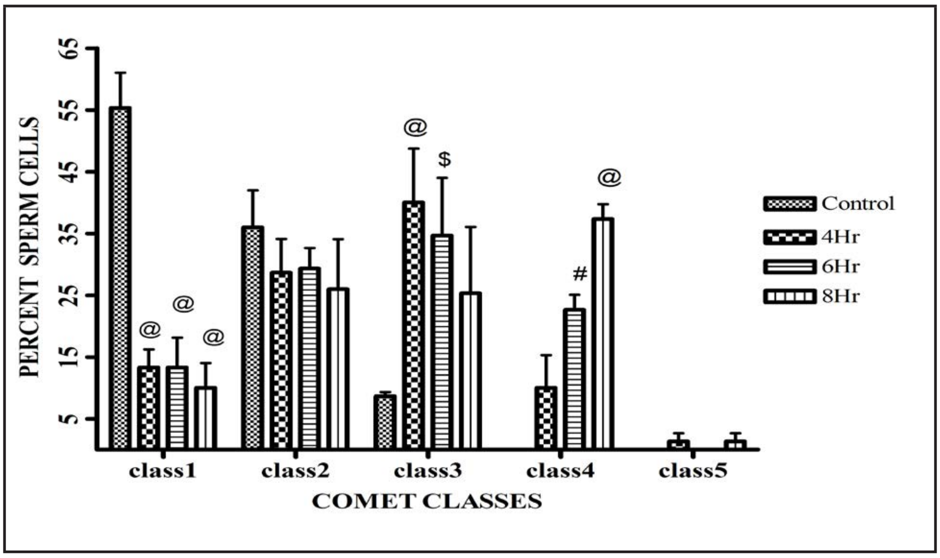
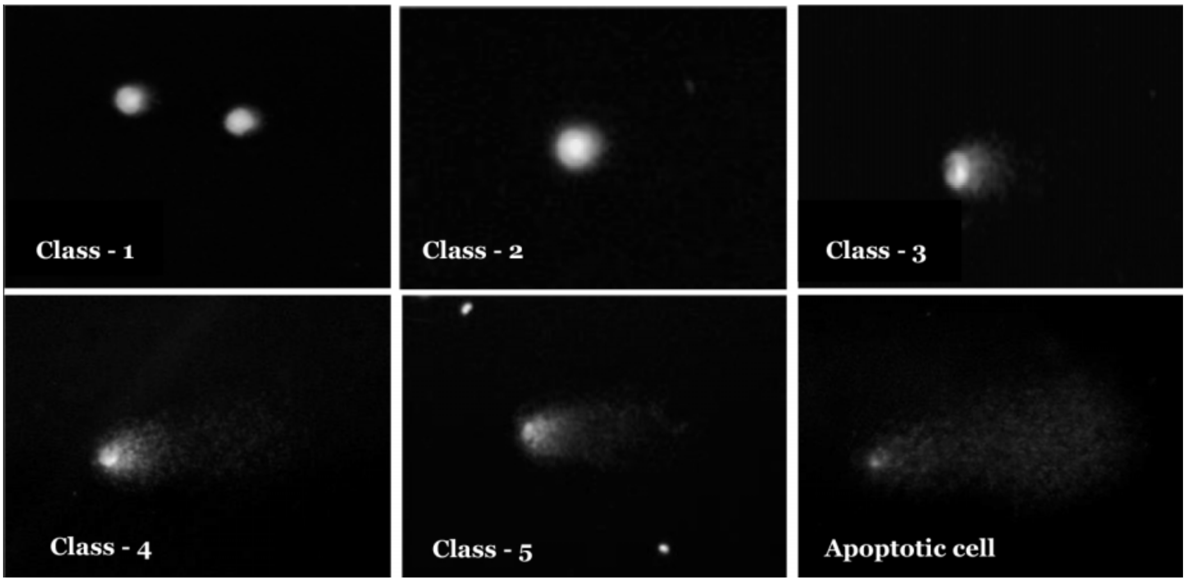



***Fig.6.*** *Gel pictures of comet assay showing classification of comets based on tail DNA: class1(<5%), class2 (5-20%), class3 (20-40%), class4 (40-90%) and class5 (>90%).*




***3.5 Sperm morphology and Histology:*** Scanning electron microscopy of epididymal sperms revealed ultra-structural changes in sperm cells of exposed mice. Various short and stubby cells with poorly formed surface structures were observed. Histological examination of testis sections of exposed mice showed damaged spermatocytes and spermatids and decreased population of mature spermatozoa in the tubular lumen.

## 4. DISCUSSION

The results of the present study demonstrate that duration of exposure to radiofrequency radiations (900-1800MHz) has dose dependent effect on DNA integrity of male germ cells, oxidative homeostasis of testis and sperm morphologies. Earlier researches have reported the frequency or SAR dependent effects. It is noteworthy that despite of numerous epidemiological reports on relationship between duration of cell phone usage and deranged semen parameters [3,5, 19,20] , this report confirms the similar effect in test animals to evaluate the experimental evidence of such phenomenon. This study provides reliable extrapolation of data with understanding of the underlying mechanism of RFR induced reproductive and germ cell toxicity. RFR possess both electric and magnetic properties and upon exposure in response to it, polar molecules and cellular components rotate. Since, the field is oscillating constantly; dipole distribution is never uniform resulting in uncancelled residual charge which could be the etilogy for radiation toxicity. However, this rotation is opposed by inertia and viscous forces resulting in time dependent behaviour [21].

Superficial position of testis is strategically important due to two reasons, first lower physiological temperature required for spermatogenesis and dependence on surface conduction for temperature regulation that ultimately makes it unusually vulnerable to more RFR absorption which may correspond to oxidative stress and production of abnormal spermatozoa.Our results show no significant change in tissue indices for reproductive organs – testis, epididymis and vasdeferns following the 35 days exposure which was in accordance with the previous data showing that RFR do not alter the relative weights of organs [22, 23].

Many animal studies have reported the negative colleration between cell phone usage and alterations in sperm count, morphology, motility and viability [4, 7, 24, 25, 26]. Our results indicating the duration dependent decrease in epididymal sperm count along with positive correlation between increasing sperm abnormalities are consistent with published reports. Further it supports the evidences from epidemiological data [3,5,19]. An observational study conducted on 361 men divided into four groups: no use, upto 2 h/day, 2-4hr/day and more than 4hr/day found positive correlation between duration of cell phone usage and altered sperm morphology with >80% abnormal sperm in highest exposed group as compared to low usage group with ≈ 60% abnormality [20]. In contrast, few other studies did not show any association between radiation and alteration in sperm count and morphology [27,28].

ROS have been implicated as the fundamental mechanism of RFR induced damage on sperm through alteration of macromolecules- membrane lipids, vital proteins and DNA [29]. Sperms produce ROS to perform many physiological functions but at the same time , they are vulnerable to its damaging effects due to limited cytoplasmic antioxidant reserve and high membrane content of polyunsaturated fatty acids such as docosahexaenoic acid with six double bonds per molecule which is the target to free radical attack because of the lowest carbon hydrogen dissociation energies at the bisallylic methylene position. The initial oxidative stress induces lipid peroxidation culminating in the production of lipid aldehydes such as 4-hydroxynonenal (4HNE), acrolein and malondialdehyde, collectively known as Thiobarbituric acid reactive species (TBARS). TBARS bind to proteins in the sperm mitochondrial electron transport chain, and causes dramatic increase in ROS generation [30]. Hence, investigation of Lipid peroxides in the current study was imperative. Consistent with earlier reports [4,6,7] we found very high levels of testicular TBARS in mice exposed to RFR for most time duration as compared to others however mitochondrial origin of ROS remain elusive and can be a future direction to investigation. Consequently, depleted total GSH concentration in testis corresponds to decreased availability of pro-oxidants resulting in destruction of oxidative homeostasis, which adversely affects the normal spermatogenesis in testis affecting sperm production. Hence, it can be inferred that lipid peroxidation is a key factor in the etiology of defective sperm morphology as well as function. Decreased levels of SOD activity is suggestive of drop in cellular antioxidant capacity due to rise in the generation of reactive superoxide ions, as also reported by Alvarez et al. [31]. Kesari et al [6], Dasdag [33], Amara, [32], Kesari et al [7] who concluded that increasing oxidative stress induced by RFR exposure results in decreased SOD activity compromising cellular anti-oxidative strength.

Genotoxic effects on sperm was studied through comet assay which measures the damage as DNA breaks .The results depicted duration dependent increase in fold decrease in head DNA and increase in tail DNA and OTM along with the increase in frequency of comet class 3, 4 and 5 cells in exposed groups in contrast to controls consisting of maximum proportion of cells in comet class 1 and 2. DNA damage in germ cells have important implication on subsequent generations as they are cumulative in nature. Normally, cell maintains the balance between spontaneous and induced damages by homeostatic mechanism of DNA repair. However, Double DNA breaks can sometime be irreparable and can lead to apoptosis. We observed apoptotic cells as well which could be correlated with lowered sperm count, supported with previous reports [6,5, 34,35]. As described by Panagopoulos et al [36], RFR disturbs the electrochemical balance of plasma membrane causing the disruption of membrane channel functions by coherent vibration of electric charge thus circumventing the membrane barrier, penetrating the nucleus and causing DNA breakage.

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# EVALUATION OF THE PULSED MAGNETIC FIELD ON ATP-SENSITIVE POTASSIUM CHANNELS IN DIABETIC RATS

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*ABSTRACT*

*Known as an autoimmune disease, type 1 diabetes is characterized by the damage of pancreatic β-cells and increased glucose metabolism. In the presence of high glucose metabolism, ATP levels increase, and the KATP channels close causing the membrane potential of the cell to depolarize, thus promoting insulin release. Aim of this study was to evaluate influence of pulsed magnetic field (PMF), on vascular complications and contractile activities of aortic rings along with Kir 6.1 and Kir 6.2 subunits expression of ATP-sensitive potassium channels in aorta of controlled-diabetic and non-controlled diabetic rats. Both controlled-diabetic and non-controlled diabetic rats were exposed to PMF for 30 days. At the end of this period, blood glucose levels elevated and body weight decreased, contractile activities however increased in non-controlled diabetic rats. Pulsed magnetic field therapy repressed Kir 6.1 mRNA expression in non-controlled diabetic rats but not in controlled diabetic rats. On the other hand, Kir 6.2 mRNA expression was drastically repressed both in controlled diabetic and non-controlled diabetic rats by PMF treatment. Our findings here may suggest that the positive therapeutic effects of PMF act possibly through ATP-sensitive potassium channel subunits, which may frequently occur in the insulin-free conditions.*

**Key words:** *Diabetic rats, pulsed magnetic field, K+ channels.*

## *1. INTRODUCTION:*

Physiological functions of endothelial cells are altered in certain cardiovascular and diabetes disease states [1-3]. Diabetes mellitus, a chronic metabolic disorder, is caused by a combination of genetic and environmental factors and characterized by the damaged of pancreatic β-cells and elevated blood glucose level that is resulted from the failure of insulin secretion or a disorder in insulin action [4-7]. In pancreatic beta cells, which are sustained primarily by ATP, the ATP/ADP ratio determines KATP channel activity and these channels play an important role in the regulation of the vascular contractility. KATP channel activities play an important role in the vascular complications such as reduced endothelium-dependent relaxation (EDR) and enhanced receptor-mediated contractions in diabetes. It was reported that elevated blood glucose level increases fat accumulation in blood vessels and arteries, as well as adversely affecting smooth muscle cell wall. In these studies, it was also indicated that there are some defects in relaxation response of blood vessels) have recently demonstrated that these adverse effects of diabetes on relaxation response can be ameliorated by pulsed magnetic field (PMF) [8,9]. The ATP-sensitive potassium channel which is an octomeric protein complex composed of Kir 6.1, Kir 6.2 and sulphonylurea receptor subunits is one of the most important cell elements having a regulatory role in the smooth muscle cells, especially in the relaxation response ([10,11].The rat aorta is widely used to study and evaluate the various aspects of vascular complications in diabetes states and contained high conductance ATP-sensitive K channels and inwardly rectifying potassium channels (Kir6.0 family: Kir6.1, 6.2) . In vascular smooth muscle cells (VSMCs), KATP channels couple intermediary metabolism to cellular activity and play an important role in the auto regulation of vascular tonus [12]. Under normal conditions, the KATP channels in pancreatic beta cells are spontaneously active, allowing potassium ions to flow out the cell. In the presence of higher glucose metabolism such as diabetes mellitus disease, and consequently increased levels of ATP, the KATP channels close, causing the membrane potential of the cell to depolarize, thus promoting insulin release.

The overall, aim of this study is to evaluate influences of PMF, whether positively affects may be on vascular complications and their contractile activities of aortic rings, on Kir 6.1 and Kir 6.2 subunits of ATP-sensitive potassium channels in insulin-treated diabetic and non-treated diabetic rats

## 2. METHODS

### 2.1. Animals

Animals were housed according to the National Institutes of Health Guide for the Care and Use of Laboratory Animals. All experimental procedures were approved by the Cukurova University Animal Care and Use Committee. In this study, adult male Wistar rats weighing (250–300g), were studied (n =40) and obtained from the Medical Sciences Research Center of Cukurova University. They were housed for 4 weeks (30 days) under controlled temperature conditions of 21±3°C and were maintained on a 12-h light/dark cycle (0600–1800 hours), with standard chow and water ad libitium.

For the PMF treatments , the rats were divided into six groups, Sham-control-PMF-treated (SC-PMF), sham-diabetic- PMF-treated (SD-PMF), sham-controlled diabetic PMF-treated (SCD-PMF), control-PMF-treated (C-PMF), controlled diabetic-PMF treated (CD-PMF) and PMF were applied to the groups (1h/day, intensity; 1.5mT, consecutive frequency; 1, 10, 20, 40 Hz) for one month. Also, since there is no difference between sham groups of PMF treatment, data of these groups were not shown in this study.

### 2.2. Induction of diabetes

First of the all; rats were divided into two groups of age-matched rats; controlled-diabetic groups (CD-PMF) and non-controlled diabetic groups (D). Then, diabetes mellitus was induced by a single intravenous (tail vein; i.v.) injection of streptozotocin (STZ), 45 mg/kg dissolved in 0.9% saline solution. To provide non-diabetic control group (C), an equivalent volume of sterile saline was injected. Diabetes induction was confirmed after 48 hours by determining blood glucose levels using a glucometer (Accutrend GCT, Roche, Mannheim, Germany). 300 mg/dL (16,7 mmol/L) is considered to be the minimum blood glucose concentration for diagnosis of diabetes in the animals used [13-17].

### 2.3. Controlled Diabetic Groups

To reduce the complications risk in diabetes, glycemia was kept under controlled. In order to prevent sudden fall and rise in blood sugar levels and unwanted loss of body weight, long-acting insulin-glargine (24 hours) was administered at any time of day to rats every other day 2-3 U / 100 g ((IG; Lantus®) A-ventis Pharma, Germany) subcutaneously (CD) Experiments were pursued for 4 weeks. Throughout the treatments the weights and blood glucose levels were controlled or measured regularly once a week at the same time of the day.

### 2.4. Preparation of Tissues

Rats were anesthetised with sodium pentobarbital (50 mg/kg,ip).The thoracic aorta was dissected free and the surrounding connective tissue and fat were removed. The aorta was then cut into 2-3 mm rings with undamaged or mechanically removed endothelium [15] were mounted on parallel wires and placed in tissue baths (20 ml) containing Krebs solution that was gassed continuously with 95% O2 and 5% CO 2 and controlled temperature (37°C) of tissue baths. Krebs solution containing the following (in mM): 118 NaCl, 4.7 KCl, 1.2 MgSO4, 1.2 KH2PO4, 2.4 CaCl2, 25 NaHCO3,11 glucose, 0.03 EDTA.

The rings were then progressively stretched to a preload tension of 2.0 g and allowed to equilibrate for 120 min. During this period the bath solution was replaced every 15 min. Each ring was equilibrated for 120 min. before generation of concentration-response curves to cumulative concentrations of phenylephrine (PE; 1nmol/l to 1µmol/l). Because α-adrenoceptor agonists-induced contractions are increased in the diabetic mellitus [4, 15], rings were then contracted with a sub-maximal equipotent concentration of phenylephrine (usually 1µmol/l) to give 80% maximal response [5-7]. At the plateau of contraction, concentration-dependent relaxations to acetylcholine were recorded by connection to a data acquisition system (MP 150 Biopac Systems, Ankara, Turkey).

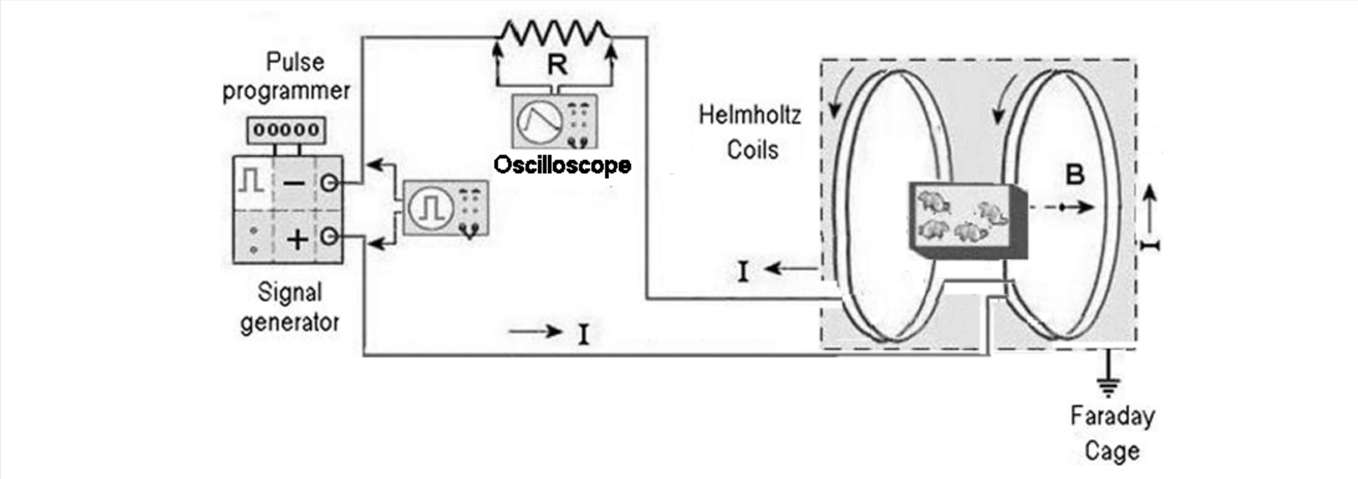
The effect of the ATP-sensitive K channel opener cromakalim (10–5 M) on contractile responses was assessed by treating arterial segments for 30 min prior to addition of phenylephrine. Similarly, the effect of ATP-sensitive K channel blocker glibenklamide (10–5 M), on contractile responses was assessed by 30 min treatment prior to addition of phenylephrine and then concentration-dependent relaxations to acetylcholine were recorded.

### 2.5. PMF-treatment

For the PMF treatment, the rats were divided into three groups, PMF-treated control (C-PMF). PMF-treated controlled diabetic (CD-PMF), PMF-treated non-controlled diabetic (NCD-PMF), and Before the PMF treatment, all rats were acclimated to their environment for a week. To perform habituation to the treatment conditions, the rats were placed in the restrainer at least three times for 30 minutes. PMF application was performed using Helmholtz coils, 60 cm in diameter and placed 30 cm apart, which produce magnetic field peak amplitude of 1.5

mT when connected to a signal generator (ILFA Electronic, Adana, Turkey). All rats were treated with PMF for a period of 6 weeks. Each animal was placed in a plastic restrainer (30 cm long, 20 cm wide and 15 cm high) and whole-body exposure to PMF was applied for 1 h each day. Distribution of the magnetic density was measured by a Gauss Meter and kept homogenous within maximum 5% difference in the exposure area. In previous studies, rats were subjected to circadian cycle [18] and it was also reported that light can be a source of aversive stimulus [19]. Considering these, PMF treatments were carried out at the same period (8:00-12:00) or (12:00-15:00) and under the same light conditions in a quiet laboratory. Throughout the treatments, the temperature (23-25 ºC) and the humidity (40-60 %) were monitored continuously.

***Figure 1.*** *Diagram of pulsed magnetic field (PMF) exposure system. PMF was generated in a pair of Helmholtz coils 60 cm in diameter, with 100 turns of 18 gauge copper wire each in a Faraday cage.*




PMF application was performed in trained repeated three sequences. Each sequence included four different consecutive pulse trains (1, 10, 20, and 40 Hz). The duration of each pulse train was 4 min with an interval of 1 min between each pulse train. A digital timing device controlled the timing. The waveforms of magnetic field explored by a search coil probe showed no clear differences in shape and magnitude of waveforms of magnetic field. Each animal was placed in an all plastic restrainer located between the coils and whole-body exposure to PMF was applied for 1 h each day. The temperature (23–25 °C) and humidity (40–60%) were monitored continuously throughout the treatments. Sham exposure to animals was performed under the same environmental conditions by using another apparatus including only Helmholtz coils, in a Faraday cage (Figure 1).

### *2.6. RNA isolation and quantitative real-time RT-PCR*

After PMF treatments, the rats were euthanized by decapitation and their thoracic aortas were isolated. Half of thoracic aorta tissue sample was used for muscle contraction assays and the rest was used for RNA isolation. Total RNAs were extracted using TRIzol reagent according to the manufacturer's instructions (Invitrogen, Carlsbad, California, USA). On column, DNAse digestions were carried out using a DNAse I kit (Qiagen, Valencia, CA). The integrity of the isolated RNAs was verified by running 5µg of total RNA on a 1% formaldehyde gel. cDNAs were synthesized using oligo (dT) primers with SuperscriptTM III first-strand kit as recommended by the supplier (Invitrogen, Carlsbad, California, USA). Using five microliters cDNA, real-time PCR was performed with the Power SYBR® green PCR kit (Applied Biosystems, Foster City, California, USA) in an ABI 7900 HT fast real-time PCR system (Applied Biosystems). The primers used were as follows: Kir 6.1; forward 5'-catagctcatcgggttcacaccatt-3', reverse 5'-gcatcga gacacacaggtgctgttgt-3'; Kir 6.2; forward 5'-agctggctgctcttcgctatca-3', reverse 5'-ccctccaaacccaatggtcact-3'; GAPDH; forward 5'-tctacccacggcaagttcaat-3', reverse 5'-accccatttgatgttagcgg-3'.

Polymerase chain reaction was carried out in triplicate in 25 µl reaction volume using SYBR green PCR mix. The reactions were incubated at 50ºC for 2 min and 95ºC 10 min, followed by 40 cycles of 95ºC 15 sec and 60ºC 1 min. The threshold cycle (CT) is defined as the fractional cycle number at which the fluorescence passes the fixed threshold. TaqMan CT values were converted into absolute copy numbers. All RNA samples were normalized to the expression levels of a glyceraldehyde-3-phosphate dehydrogenase (GAPDH) gene endogenous control. "No template" and "no-RT" controls were used to ensure the absence of genomic DNA and reaction specificity. Three independent experiments were performed to demonstrate reproducibility. Real-time RT-PCR product specificity was confirmed by melt curve analysis, gel electrophoresis, and product sequencing.

## 2.7. Drugs and chemicals

All chemicals were purchased from Sigma Chemical (St Louis,MO,USA). Glibenklamide was freshly dissolved in DMSO solution. All the other testing drugs were dissolved in distilled deionised water to prepare stock solutions, and further dilutions were made in Krebs solution. Streptozotocin was freshly dissolved in 0.9% saline solution.

## 2.8. Data and statistical analysis

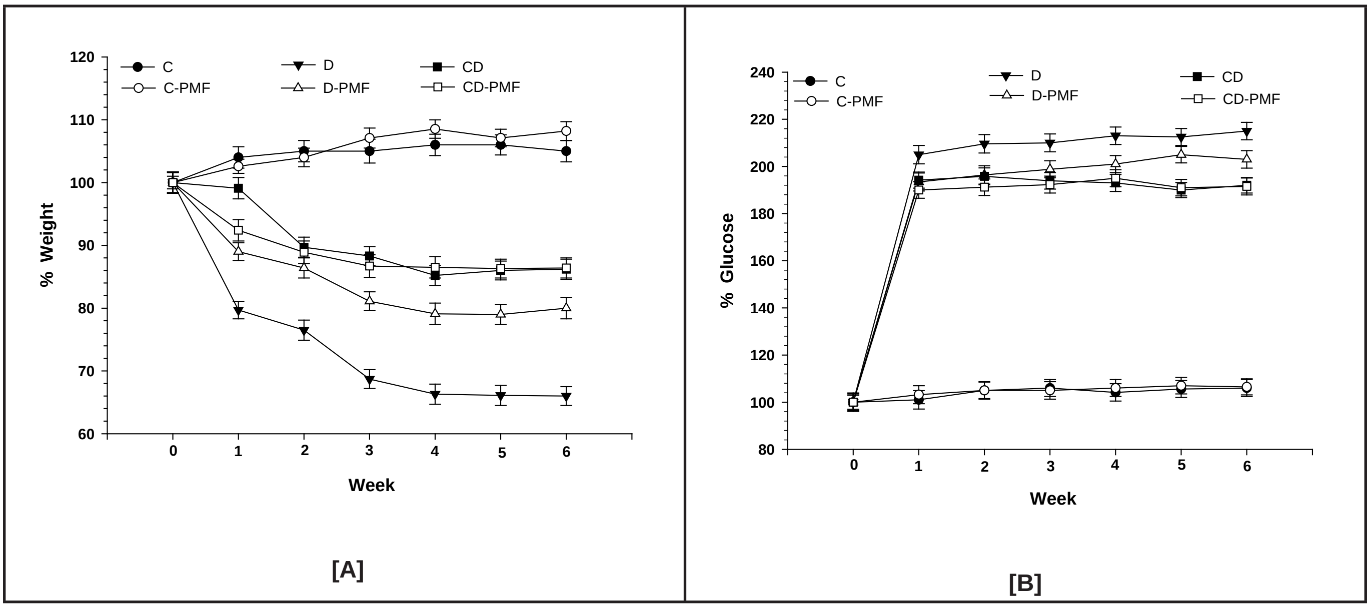
Data are expressed as the mean ± S.E.M. Relaxation responses for cromakalim and contraction responses glibenklamide are expressed as a percentage decrease of the maximum contractile response induced by phenylephrine. Statistical analyses were performed by Welch paired t-test and one-way ANOVA followed by Tukey multiple comparisons test using the StatView 5.0 Statistical Software package (SAS Institute, Cary, NC, USA). Significance was determined at $\alpha$=0.05 and $\beta$=0.20.

# 3. RESULTS

## 3.1. Effects of PMF on changes of rat weights and glucose levels

When weight losses of rats in experimental groups were compared to D-PMF group, CD-PMF was observed to lose weight to a lesser extent(Figure 2. [A]). Although blood glucose levels of rats in group D increased, blood glucose levels of rats in D-PMF, CD and CD-PMF groups decreased over 6 weeks (Figure 2.[B].)

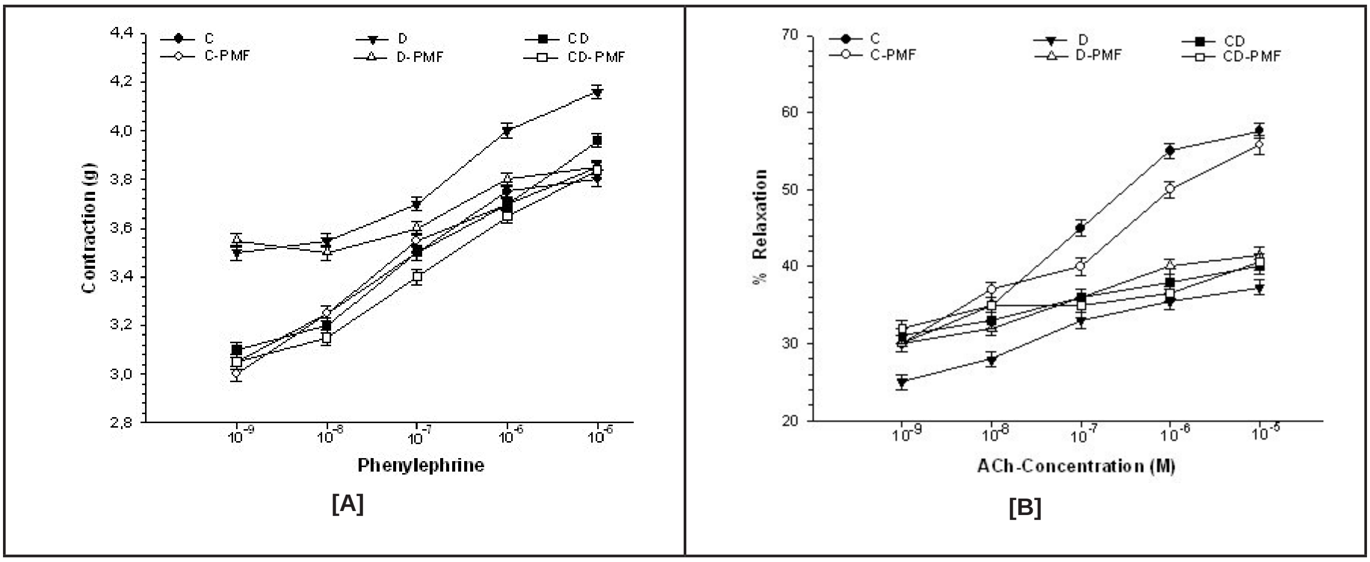
***Figure 2.*** *[A] C; control, C-PMF; control-exposed to pulsed magnetic field, D; experimental diabetic, D-PMF; diabetic-exposed to pulsed magnetic field. Mean weights of the rats in the six groups were measured once a week during the one month period (means ± SEM). [B] C; control, C-PMF; control-exposed to pulsed magnetic field, D; experimental diabetic, D-PMF; CD; controlled diabetic, CD-PMF; controlled diabetic exposed to pulsed magnetic field. Plasma glucose levels of rats in each group (means ± SEM)*




## 3.2. Effects of PMF on Contraction and Relaxation of Rat Aorta

When phenylephrine concentration was added to the cumulative concentration in organ bath, while contraction in aorta rings of rats in group D gradually increased, less contraction was observed in groups D-PMF and CD-PMF. In addition, upon acetylcholine concentration addition to the cumulative concentration in organ bath, relaxation of aorta rings of rats in group D was gradually decreased, however relaxation percentage in D-PMF and CD-PMF groups were higher compared to group D (Figure 3. [A], [B]).

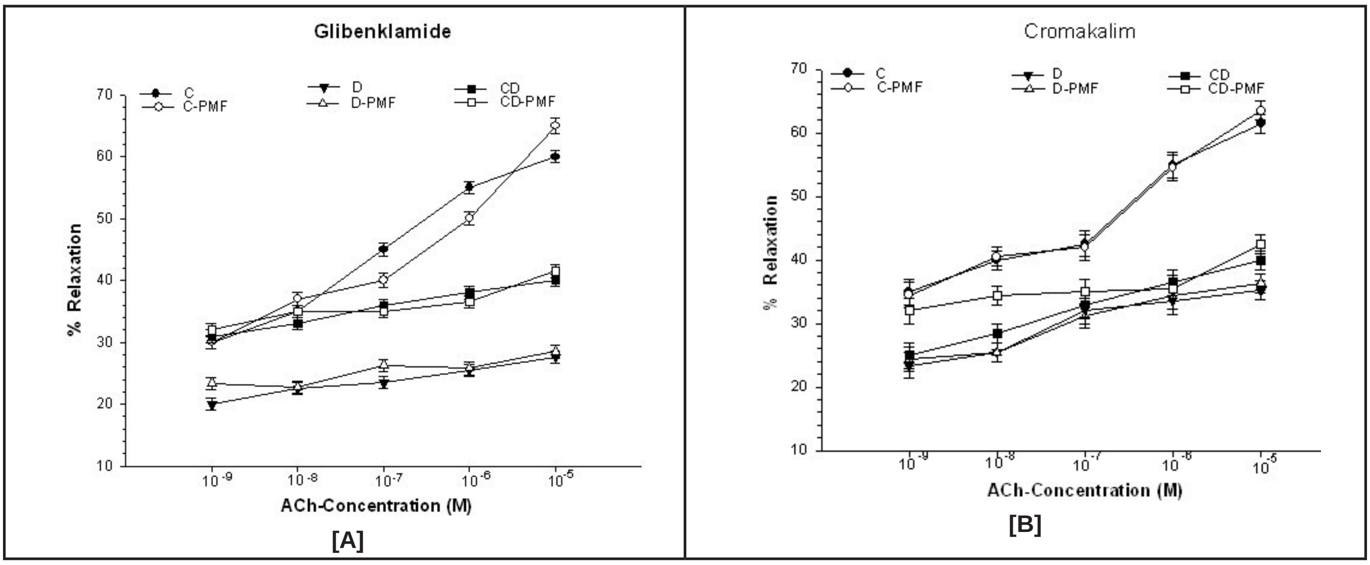
***Figure 3.*** *C; control, C-PMF; control-exposed to pulsed magnetic field, D; experimental diabetic, D-PMF; diabetic-exposed to pulsed magnetic field, CD; controlled diabetic, CD-PMF; controlled diabetic exposed to pulsed magnetic field. [A] The contraction forces in the thoracic aorta were induced by 10-7 M phenylephrine in each group (means ± SEM). [B] The relaxation of the thoracic aorta was induced by 10-6 M acetylcholine in each group (means ± SEM).*




### 3.3. *Effect of PMF on Relaxation of Rat Aorta*

When the 10-5 M ATP-sensitive K+ channel opener cromakalim was added in organ bath, the percentage of contraction decreased, and the percentage of relaxation increased. However, when 10-5 M glibenklamid (ATP-sensitive K+ channel blocker) was added in organ bath, both percentage of contraction and relaxation decreased (Figure 4 [A], [B]) Once 10-5 M glibenklamid and 10-5 M cromakalim were added together, neither contraction nor relaxation was observed. These results were not shown in this study.

***Figure 4.*** *[A] After the added the Glibenklamide(10-5 M) in organ bath. The relaxations of the thoracic aorta were induced by 10-6 M acetylcholine in each group (means ± SEM). [B] After the added the Cromakalim(10-5 M) in organ bath. The relaxations of the thoracic aorta were induced by 10-6 M acetylcholine in each group (means ± SEM).*

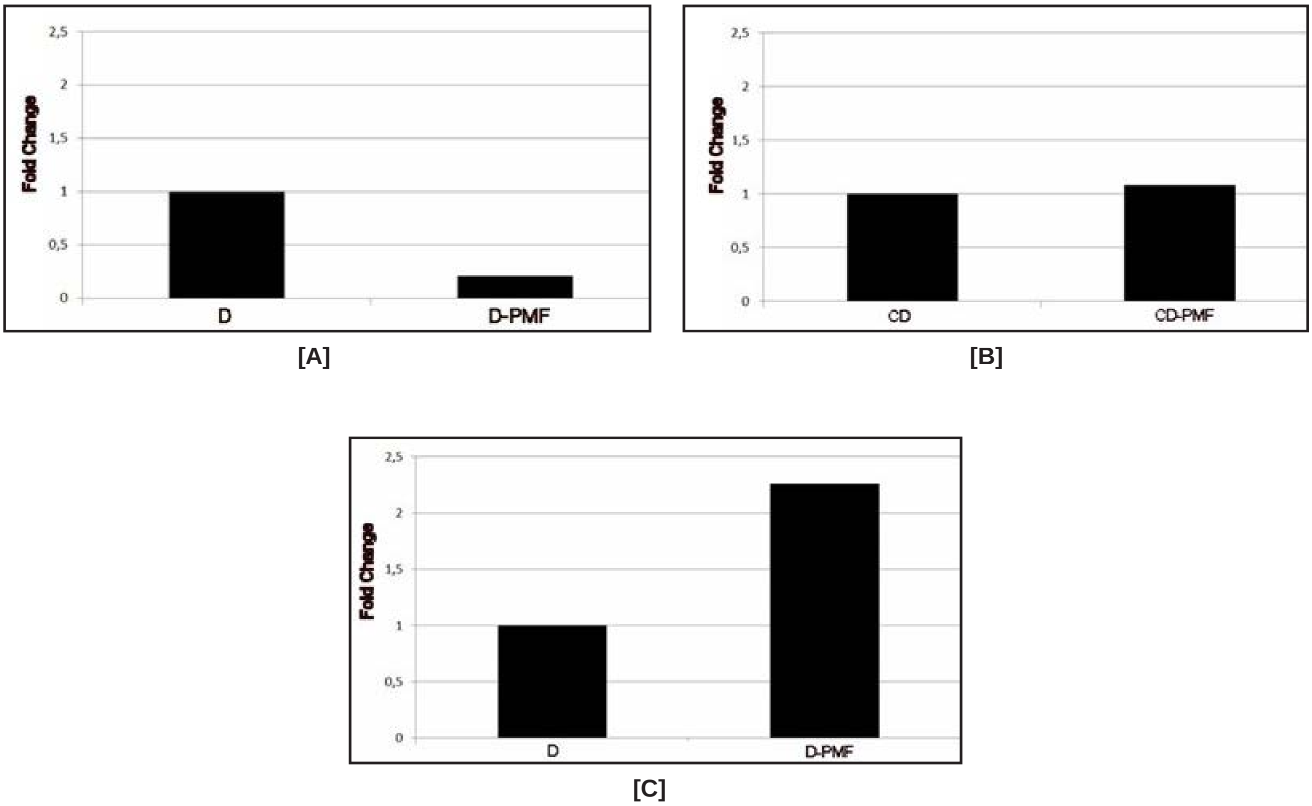



### 3.4. *ATP-sensitive potassium channel subunit, Kir 6.1 and Kir 6.2, mRNA expression levels*

The rats were sacrificed after 6 weeks of PMF treatment and thoracic aortas were collected and analyzed by quantitative real-time RT-PCR to determine Kir 6.1 and Kir 6.2 mRNA expressions in thoracic aorta tissues. After 40 cycles of PCR, if the Ct value is underdetermined, we considered Kir 6.1 and Kir 6.2 mRNAs below the detection level. We found some evidences that there is an association between ATP-sensitive potassium channel subunits Kir 6.1 and Kir

6.2 mRNA expressions and PMF which has a significant influence on the formation of relaxation response of thoracic aorta rings in STZ-induced rat models. The PMF treatment suppressed Kir 6.1 mRNA expression in the D-PMF group, but it did not show similar effect on the CD-PMF group (Figure 5 [A], [B], [C]). Kir 6.2 mRNA expression was induced in the D-PMF group, while it was suppressed in the CD-PMF group (Figure 5 [C]).

***Figure 5.*** *[A] The effect of PMF on diabetic rat aorta Kir 6.1 mRNA expression. Fold changes of mRNA expression were compared between diabetic (D) and PMF-treated diabetic (D-PMF) rats.[B] The effect of PMF on insulin-treated diabetic rat aorta Kir 6.1 mRNA expression. Fold changes of mRNA expression were compared between controlled-diabetic (CD) and controlled-diabetic PMF-treated (CD-PMF) rats. [C] The effect of PMF on diabetic rat aorta Kir 6.2 mRNA expression. Fold changes of mRNA expression were compared between diabetic (D) and PMF-treated diabetic (D-PMF) rats. Results were normalized to the expression levels GAPDH gene endogenous control*




## *4. DISCUSSION*

Impaired has been linked to a number of pathological conditions, which may lead to vasoconstriction. Also,impaired K+ channel function such as ATP-sensitive K+ and inward rectifier K+ channel (Kir), functions in vascular smooth muscle cells has been linked to a number of pathological conditions including hypertension, diabetes, ischemia/reperfusion, and brain injury. The fundamental properties of these channels, as well as their responses to various stimuli including vasoconstrictors and vasodilators, and their associated signal path ways have been described in several reports [20-25]. Some studies clearly demonstrated impaired ATP K+ channel function and altered gene expression in various arteries [25-30].Recent evidence suggests that Kir channels are also affected by hypertension, ischemia, hypertrophy, and diabetes [20-30] but additional studies are necessary to establish a mechanism. ATP-K+ channels in smooth muscle are known to be inhibited by anti-diabetic sulphonylurea drugs such as glibenclamide. Glibenclamide is the most frequently used inhibitor of ATP K+ channels in studies of arterial smooth muscle, with a half-inhibition value between 20 and 200 nM [25-31]. Several isoforms of these channels exist in different cellular types. The understanding of their role in the insulin secretion in the pancreatic beta cell has allowed identification of several mutations responsible for persistent hyperinsulinism or neonatal diabetes mellitus, and therefore change the therapeutic issue of these patients. In vascular smooth muscle cells (VSMCs), K+ ATP channels couple intermediary metabolism to cellular activity and play an important role in the autoregulation of vascular tonus. Decreased endothelium-dependent relaxation in diabetes mellitus has been reported in previous studies [12]. In addition, an increased vasodilator response to pulsed magnetic field may also be thought as a compensatory way against enhanced activation in contractile mechanisms of vascular smooth muscle in the diabetic mellitus. However, long-term exposure to pulsed magnetic field as probably in the case of later stages of diabetes may result in loss of normal vasorelaxant tone and induce widespread molecular injury.Although there are more than 100 millions of diabetic people worldwide and the number of patients increase day by day, there is not any tangible progress in the treatment of diabetes other than the amelioration of the symptoms. As a result, this situation could not contribute to improve life standards of diabetic patients' permanently. In our country, the increase in the number of the diabetic patients and the large budgets allocated for the treatment of diabetes lead us to apply alternative treatment methods. Electrical resistance of the β-cells in which insulin secretion takes place depends on ATP-sensitive potassium (K+ATP) channels. Activation of these channels is of great importance for diabetes. While over activation or inactivation of K+ATP channels cause complications of diabetes, decreasing activation of the over activated channels contributes to diabetes treatment. Decreasing the activation of the channels increases insulin secretion and with the changes occurred in endothelial cells, may help to eliminate cardiovascular side effects of diabetes. Besides, mutations found in K+ATP channel genes causes pathologies such as neonatal diabetes, hyperinsulinemia, and dilated cardiomyopathy. K+-ATP channels have different subunit compositions in different tissues and can be regulated in a tissue-specific manner. In addition, it was found that different subunits are regulated in different ways. Moreover, rat aorta Kir 6.1 and Kir 6.2 expressions did not show any differences between diabetic and healthy cases [3, 10-12]. Effects of pulsed magnetic field (PMF) on biological systems are investigated in many current studies. In previous studies, it was showed that pathologies in tissues where channels are found can be treated with the induction of K+ATP channels by PMF [13,32]. In our study, we found that PMF shows its therapeutic effect via subunits of K+ATP channels and this effect emerges more intense especially in insulin-free occasions. PMF treatment which is noninvasive and having no side effects like pharmacological drugs may contribute to eliminate cardiovascular effects of diabetes. If PMF that we applied can be improved as an pulsed magnetic field invasive therapy method in the treatment of complications that occur on cardiovascular system due to diabetes, mortality caused by diabetes may also decrease. In addition, this method can be a low-cost treatment method for diabetes patients providing higher life standards. Decrease in elevated blood glucose level by PMF may indicate damage in pancreatic β-cells of diabetic rats with a decrease in insulin secretion of these cells [33,34,15-17] Antihyperglycemic efficacy of PMF may imply that PMF treatment may prevent the destruction of pancreatic β-cells produced by STZ. Previous in vivo and in vitro studies have also shown that exposure to magnetic field caused an increase in serum insulin concentration and insulin secretion and led to reversible ultrastructural changes of pancreatic islets and an increase cell number [32,35]. These findings have suggested that PMF could have a positive role in glycemic control. The possible reasons of decrease in loss of body weight in diabetic rats by PMF can be stress factors or water retention in the body due to the decrease of elevated blood glucose level. Loss of body weight is one of the most prominent signs in STZ-induced diabetes. The STZ-treated animals had 15% less body weight than the weight-matched control rats on week 1 and 25% less on week. Diabetes mellitus is a clinical syndrome characterized by altered glucose metabolism [34]. Hyperglycemia is the primary pathophysiologic mechanism in diabetes mellitus, and elevated blood glucose levels have been associated with the development of the other diabetic complications [13, 36]. In STZ-induced diabetic rats, blood glucose levels elevated and the body weight decreased after the administration of STZ . But the effects of PMF on decreased of weight losses and blood glucose levels in PMF and controlled diabetic groups, PMF is probably related to the acute hyperglycemia, with osmotic diuresis and dehydration and different Kir 6.1 and Kir 6.2 expressions subunits might regulated by different ways in diabetes mellitus [33,37,38].

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# EFFECTS OF HORIZONTAL OR VERTICAL PULSED MAGNETIC FIELD IN DIABETIC RATS

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## ABSTRACT

*Human beings are unavoidably exposed to non-ionized electromagnetic fields generated by every instrument that uses electricity and World Health Organization has been limited to exposure to non-ionized pulsed electromagnetic field intensity, duration and direction.The purpose of the study, more affective of which directional of pulsed magnetic field in diabetic male rats and the whether it is possible use to alternative treatments was to investigate.In this study, animals divided into two groups Sham PMF treated and PMF treated diabetic rats. Diabetes was developed in both experimental groups. Experimental groups were exposed to the horizontal and vertical directional pulsed magnetic field (1h/day, intensity; 1.5mT, consecutive frequency; 1, 10, 20, 40 Hz) for one month. During the experimental period, blood glucose and body weight of rats in groups were measured in once a week.Diabetic rats caused significant an increase in blood glucose level and a decrease in body weight. The vertical directional pulsed magnetic field application to diabetic rats significantly prevent the increase in glucose level and the loss in body weight as compared the horizontal directional pulsed magnetic field application.Consequently these result suggested that the vertical directional pulsed magnetic field application can be more effective for the treatment in diabetic conditions*

**Key words:** *Diabetic rats, magnetic field, directional pulsed magnetic field and PMF-treatment.*

## 1. INTRODUCTION:

Over the last years, a wide debate has developed on the possible health effects of exposure to electromagnetic fields. With the rapid development of new technologies, exposure of both workers and the general population to EMF has enormously increased in recent years. At the same time, concern has been expressed for possible adverse effects of such exposures on human health. The possible adverse and positive effects of EMF can be depends on direction, duration on intensity of PMF. At the cellular level, changes of intracellular calcium (Ca2+) by magnetic field exposure are often suggested. Control of (Ca2+) is a fundamental regulatory process affecting cell survival and function. Various important physiological activities, including actions of the endocrine system and the immune and according to some researches, vertical and horizontal magnetic fields were independently applied sequentially to thymocytes [1,2]. Other than the magnetic field directional, the experimental approach was kept this study.

The biological basis of the effects of magnetic fields on cells in highly complex and cannot be analyzed exhaustively here. In an ideal cell at rest, the proteins are distributed evenly over the membrane, but in the presence of an electric field crossing the membrane, they undergo electrophoretic attraction or repulsion, tending to shift towards the poles which the cell presents in the directions of the electric field. Therefore the cell membrane, by virtue of its bioelectrical properties, is the site where influences of this type are mostly likely to be exerted, though other possible candidates are the large macromolecules organized in repetitive units, such as the nucleic acids [3,4], or the proteins of the cytoskeleton, particularly the microtubules [5]. Diabetes has profound effects on the metabolism of variety of tissues of diabetic animals, both glycolysis and glucose oxidations are decreased and there is an overall decrease in ATP production. [6]. There were other investigations revealing an increase in insulin release in diabetic rats, increase in glycogen, and decrease in glucose level in rats exposed to magnetic fields [7,8], have demonstrated that the blood cholesterol, glucose and triglyceride levels of diabetic rats were lowered by acute exposure to magnetic field. The pulsed magnetic field can be affected on direct or hormonal system that on retard of liver metabolism or the other metabolism. Some researcher that studied concerned with magnetic field referred similar exchanges too [8,9]. Also Gordon et al., on the other hand showed the selective effect of electromagnetic fields on atherosclerotic lesions without harming the blood vessels, by demonstrating the biophysical changes caused by electromagnetic fields on the atherosclerotic plaques which led to their suggestion that this could serve as a new field in the selective treatment of diabetes mellitus.

For these reasons, our aim is to examine the effects of different directional pulsed magnetic field on body weights and blood plasma parameters of diabetic and healthy in this study rats.

## 2. METHODS

### 2.1. Animals

Animals were housed according to the National Institutes of Health Guide for the Care and Use of Laboratory Animals. All experimental procedures were approved by the Cukurova University Animal Care and Use Committee. In this study, adult male Wistar rats weighing (250–300g), were studied (n =40) and obtained from the Medical Sciences Research Center of Cukurova University. They were housed for 4 weeks (30 days) under controlled temperature conditions of 21±3°C and were maintained on a 12-h light/dark cycle (0600–1800 hours), with standard chow and water ad libitium.

For the PMF treatment, the rats were divided into eight groups, Sham-horizontal control- PMF-treated (H-SC-PMF), sham-vertical control-PMF-treated (V-SC-PMF), control-horizontal PMF-treated(HC-PMF), control-vertical-PMF-treated (VC-PMF), sham diabetic horizontal_PMF-treated, (H-SD-PMF), sham-diabetic vertical-PMF-treated (V-SD-PMF), horizontal-diabetic-PMF-treated (HD-PMF), vertical-diabetic-PMF-treated(VD-PMF) and PMF treatments were applied to the groups during the one month.(1h/day, intensity; 1.5mT, consecutive frequency; 1, 10, 20, 40 Hz).Since there is no differences in sham groups, they were not shown in this study

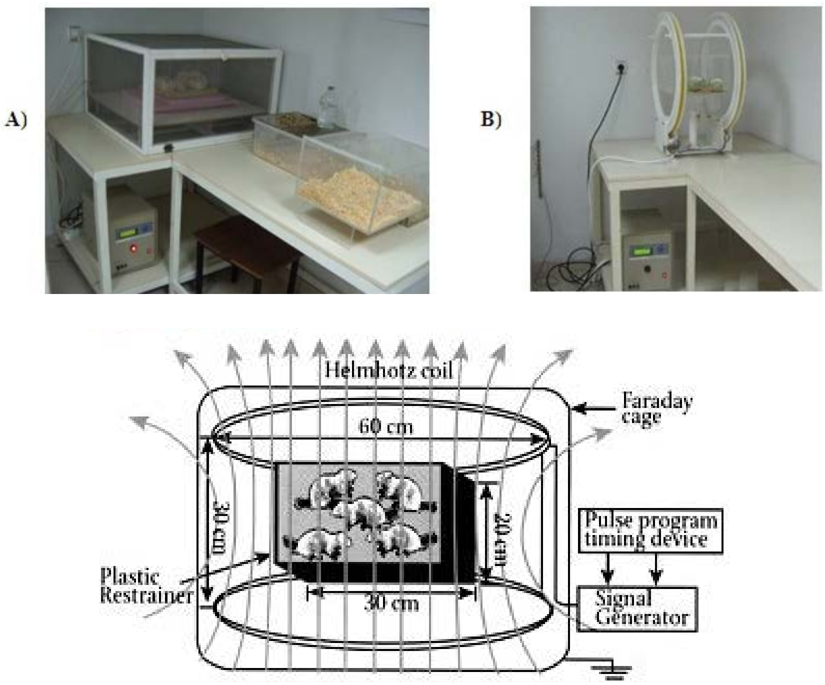
### 2.2. Induction of diabetes

Diabetes mellitus was induced by a single intravenous (tail vein; i.v.) injection of streptozotocin (STZ), 45 mg/kg dissolved in 0.9% saline solution. To provide non-diabetic control group (C), an equivalent volume of sterile saline was injected. Diabetes induction was confirmed after 48 hours by determining blood glucose levels using a glucometer (Accutrend GCT, Roche, Mannheim, Germany). 300 mg/dL (16,7 mmol/L) is considered to be the minimum blood glucose concentration for diagnosis of diabetes in the animals used [10-13].

### 2.3. PMF-treatment

Before the PMF treatment; all rats were acclimated to their environment for a week. To perform habituation to the treatment conditions, the rats were placed in the restrainer at least three times for 30 minutes. PMF application was performed using Helmholtz coils, 60 cm in diameter and placed 30 cm apart, which produce magnetic field peak amplitude of 1.5 mT when connected to a signal generator (ILFA Electronic, Adana, Turkey). All rats were treated with PMF for a period of 6 weeks. Each animal was placed in a plastic restrainer (30 cm long, 20 cm wide and 15 cm high) and whole-body exposure to PMF was applied for 1 h each day. Distribution of the magnetic density was measured by a Gauss Meter and kept homogenous within maximum 5% difference in the exposure area. In previous studies, rats were subjected to circadian cycle [14] and it was also reported that light can be a source of aversive stimulus [15]. Considering these, PMF treatments were carried out at the same period (8:00-12:00) or (12:00-15:00) and under the same light conditions in a quiet laboratory. Throughout the treatments, the temperature (23-25ºC) and the humidity (40-60 %) were monitored continuously.

***Figure 1.*** *Pulsed magnetic field (PMF) stimulation and pulsed program timing device, animals were placed in plastic restrainer located between Helmholtz coils. A) Vertical directional pulsed magnetic field B) Horizontal directional pulsed magnetic field.*



PMF application was performed in trained repeated three sequences. Each sequence included four different consecutive pulse trains (1, 10, 20, and 40 Hz). The duration of each pulse train was 4 min with an interval of 1 min between each pulse train. A digital timing device controlled the timing. The waveforms of magnetic field explored by a search coil probe showed no clear differences in shape and magnitude of waveforms of magnetic field. Each animal was placed in an all plastic restrainer located between the coils and whole-body exposure to PMF was applied for 1 h each day. The temperature (23–25ºC) and humidity (40–60%) were monitored continuously throughout the treatments. Sham exposure to animals was performed under the same environmental conditions by using another apparatus including only Helmholtz coils, in a Faraday cage (Figure 1.).

### *2.4. Data and statistical analysis*

A percentage of body weight losses and blood glucose levels were expressed as the mean ± S.E.M. Statistical analyses were performed by Welch paired t-test and one-way ANOVA (SAS Institute, Cary, NC, USA). Significance was determined at $p<0.05$.

## 3. RESULTS

### *3.1. Effects of Horizontal and Vertical Directional PMF on Body Weight*

***Figure 2.*** *V-C; Vertical directional-control, VC-PMF; vertical directional control-pulsed magnetic field, V-D; vertical directional diabetic, VD-PMF; vertical directional diabetic-pulsed magnetic field. Mean weights of the rats in the four groups were measured once a week during the one month period (means ± SEM).*

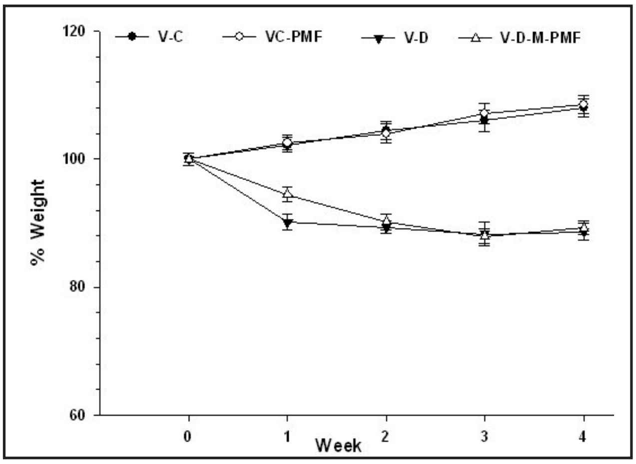
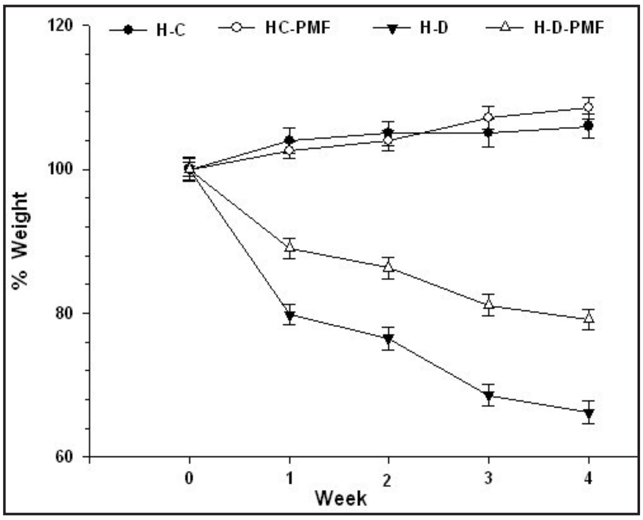



***Figure 3.*** *H-C; Horizontal directional-control, HC-PMF; horizontal directional control-pulsed magnetic field, H-D; horizontal directional diabetic, HD-PMF; horizontal directional diabetic-pulsed magnetic field. Mean weights of the rats in the four groups were measured once a week during the one month period (means ± SEM).*



### 3.2. *Effects of Horizontal and Vertical Directional PMF on Blood Glucose levels*

***Figure 4.*** *V-C; vertical directional control, VC-PMF; vertical directional control-pulsed magnetic field, V-D; vertical directional diabetic, VD-PMF; vertical directional diabetic-pulsed magnetic field. Blood glucose levels of rats in each group (means ± SEM)*

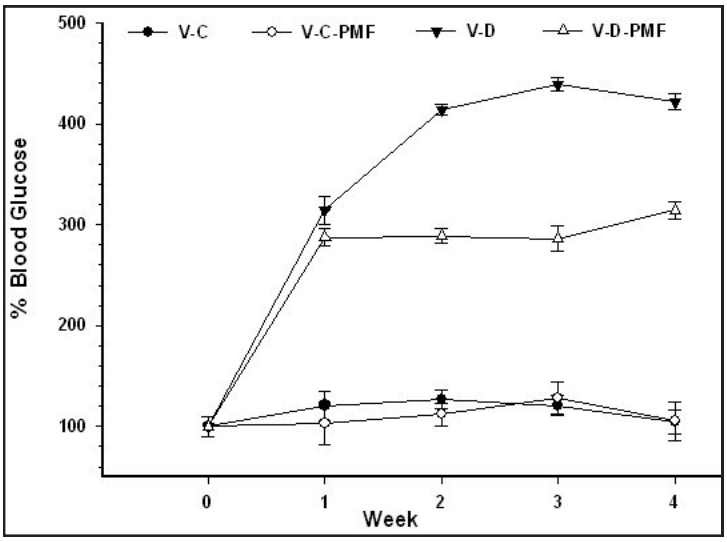
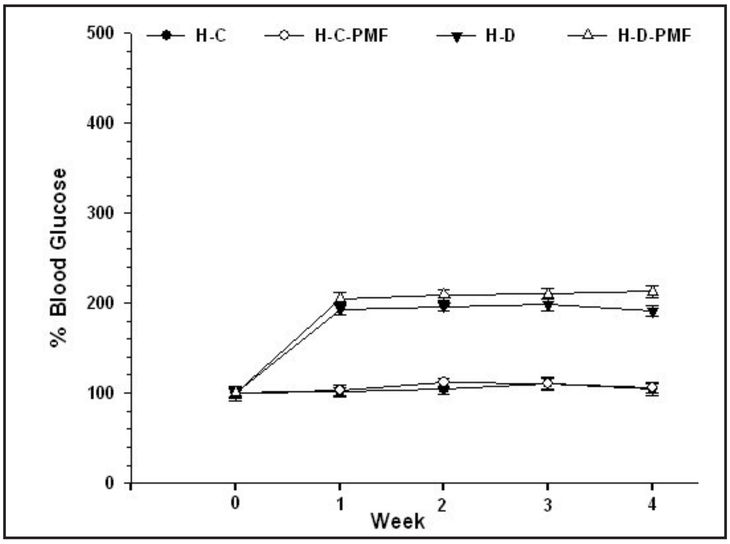



***Figure 5.*** *H-C; horizontal directional -control, HC-PMF; horizontal directional control-exposed to pulsed magnetic field, H-D;horizontal experimental diabetic, HD-PMF; horizontal diabetic-exposed to exposed to pulsed magnetic field. Plasma glucose levels of rats in each group (means ± SEM)*




## *4. DISCUSSION*

Data from this study show that exposure to direction of pulsed magnetic field can interact to the healthy and diabetic metabolism and might be indicating a transiently healthy response by rats to the pulsed magnetic field. The decrease in blood glucose level was statistically significant ($p<0.05$)

The body weight losses and blood glucose levels of rats exposed to vertical directional pulsed magnetic field in diabetic groups were decreased according to horizontal directional pulsed magnetic field. The decreased of the body weight losses and blood glucose levels makes us to think that vertical pulsed magnetic field affect the hormonal systems, directly or indirectly, and slows down metabolism or hidratation.

Some researchers have addressed the specific possibility that the cell membrane lipids are the target of the electromagnetic field interaction at high frequencies. In general, a cell membrane phospholipid is composed of two parts: one head and two tails with similar chemical and physical composition. It has been recently shown [16] that in some phospholipids the polar heads align themselves nearly parallel (within 30°) to the membrane surface and that the heads' group directional is identical in artificial bilayers and in biological membranes. Different conformations of a phospholipidic bilayer are possible.

The transition between one conformation to the other is affected by the concentration of bound water at lipid-water interface, and therefore it can be bound water concentration (hidratation). The presence of charges or dipolar molecules external to the membrane but in the proximity of the heads can modify the bistable nature of the phospholipidic bilayer [16,17]. Although the amount of the consumed food and water did not change, decreased body weight losses can be explained changes of metabolism or hidratation. Also recent investigations revealing an increase in insulin release in diabetic rats, increase in glycogen, and decrease in glucose levels in rats exposed to magnetic fields, have provided the stimulus for the current studies. In individuals with normal metabolism the free oxygen radicals that are released to a limited extent are removed by the antioxidative defense systems which provide for the homeostasis of the organism.

Free oxygen radicals and lipid peroxides are known to be responsible for the pathogenesis of most diseases including atherosclerosis, infectious diseases, diabetes and cancer [18,19]. Living systems generate free radicals as the result of biochemical reactions (e.g. oxidative metabolic processes). Static magnetic fields (on the order of 1 mT) have been proved to affect free radical chemical reactions in vitro [3]. This suggests the possibility that modulated magnetic field effects on living systems may involve changes in free radicals. They can be formed by a simple bond-breaking process, in which each of the two electrons of opposite spins forming the bond ends up on a separate radical.

The spin is conserved in the reaction, so that the electrons in the resulting pair of radicals have opposite spins, at the instant of radical formation. The corresponding radicals constitute a singlet radical pair, whose reaction rate is the influenced by even low magnetic fields [4,20]. In the reaction of pyrene with dimethyaniline, for example, Hamilton et al. [21] reported a critical static magnetic flux density of 1 mT. Under reactions proceed through triplet state, where the electron spins are parallel, and its reaction with another molecule yields a pair of free radicals also in the triplet configuration. Since bond formation needs a singlet pair, the radicals, which are initially prevented from reacting by having the wrong relative spins, diffuse apart so that the spins may became favourably oriented and the back reaction may occur if they re-encounter.

The main effect of magnetic field is the removal of the degeneracy of the energy levels of the triplet radical pair. The change in rate of the above processses under magnetic exposure may be very significant biologically. Furthermore any molecular region of high local viscosity does not allow the radical to diffuse too far away, so that it may be biologically very active. The difference in energy levels of triplet state electrons is a function of the increasing of magnetic field strength. Combined static and modulated magnetic fields could modify free radical reactions in situations where the intrinsic magnetic flux density was in the range of the critical level. If themodulated magnetic field intensity is equal to the difference between the intrinsic and critical level, and if the period of the field is sufficiently long to permit a transition, the alternating field could act on the biochemical processes.

An interesting property of this mechanism is that a relatively small energy exchange between an external magnetic field and a free-radical controlled reaction could induce physiologically significant changes, since the most of the energy could be given by biochemical activation energy. The role of free radicals in the development of complications in diabetes is significantly great.

The increase in the production of free radicals is due to glucose autooxidation, leukocyte activation, and the transition metals [22]. Especially, in diabetic patients with micro- and macro-vascular complications, the free radicals have been demonstrated to increase tissue injury whilst suppressing the levels of the various antioxidants [23]. Also free radicals and peroxides, despite their apparent similarities with diabetogenic agents are believed to play an important role in the relationship between nitric oxide formation and guanilate cyclase activity, peroxidase regulation, and prostaglandin synthesis [22-24].

Bellossi et. al., have demonstrated that the blood cholesterol, glucose and triglyceride levels of diabetic rats were lowered by acute exposure to magnetic field [9,25]. The increase of liver organ compared to the body that Bellossi and Kost et al [9,25,26] observed while applying acute magnetic fields applied to healthy and diabetic rats cause to slow down the metabolism that causes the change of homeostasis of living-organism and enhanced insulin release to the diabetic rats. Liver plays an important part in general metabolism, especially diabetic mellitus patients and very probably plays a part in the healing process.[6,9,24-26].

Magnetic field was suggested to decreases metabolism of liver. As a result of slowdown liver metabolism, the production of oxygen-derived free radicals may be decrease. Its need to study concerned with advanced research as to determine free radicals, enzymes or liver metabolism. Studies are continuing in this regard

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# COMPARING MVH GENE AND PROTEIN EXPRESSION IN DIFFERENTIATED AND UNDIFFERENTIATED CELLS DERIVED BMSCS DURING BMP-4 AND 4MT SMF TREATMENTS

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## ABSTRACT

*Bone morphogenetic protein (BMP)-4 has a crucial role on Primodial Germ cells (PGCs) development in vivo which can promote stem cell differentiation to PGCs. Also, static magnetic field (SMF) can effect on the rate of differentiation of bone marrow stem cells (BMSCs) to rat PGCs. We investigated the profiling of specific gene expression and Mvh protein performed on BMSCs induced to differentiate by BMP-4 and SMF to identify Mvh gene and protein changes. This method could leads to a possible cell based therapy for infertility treatment. Passage 4 of rat BMSCs were characterized by CD90, CD29, CD11b and CD45 markers and osteo-adipogenic differentiation. The cells were simultaneously treated BMP4 and 4 mT SMF (24 and 48 h). Expression of Mvh gene and protein were analyzed by qPCR and immunocytochemistry (ICC) in BMSCs derived PGCs respectively. CD90+, CD29+, CD11b- and CD45- BMSCs were able to differentiate to osteo-adipogenic lineages. QPCR and ICC results indicated that there was significant enhancement (p≤0.05) in expression of Mvh gene and protein with BMSCs. The outcomes of this study showed that treatment with BMP4 and 4 mT SMF had a positive effect on early germ cell induction and caused up regulation in specific gene and protein expression in BMSCs derived.*

***Key words:*** *Primordial germ cells, BMP4, Static magnetic field, Bone marrow stem cell*

## 1. INTRODUCTION

Natural magnetic fields (MFs) vary over the earth's surface based on the geographic longitude and latitude of the locations between 0.035 and 0.07 mT (1). The interest in the variation biological effects of non-ionizing electromagnetic fields (EMFs) on the whole organism, as well as on cellular systems, has considerably increased in recent years in consideration of their probable health risk for humans (2). Many experiments were recently performed to study the interaction between organisms and MFs (3, 4). A recent study investigated the effects of MFs of 50 Hz and 1.1 mT on the differentiation and intracellular free calcium of bone marrow mesenchymal stem cells (5). They showed that MFs enhanced the cellular differentiation and the intracellular free Ca2+ concentration in MSCs. Converging data indicate that the primary site of action of magnetic fields is the plasma membrane (6, 7). The influence exerted by MFs (static or oscillating) on the plasma membrane has been described at different levels on: the plasma membrane surface (8), the distribution of membrane proteins and membrane receptors (9), cell-cell and cell-matrix junctions (10), cell membrane sugar residues (11, 12) and the trans-membrane fluxes of different ions, especially calcium (13); in turn these perturbations influence the apoptotic rate, cellular and cytoskeleton shape (3, 12).

Understanding in vivo procedures involving germ cell differentiation helps researchers to establish protocols for in vitro stem cell differentiation into the germ cell lineage which could be an alternative treatment for male infertility. Cell proliferation, survival, and differentiation in primordial germ cells (PGCs) are dependent on bone morphogenetic proteins (BMPs) -4, a member of the TGFb super family, secreted by extra embryonic tissue (14). BMP4 elicits expression specific genes PGCs such the Dpp3a (Stella), Fragilis and mouse vase homologue (Mvh) gene (15, 16). The gene Mvh encodes a DEAD (Asp-Glu-Ala Asp) -family protein of putative RNA helicases in Drosophila. Mvh appears to be a true homolog of Drosophila vas, based on sequence similarity, germ cell-specific expression, and intracellular localization. Mvh protein was exclusively detected in developing germ cells (15). Therefore, Mvh is regarded as a molecular marker demonstrating that germ cells, at least after colonizing the embryonic gonad are converted from pluripotent into the differentiated cells (17, 18).

Up until now, few studies have investigated the effects of SMF on expression of genes, especially those involved in differentiation rate. The aim of this study was to evaluate the differentiation capacity and alteration in Mvh gene expression pattern during in vitro differentiation of bone marrow stem cells (BMSCs) into PGCs using SMF (4mT) and BMP-4 (25 ng/ml).

## *2. METHODS*

Isolation, culture and treatment of MSCs: BMSCs were isolated from bone marrow of eight to ten week-old rats as described by Woodbury (19). Cells were seeded in αMEM supplemented with 20% fetal bovine serum (FBS, Invitrogen LT, Merelbeke, Belgium), 100 U/ml penicillin (Gibco, Germany), 100/ml streptomycin (Gibco, Germany) in a 75 cm2 flask and incubated at 37°C with 5% humidified. Flow cytometry assay was performed to make sure that the isolated cells were free of any contamination of VSELs using CD90 and CD29 markers according to Chemicon protocol. Spindle-shaped cells were used from fourth passages for both physical (SMF) and chemical (BMP-4) treatments (Figure 1). After four passages when the density of cultured BMSC was approximately 5 x 104 cells/cm2, BMSC were ready to treat with BMP4 (19). Bone Morphogenic Protein (BMP)-4 (25 ng/ml; Chemicon, USA) was added to the fourth-passage BMSCs daily for different times (0, 24, 48, 72 and 96 h) based on the method described by Mazaheri et al. (17).

Magnetic field application: Exposure to MF was performed using a locally designed SMF generator (Figure 2). The electrical power was provided using a power supply working in range of 0-50 V and 0-20 A with a maximum power of 1 kW. Using three different sensors the controller system was able to control the temperature, humidity and CO2 level. The accuracy of the teslameter was ± 0.1 % for MF and the range of measurements was 3 μT–30 mT. With respect to this research, a 4mT static magnetic field was the optimized intensity (20). Three flasks were placed at the center of the incubator (10 cm distance from the center in each side) within solenoid generating a homogenous magnetic field, in each exposure. The duration of exposures was 24 and 48h. Before each exposure, the MF intensity was set to appropriate intensity (4mT) using a teslameter (20-23).

Quantitative analysis of gene expression: Total RNA was extracted from the exposed BMSCs treated with BMP4 for different times (0, 48 and 96 h) using RNeasy Mini Kit (Qiagen, USA) according to the manufacturer's recommendations. Concentrations of RNA were determined by UV spectrophotometry (Eppendorff, Germany). cDNAs were synthesized from 500 ng DNase-treated RNA samples with a Quantitect Reverse Transcription Kit using oligo (dT) primers. The specific primers used for PCR reactions are listed in Table 1. These primers were synthesized by Pishgam Company (Tehran, Iran). PCRs were performed using Master Mix and Eva green in an Applied Biosystems, StepOne™ thermal cycler (Applied Biosystems, USA). The PCR program started with an initial melting cycle for 5 min at 95°C to activate the polymerase, followed by 40 cycles of melting (30 Sec at 95°C), annealing (30 Sec at 58°C) and extension (30 Sec at 72°C). The quality of the PCR reactions was confirmed by melting curve analyses. Efficiency was determined for each gene using a standard curve (logarithmic dilution series of cDNA from the testes). For each sample, the reference gene (Gapdh) and target gene were amplified in the same run. Reference genes were approximately equal. The target genes were normalized to a reference gene and expressed relative to a calibrator. Mouse embryonic stem cell line (CCE) and immature rat testis was used as positive control for pluripotent stem cell genes and primordial germ cell-specific genes respectively.

Immunocytochemistry analysis: For immunocytochemistry, the cells in each group were washed with phosphate-buffered saline (PBS) at pH 7.4 and fixed in 4 % paraformaldehyde (PFA) for 30 min at room temperature (RT). Fixed cells were permeabilized with 0.2 % Triton X-100 for 10 min at RT followed by three washes with PBS. To block unspecific binding of the antibody, cells were incubated with 10 % goat serum for 30 min at RT. Then, cells were incubated with primary antibodies overnight at 4°C. Primary antibody was Mvh (1:100; Abcam). The following day, cells were washed twice with PBS and incubated with the appropriate secondary antibody (goat anti-rabbit polyclonal IgG-fluorescein isothiocyanate FITC) (1:1,000; Abcam). Antigens were visualized using appropriate fluorochrome-conjugated secondary antibody. After two washes with PBS for 5 min, cells were mounted and images were captured with an Olympus phase contrast microscope (BX51, Olympus, Tokyo, Japan).

Statistical analysis: Data were presented as mean±SD (standard deviation) and were analyzed using One-way repeated measure analysis of variance (ANOVA) followed by Tukey's post hoc test. The statistical software package SPSS Version 19.0 was used to perform the analysis. If $p<0.05$ results were judged to be significant. For the real time PCR data the logarithmic values had to be converted to real values by raising 2 to the power of the ΔΔCt value before statistical analysis was performed.

## 3. RESULTS

Differentiation of BMSCs to osteogenic and adipogenic lineages and characterization of mesenchymal stem cells were reported elsewhere (20). MSCs were positive for CD90 and CD29 markers, whereas VSELs were negative for these markers (24). Further information was reported in our previous published article (20). Analysis of the cell surface antigens CD90 and CD29 markers revealed that the isolated cells from bone marrow did not contain a significant number of contaminating VSELs.

Quantitative real-time PCR: To analyze the expression of Mvh gene, Real-time PCR was performed in samples at two time points: (1) 4 hours after initial isolation of the cells and (2) after the 4th passage in culture. Results demonstrated that the expression of Mvh gene has significantly decreased after 4h and forth passage in comparing with the positive control group, but the expression of this gene was similar in both groups (Figure 3).

Increasing of the exposure time of the 4 mT SMF (24 and 48h) and treatment time with 25ng/ml BMP4 (48 and 96 h) showed a marked up regulation of expression of Mvh gene compared with the control group (Figure 4). The most significant increase in expression of Mvh gene was observed in the group exposed to 48 h SMF and treated with 96 h BMP4. In this group, the expression of primordial germ cell-specific gene (Mvh) increased from 1 (in control group) to 554.221 (Figure 4).

Immunocytochemistry (ICC) assay: To analyze the expression of Mvh protein as a primordial germ cell-specific protein, the ICC was performed in the BMSCs in both groups. The expression of Mvh protein has significantly increased in both groups compared with the positive control group, but the expression of Mvh protein was similar in both groups (Figures 5 and 6).

Increasing of the exposure time of the 4 mT SMF (24 and 48h) and treatment time with 25 ng/ml BMP4 (48 and 96 h) showed a moderate increase in Mvh protein compared with the control group (Figure 7). The most significant increase in expression of Mvh protein was observed in the group exposed to 48 h SMF and treated with 96 h BMP4. In this group, expression of Mvh protein increased from 7.9% (in control group) to 30.9% (Figure 7).

## 4. DISCUSSION

There is an ongoing intensive effort in the characterization of BMSCs to apply them in different clinical assessments due to its great potential usefulness (20). Efficient derivation of PGCs from different sources of stem cells in vitro has been challenging in the treatment of male infertility (25). Previous reports suggested a plethora of chemical and physical stimulators for improving the biological condition of BMSCs. Hereby we report our investigation in which we evaluated the differentiation capacity and alteration in gene expression patterns during in vitro differentiation of bone marrow stem cells (BMSCs) into PGCs using SMF (4 mT) and BMP-4 (25 ng/ml).

Arginine methylation and histone acetylation (26), $Ca2+$ concentration (27) and enzyme phosphorylation (28, 29) have been implicated in the regulation of gene expression. In the other hand, the magnetic field can interfere with cell division, differentiation, and membrane voltage fluctuations, possibly by altering intracellular $Ca2+$ concentration. MF interacts with cell differentiation through two opposing mechanisms. MF can prevent the shift in surface charge potential promoted by differentiating agents. Simultaneously, MF stimulates the increase in intracellular $Ca2+$in a dose-dependent manner. The increase in cytoplasmic divalent ions, by opening the KCa channels, acts as a rescue agent reestablishing cell's commitment to differentiation (30). Our result showed that SMF could alter the gene expression and these changes can be produced by oscillation of $Ca2+$ concentration.

Our results showed that increasing of the exposure time of the 4 mT SMF and treatment time with 25 ng/ml BMP4 caused a significant increase in primordial germ cell-specific gene and protein compared with the control group. These alterations showed the progress of differentiation from BMSCs into PGCs at the protein level which is a complementary result to the obtained gene expression results. Simultaneous application of SMF and BMP4 exaggerates this enhancement. However, further investigations should be performed to find out its exact mechanisms. Final results showed that in a synergistic manner, the combination of SMF with BMP4 exaggerates the differentiation potential of BMSCs to PGCs by activating the MAPK pathway and altering the $Ca2+$ concentration.

### FIGURES

***Figure 1.*** *Primary cell culture of bone marrow mesenchymal stem cells: A, the population of heterogeneous of cells after 4 h culture; B, a homogeneous population cells after a four-passage culture.*

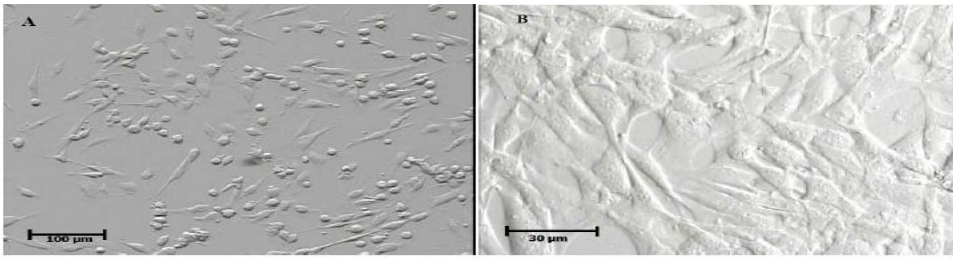


***Figure 2.*** *Photograph showing the apparatus used to generate static magnetic field (a) the whole body of the system (b) the incubator within solenoid.*

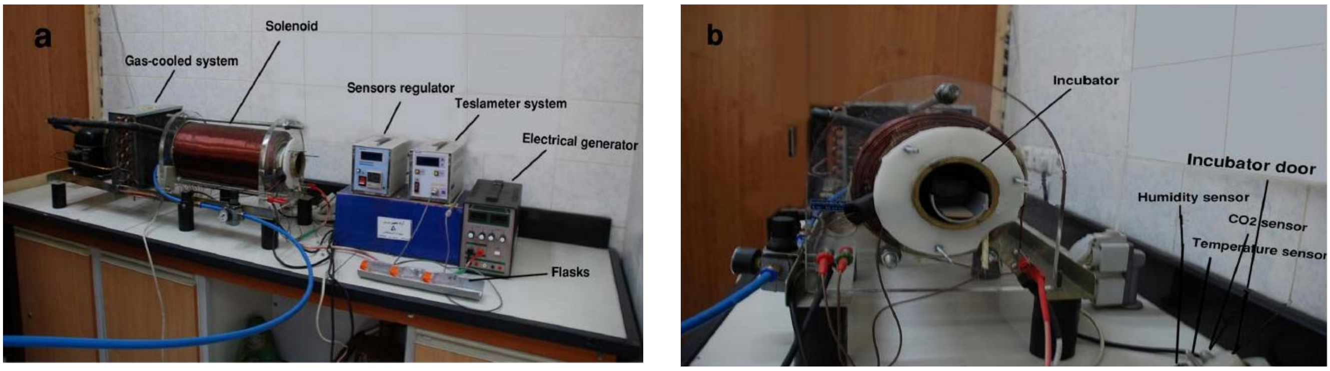


***Figure 3.*** *Real Time-PCR analysis. mRNA levels were normalized with respect to Gapdh, chosen as an internal control. Profile of Mvhgene expression in samples at two time points: (1) 4 hours after initial isolation of the cells and (2) after the 4th passage in culture. Testis suspension was chosen as calibrator. Histograms show mean expression values (± SD, n=3; P < 0.05). α: significant difference with other group in the same gene. BMSCs: Bone marrow mesenchymal stromal cells.*

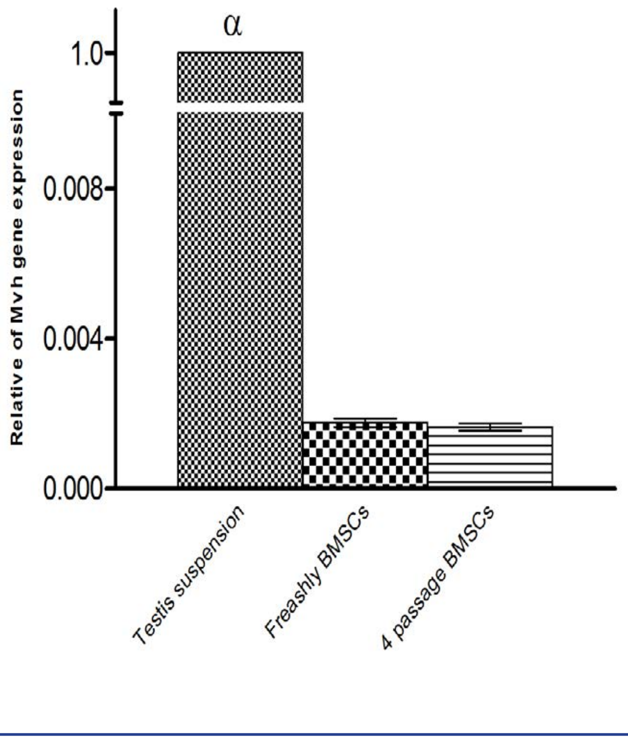


***Figure 4.*** *Real Time-PCR analysis. mRNA levels were normalized with respect to Gapdh, chosen as an internal control. Profile of specific gene expression during of treatment with BMP4 (25 ng/ml) and SMF (4 mT). Histograms show mean expression values (± SD, n=3; P < 0.05). Different letters refer to significant differences according to Tukey test.*

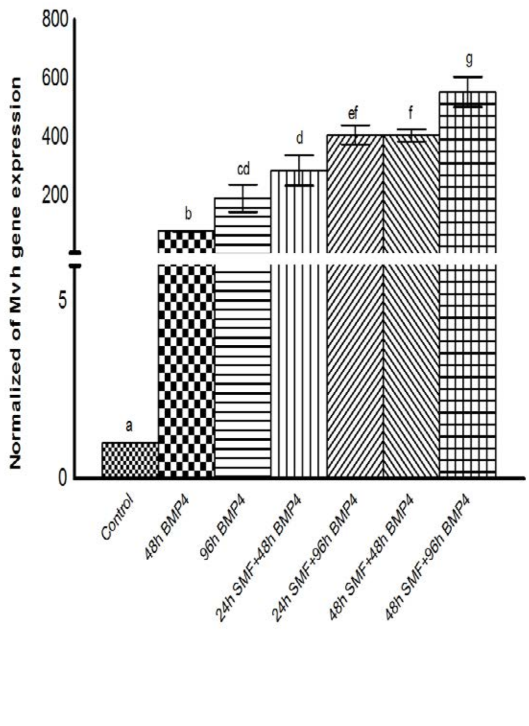

***Figure 5.*** *Immunocytochemistry analysis. Profile of Mvh expression in samples at two time points: (1) 4 hours after initial isolation of the cells and (2) after the 4th passage in culture. Testis suspension was chosen as positive control. Histograms show mean expression values (± SD, n=3; P < 0.05). α: significant difference with other group in the same proteins. BMSCs: Bone marrow mesenchymal stromal cells.*

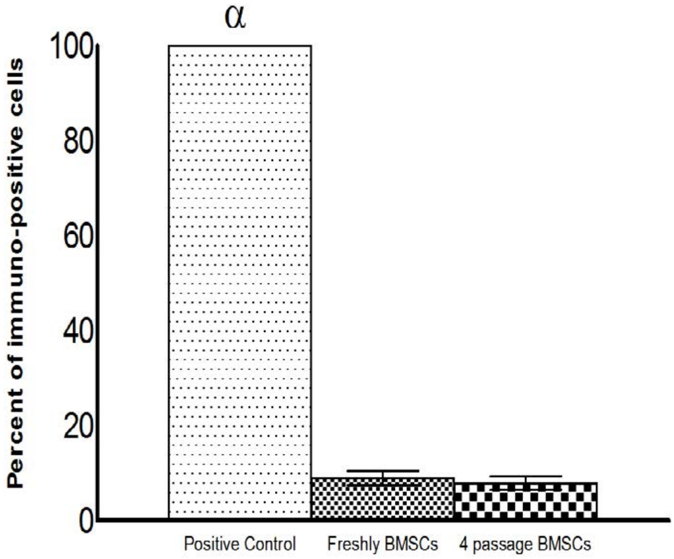


***Figure 6.*** *Immunostaining for Mvh protein. A-C: Testis tissue as a positive control (A: Positive staining, B: Phase contrast image, C: Negative control staining), D-F: BMSCs after 4 hours (D: Staining with secondary antibody conjugated with FITC, E: Staining with PI, F: Merging of D and E parts), G-I: BMSCs after 4 passages (G: Staining with secondary antibody conjugated with FITC, H: Staining with PI, I: Merging of G and H parts)*

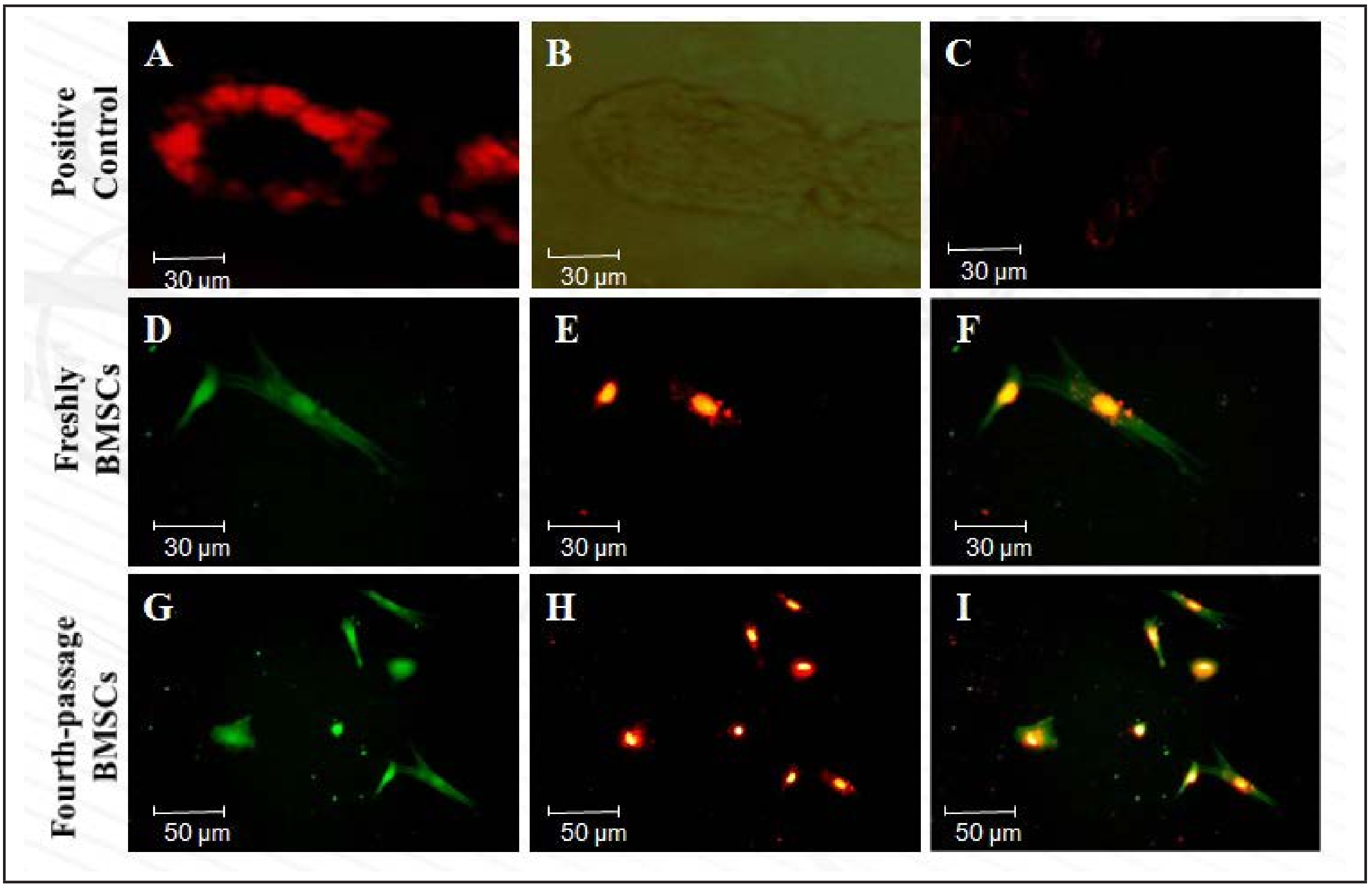

***Figure 7.*** *Immunocytochemistry analysis.*
*Profile of Mvh profile during of treatment with BMP4 (25 ng/ml) and SMF (4 mT).*
*Histograms show mean expression values (± SD, n=3; P < 0.05).*
*Different letters refer to significant differences according to Tukey test.*

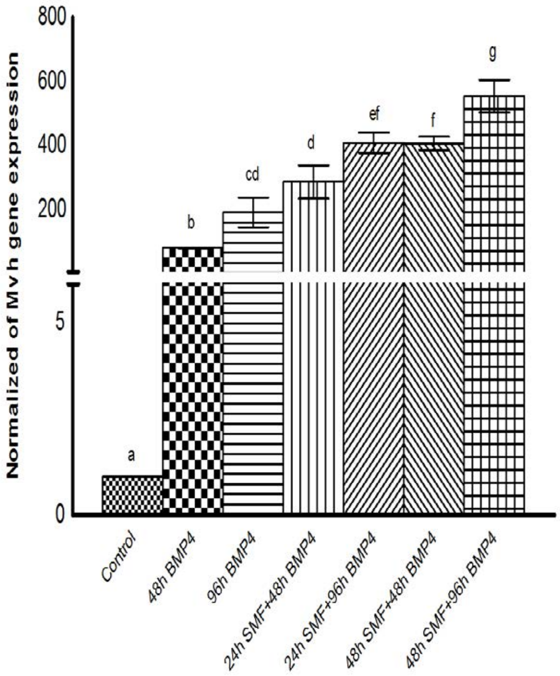


***Table 1.*** *Primer used for real- time PCR*

| *Accession Number* | *Gene* | *Product Length* | *Primer Sequences* | *Melt Temperature (°C)* |
|---|---|---|---|---|
| **NM_001077647** | Mvh | 155 | Forward: GCTCTGGTTTCTGGAAAG<br>Reverse: ATCTTGGTCATATTCACTATCTC | 70.5 |
| **NM_017008.3** | Gapdh | 212 | Forward: TGTGACTTCAACAGCAACTCCCAT<br>Reverse: CTCTCTTGCTCTCAGTATCCTTGC | 85.9 |

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# EFFICACY AND SAFETY OF AN EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELD (MAGNET-XPRO) IN PATIENTS AFFECTED BY SUDECK'S DISEASE

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## ABSTRACT

***Introduction:*** *Numerous studies have demonstrated the utility of extremely low frequencies (ELF) electromagnetic fields in clinical practice. Moreover, the effects of these fields seem to depend on their respective codes (frequency, intensity, waveform). In our study we want to value the effects of the Extremely Low Frequency Electromagnetic Field device called Magnet-XPRO, in the treatment of patients affected by Sudeck's disease.*

***Methods:*** *Thirty subjects, affected by Sudeck's disease, were enrolled in the study and randomly divided into three groups of 10 patients each: A exposed to medical therapy, B exposed to Magnet-XPRO, C exposed to a simulated field. All subjects of B and C groups underwent a cycle of 15 daily sessions of 30 minutes each and all the patients of 3 groups underwent a clinical examination upon enrolment, after 7 days of therapy, at the end of the cycle and at a follow-up 30 days later.*

***Results:*** *All the patients of groups A and B completed the therapy without the appearance of side effects: they presented a significant improvement of the subjective pain and the functional limitation, which remained stable at the follow-up examination. In group C, there was no improvement of the pain symptoms or articular functionality.*

***Conclusions:*** *This study suggests that the Magnet-XPRO system is efficacious in the control of pain symptoms and in the reduction of functional limitation in patients with Sudeck's disease. Moreover, the effects of the Magnet-XPRO system cover those produced by the medical therapy.*

***Key words:*** *electromagnetic fields, therapy, Sudeck's disease, Magnet-XPRO.*

## 1. INTRODUCTION

The effects of the various types of low frequency electromagnetic fields used in clinical practice depend on their codes (frequency, intensity, waveform, the number of impulses per train and the interval between one train and another). The electromotor forces induced at a given point of a biological system act on the electric charges present which respond, causing functional modifications in the cellular microenvironment (1-3).

Our group has already shown the efficacy and tolerability of the extremely low frequency (ELF) field in patients affected by osteoporosis (4), rheumatoid arthritis (5) and osteoarthritis (6). Recently to evaluate the utility of applying the widest possible magnetic field, we introduced the new Magnet-XPRO device.

Sudeck's disesase called complex regional pain syndrome type 1 (CRPS-1) is relatively common and has been reported to occur after 5% of all traumatic injuries. It may occur following fractures to the extremities, joint sprains or following surgery. It has also been reported following immobilisation and frostbite. It is thought to be caused by a dysfunction of the sympathetic nervous system, which is involved in the regulation of blood supply to the affected part. The condition is often not diagnosed until sometime after the initial symptoms begin (7,8).

The symptoms are variable and will present themselves differently from patient to patient. The most common symptoms overall are pain sensations, including burning, stabbing, grinding, and throbbing. Moving or touching the limb is often intolerable. The patient may also experience muscle spasms, local swelling, sensitivity to things such as water, touch, and vibrations, abnormally increased sweating, changes in skin temperature (usually hot but sometimes cold) and color (bright red or a reddish violet), softening and thinning of bones, joint tenderness or stiffness, and/or restricted or painful movement. Regional Osteoporosis is possible. In severe cases, the affected body part may swell and, due to sympathetic nervous system dysfunction, the body part may perspire more than usual (9).

The aim of this study is to evaluate the efficacy of the Magnet-XPRO system in the treatment of Sudeck's disesase. In particular, we wished to ascertain if the effects of the magnetic fields are equivalent to the effects of the medical therapy.

## 2. METHODS AND PATIENTS

### *Methods*

We have used a new device called Magnet-XPRO, with low-frequency electromagnetic fields (ELF) that we can modulate for each treatment. For this study the field is modulated at the frequency of 100Hz, sinusoidal waveform and around 50 gauss at the mid-point of the interpolar distance (30cm), it is generated by an opposing pair of heteronomous polar expansions and thus presents the relative characteristic spatial conformation. The polar expansions consist of the sides of two iron-silicon nuclei. The coils (4.5 cm long) consist of 900 turns of copper wire (0.7 mm diameter).

### *Patients*

Thirty subjects (13 females and 17 males), between 45 and 66 years old, affected by Sudeck's disease, were enrolled in the study and randomly divided into three groups: A = 10 patients subjected to medical therapy (analgesic and bisphosponates), B = 10 patients subjected to the Magnet-XPRO system and C = 10 patients subjected to a simulated field. Group C was introduced because of the possibility of the presence of a substantial placebo effect.

There is no specific diagnostic test for Sudeck's disease and the diagnosis is based on history, clinical examination, and supportive laboratory findings and we used the current diagnostic criteria for CRPS, codified by the International Association for the Study of Pain's taxonomy committee, and newer statistically derived criteria (the «Budapest» criteria) (10).

All the subjects were out-patients and, correctly informed of the experimental plan, gave their written consent. All the patients of B and C groups underwent a cycle of 15 daily sessions of 30 minutes each, with application of the magnets in contact with the lateral zones of the foot. In the past, all the patients had been treated occasionally or cyclically with analgesic (paracetamol) or non-steroidal anti-inflammatory drugs (diclofenac, or piroxicam, or celecoxib, or rofecoxib), but they had suspended any drug at least 15 days before the beginning of the cycle. The clinical examination in the 3 groups was performed when the patients were enrolled in the study, after 7 days of therapy, at the end of the cycle and at a follow-up, 30 days later.

For the evaluation of the possible therapeutic effects we have divided the evaluation of pain from the evaluation of articular function because of the well-known subjectivity of pain to the placebo effect (11).

### *Statistical analysis*

The differences between the means of the various parameters at 0, 7,15 and 45 days were tested by Student's t test or Mann-Whitney-U test as appropriate.

## 3. RESULTS

Above all, we specified that no significant differences were found between the three groups of patients, concerning private data and their degree of disease. All the patients of group A and B completed the therapeutic cycle, without side-effects that might have required suspension of the treatment. With regard to the efficacy of the therapy, it should be underlined that none of these patients had to take analgesic-antiinflammatory drugs during the cycle and that all the patients presented a significant improvement of both subjective pain and regional functional limitation. In particular, in the A group, the subjective pain progressively decreased in all subjects even after the first week and regressed completely at the end of treatment in 9 (90%) of the 10 patients. In the remaining patient (10%), the pain symptoms, albeit not totally regressed, decreased significantly with respect to the basal values and to those recorded after the first week. In the B group, the time course of subjective pain was equivalent to that of the A group, with complete regression in 8 patients (80%) and a significant reduction in the remaining 2 patients (20%). With regard to the evaluation of articular functionality, there was a significant partial recovery of mobility in all patients, starting from the first week (thus concomitant with the improvement of subjective pain. At the end of the cycle, in the B group, 8 patients (80%) manifested a total recovery of the partially compromised articular functionality, while 2 patients (20%) showed a significant further improvement with respect to the already positive trend recorded after the first week of therapy, although they did not achieve a total functional recovery. In the A group, there was a total functional recovery in 7 patients (70%), while in 3 patients (30%) the change was similar to that of the Magnet-XPRO group. The clinical follow-up, one month after the end of the cycle, revealed that in 9 group A patients (90%), there was no appreciable variation in the regression or improvement of pain symptoms from what was recorded at the end of the therapy; in the other subject (10%), there was a clear relapse of pain. However, this was not accompanied by a concomitant worsening of articular functionality, which continued to show the same recovery as recorded at the end of the therapy one month previously. There was a very similar pattern in group B: in 9 patients (90%), there was no change from the situation at the end of therapy, whereas 1 subject (10%) reported a relapse of the pain symptoms. The time course of the pathology was clearly different in the 10 subjects of group C. Only 1 of them (10%) presented a slight subjective improvement of the symptoms in the first 5 days of the cycle, while the other 9 patients (90%) reported no significant pain reduction. After the first week, application of the simulated magnetic field had to be suspended in 2 group C patients (20%) because of its ineffectiveness, while the remaining 8 patients (80%) completed the cycle. At the end of treatment and at the clinical follow-up one month later, all the patients who completed the cycle reported no improvement of pain symptoms or articular functionality; indeed, there was a slight worsening of pain.

## *4. DISCUSSION*

All the patients treated with medical therapy and Magnet-XPRO system completed the therapeutic cycle and manifested a significant improvement of the clinical picture. The electromagnetic fields had therapeutic effects and produced a so-called "tail effect», continuing after the suspension of therapy, as if the biophysical action interfered with the pathogenetic mechanisms of the disease, probably by inhibition of the inflammatory process (4,5). Moreover, the effects of low frequency electromagnetic fields on cartilage and bone have been evaluated recently by various authors (4,12): they demonstrated in vitro that electromagnetic fields exposure exerts a chondroprotective effect on articular cartilage, increase the rate of differentiation of these cells and enhance synthesis of normal matrix proteins and increase the biochemical markers of bone turnover. The lack of efficacy in the group C patients confirms the therapeutic effects of the ELF fields. Indeed, considering the known relationship between the pain pathways and the psychic habitus of the patient (13-15), only the slight improvement of pain symptoms initially shown by the group C subjects could be attributed to the placebo effect.

It should be mentioned that all the patients subjected to Magnet-XPRO applications manifested a psychological attitude of trust and satisfaction. It also seems that these patients showed more evident and quicker responses, although this was not statistically significant and is reported only as an impression and a possible topic for future research.

Our results confirm the efficacy and tolerability of low frequency magnetic fields as previously reported (4-6,16), also support the hypothesis that the effects of magnetic fields like those produced by the Magnet-XPRO system, are equivalent to the effects of the medical therapy.

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# IN VITRO EFFECTS OF EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS ELF AND TAMMEF ON HUMAN PRIMARY OSTEBLAST PROLIFERATION

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*ABSTRACT*

*Stimulation of bone and cartilage through the application of specific electromagnetic fields (EMFs) could interfere in mechanisms such as inflammation, growth and repair. The potential effects of EMFs on human cells are related to the method of cell culture and the properties of EMFs (frequency, intensity, waveform). In the present study, human primary osteoblasts were left untreated or exposed for 15 days to ELF and TAMMEF systems. After 0, 3, 10 and 15 days of treatments, osteoblast morphology and proliferation were evaluated through light microscopy analysis and MTT test, respectively. Light micorscopy analysis demonstrated that there were no morphological alterations (vacuolization, blebbing) in osteoblasts treated with both ELF and TAMMEF respect to untreated ones. MTT assay showed an increased proliferation of osteoblasts treated with ELF and TAMMEF respect to untreated ones in the first 10 days of treatments followed by normalization of rates from day 10 to 15. These results encourage the application ELF and TAMMEF systems in the treatment of bone remodeling diseases.*

**Key words:** *Electromagnetic fields, TAMMEF, Osteoblasts, Cell morphology, Cell Proliferation.*

## 1. INTRODUCTION

The application of magnetic fields for therapeutic purposes is among the oldest healing methods used by man (1). It 's been shown that the interaction between the electromagnetic field and organisms or cells induce changes in the cell physiology. In particular, on the cells of the bone tissue were observed beneficial effects that promote the consolidation of fractures (2). In literature there are works that identify some characteristics with which the low-frequency fields interact with some of the constituents of the cells (3-9). When a biological system is set in such a field, its electric charges (ions, free radicals, dipolar structures), requested by the induced electromotive forces, respond performing movements permitted by respective constraints. Therefore, while high frequency electromagnetic fields can cause microvibrationsg interpreted as resonance phenomena, induced changes in cellular function by alternating low-frequency fields appear attributable to share rather weak and relatively slow (10-12). The global biophysical effect which may be detected by observing only, due to the level of complexity of the system does not allow to predict which action mechanisms predominate. In addition, while working with a range experienced for a long time, there is no certainty that the code responds to an optimal choice, as always assumed that alternate fields can produce equivalent or better benefits. On the other hand, a systematic exploration of all possible low frequency fields appears not a way to be carried on today, requiring a too high number of comparisons. Said that, we considered instead possible to compare the effects of a given field with those of a comprehensive field, whose parameters continuously change in time: in this way, during the exposure, all codes eligible may follow one another. The need to characterize this phenomenology by tests «in vitro» is generally recognized, so our research submits samples of human cell cultures to ELF fields and TAMMEF, in order to evaluate the results in terms of efficacy and tolerability. As is known, the cells of human origin, in the case osteoblasts, constitute the best experimental approach, representing the stage closest to the conditions in vivo.

«In vitro» experimental observations have shown that electromagnetic fields positively influence the metabolism of fibroblasts (13), chondrocytes ( 14,15) and osteoblasts (16), while modulating the effects of hormones and neurotransmitters on receptors of different cell types (17). These fields are then able to modify certain physiological parameters such as proliferation, transcription, synthesis and secretion of growth factors (18,19) of the «in vitro» cultured cells. The goal was to determine whether ELF fields and TAMMEF affect the stimulation of "in vitro" osteogenesis, including morphological alterations.

## 2. METHODS

In carried out experiments, human osteoblasts cell cultures, contained in specific sterile structures, are submitted to electromagnetic fields in a region of space at a controlled temperature (37 ° C).

Experimental apparatus. The ELF system is a classical electromagnetic field generator to 100Hz, while the system TAMMEF (Fig. 1) is composed by an audiotape that sends the corresponding microphone signal - monochannel –to two low frequency amplifiers A and B, both from adjustable gain. The output power from the amplifier A, modulated according to the recorded signal, feeds two electromagnets with nuclei in iron-silicon, connected posteriorly by an arc ferromagnetic. The faces of the pole pieces, between which is interposed the volume to be treated, have dimensions of 3x4 cm. The windings, 4.5 cm long, each consist of 900 turns of copper wire with a diameter of 0.7 mm. The amplifier gain A is adjusted so that, when the audiotape contains a sinusoidal signal with frequency of 100 Hz, the electromagnetic field is equal to that generated by the ELF (about 3 gauss at the center of the interpolar distance of 30 cm ). Consequently, the variations of the parameters of the field at each instant reproduce those of the pilot signal recorded in the audiotape without placing any limit to the versatility of the device. Therefore, by inserting a cassette containing a signal with the capriciously variable code in time (for example, a piece of music), a comprehensive TAMMEF field is obtained. The experiment allows to compare the clinical and biological effects of ELF field with those of a selected field TAMMEF. Cell cultures. The human osteoblasts cultures were taken from femoral heads by surgery to prosthetic implant. The fragments of trabecular bone were washed in PBS (Phospate Buffered Saline solution) and placed in sterile Petri plates with Dulbecco's modified Eagle's Medium (DMEM) (Gibco, Life Technologies, Paisley, Strathclyde , UK), FCS (Foetal Calf Serum) to 10% (Sigma, St. Louis, MO, USA) and 2 mM L-Glutamine (Gibco, Life Technologies) and antibiotics (10,000 units of penicillin and 10 mg streptomycin per ml of medium with 0.9% sodium chloride). The plates were incubated for 24 hours at 37° C in an incubator with a humidified atmosphere of 7% $CO_2$ / 93% air. The cells grew up «in vitro" with complete medium (DMEM) supplemented with 10% FCS. The cells reached a confluent monolayer after 5-6 weeks. The cell monolayer was washed with PBS and then treated with a solution of Trypsin / EDTA (0.05% / 0.02%) (Gibco, Life Technologies) for 5 minutes. The cells thus detached were transferred into a 12 multi-well plate (Corning Costar Corp., Cambridge, MA USA) at a density of 60,000 cells per well with complete medium.

For each experiment were set up:

- multiwell plate to be submitted to ELF magnetic field
- multiwell plate to be subjected to the magnetic field TAMMEF
- 1 control plate placed in an area without measurable magnetic fields and under the same conditions (temperature, humidity, etc.) of the treated plates.

The Fig. 2 reproduces the detail of the coil system for electromagnetic cell "in vitro" exposure. The cells are contained in the multiwell plate, visible between the two coils, while the circulating power generated the magnetic field.

Cell cultures were exposed to the fields for 1 hour per day for 15 days and the experiments were repeated 4 times.

At time 0, after 3 days, after 10 and after 15 days, the cells were removed from the plates by trypsinization and counted to assess proliferation.

The evaluation of the morphology and cell proliferation was carried out using both optical microscopy techniques and a MTT colorimetric assay.

- Cytomorphological evaluation.
- Cell cultures were examined with an inverted optical microscope (Nikon Eclipse 300 Te) with 10x ocular, objective and camera (Nikon F70).
- Test of cell proliferation.

The proliferative response of osteoblasts to electromagnetic fields was determined by the MTT colorimetric assay (Boehringer Mannheim, Germany), with the organic compound tazolico (yellow soluble salt) from the chemical name 3 - (4,5-dimethylthiazol-2-yl) -2,5 - dyphenyl-tetrazolium bromide (MTT). This compound through the cellular dehydrogenase (mitochondrial enzyme are present only in metabolically active cells) is transformed into a purple crystalline precipitate (insoluble in water) called formazan (red-purple).

After the formazan formation, the cell suspension present in the cockpit is transferred into a test tube and centrifuged at 650g for 10 min and the pellet is solubilized in dimethylsulfoxide (DMSO). Subsequently the solution is titrated in optical spectrometry at a wavelength of 560nm. (Pharmacia Biotech Ultraspec 3000).

## 3. RESULTS

The Fig. 3a-3b-3c show the cultured cells (osteoblasts) in the third day, respectively in the control group and in the groups treated with ELF and TAMMEF fields. In all the experiments was not observed any loss of the cell monolayer which is a clear sign of cell suffering , either intra-cytoplasmic vacuolation denoting an altered morphology. So, from a first morphological analysis in cultures exposed to ELF and TAMMEF fields compared to the control, there were no differences among the three cell cultures. The treated cells show themselves perfectly adherent with flattened and elongated morphology (characteristic of osteoblasts in culture) and are not visible alterations compared to the control. The count of osteoblasts showed an increase in the number of cells in cultures exposed to ELF and TAMMEF fields compared with controls; more precisely, this proliferation was increased in cultures treated with ELF fields compared to those treated with fields TAMMEF, although not evident from Fig.3b/3c: in the first 3 days, the mean increase in proliferation was equal to 18.76% and to 14.07% for ELF and TAMMEF, for the next 7 days. At the 10th day, the average increase since the last measurement (3 days) was 5.49% for the ELF and 4.47% for TAMMEF. The last period, from the 10th to the 15th day, the proliferation was normalized, with a decrease of approximately 3.3% for the ELF and 0.85% for the TAMMEF. Looking at the graph (Fig. 4), it is possible to observe a clear increase in osteoblast proliferation observed in the treated groups compared to the control group during the first three days of the experiment.

## 4. CONCLUSION

In this study, we evaluated the action of electromagnetic fields at low frequency ELF and TAMMEF on cell proliferation of human osteoblasts, obtained from femoral heads, checking the possible ability to stimulate new bone formation " in vitro".

We found that osteoblast cell cultures treated with the two magnetic fields receive a greater incentive to split since the early days of the application, and then to proliferate, compared to the control culture; also the stimulus by the magnetic fields does get the treated cells to confluence in a shorter time, improving the bone tissue repair mechanism. The findings, at the tenth and at the fifteenth day, show a return to growth equivalent to that of osteoblasts in the control group, and then the normalization of cell reproduction mechanism, which excludes uncontrolled growth and tumor evolution.

The differences we observed on cell proliferation between the control and the two cultures treated with ELF and TAMMEF fields, can be interpreted as a possible influence of magnetic fields on the stability of the state of the cellular electric charge (20). The interaction between electromagnetic fields and cells produces effects of varying degrees of numerous biological processes. The ability to control cellular functions by exposure to electromagnetic fields is extremely interesting both from a biological and medical point of view. In last years, several models have been developed (21) in order to explain the mechanism through which the fields of low intensity and frequency can cause significant biological effects. The model proposed by Liboff (22) suggests the resonance of the ions as a mechanism that facilitates the ions transportation through the membrane channels in the presence of a constant magnetic field and of an alternating magnetic field at low frequency.

The variations of the magnetic field produce induced electromotive forces which act on the electric charges present in the cell microenvironment (ions, free radicals, bipolar structures, etc..). The processes involved are resolved in possible modifications of cellular function (23).

Bone is a living tissue that dynamically renewalls, maintaining all of its physiological properties; osteoblasts, in particular, ensure the synthesis and mineralization of the matrix. The regulation of the bone cell differentiation and its activity is complex involving hormones, cytokines, transcription factors and their receptors (24, 25).

The possibility of increasing, by means of a physical stimulus which the magnetic field, cell proliferation has obvious advantages, among the first to be able to achieve higher cell growth in the first days of treatment compared with conventional procedures. These preliminary data lead us to believe that the use of ELF and TAMMEF fields can produce good results in the treatment of bone diseases; osteonecrosis of the hip, bone engraftment, Perthes Disease and osteoporosis (27-32).

## *FIGURES*

***Figure 1.***
*TAMMEF and ELF  System*


***Figure 2.***
*Coil system for electromagnetic cell "in vitro" exposure*

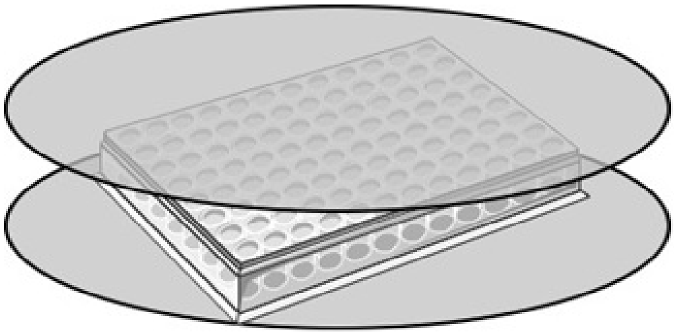


***Figure 3.***
*3a: Cell control. 3b: Cell treated ELF.*
*3c: cell treated TAMMEF*

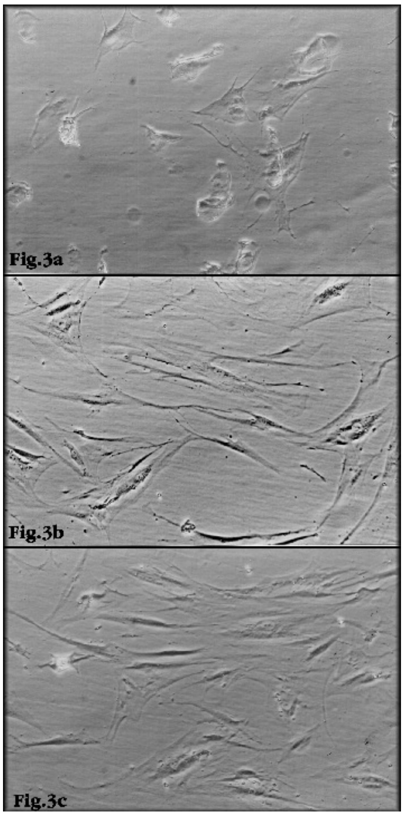
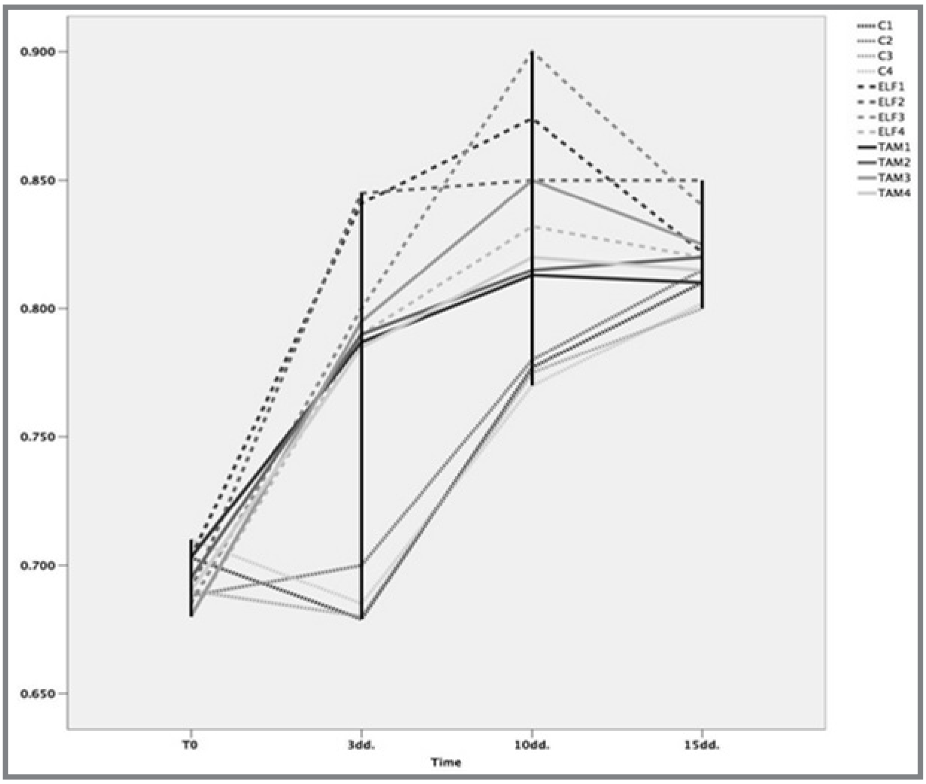



***Figure 4.***
*Sequence of absorbance value*

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# FEM-DRIVEN PARAMETER OPTIMIZATION OF A FULLY FUNCTIONAL PROTOTYPE FOR ESTABLISHING ELECTROCHEMOTHERAPY IN INTERSTITIAL USAGE

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## ABSTRACT

*In order to establish electrochemotherapy (ECT) for an interstitial use, we developed a needle-shaped probe, which can be used as percutaneous, image-guided, minimally invasive treatment option for malignant liver tumors. The probe is fitted with four expandable electrodes, which are hollow for injecting the chemotherapeutic agents inside the tumor within the area of the electric field.*

*Compared to ECT in treatment of malignancies of the skin, it is much more challenging to generate the desired electric field for the treatment of hepatic malignancies, because of the inhomogeneous electrical properties of the target tissue and the approximated spherical 3D geometry of liver tumors. For that, the probe is designed in CAD (SolidWorks 2012, Massachusetts, USA) with a live-link to an FEM simulation software (Comsol Multiphysics 4, Göttingen, Germany).*

*Changes in design can be revalued quickly with the FEM simulation, regarding different quality criteria for field strength inside and outside the tumor. Additionally, the probe offers an option to adapt the field geometry to the tumor geometry by connecting the five electrodes to five individually chosen potentials.*

*To rate the criteria for field strength, a set of formulas with weighting coefficients has been developed. By tuning these coefficients, the physician can adapt the 3D field distribution to the geometrical shape of each single patient's tumor. Doing so, he can avoid to leave even small areas of the tumor tissue unharmed and at the same time guarantee that only small areas of healthy tissue are electroporated.*

***Key words:*** *electroporation, electrochemotherapy, liver, FEM, simulation, electrode, minimally invasive, dielectric properties.*

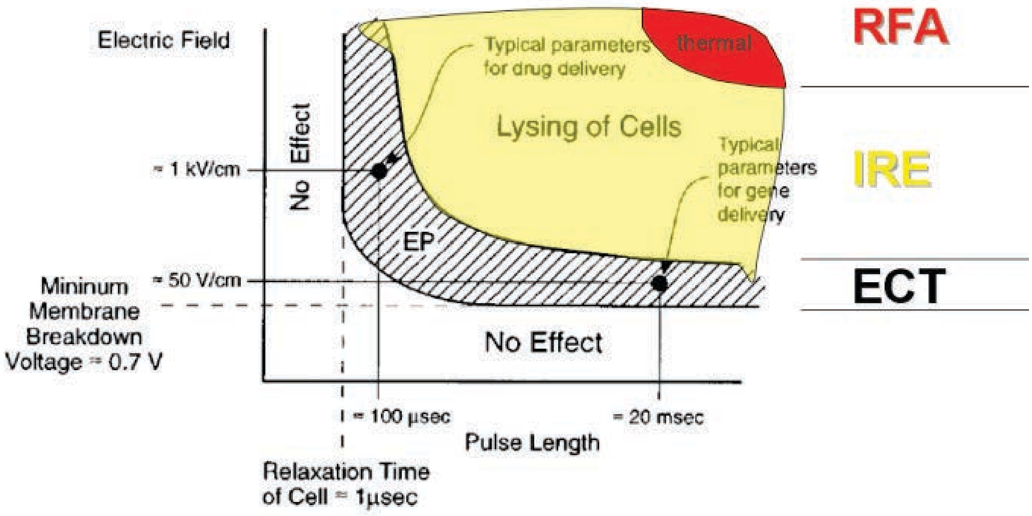
## 1. INTRODUCTION

With about 220,000 cancer-related deaths per year [1], malignant tumors are the second most common cause of death in Germany. In numerous tumor diseases, metastasis is a major limiting factor of the patient's life expectancy. While surgical resection of the primary tumor and its metastases is the treatment of choice in case of operability, this option is only available for a minority of patients because of tumor spread and / or comorbidities. As an alternative to chemotherapy, various minimally invasive endovascular and percutaneous tumor treatments have gained clinical acceptance. Widespread treatments are percutaneous thermal ablation procedures like radiofrequency ablation (RFA) or microwave ablation (MWA), both using different technologies to apply heat to destroy the tumor.

In contrast, irreversible electroporation (IRE) is a new, non-thermal ablation procedure employing multiple short-termed electrical pulses that irreversibly destroy cells in the application area. A similar procedure, called electrochemotherapy (ECT), also uses electrical pulses to temporary affect the mass transfer through cell membranes (reversible electroporation) to channel chemotherapeutics into the cells that per se are not able to pass the membrane. Benefits of these non-thermal approaches over RFA and MWA are that blood vessels, bile ducts as well as lymph and nerve pathways remain mostly unaffected. Moreover, in contrast to thermal ablation procedures, tumors adjacent to large blood vessels can be treated completely since thermal convection by means of the blood flow is irrelevant in IRE applications.

In both, IRE and ECT, success of the procedure highly depends on an appropriate application of the electric field to the tumor cells in order to apply a clearly defined alteration the membrane permeability [2]. Parameters that affect the applied electric field in-situ are: probe design and position, electric pulse protocol (i.e. pulse length and amplitude (see Fig. 1), quantity, frequency, slopes), as well as the tissue-specific electrical properties [3, 4].

***Figure 1.*** *Correlation between "Pulse Length" and "Electric Field" within application of electroporation. Above these values, heat is generated (red area). Modified after [4, 5].*




*2. METHODS*

The aim of this research project is the development of a minimally invasive, interstitial / intra-abdominal application for ECT. We focused on malignant liver tumors. Because of their approximated spherical 3D geometry, it is much more difficult to create a homogeneous field inside hepatic malignancies than in malignant melanoma (where a rectangular geometry is assumed [6]). For this purpose an electrode for percutaneous application was developed. A needleshaped probe with four expandable electrodes was prototyped from Nitinol alloy. The probe was designed in a CAD environment (SolidWorks 2012, Massachusetts, USA) with a live-link to a FEM simulation software (Comsol Multiphysics 4, Göttingen, Germany). We analyzed different geometries in reference to the geometry of the generated electrical field and optimized the best one in different parameters (electrode radius, length, distance to main probe, length, distance of insulating layer etc.).

For the treatment of malignant skin lesions a field strength of about E = 1.4 kV/cm (depends on quantity, frequency and pulse width) has been established as a working value [7, 8]. For an almost spherical setups, the electrical field is defined by

$$E = \frac{1}{4\,\pi\,\varepsilon_0\,\varepsilon_r}\,\frac{Q}{r^2}\,\vec{r} \qquad (1)$$

Besides geometry, the electrical field depends on the relative permittivity $\varepsilon r$, which is a material constant. For healthy tissue, permittivity data from ex vivo measurements is referenced [9]. Recent works provide variations up to 25% for $\varepsilon r$ for normal liver tissue in vivo vs. ex vivo [12]. To our knowledge, for electric parameters of tumorous liver tissue there are only few publications with reference values available [e.g. 10, 11], which also only provide data from ex vivo measurements. Based on this reference data we appraised the difference between tumorous and healthy liver tissue to use it as input parameters for our simulation, knowing that these values are still underexplored.

A simplified electrostatic simulation indicates the influence of the relative permittivity (Fig. 2, estimations for $\varepsilon r$ taken from [9, 10]): Inside tumor tissue the electric field strength decreases, if the assumed relations between data for $\varepsilon r$ are correct. Thus, for a simulation model applicable to clinical practice, more basic research in the topic of electric tissue parameters is essential. However, these values are independent from the geometrical model which we developed.

Furthermore, during this project an evaluation has been developed to rate the geometric parameters and also later the effectiveness of the therapy.

**Figure 2a.** *Electrostatic simulation of normal (red, E1 = 914 V/cm) and tumorous live tissue (green, E2 = 761 V/cm) in an homogeneous electric field, generated with a usual potential difference of U = 3 kV.*

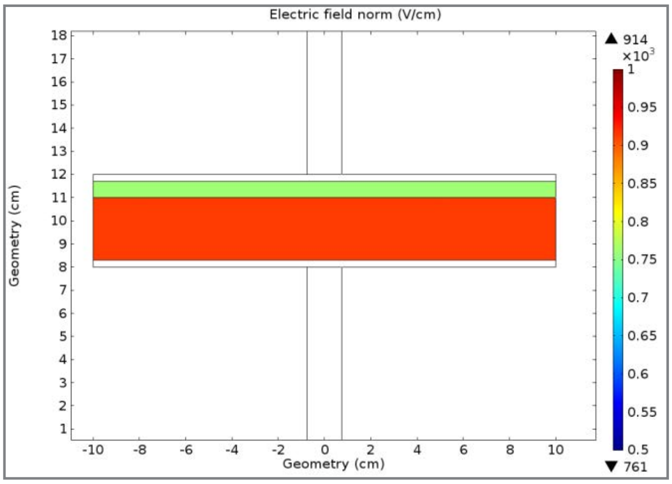
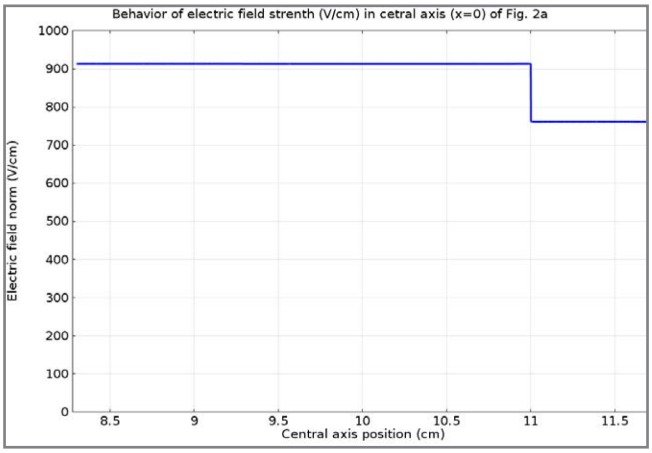



**Figure 2b.**
*Decrease of electric field strengthin crossover from normal (x < 11 cm) to tumorous liver tissue (x > 11 cm).*




## 3. RESULTS

With the results of the simulation processes (sectional plane of electric field distribution in a tumor between liver tissue is shown in Fig. 3) we built up a fully functional electrode prototype with a diameter of d = 5 mm (see Fig. 4). A shape memory alloy (nitinol) is used for the four expandable electrodes: When they are pushed out from their rectilineal position inside the main probe, they deploy reversible in a predefined radius of 70 mm and up to 35 mm in length. In this fieldgenerating arcuate position they can span an electrical field with almost spherical borders. For the insulating areas a Teflon-coating is used. Another option to optimize the field geometry is to connect each single electrode to a different and time-dependent potential. This transient signaling is a part of current simulations and results will be published in upcoming communications. All four movable electrodes are hollow for injecting the chemotherapeutic agents inside the tumor.

Changes in design can be revalued quickly within FEM simulation, regarding different quality criteria for field strength inside and outside the tumor. To rate these criteria, the following set of formulas has been developed:

$$G = \begin{cases} 0, & if\ V_{T,unp} > 0 \lor \frac{V_{R,unp}}{V_R} > p\ [in\ \%] \\ 100 - \left(\frac{V_{R,unp}}{V_R} + 25\frac{V_{G,irr}}{V_T + V_R}\right) - \left(10\frac{V_{G,rev}}{V_T + V_R} + \frac{V_{R,irr}}{V_R}\right), & else \end{cases} \quad \textbf{(2)}$$

The quality factor G is defined such that it adopts values between Gmin = 0 and Gmax = 100. The upper value represents the ideal case: The solid tumor (Volume VT) is fully porated (reversible/irreversible), boundary areas (Volume VR) undergo a reversible poration and healthy tissue (everywhere outside VT + VR) is not harmed at all.

With weighting coefficients the physician can tune the quality factor to the needs of individual patients. E. g.: It is significantly worse to leave even small areas of the tumor tissue unharmed than to porate some healthy tissue. A bigger, unporated boundary volume segment will increase the quality factor more than a small one.

The quality factor is set to Gmin := 0, if the solid tumor is not porated completely (VT,unp ≠ 0) or if more than p [in %] of the boundary area remains unporated.

Independently, Županič et al. did optimizations for electroporation similar to our model with Comsol [13]: Both studies made use of similar assumptions and similar simplifications, independently. Because of the crossover from tumorous to healthy tissue inside this area, consequently the crossover of the permittivity, the model presented here additionally includes a separate boundary area. Furthermore, because of the combination of IRE and ECT used with the prototype shown above, an explicit discrimination between irreversible and reversible poration was made, especially in this boundary area.

Summarizing, the quality factor given in Eq. 2 is a sum of weighted coefficients, which describe events that should not occur. These events - respectively these coefficients - decrease the quality factor down from Gmax = 100. Tab. 1 shows relevant different cases for calculating G, subdivided in the different volume segments, with preselected weighting coefficients.

With the calculated value of G, effects of different geometry parameters, different wiring of the electrode, and different voltages can be determined and compared to each other. The value of G therefore allows to optimize the electrode to numerous tumor geometries and provides an estimation on how precisely the production line has to keep/ maintain the geometric parameters. Further, the physician is able to optimize the place for positioning the electrode inside the liver for surgery / treatment/ therapy purposes.

Next steps are to specify the used values for permittivity and to prove the simulation results in vivo [14].

***Figure 3.*** *Cross-sectional image of the simulated electrical field (scale: d = 5 mm).*
*Red area: E ≥ 2 kV/cm, tissue in this area will be irreversibly porated.*
*Blue to turquoise area: E ≤ 0.5 kV/cm, tissue in this area will not be porated.*
*Area in-between: reversible poration, target area for chemotherapeutic drugs*

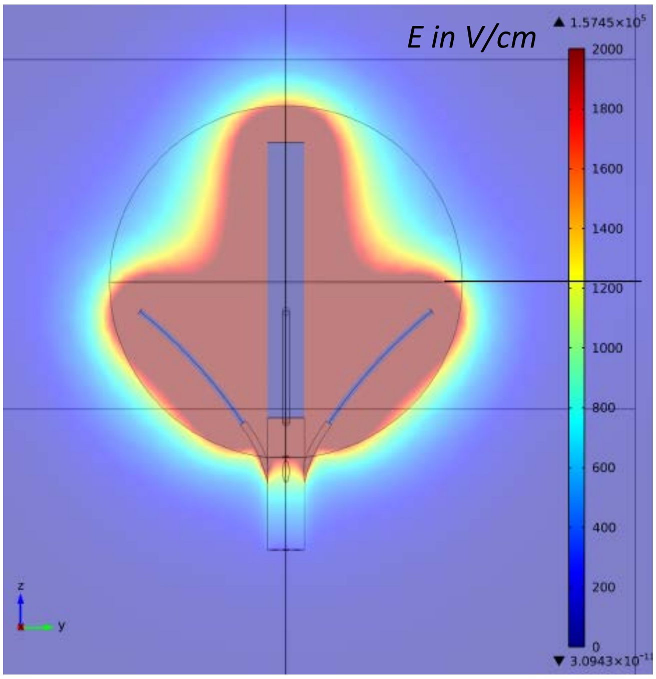



***Figure 4.*** *Prototype for interstitial application of electrochemotherapy to malignant liver tumors.*
*Top: Complete view with drug and electrical supplies on the right.*
*Bottom: Expanded hollow electrodes for drug application and field generation,*
*as shown in simulation of Fig. 3 (d = 5 mm*

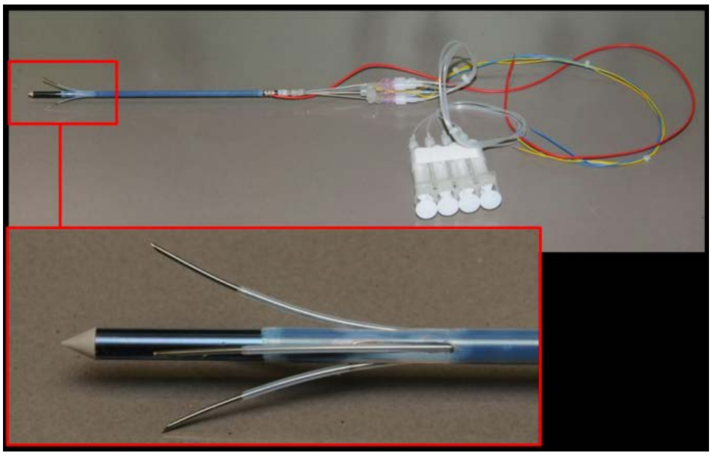


***Table 1.*** *Volume segments for computing the quality factor and preselected associated weighting coefficients (wc)*

| *symbol* | *description* | *radius* | *wc* |
|---|---|---|---|
| ***VT,unp*** | solid tumor, unporated | $r \leq 20mm$ | – |
| ***VR,unp*** | boundary area, unporated | $r > 20mm$<br>$r \leq 25mm$ | 100 |
| ***VR,irr*** | boundary area, irrev. porated | $r > 20mm$<br>$r \leq 25mm$ | 25 |
| ***VG,irr*** | healthy tissue, irrev. porated | $r > 25mm$ | 10 |
| ***VG,rev*** | healthy tissue, rev. porated | $r > 25mm$ | 1 |


## *ACKNOWLEDGMENT*

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# OCCUPATIONAL AND ENVIRONMENTAL EXPOSURE TO EXTREMELY LOW FREQUENCY-MAGNETIC FIELDS IN A LARGE GROUP OF WORKERS

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*ABSTRACT*

*The aim of this study was to provide: a) an evaluation of current ELF-MF exposure in workers, b) the specific contribution of occupational exposure to overall 24-hour exposure, and c) the representativeness of a Job Exposure Matrix. 543 workers were monitored for 2 whole days using personal meters. Time-Weighted Average (TWA) levels at work, at home, and outside the home (respectively work TWA, home TWA and environmental TWA) were calculated. Tasks were classified according to the ISCO 88 International Standard Classification of Occupations. In about 10% of the entire sample, the monitoring was repeated after 6-9 months. In the whole sample, the median of TWA am during work was 0.14 µT (5° - 95° percentiles: 0.04 - 2.50 µT). Median Home TWA and Environmental TWA were respectively 0.03 (5°-95° percentiles 0.01 - 0.24 µT) and 0.05 µT (5th-95th percentiles 0.02 – 0.28 µT). The correlation between TWA values during the first monitoring and the replication was r =0.80. The contribution of occupational exposure to the overall 24-hour exposure was estimated showing that, during working days, about the 60% of exposure is related to work. The variability of individual work TWA among subjects included in the same ISCO 88 task, evaluated using ANOVA, proved significant in 56% of the tasks*

***Key words:** ELF-MF, Occupational Exposure, Environmental Exposure, Personal Monitoring, TWA, Job Exposure Matrix*

## 1. INTRODUCTION

An adequate evaluation of exposure is a recognized problem in epidemiological studies on the possible adverse effects of occupational exposure to Extremely Low Frequency-Magnetic Fields (ELF-MF) [1], as misclassification of exposure can lead to misleading conclusions [2]. The aim of this study was to provide an evaluation of current ELF-MF exposure in workers, the specific contribution of occupational exposure to overall 24-hour exposure, and the representativeness of a Job Exposure Matrix based on the ISCO 88 classification [3].

## 2. METHODS

Five hundred and forty three workers (383 men and 160 women) were monitored. Tasks were classified according to the ISCO 88, yielding 31 ISCO 88 tasks. ELF-MF exposure was monitored for 2 whole days, including both working and non-working periods, using personal meters (EMDEX Lite). Time-Weighted Average (TWA) levels at work, at home, and outside the home were calculated, respectively work TWA, home TWA, and environmental TWA. To evaluate the repeatability of exposure data measurements, in about 10% of the whole sample, the monitoring was repeated after 6-9 months, using the same procedure. The variability of individual work TWA among subjects included in the same ISCO 88 task was evaluated using ANOVA.

## 3. RESULTS

For the whole sample, the median of TWAs am during work (work TWA am) was 0.14 µT, and the 5° - 95° percentiles were 0.04 - 2.50 µT, respectively; the median of TWAs gm was 0.08 µT (5°-95° percentiles 0.02 - 0.57 µT). Spearman's correlation coefficients between individual TWA am and TWA gm was $r = 0.85$ ($p < 0.001$): due to the high correlation found, in the rest of the paper, we have decided to focus discussion mainly on the results as TWA am, as this is the parameter currently applied in most epidemiological studies.

The correlation between individual work TWA am measured during the first monitoring and in replication performed in 53 workers some months later was: r =0.80 ($p < 0.001$), showing a good reliability. Similar results were obtained considering home TWA and environmental TWA.

The variability of work TWA among workers included in tasks classified according to ISCO 88 (ISCO 88 task), evaluated using ANOVA, is significant, showing differences in individual work-related exposures among workers included under the same ISCO Code, in more than half of the tasks considered (56%) (Table 1).

Median Home TWA (0.03 µT) was less than 20% of work TWA; the 5°-95° percentiles were 0.01 - 0.24 µT, respectively. The Environmental TWA was similar from a practical point of view: the median value was 0.05 µT and 5th-95th percentiles 0.02 – 0.28 µT. Finally, the contribution of occupational exposure to the overall 24-hour exposure was estimated (Table 2). Accordingly, for each subject, the ratio between work TWA am and the 24-hour exposure was calculated; the median ratio was found to be 0.59.

***Table 1.*** *Results of variance analysis of the individual work TWA am of workers included in 24 jobs classified according to the ISCO 88 classification of occupations. The significance of differences was evaluated using Fisher's F distribution.*

| ISCO 88 Classification | F | p value |
|---|---|---|
| 3111-chemical and physical science technicians | 21.65 | 0.000 |
| 3115-mechanical engineering technicians | 8.23 | 0.001 |
| 411-secretaries and keyboard-operating clerks | 2.46 | 0.003 |
| 4131-stock clerks | 24.83 | 0.000 |
| 4211-cashiers | 3.65 | 0.083 |
| 521-shop salespersons and demonstrators | 5.48 | 0.000 |
| 721-welders | 11.33 | 0.009 |
| 723-machinery mechanics and fitters | 2.45 | 0.004 |
| 7241-electrical mechanics and fitters | 0.43 | 0.659 |
| 7411-meat butchers and preparers | 0.97 | 0.436 |
| 8121-metal converting and refining furnace operators | 1.18 | 0.397 |
| 813-ceramic and related plant operators | 0.60 | 0.797 |
| 8211-machine-tool operators | 2.66 | 0.001 |
| 823-plastic machine operators | 1.00 | 0.375 |
| 8240-wood products machine operators | 1.20 | 0.306 |
| 8251-printing machine operators | 1.12 | 0.350 |
| 8269-other textile products machine operators | 8.73 | 0.001 |
| 827-food and related products machine operators | 4.19 | 0.004 |
| 8271-meat processing machine operators | 11.01 | 0.000 |
| 8279-brewers and wine and other beverage machine operators | 0.65 | 0.542 |
| 8281-mechanical machinery assemblers | 6.26 | 0.001 |
| 8283-electronic equipment assemblers | 0.77 | 0.647 |
| 8333-crane, hoist, and related material-moving equipment operators | 61.67 | 0.000 |
| 9322-hand packers and other manufacturing labourers | 0.33 | 0.667 |

***Table 2.*** *Occupational and Non-Occupational exposure at home and outside the home in the whole group of 543 workers monitored for 2 days using personal meters. Values are presented as TWAam, expressed in µT*

| | *Exposure at Home* | *Environmental Exposure (Outside the Home)* | *Occupational Exposure* |
|---|---|---|---|
| ***Median value*** | 0.03 | 0.05 | 0.14 |
| ***5° - 95° percentiles*** | 0.01-0.24 | 0.02-0.28 | 0.04-2.5 |
| ***% of Workers with TWA levels exceeding:*** | | | |
| ***0.2 uT*** | 94% | 91% | 65% |
| ***0.3 uT*** | 96.81% | 95% | 75% |
| ***0.4 uT*** | 97.20% | 96% | 80% |

## 4. CONCLUSIONS

Current ELF-MF work-related exposure in workers engaged in the main occupational activities in our area proved low, and relatively higher levels were only observed in a small fraction of subjects: work TWA exceeding 0.4 μT, i.e., the threshold suggested for suspected long-term effects, was found in less than 20% of the whole sample and, considering the median value, in 13% of the ISCO 88 task-related TWAs.

Individual exposure at home was lower than the occupational exposure (the median home TWA am is about 20%) and, in the vast majority of subjects (97.2 %) lower than 0.4 μT ; the median exposure during periods spent outside the home (environmental TWA) was similar. In the group as a whole, exposure during occupational activities makes the largest contribution to overall 24-hour exposure: about 60% compared to less than 40% for home and outside exposure combined.

One last conclusion transpiring from this study is related to the use of JEMs for epidemiological research. In fact, by using the ISCO 88, i.e., one of the most common classifications, the same code frequently groups together workers with significantly different individual work-related TWAs, and there are no reasons to suppose that the problem can be avoided using other currently applied classifications, as most of them were developed for reasons other than the evaluation of exposure to hazardous risk factors. This problem, which could lead to misclassifications, should be adequately considered in future epidemiological studies.

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# DEVELOPMENT OF NEW ASPECTS OF POWER FREQUENCY ELECTROMAGNETIC FIELD SAFETY

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*ABSTRACT*

*Maintenance of power frequency (PF) electromagnetic field (EMF) safety includes two independent aspects: electric and magnetic fields. Occupational and general public PF EMF exposure hygienic norms in the Russian Federation are strict. For the control of PF EMF created by various sources, settlement and tool methods are used. There are various PC programs, that allow calculate EMF levels.*

*The decision of PF MF shielding by traditional methods (application of materials with high magnetic permeability) for long distance sources, such as overhead and cable transmission lines, is practically impossible.*

*In addition to electric and magnetic field time-dependent hygienic regulations some new technical solutions directed to electric and magnetic field reduce in work places or places of general public residing are developed: shielding of extremely high voltage overhead transmission line electric fields by means of passive, active and resonant rope screens as well as magnetic fields by means of passive, active and resonant directed contour screens; electromagnetic screens for decrease of electric reactors without the ferromagnetic core magnetic field intensity and designs of electrical reactors without the ferromagnetic core with the lowered levels of created by its in surrounding space magnetic field.*

***Key words:*** *electrical field, magnetic field, power frequency, overhead and cable transmission lines, electrical reactors, principles of control, shielding, computer programs.*

## 1. NTRODUCTION:

Power frequency (PF) – 50/60 Hz electromagnetic field (EMF) sources are various types of power objects. Power object staff – are the personnel carrying out exploration and maintenance of:

- high-voltage (ultra-high, extremely high) substations,
- high-voltage (ultra-high, extremely high) transmission lines,
- devices containing current wires,
- electrical transport,
- industrial and medical equipment,

Personnel of power transmission objects, first of all, carrying out operation and service of extremely and ultra high voltage open switchyard and overhead transmission lines are most occupationally exposed by PF EMF, and also the personnel which is carrying out service of cable transmission lines.

General public can be exposed by PF EMF, created by various technical devices. In the open territory is, as a rule, overhead and cable transmission lines (OTL and CTL), transformer and distributive substations, and also electrical transport; as well as household electrical devices: refrigerators, electric stoves, electric irons, vacuum cleaners, electric razors, hair driers, teapots, coffee makers, coffee grinders, electric hot-water bottles, electric blankets, etc., in garages and on summer residences – electric tools, pumps and so forth.

Maintenance of power frequency electromagnetic field safety includes two independent aspects: electric and magnetic fields because of human exposure in near field. The solving of PF EMF safety problems is very important in case of general public exposure especially because of possibility of carcinogenic risk elevation. IARC in 2002 has classified extremely low frequency magnetic field as possibly carcinogenic to humans (Group 2B) (childhood leukemia) [1].

## 2. METHODS

According main principle of electromagnetic safety there are 3 types of approaches:

- Protection by time. It is applied when there is no opportunity to reduce EMF intensity up to all day (or all working day) maximal permissible levels. This principle is realized in hygienic norms both for occupational, and for environmental exposure.

- Protection in distance. It is the most effective method. In case of occupational exposure it consists in deducing staff of a zone of raised EMF levels. It is carried out by means of mechanization, automation, use of remote control, manipulators, accommodation of workplaces in view of emission direction and properties. In case of general public exposure it is realized by the maximal removal of population places of residing (constant stay) from EMF source. In particular, for general public protection from OTL electric field will be organized sanitary-protective zones (now it is named “sanitary breaks”).

- Protection by protective means. Protective means can be collective and individual. As collective protective means for occupational conditions the devices limiting receipt of electromagnetic energy on workplaces (shielding) are used. To individual protection from PF electric field apply screening clothes. The basic characteristic of any protective means is the degree of EMF reduction, expressed in factor of shielding.

Because of possible unfavorable effects (carcinogenic including) of PF MF the decision of questions of PF MF sources or places of general public residing shielding traditional methods (application of materials with high magnetic permeability) for long distance sources, such as overhead and cable transmission lines, is practically impossible. In this connection development of new principles of MF emitted by transmission lines in occupied territory decrease (shielding) was represented necessary.

As the perspective development directed on human health preservation maintenance under conditions of PF EMF exposure can be considered:

- The Antenna method of extremely high voltage overhead transmission line corona discharge electromagnetic field decrease;
- Shielding of extremely high voltage overhead transmission line electric fields by means of passive, active and resonant cable screens;
- Shielding of extremely high voltage overhead transmission line magnetic fields by means of passive, active and resonant directed contour screens;
- Electromagnetic screens for decrease of electric reactors without the ferromagnetic core magnetic field intensity;
- Designs of electrical reactors without the ferromagnetic core with the lowered levels of created by its in surrounding space magnetic field.

There are developed computer programs for calculation of electric an magnetic field levelsemitted by OTL and CTL

## 3. RESULTS

Hygienic standardization and protection in distance

Hygienic EMF standards in RF are developed, as a rule, on the basis of complex of hygienic, clinical and physiological, experimental, and last years epidemiological researches in view of published in the world scientific peer reviewed publication data. Occupational and general public power frequency electric and magnetic field hygienic standards are developed in Russia with realization of protection by time principle.

Now in the Russian Federation there are some statutory-methodical documents of PF EMF occupational exposure regulating.

The main documents are the following:

- Sanitary Rules and Norms (SanRaN) 2.2.4.1191-03 “Electromagnetic Fields under Occupational Environments”; which regulates conditions of PF electric and magnetic field occupational exposure [2];

- GOST 12.1.002-84 System of Labor Safety Standards (SLSS). “Power Frequency Electric Fields. Permissible Levels of Intensity and Requirement to Control Procedure on Workplaces” [3]. This document regulates occupational exposure PF electric field only.

According to SanRaN 2.2.4.1191-03 and GOST 12.1.002-84 maximum permissible level of electric field (EF) intensity on workplace during all labour shifts is equal 5 kV/m.

At EF intensity from more 5 up to 20 V/m inclusive permissible work time in EF - T (hour) calculates by formula:

$$T = 50/E - 2, \text{ where}$$

***E*** – EF intensity in a controllable zone, kV/m;

***T*** – permissible work time of EF occupational exposure at corresponding E field strength, h.

EF level from 20 to 25 kV/m: permissible work time in EF exposure condition is no more than 10 minutes. Work in EF > 25 kV/m without protective means is disallowed. According to requirements of these documents, permissible work time in EF conditions can be realized for once or is fractional within the shift. In other working hours it is necessary to be outside of zone of EF influence or to apply protective means.

PF magnetic field occupational exposure maximal permissible values are time-depended and established for total (all body) and local (extremities) exposure (Table 1).

***Table 1.*** *Power frequency (50 Hz) periodic magnetic field occupational exposure maximal permissible level*

| *Time of work (hour)* | *MF maximal permissible levels, H [A/m] / B [ μT] under exposure* | |
|---|---|---|
| | **Total** | **Local** |
| ≤ 1 | 1 600/2 000 | 6 400/ 8 000 |
| 2 | 800/1 000 | 3 200/4 000 |
| 4 | 400/500 | 1 600/2 000 |
| 8 | 80/100 | 800/1 000 |

According Russian legislation 3 high voltage power network staff group (substation electrician maintenance personnel, linemen and test of high-voltage equipment staff) are liable to favourable pensionary.

General public PF electric and magnetic field hygienic standards are time dependent too and are regulated by different documents.

From 1984 in RF 50 Hz EF general public exposure standardization was carried out according to requirements "Sanitary norms and rules of general public protection from exposure of electric field created by overhead transmission lines of power frequency alternating current power transmission" № 2971-84 [4]; from 2010 SanRaN 2.1.2.2801-10 «Changes and Additions №1 to SanRaN 2.1.2.2645-10 "Sanitary-epidemiological requirements to the living conditions in residential buildings and premises» [5].

PF magnetic field general public exposure is regulated from 2007 by Hygienic Norms (HN) 2.1.8/2.2.4.2262-07 "50 Hz magnetic fields maximum permissible levels in premises of inhabited and public buildings and residential territories" [6].

***Table 2.*** *Power frequency electromagnetic field general public hygienic standards*

| *50 Hz electric field* | | *50 Hz magnetic field* | |
|---|---|---|---|
| **Area** | **Permissible level** | **Area, type of exposure** | **Permissible level** |
| Inside of residential buildings and constructions | 0.5 kV/m | Premises, children's preschool, school, general educational and medical institutions | 5.0 μT (4.0 A/m) |
| Territory of a housing estate; at the border of sanitary-hygienic zones of 330 kV-1150 kV OTL | 1.0 kV/m | Uninhabited premises of residential buildings, public and office buildings, manned territories, including territory of gardens | 10.0 μT (8.0 A/m) |
| Occupied district, outside a zone of a housing estate, and also in territory of kitchen gardens and gardens | 5.0 kV/m | Occupied district outside of zone of housing estate, including OTL and CTL zone above 1 kV; work of persons, professionally not connected with power objects maintenance | 20.0 μT (16.0 A/m) |
| Crossing with highways I-IV class | 10.0 kV/m | | |
| Not occupied district | 15.0 kV/m | Not occupied and remote district | 100.0 μT (80.0 A/m) |
| Remote district | 20.0 kV/m | | |

According SanRaN 2.2.1./2.1.1.1200-03 «Sanitary-hygienic zones and sanitary classification of of enterprises, constructions and other facilities" there are sanitary-hygienic zones of extremely high voltage OTL: 330 kV (20 m); 500 kV (30 m); 750 kV (40 m), and 1150 kV (55 m).

### *Protective means*

Protective against 50 Hz EF effects means should correspond:

- Stationary shielding devices - to requirements of GOST 12.4.154-85 SLSS “Devices shielding for protection against power frequency electric fields. The general technical requirements, basic parameters and the sizes”;
- Screening (conductive) suits - to requirements of GOST 12.4.172-87 SLSS “Screening suit complete set individual for protection against power frequency electric fields. The general technical requirements and methods of control”.

Long-term EHV installations operating experience in Russia and abroad shows, that the most universal and effective means of EF adverse effects protection of personnel are individual screening suit complete sets. The modern shielding complete set represents the hi-tech product creating closed electrical spending space around of human body (individual «Faraday’ cell»), excepting penetration of electric field even very high intensity inside of screening spaces. Possessing high conductivity, complete sets shunt human body, excepting course through body displacement and pulse currents.

Conductive (screening) suits for bare-hand (hot-line) work besides protect user breath from dangerous air-ions formed as a result of air ionization under high voltage exposure. Shielding complete sets of the best world manufacturers combine high protective characteristics with demanded sanitary-and-hygienic parameters. Such complete sets are developed in Germany, USA, Japan, etc. Complete sets are widely applied today all over the world at repair and service of extremely high voltage (EHV) installations, in particular at carrying out of various kinds of works on energized TL. In Russia application of individual shielding complete sets is obligatory at repair and service of the equipment in EHV installations zone of influence.

Screening suit protects human body from EF exposure, and concomitant factors too. Unlike PF EF, protection workers from PF MF exposure adverse effects can be provided practically only by means of protection by time and protection in distance; application of protective means is limited. It speaks that for MF any EF shielding means, including the conductive suit is transparent, i.e. from magnetic field exposure screening suit does not protect human body.

### *PF EMF Evaluation Calculative methods*

For PF EMF created by various sources control, settlement and tool methods are used. Settlement methods are mainly used at designing new or reconstruction operating power objects. There is a number of the computer programs, allowing to calculate: EF and MF levels. So, in particular, developed by collective of authors program “Electromagnetic parameters of overhead transmission lines (OTL EMF) [7, 9] allows to define linear density of wires charges (of split phases and lightning-protective cables), electric field strength on surface of phases wires, capacities and inductance of phases, wave resistance, natural capacity and phase current value of line at capacity of loading of equal natural capacity of line, distribution electric and magnetic fields in space surrounding line for various values of voltage and currents of line. The program not only provides estimation of overhead transmission line PF EF and MF levels, but can be used also for cable transmission line MF strength calculation. From the data presented on fig. 1-2, on example of PF EF and MF levels distribution within 500 kV OTL sanitary-protective zone depending on ground-wires distance, is visible type of its change depending on possible workplace of personnel.

***Figure 1.*** *Distribution of Emax strength under 500 kV TL at 1,8 m high for 8-16 m “bottom wire-ground” distance.*

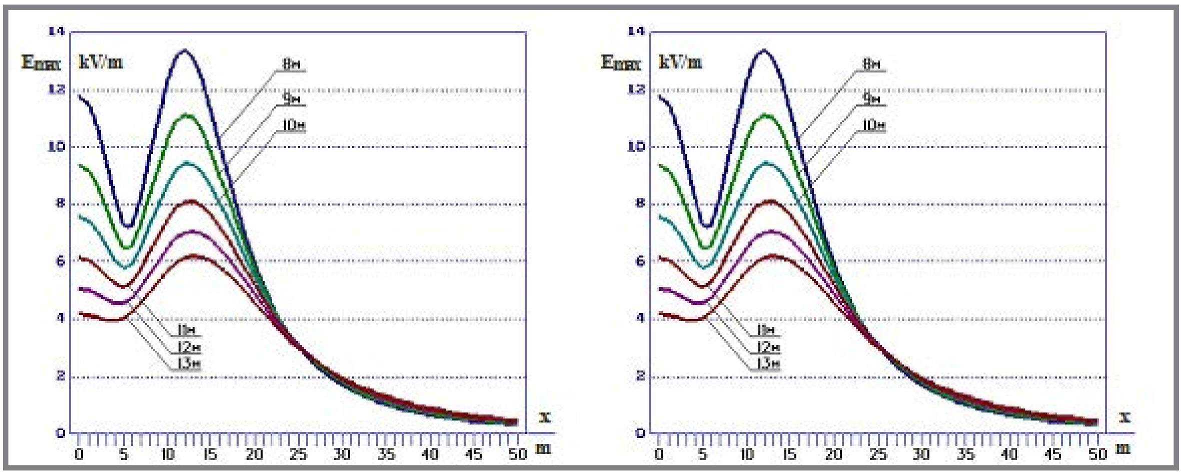
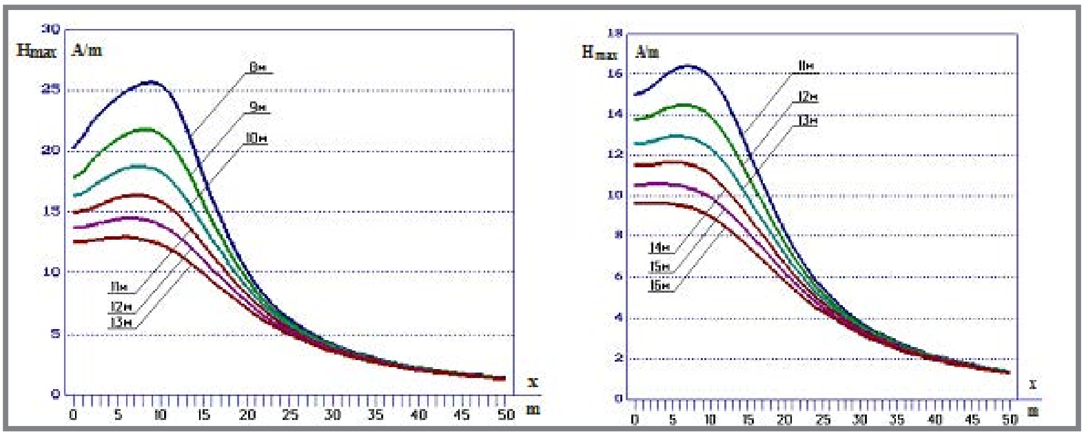


***Figure 2.*** *Distribution of Hmax strength under 500 kV TL at 1,8 m high for 8-16 m "bottom wire-ground" distance.*



The program which allows calculating distribution of created by three-phase multilayered and multi-numbered air reactors in surrounding space magnetic field intensity, i.e. by reactors without the ferromagnetic core has been developed. Such calculations often happen are necessary for determination of different work places, including computer equipped, opportunity of accommodation ("Magnetic fields of three-phase reactors without the ferromagnetic core" (Reactor of MF) [8].

***Technical solutions of PF EMF levels decrease problem***

By decrease in PF EMF levels on workplaces of the personnel, and also in places of general public residing, technical modernization of power equipment is possible, allowing reduce in surrounding space MF levels emitted by this equipment.

The main PF MF sources at work places are transmission lines with their switching equipment and reactors without closed ferromagnetic core. Cable transmission lines play especially important role as until recently they were not considered as potential source of PF MF human health adverse effect.

For general public basic PF EF and MF sources of elevated intensity are the high-voltage overhead transmission lines which are passing on occupied territories, and also cable lines passing both on zone of housing estate, and in the residential buildings, laid on external surfaces of walls, in interfloor overlapping, under ceiling of the built in transformer substations, etc.

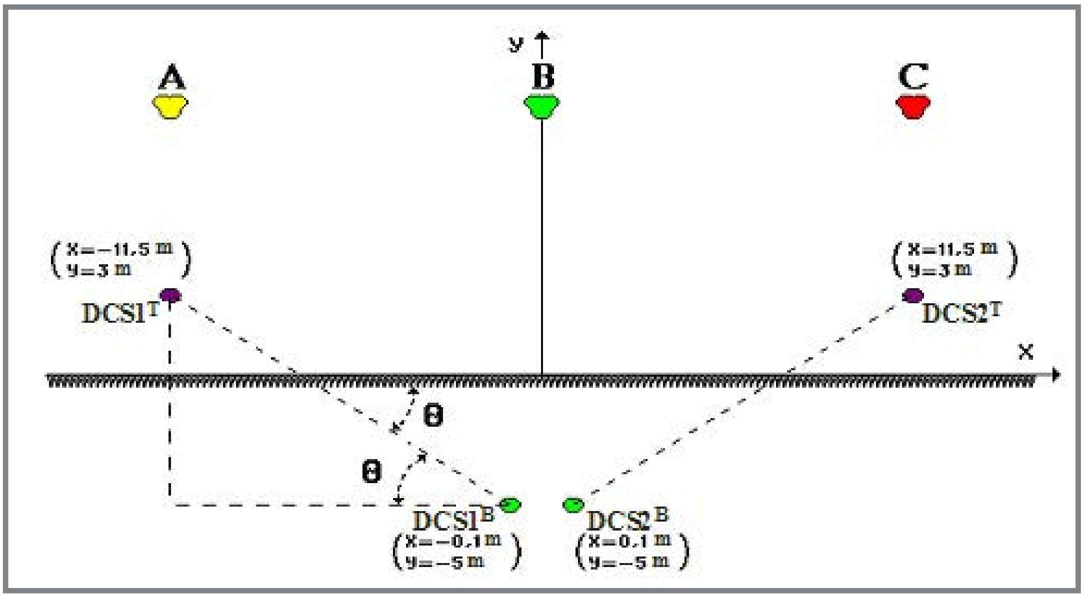
In this connection one of paramount problems becomes necessity of decrease in levels of MF emitted by constantly functioning sources, placed as inside, and outside of inhabited and public buildings, including on occupied territories. Thus it is necessary to mention, that the decision of questions of PF MF sources or places of general public residing shielding traditional methods (application of materials with high magnetic permeability) for long distance sources, such as overhead and cable transmission lines, is practically impossible. In this connection development of new principles of MF emitted by transmission lines in occupied territory decrease (shielding) was represented necessary.

As the perspective development directed on human health preservation maintenance under PF EMF exposure can be considered:

- The Antenna method of extremely high voltage overhead transmission line corona discharge electromagnetic field decrease;
- Shielding of extremely high voltage overhead transmission line electric fields by means of passive, active and resonant rope screens;
- Shielding of extremely high voltage overhead transmission line magnetic fields by means of passive, active and resonant directed contour screens;
- Electromagnetic screens for decrease of electric reactors without the ferromagnetic core magnetic field intensity;
- Designs of electrical reactors without the ferromagnetic core with the lowered levels of created by its in surrounding space magnetic field.

For example, for general public protection from high-voltage OTL PF EF are developed designs of passive, active and resonant rope screens, allowing to reduce of EF intensity under line up to values, no more than 5 kV/m, and also to reduce in 1.5 - 2 times width of zone EF intensity exceeds 1 kV/m. The decision of PF MF levels decrease problem in places of general public residing is provided by design of passive, active and resonant vertical and directed contour screens (fig. 3), allowing to decrease MF level under line up to values no more than 20 μT and also to reduce a zone with MF intensity exceeding 10 μT (8 A/m) – MPL for a zone of housing estate up to two times.

***Fig.3.*** *Directed contour screen, intended for 500 kV overhead transmission line MF restriction.*




For human health safety under conditions of PF MF exposure questions decision, was developed:

- The principle of cable lines configuration by method of rapproachement of virtual cables axes, allowing to lower created by cable lines MF intensity in 50 - 1000 times,
- Designs of air reactors and electromagnetic screens to the reactors, allowing reducing MF intensity in 5 - 50 times [10,11].

Currently, it is often necessary to replace the extremely high voltage transmission lines of cable. Cable line does not have a sanitary-hygienic zone and conservation zone is only 1 m. This creates the danger of high levels of PF magnetic field on the earth's surface. Calculative evaluation of PF electric and magnetic field levels show that in this case there absent PF electric field above the ground, but PF magnetic field may be higher than hygienic norms and therefore may be human health risk factor (childhood leukemia risk elevation). The correct arrangement of the phases cables relative to each other allows to significantly offset the levels of magnetic fields in the environment, including residential area [12].

Calculation for choice the optimal cable line design with PF MF low level inside of building example is shown. The typical dual transforming station (TS) 10/0.4 kV built in residential building with an arrangement of 0.4 kV cable transmission lines (CL) under ceiling in asbestos-cement pipes is examined. Under typical arrangement of each phase cable and zero wire bundle in separate pipe on floor surface, located above TS on 965 mm distance from CL, CL currents (ICL = 1800 A) at maximal symmetric load induce magnetic field (MF) value up to H = 100 A/m, that in 25 times exceeds general public hygienic norms in the Russian Federation (maximum permissible level it is equal 4 A/m). The method of phases and zero wire virtual cables axes rapproachement is used. The arrangement of cables of phases and zero wire in cable bundle can be chosen for minimization of distance between axes of their virtual cables. Such CL design allows decreasing of MF intensity of MT on surface of living room up to 5×10-3 A/m.

By means of computer program "Reactor MF" [13] magnetic field (MF) levels created by four three-phase current limited reactors RTOS-10-3150-0.25-UZ in 220 kV substation management control panel building are calculated. It is shown, that in halls of 10 kV closed switch-gear (10 kV CSG) where cases with automatics containing microprocessor devices are placed, MF intensity considerably above than maximum permissible value (MPV) on handicap immunity, and in located near reactor MF levels are more than occupational exposure hygienic norms. Combined electromagnetic screens (CEMS) application for decreasing of MF induced by current limited reactors levels efficiency is shown. CEMS allow reducing MF levels up to lower than corresponding norms both on noise immunity, and occupational exposure.

Another problem: Under parallel overhead transmission line repair work linemen safety requires to know the voltage that equal voltage (electromotive force) induced in repaired OTL by working parallel OTL currents magnetic field

(MF), since linemen may fall this longitudinal voltage under conductor disconnection possibility. Longitudinal voltage values, induced by magnetic fields currents in parallel overhead transmission line are determined usually by derivative of Carson' integral equations. These equations application have broad "dead space" conditionally the spacing of transmission lines and ground conductivity that lead to great calculative error. The method of longitudinal voltage values induced by magnetic field in parallel overhead transmission lines calculation for any distance between lines is suggested with full coincidence with Carson' equation calculation (in work space) without "dead space"(with high calculation error).

## *4. CONCLUSION*

As a whole the presented data testify that complex actions applied in the Russian Federation on perfection of hygienic regulation of PF EMF electric and magnetic components, development of measures on decrease in its levels, including both collective, and individual means of protection, and also introduction of new technical decisions on maintenance of decrease in PF EF and MF levels up to corresponding hygienic norms both on workplaces of the personnel, and inside of inhabited and public buildings and in territory of zone of housing estate can serve optimum for the decision of questions of human health electromagnetic safety maintenance.

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# A NEW METHOD FOR THE EVALUATION OF CUMULATIVE SOLAR RADIATION EXPOSURE IN OUTDOOR WORKERS


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## ABSTRACT

*So far, few studies on occupational risk related to Solar Radiation (SR) in outdoor workers have attempted to retrace a detailed history of individual exposure. We propose a new method for the evaluation of the SR cumulative exposure both during work and leisure time, integrating subjective and objective exposure data. The former are collected with a questionnaire, which investigates in detail work and leisure activities during life. The latter are available through internet databases for many geographical regions and provide an estimate of the SR on the Earth's surface in specific areas and periods. These data will be integrated in a mathematical model, in order to obtain an esteem of the individual total amount of SR the subjects have been exposed to during their life. This personal exposure index can be used to evaluate specific correlations with the biological effects and to weigh the role of the personal and environmental factors that can increase or reduce SR exposure.*



***Key words:*** *Solar Radiation, ultraviolet radiation, cumulative eye exposure, cumulative skin exposure, occupational medicine.*


## 1. INTRODUCTION

The health risk related to an excessive exposure to solar radiation (SR) is well known [1]. The Sun represents the main exposure source for all the frequency bands of optical radiation, that is the part of the electromagnetic spectrum ranging between 100 nm and 1 mm, including infrared (IR), ultraviolet (UV) and visible radiation. The UV radiation (UVR) is further divided into UV-A (wavelength 380-315 nm), UV-B (315-280 nm) and UV-C (280 - 100 nm), while the infrared into IR-A (1400-780 nm), IR -B (3000 - 1400 nm) and IR-C (1 mm - 3000 nm) [2]. The SR that reaches the Earth's surface has a spectral composition which is significantly different from that emitted by the Sun. This is due primarily to an atmospheric absorption of UVR by various gaseous components, in particular the ozone, which blocks all wavelengths of less than 290 nm , and so all the UV-C and a significant part of the UV- B. Due to the filtering effect performed by the atmosphere, the SR on the Earth's surface is composed largely of frequencies within the IR and the visible radiation which constitute respectively the 45 % and about the 50% of the SR, and only for the 5% of UVR. Although it covers only a minimal part of the spectrum reaching the Earth's surface , the UVR represents the major risk for human health, because it is able to induce the most severe biological effects [3].

Thus, SR may be responsible for acute and chronic adverse effects particularly to the skin and the eyes. It has to be noted that both UV radiation and SR have been classified by IARC as human carcinogens, group I [1, 4].

According to recent studies, outdoor workers have a relevant exposure to SR and it is estimated that about 14.5 million workers in Europe are exposed to SR for at least 75 % of their working time. The exposure levels largely exceed the limit of 30 Joule / m2, effective radiant exposure (Heff) referred to a daily exposure of 8 hours, for artificial UV(European Directive 2006/25/EC) [5-8].

The highest exposure to UVR have been registered among farmers, construction and maritime workers [8-17]. For example, regarding construction workers, recent studies have showed that they are exposed to SR with a Standard Erythemal Dose (SED) of 9.9 in Australia [9]; they have a daily dose ranging from 11.9 to 28.6 SED depending on the altitude in Switzerland [10] and they are exposed to 6.11 SED in Spain [11].

For farmers, high exposure to UVR have been reported in New Zeland [12], Australia [13], Austria [14], and also in Italy, where it has been collected a measure of 1870 Joule / m2 in April [15].

In all these studies the researchers measured an acute exposure to SR in a single day or few days with personal dosimeters.

On the contrary, very few studies have attempted to retrace the history of a chronic exposure to SR in groups of outdoor workers. Rosenthal et al presented a model of ocular and facial skin exposure to UVB that combines interview histories of work and leisure activities, eyeglass wearing and hat use with field and laboratory measurements of UV radiant exposure in a group of American watermen [18]. In Australia, McCarty et al. developed a simplified model for quantifying lifetime ocular UV-B exposure considering the ambient UV-B levels, the duration of outdoor exposure, the proportion of ambient UV-B that reaches the eye and the use of ocular protection [19].

These kind of methods are important because many individual and environmental factors can modify SR exposure and therefore influence the dose of SR that determines the pathological effects. To date there is no adequate knowledge on the interaction among these factors and the occurrence of adverse effects (especially the chronic ones).

The quality and quantity of SR that reaches the Earth's surface vary depending on the time of the day, the day of the year, and geographical location (altitude and latitude). Also the composition of the atmosphere, the presence of pollutants and the meteorological conditions (clouds, rain, snow, etc) may influence the amount of UVR that reaches the ground: they can absorb, refract or diffuse UV rays. Finally, the type of surface can increase or reduce SR exposure, for example fresh snow reflects up to 90% of UV rays [3].

In addition, there are also several individual factors that can influence SR exposure:

- occupational activity: outdoor work is a recognized risk factor for many cutaneous and ocular diseases related to UVR exposure;
- key individual protecting behaviours: regular use of covering clothes, sunglasses and hat, sunscreen protections and the interruption of exposure during the central hours of the day: these factors may be important to reduce SR exposure, both during working and leisure activities [3], [7];
- individual characteristics. People with fair photo-types, such as Fitzpatrick's photo-types I and II, are more sensitive to the UV damage [20].

As previously mentioned, sunlight exposure may cause several acute and chronic effects, mainly ocular and cutaneous, but also immunological and various others. According to a recent WHO review, acute ocular effects with a strong evidence of causality are photokeratitis, photoconjunctivitis and solar retinopathy; chronic diseases are pterygium, cortical cataract and epithelial cancers of the cornea and conjunctiva [1]. Several studies have reported high rates of pterygium and cataract in groups of outdoor workers [21-23].

Regarding the skin, acute effects with strong evidence of causality are sunburns and photodermatoses; chronic effects are photoageing and solar keratoses, and skin cancers: Basal Cell Carcinoma (BCC), Squamous Cell Carcinoma (SCC) and Malignant Melanoma (MM) [1, 24-25].

Several studies have investigated the association between occupational exposure to SR and the occurrence of skin cancers. In a recent German study, outdoor workers showed a relative risk (RR) for BCC of 2.9 ( 95% Confidence Interval – CI 2.2-3.9 ) and 2.5 ( 95 % CI 1.4-4.7 ) for SCC [26]. In the multicenter European study HELIOS, the construction sector showed an Odds Ratio (OR) for epithelial skin cancers of 1.10 ( 95 % CI 0.93-1.31) and the agriculture and fisheries sectors showed an OR of 1.18 ( 95% CI 0.96-1.45 ) [27].

The only immune effect due to SR exposure with a strong evidence of causality in the WHO's review is the reactivation of latent herpes labialis infections [1].

Finally, it has to be noted that SR exposure may also induce positive effects for human health: sunlight has got a key role in the metabolism of vitamin D and therefore in the prevention of diseases such as rickets, osteomalacia and osteoporosis [1].

In future epidemiological studies, a more accurate methodology for assessing occupational and environmental exposure to SR should be useful, in order to allow a better comparison between exposure levels and early biological skin and eye effects, and to study the role of the protective factors in the onset of these diseases.

## 2. METHODS

We are developing a tool for the evaluation of the cumulative lifetime exposure to SR both during working and leisure time, that integrates subjective and objective data.

### a. Subjective data.

Subjective data are collected with an interviewer-administrated questionnaire that assesses exposure modes during work and leisure activities (tab. 1). The questionnaire is composed by three sections, dedicated respectively to work activities, leisure activities and vacation periods. The items of the questionnaire have been elaborated by a team of occupational physicians and experts in optical radiation and industrial hygiene. To answer the questions of each section, the respondent has to consider only the months of the year between March and October (except for vacations on the snow), when the exposure to SR is more intense. At the beginning of each section, the interviewer has to define the period of life, in number of years, the section refers to. In each section, the 12 items investigate the type of outdoor activity, the total time people spend outside during the activity and main personal habits that may influence SR exposure. The habits are investigated with a 5 point Likert-type frequency scale, which ranges from 0, meaning "never adopted this habit during the activity" to 5 "always adopted this habit during the activity".

The administrator has to fill out a new copy of a section – henceforth "tab" – if one of the following changes in exposure habits is detected:

- job change ( i.e. farmer, construction worker, quarryman, fisherman, forester, seaman, etc);
- workplace change, when there is a significant change in the SR exposure (different UV index);
- work tasks change (for the same job, we can have different tasks with different position adopted during work, different number of hours in the sunlight and different protective equipment);
- residence change, when there is a significant change in the SR exposure (different UV index);
- for leisure activities, change in the number of days per week the activity is done by the respondent (normally 2 days per week for working people);
- leisure activity change (i.e. a new outdoor activity, such as a new hobby or outdoor sport);
- protective habits change (i.e. the respondent states that he has started to use sunglasses, hat, sunscreen protections, etc. );
- presence of reflecting surfaces, such as water, snow, metals, etc.;
- vacation place change, when there is a significant change in the SR exposure (different UV index);
- change in the number of days of vacation per year.

To evaluate the feasibility of the questionnaire, a pilot administration was performed by one of the authors (A.M.) in a sample of patients undergoing to a skin examination in an Italian dermatologic center and in a group of volunteers working in the same Italian region. A first administration was performed between 01/16/2014 and 01/30/2014. Based on the evaluation of the preliminary results and on the comments collected, some modifications in the number and in the formulation of the items have been performed, to avoid the redundancy of the information collected and to improve the compliance.

Then, a new administration was carried out between 02/18/2014 and 02/25/2014 , in a different group of subjects. In order to assess the internal consistency of the questionnaire, test reliability was evaluated using the Cronbach-Alpha [28].

At the end of each administration, the patient was asked to rate the comprehensibility and the utility of the three sections on a 5 point Likert scale and to write down suggestions and items not fully understandable, if any.

*Table 1. Main points assessed in the questionnaire to evaluate solar radiation exposure*

| | *Working time exposure* | *Leisure time exposure* | *Working time exposure* |
|---|---|---|---|
| 1 | Type of outdoor job | Place of residence (latitude) | Place of vacation (latitude) |
| 2 | Job place | Place of residence (altitude) | Place of vacation (altitude) |
| 3 | Time spent outdoor | | |
| 4 | Lunch time and place | Practice of outdoor sports | Frequency of sunburns |
| 5 | Prevalent postures | Exposure to sunbeds | Use of suntan lotion |
| 6 | Time in the shade | | |
| 7 | Time near reflecting surfaces | | |
| 8 | Time wearing hat | | |
| 9 | Time wearing sunglasses | | |
| 10 | Time wearing spectacles | | |
| 11 | Time wearing protective clothes | | |
| 12 | Time with sunscreen protections | | |

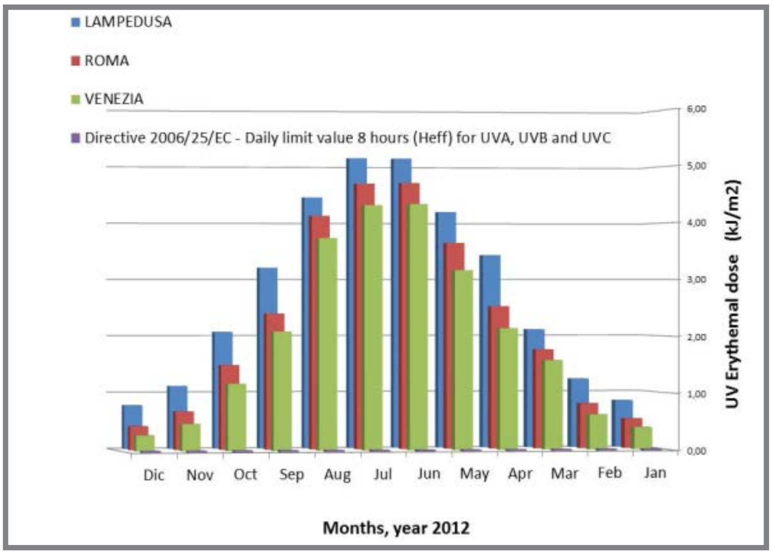
***b. Objective data.***

The second part of the method includes the collecting of objective data, and in particular climate data of the areas indicated in the questionnaire in the period of interest.

These data are available through internet databases for many geographical regions and they provide an estimate of the SR to the Earth's surface. As an example the Tropospheric Emission Monitoring Internet Service (TEMIS) spreads data collected by the satellites of the European Space Agency (ESA) [29]. The first data available is the clear sky UV index, that is the effective UV irradiance (1 unit equals 25 mW / m2 ) reaching the Earth's surface. It is based on the CIE action spectrum for the susceptibility of the caucasian skin to sunburn (erithema) and it is valid for cloud-free conditions at local solar noon. Clear sky UV index in this database is available since November 1978. Another more specific data available from TEMIS is the UV dose, that is an integration of the erythemal UV index, as derived from satellite observations, from sunrise to sunset, with a time step of 10 minutes. The integration takes the cloud cover into account, and thus leads to an estimate of the daily erythemal UV dose. UV dose in this database is available since 1995.

In figure 1 there is an example of the average daily erythemal dose registered during the year 2012 in three different regions in Italy, representing the typical exposure respectively of Southern, Central and Northern Italy: Lampedusa, 35°30' N, Rome, 41°53' N, and Venice, 45°26'N (fig. 1). The data reveal a much higher daily UV dose at the Earth's surface compared to the limits set in the European Directive 2006/25/EC in all of these three places. The chart shows also that the weight of UV doses during November, December, January and February is negligible compared to the March-October period, supporting the choice of not considering November-February in the questionnaire

***Figure 1.** Comparison of the average daily erythemal dose among three Italian regions during the year 2012*



To validate the method taking into consideration environmental and individual factors (posture, etc.), we have done some “on field” measures of personal SR exposure. The results are useful to calculate the reduction- or multiplication-coefficients of the SR exposure that reaches specific parts of the body depending on the posture and on the personal habits adopted.

Two experts in optical radiation and industrial hygiene have collected several measures of effective radiant exposure (Heff) in a group of 6 fishermen working on 3 boats in different places in Italy. The measures has been taken with polysulfon and electronic dosimeters positioned on the back, on the arm, on the chest and on the cap’s peak of the fishermen and also on the boat and on the wharf to measure the environmental exposure.

Therefore, the data collected have been elaborated to determine the ratios of exposure in various parts of the human body during the execution of the fishermen tasks.

## 3. RESULTS AND DISCUSSION

### a. Subjective data.

Here we present the results of the second administration of the questionnaire.

The questionnaire has been administered to 14 subjects. The administration of the questionnaire has taken 25-40 minutes. The respondents are 11 men and 3 women aged between 40 and 79 (mean 55,6).We administered a total of 14 tabs for the outdoor work section, with a value of Cronbach’s Alpha equals to 0.36.

Then we proceeded to identify the items that affected the value of Alpha . These items were “working near reflecting surfaces”, “working with sunglasses” and “use of sunscreen”. Regarding sunglasses and sunscreen, the possible reason that explicates the low Alpha score is the lack of these protective behaviors in this group of outdoor workers: 78% of the sample never uses sunscreen and 64% never wears sunglasses. Regarding the reflective surfaces, the poor internal consistency with respect to the other parts of this section may depend by the fact that reflection phenomena can certainly increase the eye / skin exposure, but their absence, during work time, does not indicate necessarily a lower exposure. Recalculating Cronbach’s Alpha, not considering these 3 items, the score rises to 0.6, which is an acceptable value. Workers, mostly farmers and construction workers, spend outside an average 5h 50’ per day between 9 am and 5 pm and 2h15’ between 11 am and 3 pm. More than the 40% of the outdoor workers regularly use protecting clothes ( pants and sweater ), but they only sometimes use hat.

For the section that investigates leisure activities, we have administered a total of 19 tabs with a Cronbach’s Alpha of 0.63, demonstrating good internal consistency. The respondents declare that they spend outdoor an average time of 4h 50’ between 9 am and 5 pm and 1h 45’ between 11 am and 3 pm, during the weekend between March and October. The practice of an outdoor sport is reported by 6 respondents with an average of 9h 20’ of sport per week. Only 1 subject declares he regularly uses tanning beds for many years. Over 25% of the sample affirm to perform leisure activities often/always close to reflecting surfaces. Regarding the protective habits, 21% and 37 % of the subjects report that they always wear, respectively, hat and sunglasses; only 16 % usually wears protective clothes. Sunscreens are often used by the 10% of the sample.

For the section investigating the vacation periods, we have administered a total of 25 tabs with a Cronbach’s Alpha of 0.48. After the deletion of 1 item regarding the use of suntan oils, which are never used by 77% of the subjects, the Cronbach’s Alpha rises to 0.62. The respondents declare they spend outdoor on average 6h 50’ per day between 9 and 17, and 1 h 50 ‘ between 11 and 15 during the vacation period. They are close to reflecting surfaces (mostly sea water, almost never snow) for 3h 15’ on average. Over 35% of the subjects declare they often/always experience sunburns during holidays. The 48% of the sample always uses sunglasses; the 47% never wears hat and the 59% never uses sunscreens. 5 subjects rated the comprehensibility and the utility of the questionnaire proposed. All of them gave to all the sections a high score both in comprehensibility and in utility. The outdoor work section received an average rating of 4.8 in comprehensibility and 4.6 in utility. The leisure time section has been rated 4.6 both in comprehensibility and in utility. Finally, the vacation section has been rated 4.4 in comprehensibility and 4.6 in utility. No one wrote down suggestions or indicated problems in the formulation of the items.

Summarizing the results of the questionnaire, we can affirm that the highest sun exposure, in terms of hour spent outside during a single day, can be found during the vacation periods; but if we consider the central hours of the day, when the solar radiation is more intense, the longest outdoor periods are referred during work activities. If we consider that work activities are performed all the year, and the vacation activities only few weeks, we can assume that, for outdoor jobs, work exposure is more relevant both than vacation and weekend exposure. Thus, it is very important to encourage the adoption of protective habits, especially during work activities.

### b. *Objective data*

The results of the on-field measures of effective radiant exposure in a small group of fishermen are showed in table 2.

***Table 2.*** *Average relative UV dose in kJ / m2 - effective radiant energy ( heff ) - for four different parts of the human body in 6 fishermen (one working day, sunny weather)*

| | *Back* | *Cap's peak* | *External arm* | *Chest* |
|---|---|---|---|---|
| ***First boat*** | 0.44 - 0.68 | 0.75 - 0.90 | / | 0.28 |
| ***Second boat*** | 0.15 - 0.34 | 0.4 | / | / |
| ***Third boat*** | 0.04 - 0.17 | / | 0.05 - 0.12 | 0.15 |

The highest exposure to solar UVR have been measured for the nose, ear and upper shoulder of the fishermen with a dosimeter placed on the cap's peak of the men. This information is important both to understand which are the parts of the body with a higher exposure and to evaluate the protective role of wearing hat in reducing SR exposure. Working posture is a major factor influencing back and chest exposure: if the worker bends down he shades his chest while at the same time he increases the exposure on the back. Finally, the dosimeter placed on the external arm, due to the "Coroneo's effect", represents the exposure of the external part of the face and of the eye and it is important to evaluate the UVR dose coming from the side (oblique light) [30].

These measures seems to be appropriate to characterize the relationships between working postures, protective equipment and reflecting / refracting phenomena and the exposure of different parts of the body. These measures should be carried out for different outdoor jobs, to finally elaborate specific coefficients for the factors modulating SR exposure.

This approach will allow us to integrate subjective data from the questionnaire with objective climate data, to obtain an exposure index that esteems the cumulative SR exposure of a specific tissue ( 1 ).

$$E_{(h)\ tissue} = \sum x_i \cdot y_i \cdot e_i \cdot E_a \cdot m_a \cdot n_a \qquad (1)$$

The equation (1) is an estimate of the average annual effective UV dose to a specific tissue (Eh) and it takes into account: the fraction of time (xi) the tissue i is actually exposed to SR; the average exposure ratio (yi) of the effective irradiance measured on the tissue i compared with the effective irradiance measured on the horizontal plane; the monthly coefficient (ei) multiplied by the average annual effective radiant exposure on a horizontal plane for the specific locality (Ea) to obtain the average monthly effective radiant exposure on a horizontal plane; the attenuation coefficient (ma) which takes into account the use of protective equipment (hats, sunglasses, sunscreen, etc); the attenuation coefficient (na) which takes into account the presence of environmental factors that moderate the exposure (canopies, awnings, vegetation, etc.).

The final index enable to esteem the total lifelong individual exposure to SR of the subjects, and could be a useful tool to be applied in future epidemiological studies on the effects of SR, and their prevention.

## 4. CONCLUSION

The proposed instrument is aimed to provide a detailed estimate of lifetime exposure to SR in groups of outdoor workers, taking into account individual factors such as the use of sunglasses and protective clothing, prevalent postures during work, etc. These data, integrated with long term climate data, enable the calculation of a semi-quantitative assessment of the cumulative dose of SR to the ocular surface and to various skin areas.

This method is innovative since at present a few studies in the scientific literature have attempted to retrace a detailed history of SR exposure, and it should also overcome studies based on short term instrumental measurement of radiant energy.

In conclusion, the methodology proposed here, applied in epidemiological studies, should allow a better comparison between exposure levels and early biological skin and eye effects, and a deeper study of the role of protective factors in the onset of these diseases.

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# PHYSIOTHERAPY RISK ASSESSMENT IN BULGARIA

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## INTRODUCTION

Physiotherapy is one of the medical disciplines that use various physical factors. Usually three issues are discussed: electrical safety, patient safety and operator safety. While the electrical safety is mainly duty of device manufacturers, the safety of the patients and operators requires a regular assessment of the working conditions. The physical factors generated by the medical devices used in physiotherapy are mainly part of the non-ionizing radiation (NIR) spectrum. The frequency range according to the classification made by M.Israel and P.Tschobanoff (2006) [1] is from static fields (f = 0 Hz) to optical radiation:

i. Devices for local thermotherapy ("Chinese vacuum cleaner" – Qi Gong);

ii. Equipment for galvanotherapy, ion - galvanotherapy and electrostimulation,

iii. "Bipulsator" (for therapy with electric pulses), diadynamic;

iv. Devices for local franklinization – "ion shower";

v. Equipment for low frequency diathermy, diathermal ion galvanization and diathermal electrostimulation; D'Arsonvale devices;

vi. Equipment for treatment with magnetic/electric field within the radiofrequency (RF) range (27.12 MHz), and with microwaves (2,45 GHz) for inductive-thermal therapy; Microwave electropyrexia;

vii. Devices for photo-therapy: Solaria; UV lamps for individual UV therapy; UV sources for PUVA therapy; "SOLUX" and "INFRAROUGE" Lamps;

viii. Laser diodes, gas lasers and other sources of coherent light.

In our previous analysis of the specific exposure situation in physiotherapy we marked the most significant hazards in the working environment of the personnel (Vesselinova 2012)[2]

### *Features in Physical and Rehabilitation Medicine (PRM) wards*

1. Generated EMFs are low (below the exposure limits for thermal effect);

2. Therapeutic sources in most cases operate simultaneously;

3. Location of sources is in direct vicinity in cabins with common walls;

4. The staff is overexposed by some of the equipment at distance 20–30 cm away from applicator;

5. Physiotherapists are exposed to EMF with different frequency ranges many times per day performing their daily duties;

6. Frequency background with diverse stochastic changes running during all of working time

7. Factors of working environment as air humidity, air temperature, vibrations and noise, chemical substances evaporation are not well controlled.

8. Units' location is often on the ground or even underground floor.

***Professional features***

A. Close contact with different types of physical factors of the central body line with the vital EMF sensitive organs—head, eyes, manubrium sterni region, heart, abdominal cavity and large surface from the skin

B. Absence of special protective equipment

C. Dose-control absence

D. Absence of criteria for estimation of potential hazard

E. Absence of program for prevention and prophylaxis.

Thus physiotherapies have to be under regular risk assessment.

***Legislation restrictions***

The first Bulgarian Standard "Labour Protection. Radiofrequency Electromagnetic fields. General safety requirements" is developed in 1978 by joint program with the former USSR on the basis of the Soviet Standard GOST 12.1.006-76. ("System for safety at the work places. Radiofrequency EMF. Common safety demands" / in Russian/). The question about electromagnetic fields exposure in sea transport ships and time dependent dosimetry limits was considered for the first time in Brno in 1968 by the Commission of Transport of Comecon. Thus, the collected experience in medical units along with the military detecting and defense systems development [3,4,5] had led to the development of safety limits and hygiene rules.

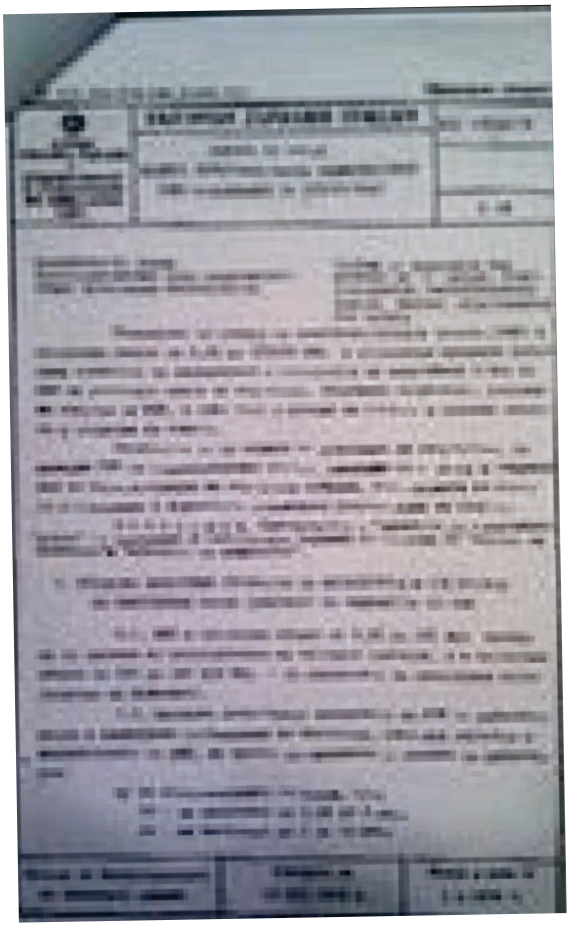


*Fig. 1. The first Bulgarian BSS of EMF safety*

A little bit later two additional standards were created separated by the frequency range characteristics: BSS (Bulgarian State Standard) 14525-78. RF EMF. "Permissible levels and control requirements" and BSS 17137-78. MW EMF "Permissible levels and control requirements". In the revision of the standards in 1990, maximal permissible time duration of exposure was implemented using s.c. parameter "energetic loading".

The development of the Bulgarian EMF safety standard concerning NIR fields used in physiotherapy was preceded by the basic residential investigation in the National Institute of Investigation of Resort Studies and Physiotherapy. The earliest problem found in the literature is cross referred by Kevorkyan [6].

The first Regulations for technical safety and work hygiene in wards of physical therapy and rehabilitation are issued in 1971. Many measures against electricity hazards are proposed: grounding the apparatuses and its placement, cabin structure, permissible exposure levels. They are in line with the accepted levels by Comecon: 10 µW/cm2 - for whole work day; less than 100 µW/cm2 - up to 2 hours per working day; and 1000 µW/cm2 for 10-15 min. work exposures –with googles.

The constructive requirements which were spelled out concern the working environment parameters – light, ventilation, air temperature, as well as safety instructions - journal of technical safety briefings, emitting sources displacement, electrical safety insurance and instructions for electro- and light therapy sections. Usually the units of physiotherapy and rehabilitation in Bulgaria consist of several basic sections based on the main therapeutic means of the specialty. They are: electro-, light therapy sections where artificial physical factors are used: electrical currents, RF and MW therapy, ultrasound therapy, magnetotherapy, UV, IR, light-therapy; kinezitherapy section where therapeutic exercises and medical gym with or without devices are used; hydro/balneology section using hydro procedures, including swimming pool for treatment and recreation; thermotherapy section; inhalation section with micro- and macro-dispersed medicine salts; laser therapy section. In balneotherapy units specific sections such a peloido-therapy section, lye-therapy section, radon-inhalation section and terrain treatment additionally exist.

For every one of them in this Regulations for technical safety and work in wards of physical therapy and rehabilitation as times have actualized the specific instructions are valid. The new medical standards, as main regulative documents for medical practice in Bulgaria were promoted after 2003,when all these criteria were incorporated along with the new European rules which after 2007 became mandatory after Bulgaria got a membership in the European Union [8].

A serious precaution measures in National legislation are set as the reduced work time in physiotherapies to 7 hours [9] and the extended annual holidays (18 days more) for the electro-light-therapy sections physiotherapists [10]. A weakness in the requirements we find in the incorrect interpretation of rules that requires at least 4 hours residence in these sections. In our large recent study we evidenced conveniently the adversity potential of such residence and the specific health influence – degenerative disorders of the muscle skeleton system, menstrual disturbances, leiomyoma uteri, cardiovascular arterial hypertonia and dystonia [11]. So further, measures should be taken to revise the requirements and to cover all physiotherapy subgroups in the risk groups under protective measures. In the ordinance of mandatory preliminary and periodical medical examination, a special Annex with rules about prevention to employ people with contraindicated diseases of some professions with health hazards is introduced [12].

Unfortunately, in last years after the political Reform and transition in Bulgaria (1989) many social processes have been disturbed including labour safety rules in National laws and ordinances. This is especially significant for the requirements of risk assessment period, not reglamented as in the past years. The new Law for health and safety labour conditions treats this issue as an open choice of managers and creates preconditions for poorly controlled work radiation environment setting it on subjective estimation [13]. In the past for the personnel of physiotherapy facilities a salary supplement as well as free lunch and yogurt per working day were provided. In very few units they are kept up to now and strongly dependent on the erudition and professionalism of their employer.

Since 2007, becoming a full member of the EU, Bulgarian legislation should be harmonized with the European regulations. The Directive 2006/25/EC (Ordinance №5/2010 concerning health and safety at work with optical and laser radiation) replaced many of national ordinances. The new Directive 2013/35/EC concerning health and safety of workers exposed to electromagnetic fields is in the stage of implementation in Member States (1 July 2016) after wide discussion by the experts all over Europe.

### *AUTHORITY INSTITUTIONS*

According to the recent legislation some Institutions have the leading role in organizing and control the EMF risk assessment. The Ministry of Health through the Health Minister and Main Health Inspector, as well the Ministry of Labour and Social Affairs through the Minister of Labour, are responsible for legal framework synchronization and control in national level. The National Centre of Public Health and Analyses, the Regional Health Inspectorates, Main and Regional Labour Inspections are authorized to provide local and specialized control and to ensure the measurements' methods and performance.

## **Professionals who contributed the EMF safety development**

### *NATIONAL CENTRE OF PUBLIC HEALTH AND ANALYSES*

This national governmental organization is the pioneer in exposure and risk assessment of occupational work conditions and the social health. These priorities it keeps up to now and gives the official health information and statistics by other national and international institutions (especially WHO).

The first chief of laboratory "EMF in the work background" since 1973 was B. DOBREV, MD

In 1987 Prof. T. SACHANSKA at first counts the EMF work conditions to the enhancing metabolic deviations factors [14].

Prof. M. ISRAEL – the longtime head of the physical factors department. He is one of the first physicists who participated in the establishing of the Bulgarian regulations and the first Bulgarian Standard of Electromagnetic Safety (BSS), also in EMF measurement and exposure assessment in physiotherapies,other occupations, also in residential areas. In the 80-es several studies concerning the exposure and risk assessment in physiotherapy have been performed. The first international conference in the field of EMF health and safety was organized by prof. M. Markov (in 1982, Pleeven), and the second one - in 2001, by Prof. M. Israel (standard harmonization issue), Varna, with the cooperation of WHO.

Dr. M.IVANOVA, the recent head of the physical factors department to NCPHA. She is dealing with the occupational

UV radiation exposure and UV protection of the general public. She concluded that the UV radiation control is compromised and the personnel from different branches of industry and medicine (incl. physiotherapies) are at risk. Therefore, the sources of optical radiation in working environment have to be under special control. In vitro method for UVA and UVB protection of cosmetic products was proposed as well. [15].

Prof. K.VANGELOVA from the laboratory of occupational medicine, as a member of the team of Prof. M. Israel, studied many biochemistry parameters in workers exposed to EMF – TV and broadcasting and physiotherapists. She and her co-authors found arising levels the stress hormones, melatonin levels decreasing especially by shift workers and an increased cardio-vascular risk by these professional groups.

The legislation based in Bulgaria in the field of physiotherapy was created in close cooperation between the scientific and administrative institutions, with the help of Mr. N. CHERNEV, a lawyer in the medical syndicate.

*MILITARY MEDICAL ACADEMY*

With its special mission in the military medicine and health along with the development the high technology medicine over the years many studies and researches in the radiation safety are provided.

In the radiology laboratory the team of Prof. V. BOSEVSKI, MD, with the active participation of the physicist S. RADEV, in 1983 after many measurements of the real exposure of military personnel to RF fields have established the critical to the EMF body zones and proposed a protective galvanized fabric. The main conclusion made is of the need to protect not only the personnel in such conditions but the patient critical irradiation zones. [16,17]. The researches were provided in the Department of Physical therapy and rehabilitation by patients with the close contribution of its chief in these decades Prof. S. GATEV,MD.

At the same time Dr. Ch. DONEV, MD from the Aeromedical Institute dedicated his dissertation on the UHF fields as a hygiene occupational factor points on the need of prophylaxis and precautions in the radio-relay staff and make a suggestion of the physiotherapy personnel [18].

Dr. P ZAREV, MD from the immunological laboratory about 10 years later turned his scientific interests on the immunological status of the military staff under UHF fields influence and did not found any complications [19].

Dr. L.VESSELINOVA, MD revealed the bio-effects of the exposure to long term exposure to low intensity EMFs in physiotherapy practice on the personnel morbidity profile in complex. Three subgroups formed by exposition burden criteria are studied and statistically significant the subgroup with the longest residence in the electro-light therapy section is evidenced as the group in the highest risk level. The main pathology established and evidenced correlation with the specific work EMF condition is: periodontitis, cardio-vascular disorders, allergies, photosensibilisation, osteoporosis, menstrual disturbances, leomyoma uteri, miscarriages and confirmation the described in the literature "radio-sickness" manifesting with neuro-behavioral disturbances: headache, weakness, sleep and libido disturbances. The results by other two studied subgroups contribute to the general conclusion that in physiotherapy units are not unexposed zones and personnel out of need of special precautions. The adverse potential the low-intensity long-term EMF is undoubtedly elucidated [11].

In the last 20 years until his death in 2012 the most of EMFs' measurements in the military as well as in the hygiene assessment we owe to our colleague, the physicists P. TCHOBANOFF.

*MEDICAL INSTITUTIONS*

Research and standardization of EMF for therapeutic use and in general hygienic estimate has been performed mainly in Research Institutes, Universities and Medical Schools. The first Ph.D. thesis was defended in late 1970s in Varna Medical School by Bozidar Stefanov, MD on the hygienic estimate of EMF. Later Dr. Stefanov became Chair of Department of Hygiene in Pleven Medical School. The second Ph.D. thesis was defended in late 1970s by Dobri Genkov in Plovdiv Medical School on effects of EMF on animals

In the 60-ties of the XX century in the National Research Institute of Resortology and Physiotherapy joint with the

Institute of post-graduate improvement of physicians a research team (S.DIMITROVA,V.MARINOV, G.PETRUNOV, T.DRAGIEV and G.ZAGORSKI) leaded from Prof. T.TODOROV, MD investigated the work conditions in physiotherapy, the health status the personnel and the importance of the constructive materials for promoting health status deviations [20,21,22]. Many ordinances, rules and standards, after that have been changed but not always in the right direction.

As a President of the Council of rehabilitation by Ministry of health in the 1980's Prof. D.KOSTADINOV, MD from the Medical University of Sofia have supported many indoor rules of safety and precautions.

Prof. N. Todorov, MD asked Acad. Ivan Daskalov to engineer Magnet-N80 –the first Bulgarian device for low-frequency magneto-therapy. Further Prof. Todorov created rules for use of this device in treatment of various medical problems and educated medical professionals for the safety use of device.

Significant contribution in magnetobiology and magnetotherapy was made in the Department of Biophysics of the Sofia University. Together with search for basic mechanisms of action, Prof. M. Markov and his co-workers developed precized dosimetric approach. Prof. Markov organized two International School "EMF and biomembranes" in 1986 and 1989 with participation of the most recognized scientists and clinicians from Europe, North America and Asia.

Prof. M.MARINKEV, MD is one of the recent followers of the emeritus Prof. Y. Gatcheva, MD (who stimulated the early Bulgarian electrotherapy development) with huge contribution to improvement of the electrophysiotherapy applications in practice, as well as by children where the school of Prof. N. Sarafova influenced his first investigations and interests.

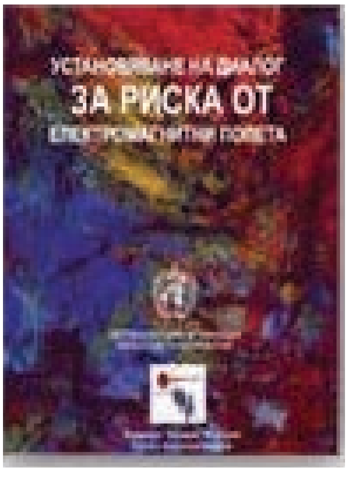
In 2000 Prof. S.KEMEROV, MD studied the mean of the application of three different types of high frequency therapy currents (metric, decimeter and centimeter range) on some structure and functional changes in the central nervous system (CNS) by experimental animals. In the results he confirmed the accepted need of treatment course interruption to prevent the deleterious effect on the central nervous system evidenced histologically and defines as more hazardous the moderate intensity fields (10 mW/cm2) especially metric waves. In the conclusions the author underlined the used in the medical practice therapeutic schemes for EMF cause by laboratory animals weak reversible structure and functional deviations in its CNS which takes to the need of control the chronic expositions in clinical practice [23].

### *FIRST NATIONAL MEETING OF "THE HEALTH RISK IN THE PHYSIOTHERAPY PRACTICE. NONIONIZING RADIATION"*

In 1998 the Bulgarian National Programme Committee (BNPC) on NIR was established as a part of the International EMF Project (WHO) in 1996. It includes 38 experts and researchers in EMFs from more than 15 National Institutions. In the beginning of the 2003 at the first annual session the BNPC our proposal of hosting a scientific meeting was accepted and in the end of the year in Sofia, in the military Medical Academy the first national colloquium took place. It was organized by WHO/BNPC and Co-organizers: Association of Physical Medicine and Rehabilitation/Faraday Foundation under the auspices of the MILITARY MEDICAL ACADEMY.

***Fig. 2.*** *The Program booklet*

***Fig. 3.*** *The WHO edition in Bulgarian*




The colloquium was with the special participation of the WHO epidemiologist Prof. L.Kheifetz presented the new WHO issue of risk communication.

Later, in 2006 it was printed in Bulgarian. At this one-day colloquium a big interest by the side of specialists of physical and rehabilitation medicine was shown – more than 75 participants. There were presented some very actual topic orientated presentations: KHEIFETS, L. – WHO and the risk assessment; ISRAEL, M. – Nonionizing radiating sources in physiotherapy facilities. Health risk"; ISRAEL, M. & L. VESSELINOVA –Normative ensuring the medical personnel protection from nonionizing radiation; VESSELINOVA, L. – Investigation the health status of the personnel from physiotherapy wards; KEMEROV, S & M. MARINKEV – Experimental studies on EMF used in the physiotherapy practice [24]. The presentations stirred up wide discussion and set up the reasonable questions of occupational safety and prevention as well as the need of following up and "back into the game" the old rules for electrotherapy sections, neglected by some contemporary public processes.

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- Scientific Project of the National Center of Hygiene, Medical Ecology and Nutrition, funded by the Bulgarian Ministry of Education and Science "Evaluation of electromagnetic radiation effects on the cardiovascular system and melatonin secretion among medical personnel" 2005 (agreement № 1010/2000) An individual exposure assessment of the radiation from the whole NIR spectrum in the physiotherapies in Bulgaria was made. The Project was leaded by Prof. Michel S. Israel. The team included many of the topical Bulgarian specialists: Ch.Deyanov, MD, M.Ivanova, P.Tchobanov, K.Vangelova, D.Velkova, M.Vatcov, L.Vesselinova MD.
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## *INSTEAD CONCLUSION*

Bulgarian experience in the risk assessment of the physiotherapy occupational environment is proven during the years. It is based on traditions of more than one generation of specialists in different fields – physicists, physicians, lawyers, trade unions and responsible administrative experts whose efforts leaded to set the first requirements for safety. In the last 25 years many standards and the legislations are changed and synchronized to the European ones. Some good old documents are replaced automatically without accounting the national peculiarities. Other are too liberalized but the need of prevention, assuming the new radiation situation and the specialties in the physiotherapy profession could not be neglected. Keeping in mind the long-years' experience of the Bulgarian risk assessment in physiotherapy is a valuable part of the entire electromagnetic safety knowledge.


## *ACKNOWLEDGEMENTS:*

All whose career made possible this fundamental report of the Bulgarian physiotherapy risk assessment "life-history"!

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# CHARACTERIZATION OF OCCUPATIONAL EMF EXPOSURE IN HYDROELECTRIC POWER PLANTS AND HIGH VOLTAGE SUBSTATIONS

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## ABSTRACT

*European legislation for the protection of workers from exposure to EMF was completed in June 2013 with the Directive 2013/35/EU, a specific one of the framework Directive 89/391/EEC and part of the overall legislation for Occupational Health and Safety (OHS).*

*Extremely low frequency (ELF) fields exposure is a very important part of the Directive since it is ubiquitous in power plants and its associated transmission and distribution systems and can reach high values in many cases. Moreover, the occupational exposure limit values are raised compared to the ones in the former 2004/40/EU Directive, following the 2010 ICNIRP guidelines. This fact, in conjunction with the relative lack of bibliographic information, makes the knowledge of the exact occupational exposure levels, in all working scenarios and practices, highly important in the framework of the risk assessment procedure.*

*Different working areas (hydroelectric power plants, open and closed type substations) have been chosen for measurements in order to access occupational exposure compared to the limit values given by the Directive and to the main principles of OHS. Measurements of the electric and magnetic fields were performed at places where the worst-case exposure conditions have been identified. The harmonic content was taken into account in order to estimate the overall ELF exposure.*

***Key words:*** *ELF fields, electrical substations, occupational exposure, Occupational Health and Safety (OHS), Directive 2013/35/EU.*

## 1. INTRODUCTION

High voltage substations are considered to be a major part of the electric power transmission and distribution system. Over the last years, there has been a steadily increasing concern in Greece (as demand for electricity was growing) expressed by people working in the area of an electric substation, whether the long term exposure to power frequency electric and magnetic fields may cause adverse health effects. Therefore, in the literature, there are several published studies concerning electric and magnetic fields measurements in working places, such as power substations [1],[2],[3],[4].

In view of the harmonization of the national legislation with the (new) Directive 2013/35/EU of the European Parliament and the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields), (OJEC L 179/1, 26 June 2013), the Ministry of Labour, Social Protection and Welfare in cooperation with the Greek Atomic Energy Commission (EEAE), have taken the initiative to design and carry out a measurement campaign and a risk assessment programme, in order to identify the existing situation concerning occupational exposure to electromagnetic fields in various working environments in Greece. This programme was agreed, under a memorandum in progress, to start by performing measurements in specific locations where high levers of occupational exposure are likely to be found. Part of the program, organized in collaboration with PPC S.A., dealt with power plants, substations, transmission & distribution systems, is presented here. Measurements were compared to the limit of the new directive, discussed below.

The Directive gives a time period of three years to Member States to adopt it. In this period, apart from the legislative procedure and consultation with the stakeholders, it's also highly important the above mentioned "technical preparation". The same, somehow, philosophy is followed by the new Directive. Article 14 prescribes that at least six months before 1.7.2016, a practical guide will be released to facilitate the implementation.

The competent national authority for the protection of the general public and the environment from artificially produced non-ionizing radiation in Greece is the Greek Atomic Energy Commission (EEAE). To this end, EEAE carries out measurements in the vicinity of all kinds of facilities emitting power frequency electric and magnetic fields (e.g. power lines, 150kV/20kV substations) in order to monitor whether the exposure limits are being adhered to. EEAE has been accredited in accordance with the requirements of the EN ISO/IEC 17025 standard for performing this kind of measurements.

The main aim of this study is to present in situ magnetic and electric field measurements in at 4 indoor and outdoor typical 150kV/20kV substations. Real time measurements were conducted inside and outside the substations and around the power lines, since the actual field exposure of workers is important. To this end, measurements were carried out in the vicinity of 150kV busses, in the control rooms, around power transformers in the substation, under the incoming overhead or above underground 150kV transmission lines and under the outgoing 20kV overhead distribution lines.

The same measuring approach was followed to three hydroelectric power plants, covering their power generators, control rooms, transmission systems and substations.

The Greek network for electric power transmission and distribution operates at 50 Hz, meaning that the fundamental harmonic component of magnetic and electric field is present at this frequency. The above mentioned substations are a component of the Greek electrical transmission system, which converts electricity at 150kV to 20kV and thereby provides the link with the electric power distribution network.

## 2. METHODS

### *2.1 Legal obligations*

In 2002, Greece put into force a legislative act, implementing the 1999 Recommendation of the Council of the European Union, for the protection of the general public. European legislation concerning the protection of workers from exposure to electromagnetic fields (EMF) is recently completed with the Directive 2013/35/EU a specific one of the framework Directive 89/391/EEC and part of the overall legislation for Occupational Health and Safety (OHS).

Power frequency exposure is a very important part of the Directive since it is ubiquitous in power plants and substations. With their associated transmission and distribution systems it can reach high values in many cases. Moreover, the occupational exposure limit values are raised compared to the ones in the former 2004/40/EU Directive, following the 2010 ICNIRP guidelines. This fact, in conjunction with the relative lack of bibliographic information, makes the knowledge of the exact occupational exposure levels, in all working scenarios and practices, highly important in the framework of the risk assessment procedure.

In 1998 ICNIRP guidelines, the reference level for magnetic flux density at 50 Hz, is set to 500 μT and to 10kV/m for the electric field strength, being in accordance with the corresponding Action Value in the repealed Directive 2004/40/EU. It must be noted that according to the Directive 2013/35/EU, the corresponding strict level (low AL) for 50 Hz is set to 1000 μT, in accordance with the 2010 ICNIRP guidelines.

The new 2013/35/EU Directive implies a system of multiple exposure limits (higher than the general public and higher than the former 2004/40/EU Directive). The following definitions are provided, which refer to occupational exposure:

a) 'exposure limit values (ELVs)' means values established on the basis of biophysical and biological considerations, in particular on the basis of scientifically well-established short-term and acute direct effects, i.e. thermal effects and electrical stimulation of tissues. ELVs can be classified to:

   (i) 'health effects ELVs' means those ELVs above which workers might be subject to adverse health effects, such as thermal heating or stimulation of nerve and muscle tissue

   (ii) 'sensory effects ELVs' means those ELVs above which workers might be subject to transient disturbed sensory perceptions and minor changes in brain functions

ELVs are non measurable, considered as the substantial limits.

b) 'action levels (ALs)' means operational levels established for the purpose of simplifying the process of demonstrating the compliance with relevant ELVs or, where appropriate, to take relevant protection or prevention measures specified in this Directive. More specifically, concerning action levels (ALs) for occupational exposure to low frequency magnetic fields, the following terminology is applied.

   (i) low ALs are, for frequencies below 400 Hz, derived from the sensory effects ELVs

   (ii) high ALs are derived from the health effects ELVs for internal electric field related to electric stimulation of peripheral and autonomous nerve tissues in head and trunk. Compliance with the high ALs ensures that health effects ELVs are not exceeded, but the effects related to retinal phosphenes and minor transient changes in brain activity are possible, if the exposure of the head exceeds the low ALs for exposures up to 400 Hz.

ALs are measurable RMS values, given by special instrumentation. Tables 1 and 2 show corresponding ALs.

***Table 1.*** *Upper and lower (measurable) Action Levels for electric field strength*

| *Frequency range* | *Electric field strength Low AL (E) [V/m] (RMS)* | *Electric field strength High AL (E) [V/m] (RMS)* |
|---|---|---|
| 1–25 Hz | 2.0 x 104 | 2.0 x 104 |
| 25–50 Hz | 5.0 x 105 /f | 2.0 x 104 |
| **50 Hz - 1.64 kHz** | **5.0 x 105 /f** | **1.0 x 106/f** |
| 1.64 – 3 kHz | 5.0 x 105 /f | 6.1 x 102 |
| 3 kHz–10 MHz | 1,7 x 102 | 6.1 x 102 |

***Table 2.*** *Upper and lower (measurable) Action Levels for magnetic flux density*

| *Frequency range* | *Magnetic flux density Low AL(B) [mT] (RMS* | *Magnetic flux density High AL(B) [mT] (RMS )* | *Magnetic flux density AL-limbs localized field [mT] (RMS)* |
|---|---|---|---|
| 1–8 Hz | 2.0 x 105 /f2 | 3.0 x 105 /f | 9.0 x 105 /f |
| 8–25 Hz | 2.5 x 104 /f | 3.0 x 105 /f | 9.0 x 105 /f |
| **25–300 Hz** | **1.0 x 103** | **3.0 x 105 /f** | **9.0 x 105 /f** |
| 300–3 kHz | 3.0 x 105 /f | 3.0 x 105 /f | 9.0 x 105 /f |
| 3 kHz–10 MHz | 1.0 x 102 | 1.0 x 102 | 3.0 x 102 |

The above values in bold are the main limits to be compared to the measurements, but also the harmonic content of the signals will be taken into account, namely:

$$\sum_{j=1\,Hz}^{10\,MHz} \frac{E_j}{E_{R,j}} \leq 1 \quad \text{and} \quad \sum_{j=1\,Hz}^{10\,MHz} \frac{H_j}{H_{R,j}} \leq 1$$

Where: Ej the electric field strength at frequency j; ER, j the electric field AL at frequency j as given in Table 1;

Hj is the magnetic field strength at frequency j; HR, j the magnetic field AL at frequency j as given in Table 2.

### *2.2 OHS basic principles*

OHS legislation is extended, sometimes highly specialized and mainly derived from the implementation of European Directives. In Greek legislation a great codification effort was made recently with law 3850/2010. The first main principle is called: “the employer’s responsibility”, meaning that the employer is responsible for the health and safety of every employee linked with him in any manner. Another important principle is the scaling of OSH corrective acts, starting from technical and organizational ones; personal protection acts are the last approach. Highly important are also the information, the consultation and the training of the workers. Finally, some of the basic prevention principles from the occupational hazards are: i) the complete avoidance of the hazards, ii) the risk assessment in cases that they cannot be avoided, iii) the substitution of hazardous activities with less ones, iv) facing the source of the hazards, v) the adaptation to the technical evolution.

### *2.3 Measuring equipment*

The magnetic flux density B (μT) and the electric field strength E (V/m) is measured with a 3-axis commercial meter EFA-300 (Narda Safety Test Solutions GmbH). EFA-300 is a portable digital unit for isotropic and non isotropic measurements, operating in the frequency range 5 Hz–32 kHz. The detection range is 100 nT–32 mT for magnetic flux density and 0,7 V/m–100 kV/m for electric field strength. The EFA-300 basic unit has an integrated magnetic field sensor and according to the used measurements methodology, selected probes are also connected to basic unit. The EFA-300 includes also a cubic-shaped, isotropic, E-field module. This E-field module contains both the sensor and circuitry that allows it to be operated independent of the base unit. Maximum root mean square (RMS) values can be measured for both fields, for selected frequencies and frequency ranges.

The above mentioned instrument has the capability of performing an evaluation of field exposure in comparison to i) major standards and guidelines for general public or occupational exposure, expressed as % percentage of the corresponding standards (e.g. ICNIRP1998 occupational or general public, BGV B11, VDE 0848), ii) harmonic and spectrum analysis using Fast Fourier Transform (FFT).

EFA-300 was operated in ‘‘field strength’’ (FS) mode and in ‘‘Exposure Shaped Time Domain’’ (STD) mode. The FS mode displayed the root mean square (RMS) of the three orthogonal measured field strengths, derived by the “flat frequency-response” probes, connected to the basic unit. The Exposure STD mode displayed the measured field as a percentage of reference levels, according to 1998 ICNIRP guidelines, by filtering the signal across the frequency range 5 Hz–32 kHz. It uses an attenuation curve simulated by first-order filters to account for the frequency response, following the 1998 ICNIRP guidelines. The reference levels, defined in the 1998 ICNIRP guidelines have been taken into account, due to the lack of measurement devices compliant with Directive 2013/35/EU. The expanded measurement uncertainties (corresponding to a 95% confidence level), were calculated as 5.5% for the measurements of magnetic flux density, 6.3% for the measurements of Exposure STD, 6.5% for the measurements of electric field strength and 7.2% for the measurements of Exposure STD. It must be noted that the calculated uncertainty values for each measurement slightly differs, but the above mentioned values are quite representative.

The locations selected for measurements were these that the workers normally spend the majority of their working time or do their tasks, in order to represent the realistic working conditions. During the measurement, the workers were not present in the work area. This was done to eliminate their influence on the electric fields. Each measurement location was also selected after extensively surveying the area of interest and selecting the position where exposure reached a maximum value.

## 3. RESULTS

This paper presents the results of measurements of the magnetic and electric fields at 4 indoor and outdoor typical 150kV/20kV substations (Ag. Dimitrios, Markopoulo, Irakleio, Elliniko) and at 3 hydroelectric power plant 150kV/20kV substations, in Greece (Louros, Pournari I and Pournari II). The substations area included transformers, circuit breakers, feeders and busses.

The electric-field sensor was placed on a wooden tripod at a position of 2 meters above ground level at all measurement positions and connected to the main instrument with a 10-m fiber optic cable. This connection and the distance between the sensor and the main instrument were necessary in order to ensure that electric field strength and distribution in the substation area, would not be perturbed by the presence of the operator.

The magnetic field at all cases was measured with the instrument hand-held at a position of 2 meters above ground level. The substation’s magnetic fields are in general, more complex than the magnetic fields near power lines or inside homes. The substations are characterized by a concentration of magnetic field sources, which consist of many interconnecting points for transmission and distribution lines. On the other hand, the line currents passing through substations busses and equipment produce magnetic fields within the substations, which have almost the same attributes as magnetic fields beneath the lines themselves. The magnetic fields in the vicinity of such power lines depend on the type of line, its load and the distance from it.

### *3.1 High Voltage Substations*

A representative configuration of an outdoor substation (Ag. Dimitrios), is presented below:

***Figure 1.****Ground plan of the substation area, in which the measurement positions are depicted*

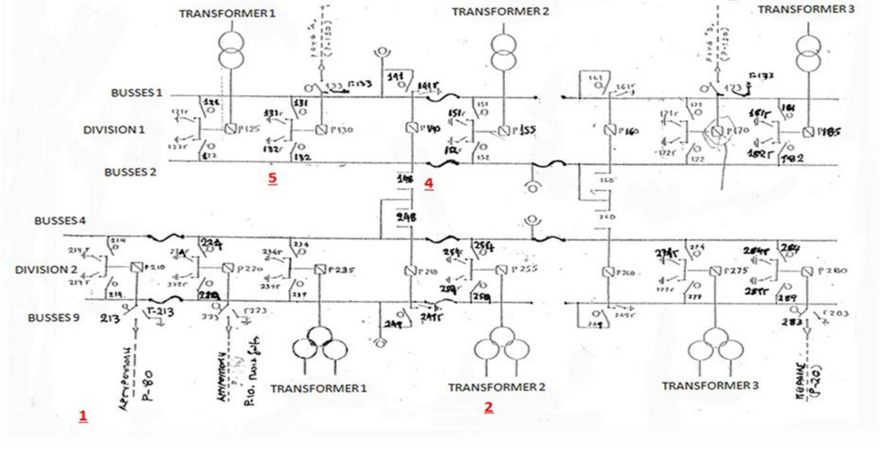


*Table 3. Measurements of the Magnetic flux density and the Electric field strength*

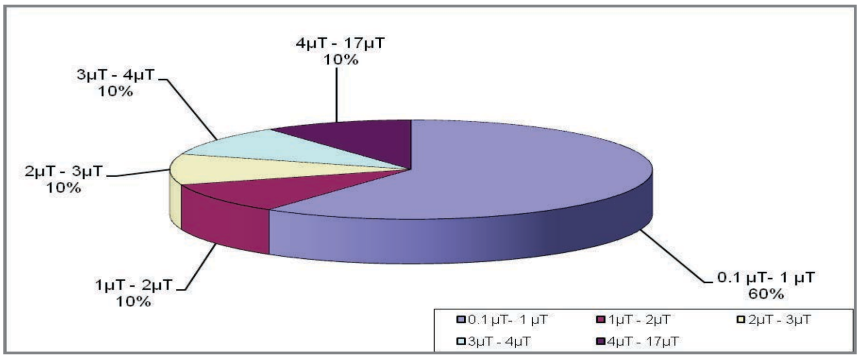
| *Measurement point* | *Magnetic flux density, B(μT)* | *Percentage (%) of the limit value of B, in the frequency range 5 Hz - 32 kHz (1998 ICNIRP occupational guidelines)* | *Electric field strength, E (V/m)* | *Percentage (%) of the limit value of E, in the frequency range 5 Hz - 32 kHz (1998 ICNIRP occupational guidelines* |
|---|---|---|---|---|
| Point 1 (see ground plan) | 0.38 | 0.06 | 169.7 | 2.31 |
| Point 2 (see ground plan) | 3.51 | 0.71 | 9.9 | 0.10 |
| Point 3 (see ground plan) | 0.43 | 0.08 | 171.4 | 2.08 |
| Point 4 (see ground plan) | 0.29 | 0.07 | 117.8 | 2.33 |
| Point 5 (see ground plan) | 0.34 | 0.06 | 479.4 | 3.22 |

*Table 4. Maximum values of the Magnetic flux density and the Electric field strength, in all 150kV/20kV substations*

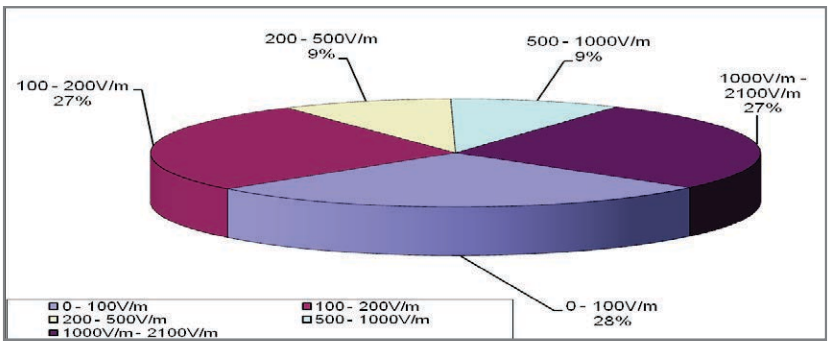
| *B and E measurement points* | *Max value of Magnetic flux density, B (μT)* | *Max value of ercentage (%) of the limit value of B, in the frequency range 5 Hz - 32 kHz (1998 ICNIRP occupational guidelines)* | *Max value of Electric field strength, E (V/m)* | *Max value of rcentage (%) of the limit value of E, in the frequency range 5 Hz - 32 kHz (1998 ICNIRP occupational guidelines)* |
|---|---|---|---|---|
| For the Markopoulo substation : near the Transformer No2 for B and under a double circuit 150kV power line, installed in lattice towers for E | 3.84 | 0.92 | 892.5 | 15.78 |
| For the Irakleio substation : at the P125 office for B and at the access path leading to the busses for E | 16.14 | 3.43 | 2038.3 | 26.23 |
| For the Elliniko substation : above the underground 150 kV transmission line for B | 2.38 | 0.41 | - | - |

The distribution of the measured RMS values in all the substations, for the magnetic and electric fields, are seen below:

*Graph 1. Distribution of the measured magnetic flux density values in all substations*




*Graph 2. Distribution of the measured electric field strength values in all substations*



At all the above mentioned cases, the fundamental frequency was 50 Hz and the harmonic components were negligible, since after performing harmonic analysis, no significant harmonic components were found. This mode (harmonic analysis) embedded in the used measuring equipment (EFA 300) enables fast, convenient evaluation of the harmonic spectrum. This equipment lists the field strengths of the measured fundamental frequency (50 Hz) along with up to the first 8 harmonics, given as percentage of the fundamental. Our methodology is to compare the total harmonic content - KT, of the first 8 harmonics (vector sum of K1 up to K8) with the overall total noise/harmonic factor - KN, as given also by the instrument as percentage of the fundamental frequency. If the KT value is very close to the KN value, this means that the harmonic components of the measured field, can be considered negligible.

The "worst" case of inconsistency between the electric field strength E (V/m) and the corresponding % exposure STD measured value (where an increased value of exposure STD is clearly recognized if compared with the measurement result of E divided by the limit value at 50 Hz), is a measurement point at the electrical substation of Markopoulo, where the measured values were 892.5 V/m for the electric field strength and 15.78% for the corresponding exposure STD (see Table 4). By using the harmonic analysis mode of the EFA 300, the results showed that the field strength of the first 8 harmonics - KT, is only 1.64% of the fundamental (50 Hz) and the total harmonic content (up to 32kHz) - KN, is only 1.65%, which is almost equal to the above mentioned value of 1.64% (total harmonic distortion <3%) [4], [5], see Table 5.

***Table 5.*** *Results of the harmonic analysis mode of EFA-300 for a measurement point at the high voltage substation of Markopoulo*

| Fundamental f (Hz) | E (V/m) | K1 (%) | K2 (%) | K3 (%) | K4 (%) | K5 (%) | K6 (%) | K7 (%) | K8 (%) | KT (%) | KN (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 892.5 | 0.045 | 0.3182 | 0.0249 | 1.5029 | 0.0115 | 0.5861 | 0.0053 | 0.0268 | 1.6453 | 1.6513 |

Applying this procedure to all measurement points, it is clear that the harmonic components are extremely small.

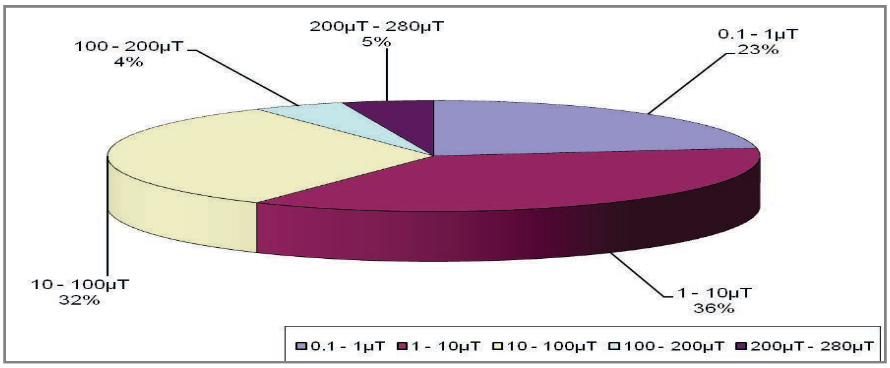
### *3.2 Hydroelectric power plants*

***Table 6.*** *Maximum measured values of the magnetic flux density (B) and the Electric field strength (E), in all hydroelectric power plant substations*

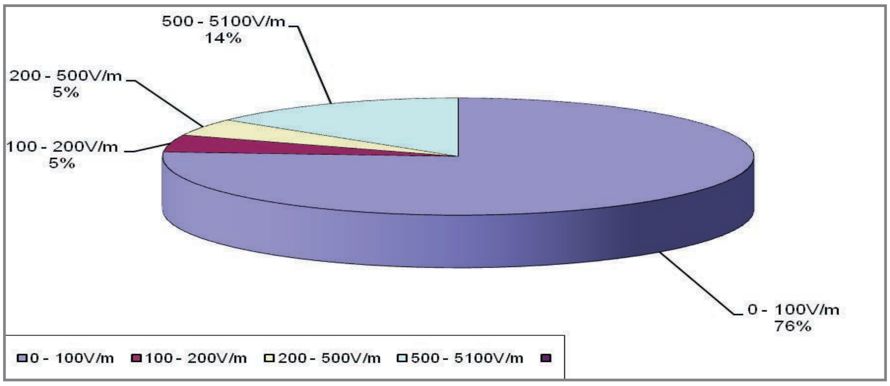
| *Measurement points for E & B* | *Max value of Magnetic flux density (μT)* | *Max value of percentage (%) of the limit value of B, in the frequency range 5 Hz - 32 kHz (1998 ICNIRP occupational guidelines)* | *Max value of Electric field strength (V/m)* | *Max value of percentage (%) of the limit value of E, in the frequency range 5 Hz - 32 kHz (1998 ICNIRP occupational guidelines)* |
|---|---|---|---|---|
| For the Louros hydroelectric power substation: in front of the 2st generator for B and in front of the switchbreak R10/150kV for E | 24.26 | 5.62 | 5056.8 | 57.68 |
| For the Pournari I hydroelectric power substation : in front of the 2nd generator bus duct for B and under the disconnect switch of Unit 2 for E | 92.78 | 18.82 | 1803 | 20.41 |
| For the Pournari II hydroelectric power substation : outside the engineering room for B and under the bridge crane for E | 276.63 | 51.09 | 2432.54 | 27.18 |

The distribution of the measured RMS values in all the power plants, for the magnetic and electric fields are seen below:

***Graph 3.*** *Distribution of the measured magnetic flux density values in all hydroelectric power plants*




***Graph 4.*** *Distribution of the measured electric field strength values in all hydroelectric power plants*




As in the case of the 4 typical indoor and outdoor high voltage substations, in all measurement points at the hydroelectric power plants, the fundamental frequency was 50 Hz and the harmonic components were negligible. By also using the harmonic analysis mode of the measuring equipment for the maximum measured value of the electric field strength (measurement point at Louros substation where the measured values were 5056.8 V/m for the electric field strength and 57.68% for the corresponding exposure STD (see Table 6), the results show that the field strength of the first 8 harmonics - KT, is only 0.747% of the fundamental and the total harmonic content (up to 32kHz) -KN, is only 0.7512%, which is almost equal to the above mentioned value of 0.74% (total harmonic distortion <3%) [4], [5], see Table 7 .

***Table 7.*** *Results of the harmonic analysis mode of EFA-300 for a measurement point at the hydroelectric power plant substation of Louros*

| Fundamental f (Hz) | E (V/m) | K1 (%) | K2 (%) | K3 (%) | K4 (%) | K5 (%) | K6 (%) | K7 (%) | K8 (%) | KT (%) | KN (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 5056.8 | 0.0619 | 0.2914 | 0.0035 | 0.5951 | 0.0086 | 0.3389 | 0.0072 | 0.0145 | 0.7470 | 0.7512 |

In general, at all 150kV/20kV typical electric power substations and hydroelectric power plant substations, the levels of magnetic and electric field to which workers are exposed to, are below the limits for occupational exposure, since as shown before, the reference levels defined in 1998 ICNIRP occupational guidelines (500 μT and 10kV/m at 50 Hz), are not exceeded in all selected working areas. Consequently, this is also valid for the corresponding low AL values, defined in Directive 2013/35/EU (1000 μT and 10kV/m at 50 Hz).

## 4. CONCLUSIONS

This paper presents the results of electric and magnetic fields measurements, performed at four indoor and outdoor 150kV/20kV electric power substations and at 3 hydroelectric power plant substations in Greece. The substations area included all transformers, circuit breakers, feeders and buses. Broadband measurements and measurements of occupational exposure expressed as percentage of limits given in standards were carried out in each measurement point. The results indicate that the vast majority of the measured magnetic flux density and electric field strength values are significantly below the reference levels of 500 μT and 10kV/m at 50 Hz (according to 1998 ICNIRP guidelines). The % exposure percentages, as given by the measuring equipment are also below the corresponding limit (100%), at all cases and consequently, this is also valid for the corresponding low AL values, defined in Directive

2013/35/EU. [6]. It is also clear after performing harmonic analysis that no significant harmonic components were found in almost all of the measurements.

Regarding the electric and magnetic fields produced in the vicinity of high voltage substations, the measurements have shown that the equipment installed into the substation does not produce any significant values of electric and magnetic fields outside the substation. It is the power lines connected to it, that produce the levels of electric and magnetic fields measured in the vicinity of the substations. The measurements verified also that far from the power lines there are insignificant levels of fields, whereas close to the power lines the typical electric and magnetic field levels in the vicinity of the corresponding lines were found [8].

In most cases, the values measured in different substations are not comparable since there are substantial differences between the installations at all substations and the measurements positions could not be identical [7]. However, it is obvious in all substations, that the lower electric field strength values are measured in the control rooms and in front of the generators. On the other hand, it must be underlined that the electric field strength values can be found much closer to the limit values than these of the magnetic flux density [5].

It is programmed in the near future to conduct also measurements in extremely high voltage (400kV) power substations and atmoelectric power plants, all over Greece.


## *ACKNOWLEDGMENT*

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# OCCUPATIONAL HEALTH RISK STUDY: POSSIBLE INTERPLAY OF BIOLOGICAL EFFECTS OF RF EMF AND SMOKING HABIT?

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*ABSTRACT*

*The aim of present study was the assessment of biological/health effects in occupational EMF exposure in broadcasting radio-communication.Dosimetric characterization of electromagnetic work environment was made. The group taken into study consists of 90 workers occupational exposed to EMF in radio TV broadcasting stations.The results were compared to a control group, with a similar mean age. It was applied a special individual questionnaire to appreciate the possible biological effects related to EMF exposure. We made clinical and paraclinical examination and, in dynamics, urinary thioethers assay. The measured values of radiofrequency and microwave levels in the work places were below the current international safety standards.At exposed group our results revealed asthenia, nervous, cardiovascular syndrome. The calculation using a logistic regression model highlighted dose-response relationships between exposure values and presented symptoms. Urinary thioethers excretion in the occupationally exposed workers to EMF was increased in comparison with control group. The increased levels of urinary thioethers in EMF exposure are suggesting that thioethers could represent a possible marker of chronic exposure to EMF. Increased values found in EMF exposed smokers could mean that chronic electromagnetic exposure combined with the noxious components of smoking cigarettes could enhance health impairments or biological effects.*

***Key words:** EMF exposure, health effects, occupational, thioethers, smoking.*

## 1. INTRODUCTION:

This study, on possible impact on health in electromagnetic fields exposure, was made in the light of the fact that an adequate characterization of specific or unspecific biological effects induced by electromagnetic fields (EMF) is a current subject of international dispute. This was a challenge to explore the potential hazard face to technologies using electromagnetic fields and to the need of health risk assessment induced by EMF.

Previous experimental work on laboratory animals exposed to EMF suggested that electromagnetic fields could act through the mechanism of free radicals, interfering with immune reactions (1,2,3). Experimental study's results stimulated the next stage of research: an occupational study on EMF exposure (radiofrequency and microwaves) workers from radio Tv broadcasting stations, aiming to outline the preliminary health risks in chronic human exposure.

In the present study EMF is considered a possible generator of electrophilic products, in which producing mechanisms are involved free radicals produced via Fenton Haber –Weiss reaction.Determination of urinary thioethers may constitue the marker of biological effect.

## 2. METHODS

### a. *Electromagnetic characterization*

EMF exposure parameter is an important marker of correlation between biological effects and parameters of health impact. Characterization of electromagnetic environment was done using approved specific technical equipment, by making measurements of the fields components with an EMR 200 Wandel/Goltermann for RF fields. Probes were used for intensity of electric field (100KHz-3GHz range), magnetic field (10 MHz and 300 KHz-30MHz) and power density (300 kHz-40 GHz). The method is digital, based on a triaxial measurement, with izotropic directional characteristics. The field analyzer stored the measured values and made average values for each parameter (4,5,6). The measurements results were compared with the ICNIRP standards, adopted by Romania and transposed in national legislation-MHO No. 1136/2006.

Measuring area included Radio TV broadcasting stations from Transylvania for a period of three consecutive months. Measurements were performed several times during the day, then calculating a daily average. EMF measurements were performed initially around the station buildings at different distances and in interior of the rooms. For exposure assessment was chosen broadcasting transmission room. The reason for this choice was that the broadcasting room is EMF exposure place of workers during professional activity. Measurements were made at several points around the room, values being recorded, then averaged 6 minutes, as requires the measurement method.For the control group (security guards) exposure assessment was performed at their workplaces companies.

### *b. Identification of preliminary effects of chronic exposure to electromagnetic fields*

The EMF exposed group consisted of 90 men, workers from broadcasting radio-Tv stations from Transylvania. Their activity consists in supervising in emission radio TV equipment, including night work.Average age of the exposed group was 41.52 ± 2,34 years and the average exposure of 16.3 ± 6.3 years.

They were studied in comparison with a control group not exposed to occupational EMF fields, with the average age 42.16 ± 2.15 years, and working age 15.8 ± 5.6 years. The control group consisted of 85 subjects, men, security guards, including night activity.

We created a special individual questionnaire to appreciate the possible biological effects linked to EMF exposure, insisting on un-equivoque link with occupational exposure. Special questionnaires registrated the age, lenght of work, EMF exposure (years/months), type of exposure, personal and heredocolateral records, habits.The reported sympthoms were quantified by a range from 0 to 3 : 0=never; 1=sometimes; 2=often; 3=very often.

Initially we distributed 110 questionnaires to workers exposed to EMF. 20 subjects were eliminated from the study because of completing errors (3 persons), inability to perform measurements of work of employees (12 persons) or for the presence of family and / or personal history that could generate error factors in evaluating symptoms in relation to exposure (5 persons). To the control group we distributed 100 questionnaires, of which 85 were returned validated.

Clinical and  paraclinical examination was made (haemathology, blood test, metabolic-biochemical investigations, electrocardiogram, neurological and psychological exam).

Identification of possible external/internal exposure or/and biological effect and impact markers in EMF exposure: was performed, in dinamycs, thioeters assay from urine by molecular absorption spectrophoto-metry , after preliminary processing of samples.

### *c. Statistical preparation*

For statistical analysis we used computer software programs Epi Info 6, SPSS, and Microsoft Excel for descriptive statistics.

The results are statistical analysed with Student test “t”, multivariate analysis, and logistic regression models, with calculation of Odd ratio (OR), and Confidence intervals (95% CI) to perform the relationship between different ranges of variables. The correlation of parameters was determined by Pearson coefficient for normal distribution and by Spearman coefficient for others.

## *3 RESULTS AND DISCUSSIONS*

The measured values of the fields of RF and MW in workplaces were within the limits set by ICNIRP. Higher values of EMF were found outside buildings areas. We considered as reference, for assessing occupational exposure to EMF, emission values measured in rooms where exposed personnel operate. For the control group, measurements were made at company level security objectives in the area of workers activity. All parameters recorded value 0 in all cases, which means that they were below the limit of the EMF monitor. Established reference exposure limit of control group is value 0(Table 1).

*Table 1.* Exposure values

| Value ranges | | Electric Field [V/m] | Magnetic field [A/m] | Power density [W/m²] |
|---|---|---|---|---|
| n | Valid | 90 | 90 | 90 |
| | Lack | 0 | 0 | 0 |
| Average mean value | | 10,72 | 0,0098 | 2,406 |
| SD | | 3,5 | 0.0031 | 0,023 |
| Minimal value | | 5,22 | 0,0028 | 0,003 |
| Maximal value | | 40,27 | 0,0143 | 4,308 |

Preliminary health outcomes were compared with control group. In the exposed group was observed the presence of asthenic autonomous system symptoms, nervous and cardiovascular syndrome in dose-response relationships with EMF exposure values.Combination of described symptoms outline a radiofrequency/microwave health impairment: asthenia / fatigue, sleep disturbances, headache, irritability, dizziness, memory impairment, depression, sexual dysfunction, cardiovascular alterations (heart rhythm disturbances, coronary heart disease, increases or / and pressure oscillations during activity), impaired skin (redness, itching), visual disorders.

In a logistic regression model, taking into account age, smoking habit, were calculated odds ratio (OR), confidence interval (CI) and p values in relation to occupational exposure to EMF measured values (Table 2).

***Table 2.*** *Logistic Regression model.Dose-response relationships were found between measured values and analyzed variables at EMF exposed group.(black SSD; white without SSD)*

| MEAN EMF VALUES | E = 10,72V/m | H=0,0098 A/m | S=2,406W/m2 |
|---|---|---|---|
| HEALTH EFFECTS | OR | CI | p Value |
| Asthenia/Fatigue | 58,74 | 7,13- 440,14 | 0,0004 |
| Iritability | 4,24 | 2,15 – 14,58 | 0,0143 |
| Diziness | 6,42 | 1,26 – 28,16 | 0,0251 |
| Headache | 8,24 | 2,35-30,25 | 0,0019 |
| Sleep disturbances | 11,25 | 3,11-40,82 | 0,0003 |
| Sexual dysfunctions | 14,93 | 3,54 – 62,34 | 0,0321 |
| Memory loss | 6,18 | 2,25-28,16 | 0,0032 |
| Impaired concentration | 9,23 | 3,26 –38,27 | 0,0165 |
| Increased sweeting | 2,18 | 1,62 – 6,35 | 0,4128 |
| Depressive tendances | 12,80 | 1,48 – 110,64 | 0,0205 |
| Skin disorders | 3,50 | 0,78 – 28,51 | 0,0628 |
| Cardiovascular disorders | 25,68 | 3,21-226,38 | 0,0038 |
| Visual disorders | 1,57 | 0,54 – 6,15 | 0,4481 |

In terms of reported symptoms, calculations showed highly significant statistical relationship between EMF values from the workplaces and 9 of the 13 symptoms reported. It is noted that the values are significantly higher OR and p values are small for these symptoms, which means increased estimated risk of damage to health that exposure to electromagnetic field values.

The strongest associations were fatigue, sleep disturbances, cardiovascular problems, headache and memory impairment. These results, related to occupational EMF long time exposure of workers, indicates the presence of microwave syndrome and dose-response symptoms correlated with low levels of EMF: asthenia/fatigue, sleep disturbances, headache, irritability, dizziness, memory disorders, cardiovascular alterations, etc.

The findings of the present study are consistent with the results of another previous study about physiotherapists exposure to EMF's: symptoms developed by studied exposed personnel (neurasthenic, cardiovascular, nervous system, ostheoarticular syndromes) integrated with significant increased levels of micronuclei, urinary thioethers and blood test alterations could suggest the "microwave syndrome" presence and genotoxic action of EMF(7). Dose-response relationship lasting exposure to EMF have been highlighted by Lilienfeld and Robinette for health impairment, neurological syndromes, cardiovascular, osteoarticular pain, cancer (8,9)

The asthenic syndrome was reported at the EMF exposed group, with dysfunctional neurological components. Data are supported by the scientific literature: many authors have found similar effects in animal or human studies with EMF exposure. In animals, documented studies of Lai and Wang have shown disruption of working memory in rats exposed to RF (10,11). Salford's team found that lower SAR values caused increases in permeability of rats blood-brain barrier with extravasation of albumin in neurons and glial cells, together with impaired neurological effects and behavior troubles (12,13).Zhu found that microwaves are harmful in vitro and in vivo for the neuronal system of the rats with cranial defect (14).British investigator Jonston said that the research must be continued concerning BBB area and neurobehavioral implications (15).

Other animal studies have not detected such effects (16,17,18,19)

Beale's studies revealed a dose-response relationship in some neurological symptoms, including sleep disorders, anxiety, depression, at people who live in proximity to power lines(20). Mild and colleagues found a significant dose-response relationship between exposure to pulsed fields generated by mobile phones and headaches, dizziness, memory impairment, discomfort, fatigue, impaired concentration(21). American authors have conducted studies on humans mobile users, finding symptoms belonging microwave syndrome (21,22).

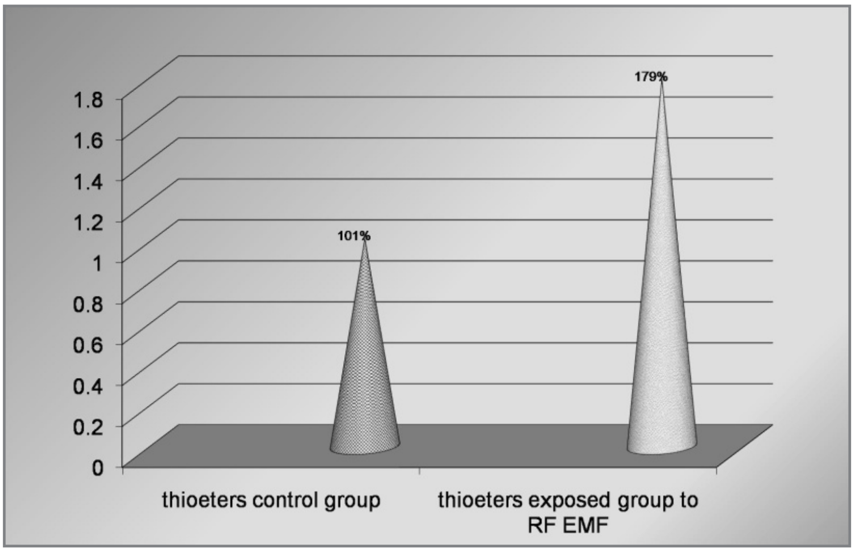
Present study found dose-response relationship between EMF exposure values and cardiac disorders, increased relative risk for arrhythmias especially, ischemic heart disease and blood pressure oscillations at exposed group.

Other researchers reported well documented cardiac damage in workers exposed to EMF in occupational environment (23). Among cardiovascular disorders were the neuro-circulatory dystonia, hypertension or low blood pressure. Sastre A. noted in his study that EMFs cause changes in heart rhythm (endogenous electrical impulses), which is linked with increased risk of heart disease. Savitz D. proved that electrical workers, increased exposure to EMF, even under the standard limits values, may increase the risk of cardiac arrhythmia and myocardial infarction. EMF effects on increasing blood pressure, heart rate and cardiovascular damage dynamics in exposure to EMF from the radar, communication and electronic industry have been well documented by many researchers (24,25).

Laboratory analysis of samples showed the following: exposed workers showed a significant increase in mean urinary thioethers (TE) and the relative standard deviation of TE values compared to the control group.

There was an increase of mean urinary thioethers and of the relative standard deviation in the group exposed to electromagnetic field (13.19 ± 5.10) than the control group (7.60 ± 1.42).

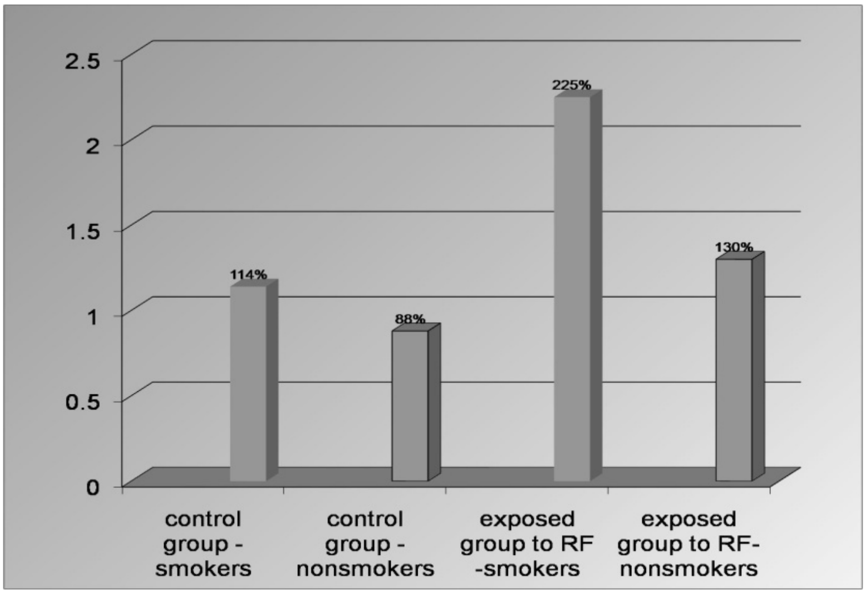
***Fig.1.*** *TE in RF EMF exposed and control groups*




The increase was particularly evident in smokers exposed group, as follows:

We noticed also a significant increase of mean urinary thioethers and standard deviation in EMF exposed smokers (16.61 ± 7.49) compared with EMF exposed non-smokers (9,27 ± 3.12). We also observed elevated urinary thioethers mean and standard deviation in EMF exposed group of non-smokers (9.59 ± 2.11) compared to the unexposed non-smokers group (5.49 ± 1.21) and a significant increase of urinary thioethers mean in EMF exposed group of smokers (16.605 ± 7.49) than in the control group of smokers (7.41 ± 1.44).

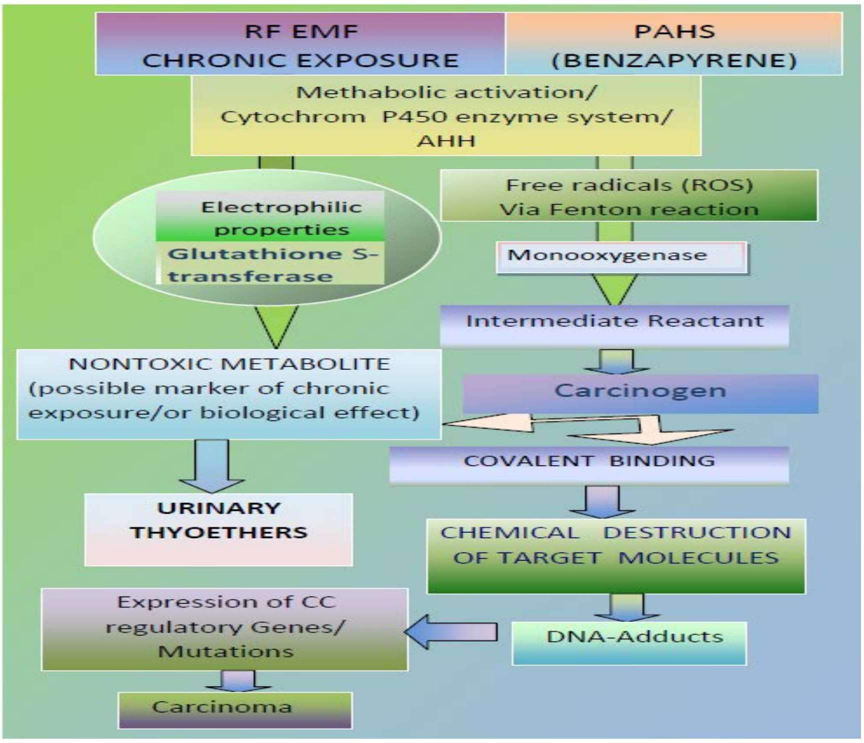
***Fig.2.*** *TE in smokers/nonsmokers groups*




Thus, excretion of urinary TE was steadily increased significantly (p <0.05) in workers exposed to occupational EMF, both non-smokers and smokers Elevated important statistical significance (p = 0.023) were found in the group exposed smokers, compared with the control group smokers. This indicates that urinary levels of TE would increase chronic exposure to EMF, but with higher growth in the presence of polycyclic aromatic hydrocarbons and other constituents of cigarette smoke. These results suggests that thioethers could be a possible marker of chronic exposure to EMF.

In scientific literature there are no similar studies about urinary thioethers behavior in EMF exposure.

***Fig.3*** *EMF(±PAH) methabolic pathway activation*




Hypothesis : EMF is considered a possible generator of electrophilic products, in which producing mechanisms are involved free radicals produced via Fenton Haber –Weiss reaction. Increased amount of urinary thioethers more important in the smoking exposed group indicate that chronic exposure to electromagnetic radiation could play an important role together with harmful components of cigarette smoke (benzo(a)pyrene and other polycyclic aromatic hydrocarbons-PAH) in the metabolic activation of enzymes involved in toxification/detoxification. In conditions of high doses or specific conditions could lead to destruction of target molecules, creating DNA adduct to mutation, degenerative diseases and / or carcinogenesis (fig.5). Metabolic activation mechanism might trigger thiol/redox balance. Along with balance glutathione disulfide / reduced glutathione, an important role in oxidative status of the cell plays local concentration of hydrogen peroxide and thus generate excess free radicals.

When antioxidant mechanisms are at optimum function, the oxidative response can be adjusted by glutathione and/or thioredoxin, besides scavenger enzyme mechanism. If oxidative stress continues for long time, as in case of EMF chronic exposure, antioxidant mechanisms are inefficient and the risk of health impairment is increased. Determination of urinary thioethers, electrophilic products metabolits, may constitue the marker of biological effect.

## *4. CONCLUSIONS*

Calculation in logistic regression model showed dose-response relationships between reported microwave syndrome symptoms and EMF workplace exposure values.

Present findings highlight biological effects of EMF exposure even at values included in standard regulations.

A link may be suggested between genotoxic action of the electromagnetic field and its action possible through nontermic mechanisms, generating free radicals with increasing TE associated with impaired health. Study results indicates that urinary levels of thioethers would increase chronic exposure to EMF, but with higher growth in the presence of polycyclic aromatic hydrocarbons and other constituents of cigarette smoke. Current findings suggest that urinary TE could be a possible marker of chronic exposure to EMF.


## *ACKNOWLEDGMENT*

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# EXAMPLE MEASUREMENTS OF EXPOSURE TO ELF MAGNETIC FIELDS ON THE METRO STATION IN FINLAND

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## ABSTRACT

*The Helsinki metro system includes two metro lines serving 17 metro stations. The aim of this paper was to present example measurements of exposure to extremely low frequency (ELF) magnetic fields (MFs) in the metro stations in Finland. The measurements concentrate on dynamic conditions. We measured magnetic fields (MFs) in 20 cases when a train was leaving the platform in the same station. We used the magnetic field meter MFM 3000. The maximum MF value measured was 5400 nT, when the distance to the conductor rail was 4.3 m and the measurement height was 1 m. The magnetic field only maintained this level momentarily, and the train influenced the general exposure situation for about one minute as the train left. The MF fields measured were thus quite low when we compare them to the ICNIRP guidelines. In Helsinki, the metro trains are powered by 750 V DC voltage supplied through a conductor rail next to the running rails. Therefore, it is possible that there are also DC magnetic fields near the metro as the train leaves the station. In the future, it is also important to measure DC fields and DC currents.*

**Key words:** *magnetic field, metro, exposure*

## 1. INTRODUCTION

In 2010, the International Commission on Non-ionizing Radiation Protection (ICNIRP) published guidelines [1]. The Directive 2013/35/EU of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) was published in 2013. The directive (2013/35/EU) includes minimum requirements for the protection of workers from risks to their health and safety arising, or likely to arise, from exposure to electromagnetic fields during their work. [2]

In Finland, the Ministry of Social Affairs and Health gave a new decree 'on the limitation of public exposure to non-ionizing radiation' in 2002 (294/2002). The decree sets binding limits for exposure to various types of radiation: ultraviolet, radiofrequency, and laser. In addition, the decree gives recommendations for maximum exposure limits for low frequency electric and magnetic fields. [3]

In Finland, there is only one metro, Helsinki metro, which includes two metro lines and 17 metro stations. The length of the metro network is 21.1 km. HKL Metro Transport has 54 carriage pairs and in 2012, the metro trains travelled 14.6 million carriage pair kilometers. [4]

According the standard EN 50500 [5] the required conditions of the rolling stock while magnetic field measurements are taking place are as follows: (1) stationary still condition (the rolling stock is not moving) and (2) dynamic condition.

The aim of this paper was to present example measurements of exposure to extremely low frequency (ELF) magnetic fields (MFs) on the metro stations in Finland. The aim is also to give more details regarding measurements. In our earlier papers [6,7], we concentrate on the maximum values. Moreover, we added some new measurement data using photos. The focus herein is on the dynamic condition.

## 2. MATERIALS AND METHODS

We conducted our measurements at one underground metro station using two measurement locations (A and B). The distance to the conductor rail was 4.3 m. Figure 1 shows the first measurement area, and Figure 2 shows the yellow conductor rail at the metro station. Figure 3 shows the structure of the metro tunnel.

A magnetic field meter MFM 3000 with a separate probe (Combinova AB, Bro, Sweden) was used. It is a magnetic field instrument with a unique combination of features, such as 1) real-time wideband spectrum analysis in three dimensions, 2) peak detection in time performing main measurement, 3) orthogonal coil sensor for field direction independence, 4) frequency range 5 Hz–400 kHz, 5) dynamic range from 10 nT to 10 mT with true RMS measurements of both the wideband or any frequency specific magnetic field, and 6) logging with RMS values and spectrum. The operating environment of the MFM 3000 is -20 oC to +50 oC and 10 to 85 % relative humidity. We also used a laptop and a tripod with the meter. The measurement height was 1 m.

***Figure 1.*** *First measurement area*


***Figure 2.*** *Yellow conductor rail at metro station*

***Figure 3.*** *Structure of metro tunnel.*

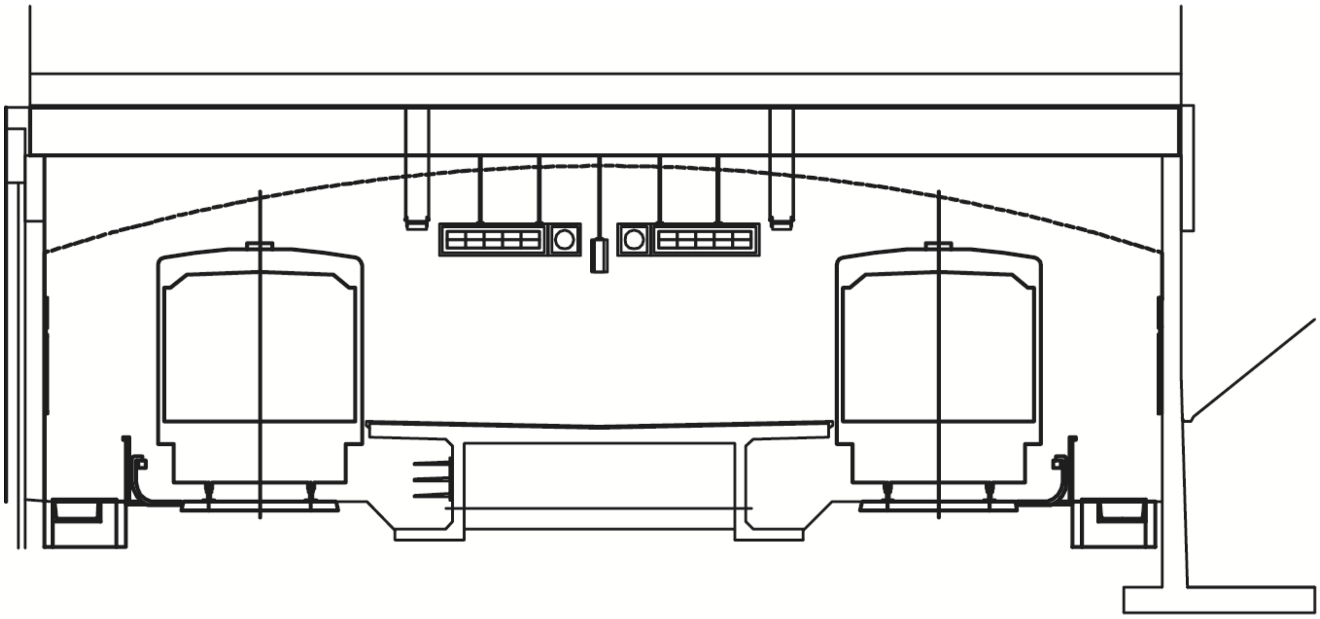

Figure 4 shows an example measurement in second measurement place B.

*Figure 4. Meter in second measurement place B.*

## 3. RESULTS AND DISCUSSION

We measured magnetic fields (MFs) on 20 separate trains, when a train was leaving the metro station. In area A, we examined 17 train departures and in place B, we observed three train departures. The maximum values were between 522 nT to 5400 nT. The temperature was 13.2 ºC.

We also measured the x-, y-, and z- components of the ELF magnetic fields. The z-component was in the direction of the yellow conductor rail. The x-component was in the horizontal direction, and the y-component was in the vertical direction.

Table 1 shows the example values of the measured x-, y-, and z- components as the train (No. 18) was leaving the station.

***Table 1.*** *Example magnetic field values of measured x-, y-, and z- components as train (No.18) left station.*

| No | Time (hh:mm:ss) | Magnetic field, x-axis, nT | Magnetic field, y-axis, nT | Magnetic field, z-axis, nT |
|---|---|---|---|---|
| 1 | 11:40:15 | 117.18 | 62.82 | 301.78 |
| 2 | 11:40:25 | 141.00 | 87.46 | 221.31 |
| 3 | 11:40:30 | 69.13 | 120.00 | 257.18 |
| 4 | 11:40:40 | 92.10 | 216.71 | 794.85 |
| 5 | 11:40:45 | 389.72 | 531.91 | 4069.7 |
| 6 | 11:40:55 | 92.43 | 147.90 | 475.8 |
| 7 | 11:41:05 | 81.03 | 64.75 | 459.25 |
| 8 | 11:41:10 | 77.47 | 55.50 | 417.34 |
| 9 | 11:41:20 | 64.41 | 43.58 | 372.81 |

In Table, 1 the highest magnetic fields are in the z- components. The maximum value of the z-components was 4069.7 nT. At the same time, the x-component was 389.72 nT and the y-component was 531.91 nT, making the z-component the most significant.

This paper presents only example measurements of exposure to ELF magnetic fields in one metro station in two places. However, we notice that the measured values are low. The highest measured value was 5400 nT (5.4 µT). In addition, the field was at this maximum level for a very short time, signifying a brief exposure period.

When we compare the measured values to the ICNIRP guidelines for limiting exposure to time□varying electric and magnetic fields (1 Hz–100 kHz) [1], the measured values are lower than the reference values. However, we measured the frequency range 5 Hz–400 kHz, so the reference values are different based on which frequency we used in the analysis.

The metro of Helsinki are powered by 750 V DC voltage supplied through a conductor rail next to the running rails, meaning that in the future, it is also pertinent to measure possible exposure to DC fields.

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# THE RELATIONSHIP BETWEEN A WORKER'S HEIGHT AND WEIGHT AND INTERNAL ELECTRIC FIELDS INDUCED IN THE BODY AT 50 HZ FOR COMPARISON WITH THE EMF DIRECTIVE 2013/35/EU

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## ABSTRACT

*A worker's height and weight can significantly affect the way in which incident low frequency electric and magnetic fields are absorbed in the body. To investigate this, several anatomically realistic human models were produced for heights between 1.56-1.96 m and weights between 33-113 kg. The human models were derived from the MAXWEL surface-based phantom, the model currently being used in the development of the EMF Directive 2013/35/EU Practical Guide to demonstrate how changes in body shape affect the magnitude and distribution of the absorbed field. Computer simulations were carried out to calculate the low frequency EMF Directive Exposure Limit Value (ELV) quantities, i.e. the induced electric fields, in these human model variations from exposure to external 50 Hz magnetic and electric fields. The computational work showed that simple relationships relating the human model's height/weight with the induced electric fields in tissue types such as bone, fat, muscle, brain, spinal cord and retina could be developed. Calculations of the fields required to produce the EMF Directive ELVs were carried out and compared with the Action Levels (ALs). It was found that the ALs provided a conservative estimate of the ELVs for the various human models studied.*

***Key words:*** *ELF, Dosimetry, Induced Electric Fields, Human Phantoms, EMF Directive 2013/35/EU*

## 1. INTRODUCTION

The European Union have recently produced a Directive 2013/35/EU (1) on health and safety requirements regarding the exposure of workers to electromagnetic fields. For low frequencies, the EMF Directive presents Exposure Limit Values (ELVs), defined in terms of induced internal electric fields and Action Levels (ALs), specified in terms of unperturbed, externally applied electric and magnetic field strengths. These ELVs and ALs are based on the basic restrictions and reference levels produced by the International Commission on Non-Ionizing Radiation Protection (2). In turn, the relationship between the ICNIRP reference levels and basic restrictions were derived from published data by Dimbylow using the just two human models, the male NORMAN and female NAOMI models for the central nervous system (CNS) and from only the female NAOMI model for the peripheral nervous system (PNS) (3, 4). These models were normalized to the dimensions of an average male and female as defined by the International Commission of Radiation Protection (5). The sizes used were 1.76 m tall and 73 kg mass for an adult male. For an adult female, the reference sizes were 1.63 m tall and a mass of 60 kg.

However, body anatomy, shape and size can significantly affect the way in which low frequency electric and magnetic fields are absorbed. The objective of this paper is to investigate the way in which a change in the mass and height of the human body influences the electric fields induced in a person, and how these induced fields compare with EMF Directive restrictions, restrictions derived from calculated fields for standard sized humans. To achieve this, induced electric fields were calculated in different height and mass versions of the MAXWEL human model from exposure to external electric and magnetic fields at 50 Hz. Human models were produced using standard values taken from ICRP Publication 89 (5) and standard deviations derived separately from the 2011 statistics in the Health Survey for England (6).

The following section describes the EMF Directive. A description of the numerical methods and human models used is presented in section 3. Results for applied magnetic and electric fields are given in section 4 and a discussion is presented in section 5.

## 2. EMF DIRECTIVE

The EMF Directive (1) presents ELVs to protect against adverse health effects from exposure to electromagnetic fields. At low frequencies, these ELVs are defined in terms of electric field values induced in the body as this is the physical quantity that determines the biological effect. The Directive presents health effects ELVs to protect against electrical stimulation of the peripheral nervous system (PNS) and central nervous system (CNS), and is applicable to all PNS and CNS tissues in the body. Sensory effects ELVs are also presented to protect against retinal phosphenes and minor transient changes in brain function. These are applicable to CNS tissue in the head. At 50 Hz, the health effects ELV is 1.10 V m-1 (peak) or 778 mV m-1 (root-mean-square or rms) and the sensory effects ELV is 0.140 V m-1 (peak) or 99.0 mV m-1 (rms).

Although the Directive does not describe the way in which induced electric fields should be calculated, the low frequency limits are based on those presented in the ICNIRP (2) guidelines. ICNIRP recommends calculating the 99th percentile induced electric field value (E99) in a specific tissue, averaged over a contiguous 2 x 2 x 2 mm3 volume. This has been chosen to remove dependency on voxel resolution and limit boundary errors inherent in the calculation of maximum electric field values when the body is discretised into cubical cells.

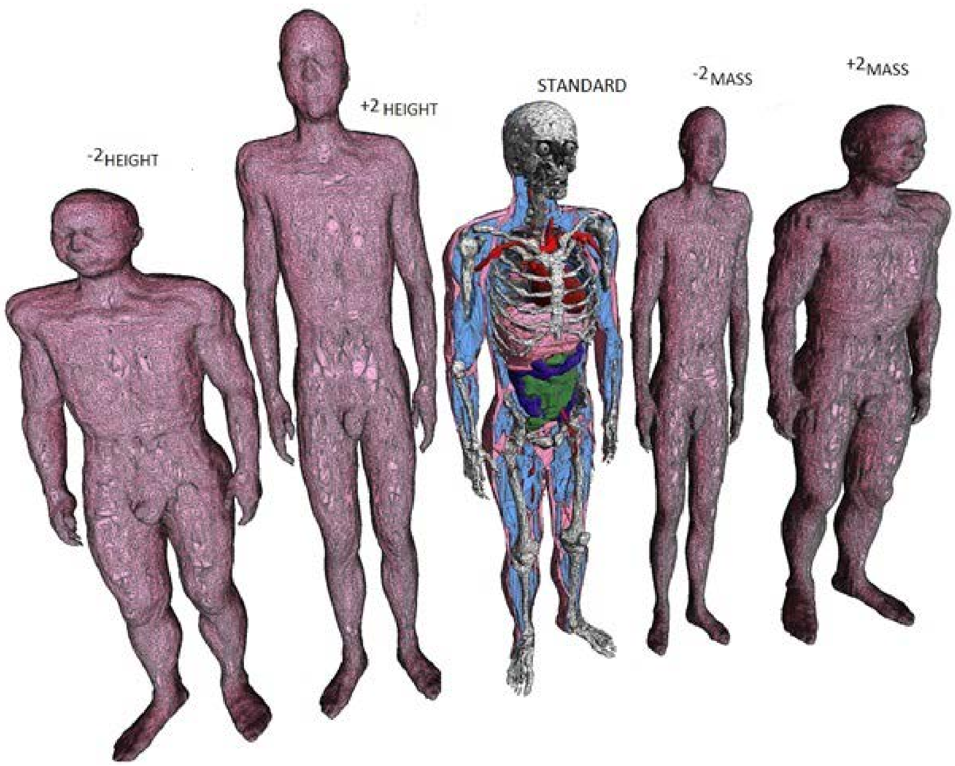
Values of unperturbed fields, defined as Action Levels (ALs) are also given as a means for assessing compliance with the ELVs. Again, the Directive ALs are based on the ICNIRP (2010) guidelines, which in turn are extracted from published data for the male and female voxel models NORMAN and NAOMI respectively (3, 4) to define the relationship between its external field reference levels and internal basic restrictions. The ALs at low frequency are defined in terms of externally applied electric and magnetic field strengths. The intention is that compliance with the external field value ALs will ensure compliance with the internal electric field limits specified in the ELVs.

### *3. NUMERICAL METHODS AND HUMAN MODELS*

For uniform applied 50 Hz magnetic fields, the Scalar Potential Finite Difference (SPFD) method (7, 8, 9) was used to calculate the induced electric fields in the human models. This method incorporates the applied magnetic field source as a vector potential term in the electric field. This equation for the electric field is then transformed into scalar potential form, which is solved using finite differences.

For the applied uniform electric fields, the electric fields induced in the body were calculated by solving the quasi-static potential equation (10, 11) on a series of nested sub-grids decreasing in resolution by a factor of two from 32 mm to 2 mm. The outer region of the domain extended sufficiently so that the perturbation in the applied field, due to the body, was small at the periphery whilst the grid near and in the body was small enough to model the structural details. The solution of the potential equation is divided into two parts. First, the coupling between the externally applied electric field and the human body, which is deemed to be a conductor at low frequencies, is calculated to provide the surface charge. This charge is then used as a boundary condition to calculate the induced potential and hence the induced electric fields in the body at a resolution of 2 mm.

***Figure 1.*** *Rendered views of the -2HEIGHT, +2HEIGHT, -2MASS and +2MASS phantoms with a cutaway view of the standard height and mass MAXWEL phantom.*



The EMFcomp male phantom is known as MAXWEL (MAle fleXible Whole-body modEL). The development of MAXWEL is described in detail in Findlay (11). The model has a height of 1.76 m and a mass of 73 kg, the dimensions of the ICRP reference adult male (5). It is segmented into 45 different tissue types. The MAXWEL model is a surface-based numerical phantom. It was produced by importing the data volume into 3D CAD software and generating surface models of the various tissues. The software utilized NURBS (Non-Uniform Rational B-Spline) based tools to create surface models of the previously voxelised tissue data.

A wire-framed model of the surface was produced, which could then be smoothed and surface rendered. Interpolation or smoothing processes after inserting a volume object can cause the appearance of artifacts in regions where the surface of the object blends with other tissue surfaces. To minimize these artifacts, resizing by decimation and noise/speckle reduction through median filters was used. A series of programming tools were written in FORTRAN to allow manipulation of surface geometries and the insertion of segmented surface tissue types into the developing model of the human body. Once the process was complete, the surface-based representations of the tissue types could be re-voxelised to a desired resolution using in-house code.

An evaluated review of the dielectric properties of all tissues in MAXWEL was performed by Gabriel et al (12). A 4-Cole-Cole dispersion model was fitted to the data for each tissue type to parameterize the conductivity and permittivity as a function of frequency. The tissue conductivities were the same as those used in Findlay (11).

To investigate the effects of human mass and height on induced electric fields in the body, resampled representations of the MAXWEL model were produced ranging from 33-113 kg in weight and 1.53-1.93 m in height. The mass of the standard MAXWEL human model was 73 kg, and the masses used were 33 kg for the -2MASS model, 53 kg for the -1MASS model, 93 kg for the +1MASS model and 113 kg for the +2MASS model. The standard MAXWEL phantom was resampled in the x and y dimensions to represent the masses of these variations. The height remained the same as the standard phantom at 1.76 m. The height of the standard MAXWEL phantom was 1.76 m, and the heights used were 1.56 m for the -2HEIGHT model, 1.66 m for the -1HEIGHT model, 1.86 m for the +1HEIGHT model and 1.96 m for the +HEIGHT model. These values for the height and mass of the human models used are summarized in Table 1.

***Table 1.*** *Height and mass values for the resampled models studied.*

| *Human Model* | *Height (m)* | *Mass (kg)* |
|---|---|---|
| **+0Height/Mass** | 1.76 | 73 |
| **-2Height** | 1.56 | 73 |
| **-1Height** | 1.66 | 73 |
| **+1Height** | 1.86 | 73 |
| **+2Height** | 1.96 | 73 |
| **-2Mass** | 1.76 | 33 |
| **-1Mass** | 1.76 | 53 |
| **+1Mass** | 1.76 | 93 |
| **+2Mass** | 1.76 | 113 |

## 4. RESULTS

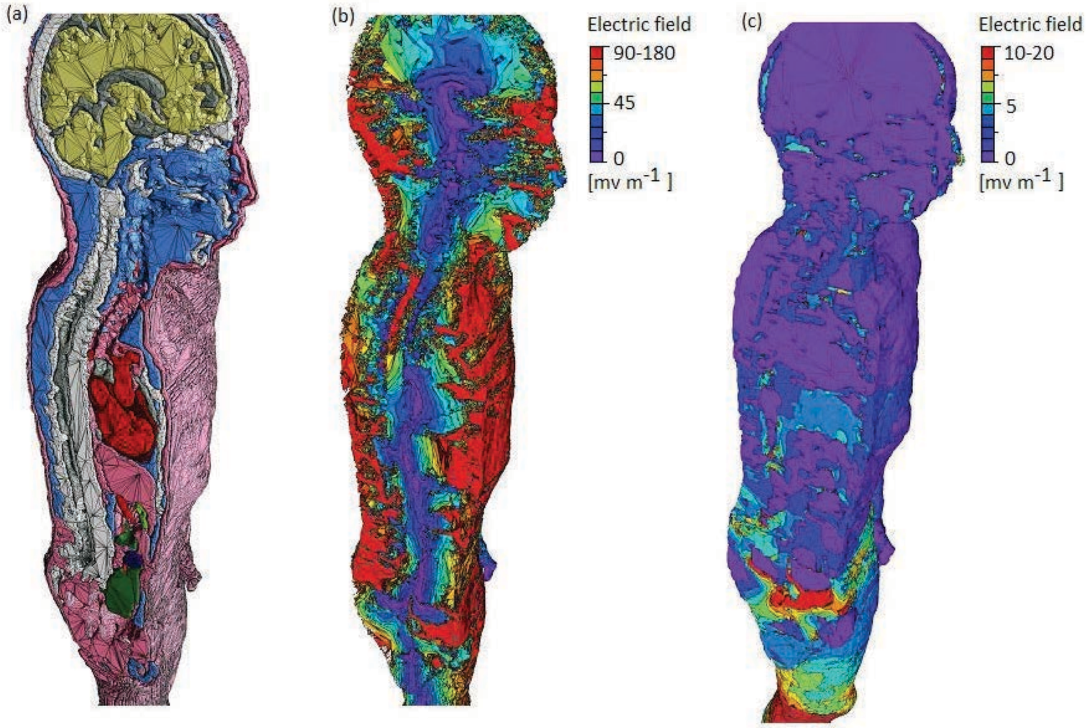
### *a. Applied Magnetic Fields*

The human body does not perturb an externally applied magnetic field, as the magnetic materials present in the body are so small that they can be ignored. The dominant magnetic field interaction with the body is the Faraday induction of an electric field and associated currents in conductive tissues.

The E99 values in the various models for selected tissue types were calculated for a frequency of 50 Hz. AP denotes the field aligned front-to-back, LAT from side-to-side and TOP from top-to-bottom. For a simple homogeneous sphere exposed to an external magnetic field, the induced electric field will be proportional to the radius, i.e. a field that is zero at the centre and a maximum at the outer boundary. Similarly, increasing the x, y and z dimensions of the sphere by, say, 10% will produce a corresponding increase of 10% in the E99 values calculated. When the human body is used as a target, this relationship between size and induced electric field becomes an approximate one due to the body's irregular shape and the fact that it is inhomogeneous. However, calculations have shown that the relationship between a change in size and a change in induced field is generally good for human exposure.

Figures 2 (b) and 3 (b) show the induced electric fields in sagittal and coronal slices of the body respectively from exposure to a LAT magnetic field. The colour map is a standard rainbow spectrum moving from red for the highest induced electric field to violet for the lowest. The induced electric field in each voxel has been normalised to the maximum value in the whole body model. The colour map was then stretched to enhance the lower part of the scale. It can be seen that the highest values of induced electric field tend to be found on the outer surface of the phantom. However, shape effects and regions of different conductivity will modify the distribution of the induced fields.

***Figure 2.*** *The sagittal tissue section (a) and corresponding induced electric field view of the MAXWEL phantom from exposure to an external LAT magnetic field (b) and external electric field under grounded conditions (c).*



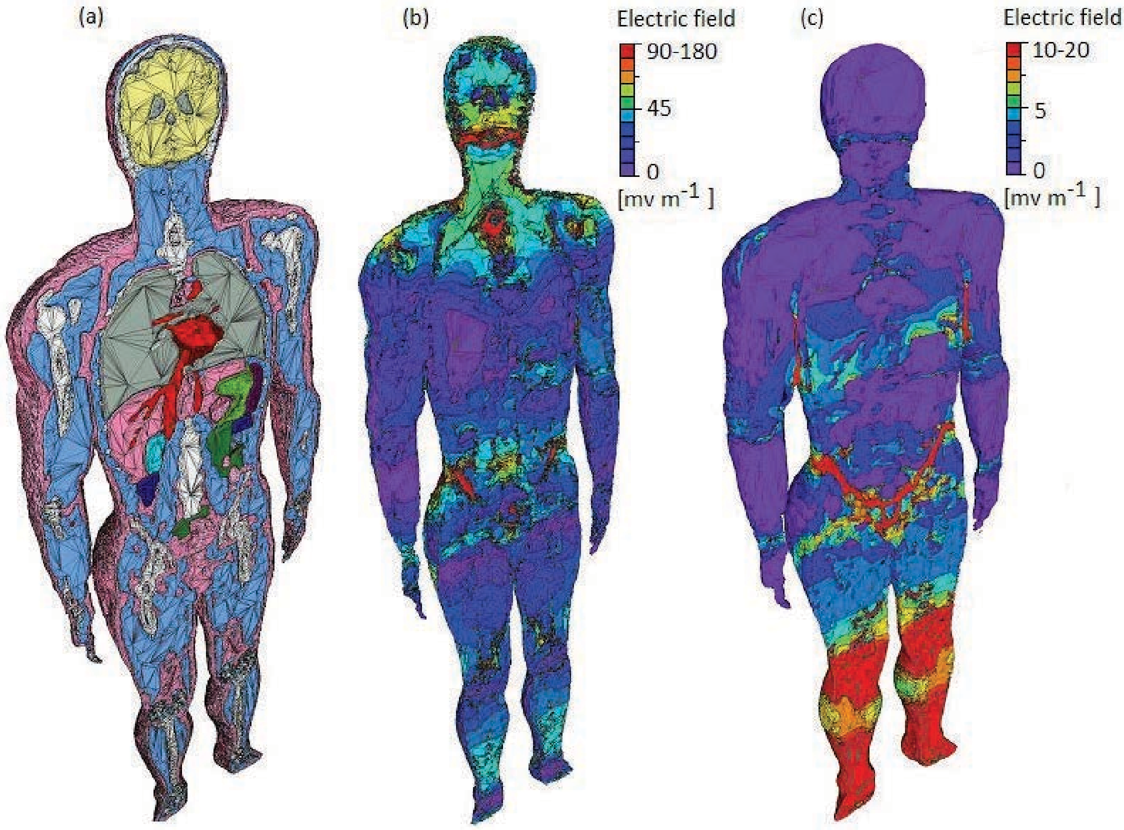

Increasing the x, y and z dimensions of the MAXWEL model by 10% produced a corresponding 10% increase of approximately 10% in the E99 values. To further investigate this relationship with human mass m, versions of MAXWEL were produced between 33 kg and 113 kg with the same height, 1.76 m. Keeping the same height but increasing the axial (x and y) dimensions of MAXWEL to produce a higher mass resulted in an increase in the surface area perpendicular to the incident field that was proportional to the square root of the mass for LAT and AP exposure. For TOP exposure, an increase in the surface area perpendicular to the field was proportional to an increase in the mass.

It was found that a plot of E99 against mass 0.5 (or mass for TOP exposure) produced an almost linear relationship. The variation of E99 values with mass for selected tissue types are shown in Figure 4 (a). Keeping the same mass and increasing the z dimension of MAXWEL produced a taller model. The mass of the model remained as 73 kg if the x and y dimensions were adjusted accordingly. It was found that the E99 value was approximately proportional to the reciprocal of the square root of the height for LAT and AP exposure for most tissues, however for the brain (LAT), retina (LAT) and spinal cord (AP) the induced field value was approximately proportional to the square root of the height. It is possible that shape effects are dominant when the surface area does not change significantly, as is the case with the variation of height.

The variation of the E99 value with height and mass can be expressed using simple relationships, displayed as straight lines in Figure 4 and presented as an example in Equation (1). The relationships is valid for the adult male model studied in this work in the range 33-113 kg (mass) and 1.56-1.96 m (height). The coefficients ki depend on the particular tissue type. The relationships produce only an approximation of the induced electric field simulations, however correlation between the values estimated and the actual computed induced electric field value is generally good. The maximum percentage deviation between the computed induced electric field and the value calculated using relationship (1) was approximately 6%.

$$E99 = k1.mass0.5 + k2 \qquad (1)$$

***Figure 3.*** *The coronal tissue section (a) and corresponding induced electric field view of the MAXWEL phantom from exposure to an external LAT magnetic field (b) and external electric field under grounded conditions (c).*




### *b. Applied Electric Fields*

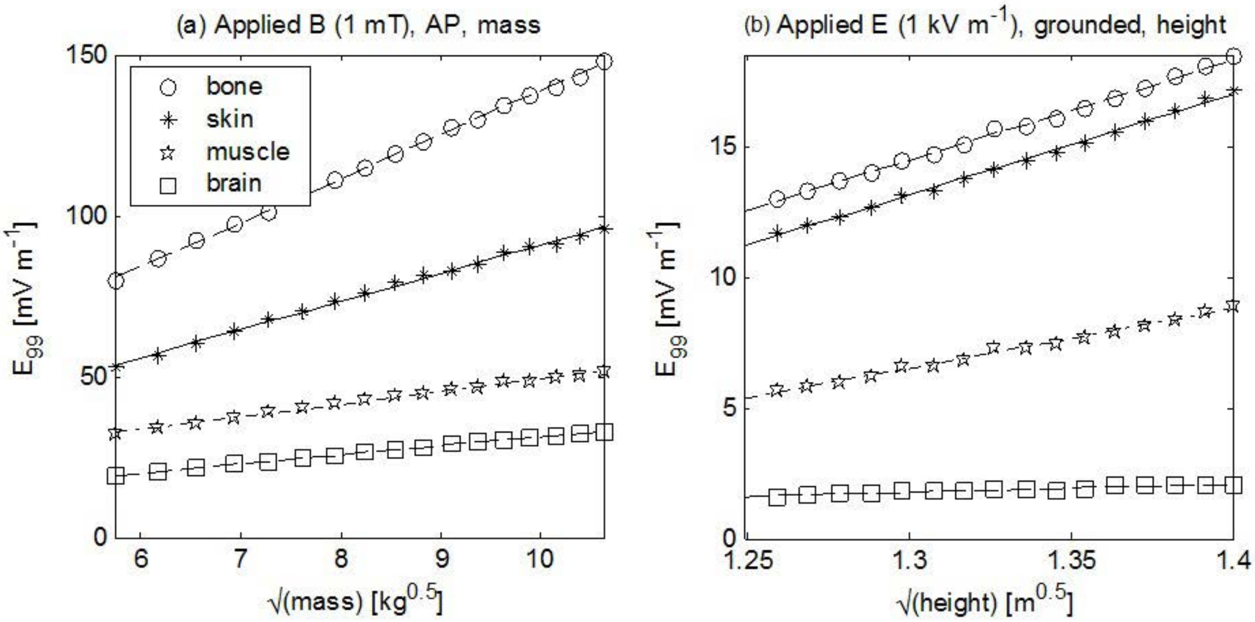
In contrast to exposure to an external magnetic field, the human body significantly perturbs an incident low frequency electric field. Exposure to an electric field causes non-uniform surface charges to be induced on the surface of the body. The electric fields in the body greatly depend on the contact between the body and the electric ground. The worst-case exposure scenario that produces the highest induced electric fields is where the body is in perfect contact with ground through both feet. If the x, y and z dimensions of MAXWEL are uniformly increased by 10% to produce a model of height 1.94 m and mass 97.2 kg, these changes have little effect of the induced electric fields as any increase in induced currents is counteracted by currents flowing through a greater axial area to ground. The induced currents will be increased with the increase in the surface area of the model exposed to the incident field, but they will also be reduced by the reciprocal of the surface area through the axial (x-y) model section.

The axial dimensions of MAXWEL were increased whilst the 1.76 m height was maintained to produce models between 33 and 113 kg. These models were used to investigate how a change in mass only would affect the E99 values induced in the body. The results for different tissue types are presented in Figure 4 (b). As the increase in axial cross-sectional area was greater than the increase in surface area, the induced electric fields decreased with increasing model mass. It was found that this change could be approximated to the reciprocal of the square root of the mass. If the height of the model was increased whilst the mass was maintained at 73 kg, this increase was found to be approximately proportional to the square root of the height.

The variation of the E99 value with height and mass when exposed to uniform electric fields can again be expressed using simple relationships, displayed as straight lines in Figure 4 and presented as an example in Equation (2) and below. These relationships are valid for the adult male model studied in this work for the values of 33-113 kg (mass) and 1.56-1.96 m (height). Similar to the applied magnetic fields, the correlation between the values estimated and the actual computed induced electric field value was good for applied electric fields. The maximum percentage deviation between the computed induced electric field and the value calculated using relationships was approximately 5% for both mass and height. This was for the skin, fat, muscle, bone, brain and spinal cord tissues. The average percentage deviation between these two values was 0.9% and 1.4% for mass and height respectively. approximately 6%.

$$E99 = k3.mass^{-0.5} + k4 \qquad (2)$$

***Figure 4.** Example relationships between mass/height and the 99th percentile induced electric field values for bone, brain, muscle and skin from exposure to 50 Hz applied magnetic and electric fields.*




*5. DISCUSSION*

The highest E99 values from exposure to external magnetic fields during this investigation were calculated in the +2MASS 113 kg, 1.76 m MAXWEL model. The maximum E99 value in the head CNS tissues was calculated as 38.3 mV m-1 (brain) for a 1 mT magnetic field. The EMF Directive sensory effects ELV at 50 Hz is 99 mV m-1 (rms). Hence, a 2.58 mT field would be required to produce the 99 mV m-1 ELV in the 113 kg MAXWEL model. The EMF Directive low AL is 1 mT at 50 Hz. Therefore, a magnetic flux density value 2.58 times higher than the AL would be required to produce an induced electric field higher than the ELV, so it can be concluded that the EMF Directive AL provides a conservative estimate of the ELV for the human models studied in this work. The maximum E99 value in all tissues was calculated as 148 mV m-1 (bone) for a 1 mT magnetic field. The EMF Directive health effects ELV at 50 Hz is 778 mV m-1 (rms) and so a 5.26 mT field would be required to produce the 99 mV m-1 ELV in the 113 kg MAXWEL model. A magnetic flux density value 5.26 times higher than the AL is required to produce an induced electric field higher than the ELV, hence this provides further evidence that the EMF Directive AL provides a conservative estimate of the ELV for the human models studied in this work.

The highest E99 values from exposure to external electric fields calculated in this work were for the 33 kg,

1.76 m MAXWEL model. The maximum E99 value in the head CNS tissues was calculated as 2.80 mV m-1 (brain) for a 1 kV applied electric field. Therefore, a 35.4 kV m-1 field would be required to produce the 99 mV m-1 ELV in the 33 kg MAXWEL model. The EMF Directive low AL for applied electric fields is 10 kV m-1 at 50 Hz. Hence, an electric field strength 3.54 times the value of the AL would be required to produce an induced electric field higher than the ELV, so again it can be concluded that the EMF Directive AL provides a conservative estimate of the ELV for the human models studied in this work. Similarly, for the health effects ELV to be exceeded in this worst case 33 kg human model, an applied electric field strength that is 3.2 times the AL would be required.

It is important to note that these comparisons with the EMF Directive used the 2 standard deviation values for body mass and are not representative of the average male adult. A 1.76 m (5 feet 9 inch) tall, 113 kg (249 pound) male adult constitutes a body mass index (BMI) of 36.5, considered obese. A 1.76 m, 33 kg (73 pound) male adult would have a BMI of 10.6, classified underweight. Further work is recommended for other male and female human models of different sizes, postures and ethnicity; however the results presented in this work suggest that the EMF Directive ALs provide a very conservative approximation of the Directive ELVs for exposure to uniform electric and magnetic fields at 50 Hz.

## 6. CONCLUSIONS

Human models of varying height and weight, derived from the surface-based MAXWEL male phantom, have been produced to investigate the way in which the body's dimensions can affect the absorption of low frequency electric and magnetic fields.

Computer simulations were carried out to calculate the low frequency EMF Directive Exposure Limit Value (ELV) quantities, i.e. the induced electric fields, in these human model variations from exposure to external 50 Hz magnetic and electric fields. The computational work showed that simple relationships relating the human model's height/weight with the induced electric fields in tissue types such as bone, fat, muscle, brain, spinal cord and retina could be developed.

Calculations of the fields required to produce the EMF Directive ELVs were carried out and compared with the Action Levels (ALs). It was found that the ALs provided a conservative estimate of the ELVs at low frequencies for the various human models studied.


## ACKNOWLEDGMENTS

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# UVR IRRADIANCE MEASUREMENTS FROM ARTIFICIAL TANNING DEVICES IN GREECE

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## ABSTRACT

*Ultraviolet radiation (UVR) from artificial tanning devices has been classified by the International Agency for Research on Cancer (IARC) of the World Health Organization as "carcinogenic to humans" – Group 1, the highest risk category as tobacco, asbestos and gamma radiation. Greek Atomic Energy Commission (EEAE) has initiated a surveillance action of the artificial tanning devices in Greece. This action aims to inform and synchronize the artificial tanning business sector with the requirements of the European Standard EN 60335-2-27:2010 "Household and similar electrical appliances - Safety - Part 2-27: Particular requirements for appliances for skin exposure to ultraviolet and infrared radiation". EEAE performed in situ measurements of UV emissions from artificial tanning devices in solaria businesses all over Greece, with a radiometer and a portable single monochromator spectrophotometer. The results from measurements conducted from October 2013 until April 2014 revealed that effective UVR in approximately 70% of the measured devices exceeded the 0.3 W/m2 limit value set by the EN 60335-2-27:2010. Analysis of the results revealed also the need to develop a code of practice for the artificial tanning services and to design an educational course for the personnel working in this field, but most of all the need to develop national legislation regarding sunbeds and solarium services in Greece, given that no relevant legislation currently exists. This work was performed in the framework of "PRISMA" project within GSRT's KRIPIS action, funded by Greece and the European Regional Development Fund of the European Union under the O.P. Competitiveness and Entrepreneurship, NSRF 2007-2013.*

**Key words:** *artificial tanning devices, effective irradiance measurements, safety limits, UV Index.*

## 1. INTRODUCTION

The use of artificial tanning devices, sunbeds or solarium as commonly known, to acquire a tan for cosmetic purposes has become increasingly prevalent worldwide over the last 20 years, especially among fair skinned populations in Europe and North America and oddly in sunny countries like Australia [1] [2] [3]. Tanning though artificial equipment is achieved by emission of ultraviolet radiation (UVR), mainly in the UVA (320-400nm) range and less in the UVB (280-320nm) range. While ultraviolent radiation is a well-known risk for human health, being the causal factor of skin and ocular diseases, and despite the warnings and recommendations of several national and international authorities, artificial tanning for cosmetic purposes remains very popular [4] [5] [6].

Artificial tanning has been attributed with a series of acute and chronic health effects, some nonthreatening but other extremely hazardous for human health. Erythema or sunburn as otherwise known, phototoxic and photoallergetic reactions as well as ocular diseases such as photokeratitis and photoconjunctivitis are among acute effects [5] [6]. Chronic effects include acceleration of skin aging, phenomenon known as premature aging, ocular effects such as cataract, pterygium and macular degeneration, skin cancers, both non-melanoma (basal cell carcinoma and squamous cell carcinoma) and the life threatening cutaneous melanoma [1] [5] [6]. A meta-analysis performed by the International Agency for Research on Cancer (IARC) revealed an association between the early age of the first exposure to UVR from artificial tanning devices with melanoma risk and especially that users who began solarium before the age of 35 had a 75% increase in the risk of melanoma [1]. An update of this meta-analysis revised the risk of melanoma up to 87%, when the first sunbed use was before the age of 35, with the risk increasing with the number of solarium sessions [7]. Data also suggest detrimental effects from the use of artificial tanning devices in the skin's immune system and in the eyes [1].

Several international authorities, the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Scientific Committee on Consumer Products (SCCP), the European Society of Skin Cancer Prevention (EUROSKIN), among others, strongly advise against artificial tanning [5] [6] [8]. They specifically point out that high risk individuals, such as those with skin phototypes I and II, aged less than 18 years, with a large number of naevi, with a history of skin cancer etc., must be particularly warned against the use of artificial tanning devices [5] [6] [8].

In 2009, the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) classified the UV emitting devices as “carcinogenic to human” – Group 1. Group 1 is the highest risk category, which includes the most dangerous carcinogens for humans, like asbestos, gamma radiation and tobacco smoke, among others [9]. Several countries worldwide have enacted legislation to regulate public’s exposure to UVR from artificial tanning devices as well as the indoor tanning businesses. European countries follow the European standard EN 60335-2-27:2010 “Household and similar electrical appliances - Safety - Part 2-27: Particular requirements for appliances for skin exposure to ultraviolet and infrared radiation”, setting the limits of exposure to ultraviolent radiation from artificial tanning devices [10]. Greece has also adopted this standard as EN ELOT 60335-2-27:2010.

According to EN ELOT 60335-2-27:2010, artificial tanning devices should be classified in the UV type 1, 2, 3 or 4 category, depending on their effective irradiance in the UVA (320-400nm) and UVBC (250-320nm) range. The devices which emit effective irradiance in the UVBC range more than 0.15 W/m2 should be used only for medical purposes (UV type 4). Devices that emit effective irradiance in the UVBC range less than 0.15 W/m2 fall into the UV type 1, 2 or 3 category, depending on the effective irradiance in the UVA range and can be used by either trained personnel or unskilled persons. The detailed classification is presented in Table 1. The key restriction that EN ELOT 60335-2-27:2010 imposes is the 0.3 W/m2 limit value of effective irradiance in the whole UV spectrum (250-400nm) [10]. The 0.003 W/m2 irradiance limit value in the UVC spectrum (200-280nm), is also set by the standard. Moreover the standard recommends that the effective UV dose during the first session should not exceed 1 SED, 100 J/m2, and the total maximum annual dose should not be more than 25 kJ/m2 weighted according to the non-melanoma skin cancer action spectrum (Figure 1) [10].

***Table 1.*** *Limits of effective irradiance according to EN ELOT 60335-2-27:2010*

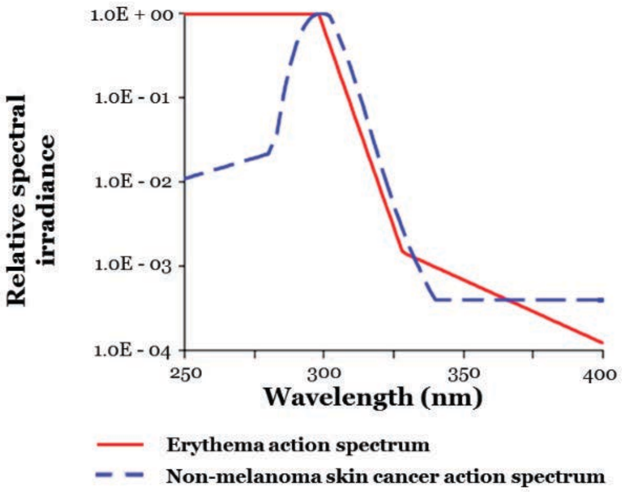
| *UV type* | *Effective Irradiance W/m2* | | |
|---|---|---|---|
| | *UVBC 250-320nm* | *UVA 320-400nm* | *Use* |
| 1 | <0.0005 | ≥0.15 | Supervised |
| 2 | 0.0005-0.15 | ≥0.15 | Supervised |
| 3 | <0.15 | <0.15 | Unskilled |
| 4 | ≥0.15 | <0.15 | Medical |

Effective irradiance, Eeff, is defined by the following equation:

$$E_{eff} = \sum_{250nm}^{400nm} S_\lambda \, E_\lambda \, \Delta_\lambda \qquad (1)$$

where Eλ is the spectral irradiance in W/m2/nm, Sλ is the relative spectral effectiveness (weighting factor) according to the reference action spectrum for erythema given in Figure 1 and Δλ is the wavelength interval (nm).

***Figure 1.*** *Erythema and non-melanoma skin cancer action spectrum*



WHO has introduced UV Index (UVI) as a simple measure of the solar UV radiation level at the Earth's surface and an indicator of the potential of skin damage [11]. The UVI is a unitless quantity defined by the formula:

$$I_{UV} = k \int_{250nm}^{400nm} E_\lambda \, S(\lambda) \, d\lambda \qquad (2)$$

where k is a constant equal to 40 m2/W, Eλ is the spectral irradiance in W/m2/nm at wavelength λ, S (λ) is the erythema action spectrum (Figure 1) and dλ is the wavelength interval. The values of the Index range from zero and upward and the higher the Index value is, the greater the potential for damage to the skin and eye is and the shorter is the time that it takes to occur. UVI values are grouped in exposure categories, Table 2 [11]. Effective irradiance 0.3 W/m2 is equivalent to UV Index 12, which WHO characterizes as extreme and corresponds to the solar UV effective irradiance at the equator [6]

***Table 2.*** *UV Index exposure categories*

| Exposure category | UVI range |
|---|---|
| Low | <2 |
| Moderate | 3 – 5 |
| High | 6 - 7 |
| Very high | 8 – 10 |
| Extreme | 11+ |

WHO and many european and international organizations encourage their member states to enact regulations and legislation regarding public safety from sunbed use. Few European counties have implemented such legislation. In Greece not only such legislation does not exist, but also none investigation regarding UV emissions from artificial tanning devices has ever been conducted. Greek Atomic Energy Commission (EEAE) recognizing the importance of the matter, the lack of data regarding UV emissions from artificial tanning devices in Greece as well as the lack of relevant legislation, has initiated a surveillance action of the artificial tanning devices in Greece. The action consists of measurements of the effective irradiance in the whole UV spectrum (250-400nm), from sunbeds at solaria businesses or other premises providing artificial tanning services (like beauty parlors) in Greece. Furthermore, effective irradiance in UVA (320-400nm) and UVBC (250-320nm) range as well as irradiance in UVC (200-280nm) range were also measured. The action aims also to inform and synchronize the artificial tanning business sector in Greece with the requirements of the standard EN ELOT 60335-2-27:2010.

## 2. METHODS

During the period from October 2013 to April 2014, irradiance measurements from artificial tanning devices in solaria businesses, beauty salons and gyms, allover Greece, have been performed. The businesses were found by searching in business directories and online search engines using key words. A letter was sent to the owners informing them about the action that EEAE initiated and asking for their cooperation. There was a reluctant response to the letter, for this reason phone communication with the business owners followed. This approach increased the number of the businesses that agreed to participate in the action.

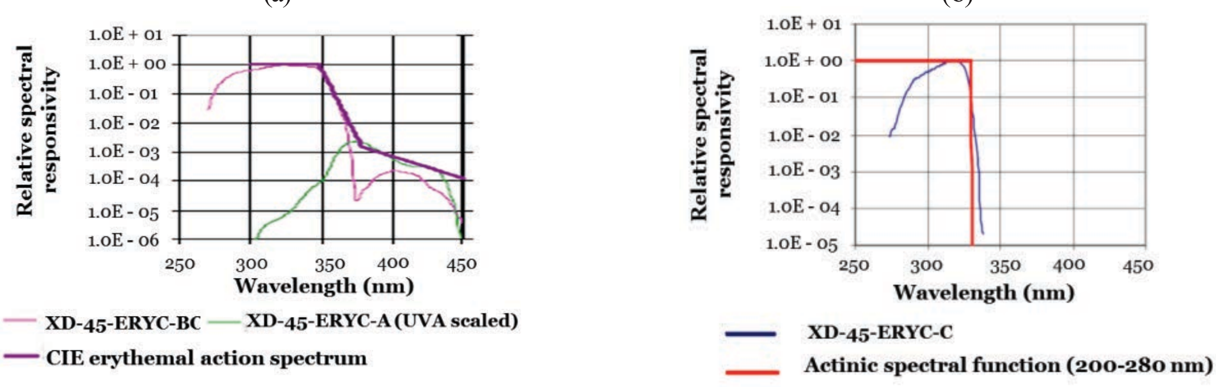
Irradiance measurements were performed using a broadband radiometer and a portable spectrophotometer according to EN ELOT 60335-2-27:2010 recommendations and specially developed protocols, at representative points in the artificial tanning devices. Special care was taken to protect the inspectors performing the measurements from exposing themselves to UV radiation, e.g. special UV blocking glasses were worn during all the measurement procedures.

### *Equipment*

For UV irradiance measurements from artificial tanning devices usually radiometers with a spectral filter with spectral responsivity that matches the erythemal action spectrum are used. Radiometers are handheld, easy to use instruments enabling fast in situ measurements. For the purposes of this action, the effective irradiance measurements from artificial tanning devices, a more sophisticated radiometer, the Gigahertz-Optik X14 – Eery and EUVC broadband radiometer was used. The instrument comprises of an evaluation and display unit and the XD-45-ERYC-4 measuring probe and is designed to measure and examine UV hazard from artificial tanning devices. The XD-45-ERYC-4 measuring probe is used to measure the effective irradiance as well as the UVC irradiance. The erythema sensor comprises of two photodiodes, one for the UVA (320-400nm) range and one for the UVBC (250-320nm) range. A spectral correction filter that mimics the respective spectral responsivities of the CIE erythemal action spectrum at the UVA and UVBC range was adjusted accordingly to each photodiode. The UVC sensor comprises of a photodiode with a spectral correction filter that suppresses crosstalk of the UVA and UVB radiation. Each sensor provides a cosine corrected field of view, and their spectral responsivity is given in Figure 2.

***Figure 2.*** *Typical spectral responsivities of the UVA and UVBC detectors (a) as well as the UVC detector (b)*

(a) (b)




This unique design of the measuring system, using two different photodiodes for UVA and UVBC effective irradiance, gives the advantage of reducing the crosstalk between the different UV ranges, where the CIE erythemal spectral responsivity changes dramatically, allowing more accurate measurements of irradiance from artificial tanning devices. Moreover it allows the classification of the tanning device according to the criteria set by the standard (Table 1), without the need of a double monochromator spectroradiometer. The expanded measurement uncertainty (95% confidence level) was calculated ± 8.23 % for the UVA sensor, ± 10.63 % for the UVBC sensor and ± 7.1 % for the UVC sensor.

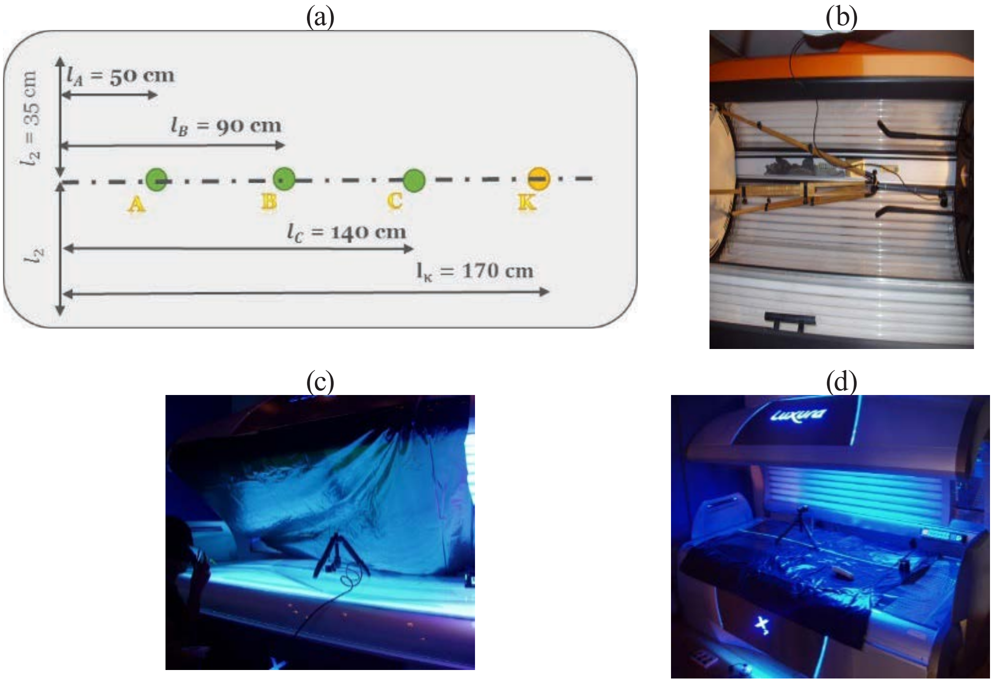
The double monochromator spectroradiometers are the only systems that can assure the most accurate UV irradiance measurements. However such instruments are expensive, bulky, delicate, and not easy to be used in routine in situ measurements of UV radiation from artificial tanning devices in solaria businesses. The modern single monochromator spectroradiometers are compact, easy to use, light and affordable instruments, suitable for onsite measurements. Single monochromator spectroradiometers consist of a single monochromator and a linear detector array, usually a CCD detector. The measurement time is considerably reduced as irradiance from all wavelengths is measured simultaneously, not successively as in the double monochromator systems. In this way, single monochromator spectroradiometers can provide spectral information while broadband radiometer are not capable of doing so. Single monochromator radiometers suffer from stray light which could downgrade measuring accuracy. Careful calibration could reduce stray light effect, permeating reliability to the measurements [12].

The Solatell Sola-Check System, a hand held, portable single monochromator spectroradiometer was used to record UV spectrum from artificial tanning devices. The system comprises of the Sola-Check probe and the Sola-Manager unit. The Sola-Manager unit is equipped with specially designed software that corrects stray light effects. More specific, the operation called “Stray Light Subtraction – Solarium Mode” is a built in unit, which rejects stray light to obtain meaningful readings. Sola-Check sensor utilizes a cosine response diffuser, provides spectral resolution 0.5nm in the 250-470nm spectral range, with less than 10nW/cm2/nm sensitivity. Its dynamic range is more than 107 and stray light rejection ratio is less than 103.

***Measurements' protocols***

The way that the user places its body inside the tanning device as well as the directions given by the standard were the guides for the development of our measurement protocols. Three or four measurements at various points inside the sunbed were performed. These points correspond to different parts of the user's body, approximately the area of the head, the trunk and the knees. The diagram in Figure 3 (a) depicts the measurement points at four different heights. Before the measurements, each device was kept in full operation for 3 minutes in order to warm up and stabilize the outputs of its lamps. The mean of three effective irradiance readings taken with the radiometer at each point was calculated and formed the measurement's result at that point. The maximum effective irradiance measured anywhere within the artificial tanning device is given as the measurement's outcome, as the worst case exposure scenario is considered. The data recorded at each point were the effective irradiance in the UVA and in the UVBC range, and the irradiance in the UVC range. Emission spectrum of the tanning device's lamps was also recorded with the single monochromator spectroradiometer.

***Figure 3.*** *(a) Diagram presenting measurement points and the corresponding distances. (b) Measurements' setup in vertical sunbeds. (c & d) Measurements' setup in horizontal sunbeds.*




For vertical sunbeds, sun booths, tanning booths or "stand-up" sunbeds as otherwise known, inside which the user is standing up and the lamps surround him vertically in an array of cylindrical symmetry, measurements were performed at four different heights. The distance from the lamps surface was 35cm, as this distance was the smallest distance from the lamps that the user could have. The sensor was mounted on the head of a camera tripod, facing the lamps (Figure 3 (b)).

For horizontal sunbeds, tanning beds or solarium as else known, the ones that have a sandwich-like layout and the user lays inside them, separate measurements were performed at the canopy and the lower lamps. When a user occupies a horizontal sunbed, he usually takes an upward facing position, laying on his back. In this way his back receives only the radiation of the lower lamps while his front receives only the radiation from the canopy. Special care was taken to mimic an occupied sunbed, as otherwise measurement conditions wouldn't match real exposure. In this direction, the layer of lamps that was not being measured, was covered with a flexible opaque material to block its light and minimize reflections that would not be present in an occupied sunbed. Measurements were performed along the central horizontal axis. The sensor was adapted on a camera tripod. To measure UV irradiance from the lower lamps, the sensor was placed on the surface of the plastic transparent material covering the lamps Figure 3 (c). To measure UV irradiance from the canopy lamps, the sensor was turned over facing the lamps (Figure 3 (d)). When the distance of the upper and lower set of lamps was more than 30cm, the sensor was adjusted at a height of 25cm from the bottom surface. When the distance was less than 30cm, the sensor touched the upper surface, as recommended by the standard. Measurements were performed with the canopy closed, at its usual position when the sunbed is occupied.

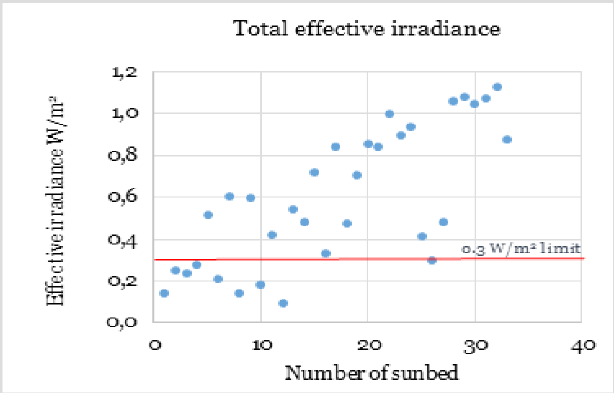
## *3. RESULTS*

From October 2013 until April 2014 a total of 18 premises offering artificial tanning services were visited in 6 cities throughout Greece. UV irradiance measurements were performed in 33 artificial tanning devices, 16 of which were horizontal sunbeds and 17 were vertical sunbeds. Most premises were beauty salons (8 premises), while gyms and artificial tanning businesses followed (6 and 4 premises, respectively). The majority of the sunbeds was found in artificial tanning businesses (14 sunbeds), where the number of sunbeds within each premise ranged from three to seven, while the number of sunbeds in beauty salons or gyms was maximum two. UV radiation from 26 different sunbed models from 9 different manufactures was measured.

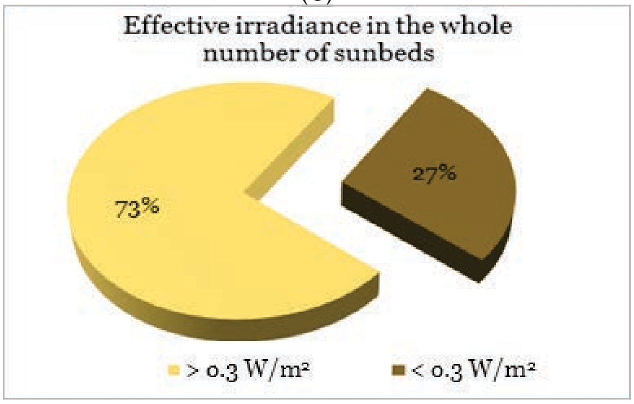
Total effective irradiance ranged between 0.09 and 1.13 W/m2, (Figure 4 (a)) with a mean of 0.60 ± 0.33 W/m2, twice over the limit. The majority of the sunbeds measured during this action, 73% in particular, emitted higher levels of UV radiation than the 0.3 W/m2 limit value set by the technical standard EN ELOT 60335-2-27:2010, Figure 4. (b).

***Figure 4.*** *(a) Total effective I UV irradiance in each sunbed measured. (b) Effective UV irradiance in the whole number of sunbeds with respect to the limit 0.3 W/m2 set by the standard EN ELOT 60335-2-27:2010.*

(a)



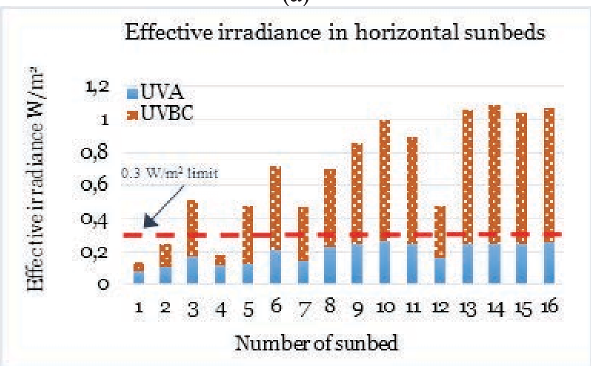

(b)



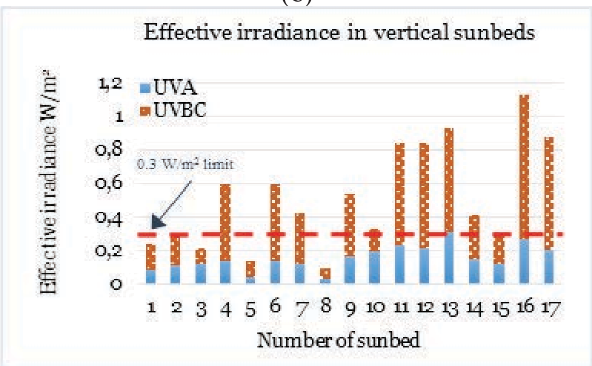

Total effective irradiance exceeded the limit of 0.3 W/m2 in the majority of the horizontal as well as the vertical sunbeds, Figure 5 (a) and Figure 5 (b) respectively. Each bar in the diagrams represents the maximum effective irradiance measured in each sunbed and it consists of two components, the effective irradiance in the UVA and in the UVBC range. It is noteworthy that the UVBC percentage of the total UV effective irradiance was dominant in almost all sunbeds, even when the total effective irradiance was below the 0.3 W/m2 limit.

*Figure 5. Total effective irradiance in horizontal (a) and vertical sunbeds (b)*

(a)



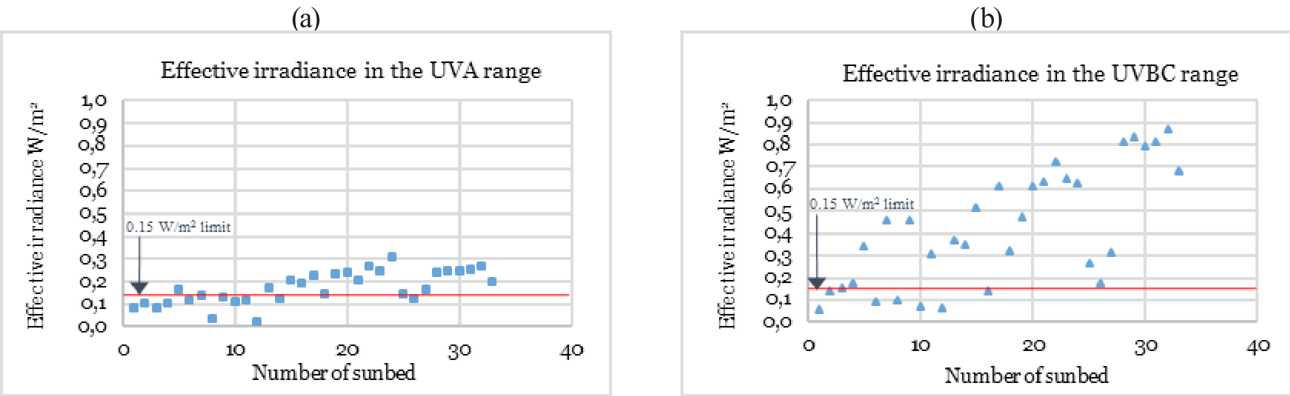

(b)




The diagrams in Figure 6 depict the measured effective irradiance values in the UVA (Figure 6 (a)) and UVBC (Figure 6 (b)) range separately. The mean UVA effective irradiance was 0.17 ± 0.07 W/m2 and the values ranged from 0.03 to 0.31 W/m2. The mean UVBC effective irradiance was 0.46 ± 0.23 W/m2, more than two times higher than 0.15 W/m2 which is the limit value set by the standard. The minimum measured value was 0.06 W/m2 while the highest was 0.87 W/m2, almost six times over the limit. It is worth mentioning than the UVBC effective irradiance exceeded the limit in 79% of the sunbeds measured.

Regarding irradiance in the UVC range, in the majority of the sunbeds measured no irradiance in the UVC range could be detected. In few sunbeds (7 sunbeds in particular) irradiance in the UVC range was detected, but its values were far below the 3 mW/m2 limit set by the standard. The values ranged from 0.6 to 2 mW/m2. In one sunbed only the irradiance exceeded the limit, since the value measured was 13.7 mW/m2, almost four times higher than the 3 mW/m2 limit.

*Figure 6. Effective irradiance in the UVA (a) and UVBC (b) range*




Classification of the sunbeds according to the criteria set by the standard revealed that only eight sunbeds fulfilled the requirements to be used as artificial tanning devices by either trained or unskilled persons, in other words fall into the UV type 1, 2 or 3 category. The complete categorization is developed in Table 3. 17 sunbeds (52% of the sunbeds measured) could not be categorized to any of the four UV types as their effective irradiance in the UVA (320-400nm) range as well as in the UVBC (250-320nm) range exceeded 0.15 W/m2.

***Table 3.*** *Classification of the sunbeds depending on their measured effective irradiance, according to EN ELOT 60335-2-27:2010 criteria*

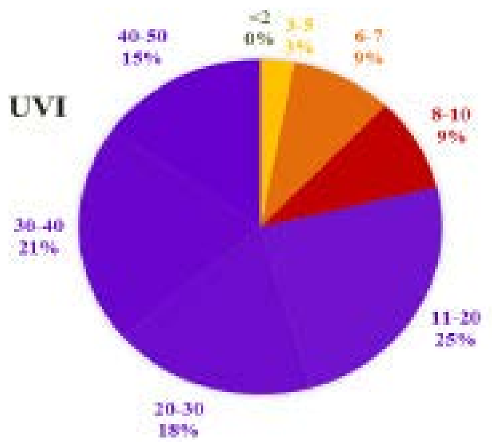
| **UV type** | ***Effective Irradiance W/m2*** | | | ***No of sunbeds*** | ***Percentage (%)*** |
|---|---|---|---|---|---|
| | ***UVBC 250-320nm*** | ***UVA 320-400nm*** | ***Use*** | | |
| **1** | <0.0005 | ≥0.15 | Supervised | 0 | 0 |
| **2** | 0.0005-0.15 | ≥0.15 | Supervised | 1 | 3 |
| **3** | <0.15 | <0.15 | Unskilled | 7 | 21 |
| **4** | ≥0.15 | <0.15 | Medical | 8 | 24 |

Transforming the effective irradiance from the sunbeds in terms of UV Index, using the values of the measured effective irradiance and Equation (2), it turned out that 79% of the sunbeds emitted extreme UV radiation (Table 4). The UV Index in the majority of those sunbeds which emitted extreme UV radiation ranged between 20 and 45 UVI (Figure 7).

***Table 4.*** *Classification of the sunbeds according to their UV Index*

| Exposure category | UVI range | Sunbeds |
|---|---|---|
| Low | <2 | 0 |
| Moderate | 3 - 5 | 1 |
| High | 6 - 7 | 3 |
| Very high | 8 - 10 | 3 |
| Extreme | 11+ | 26 |

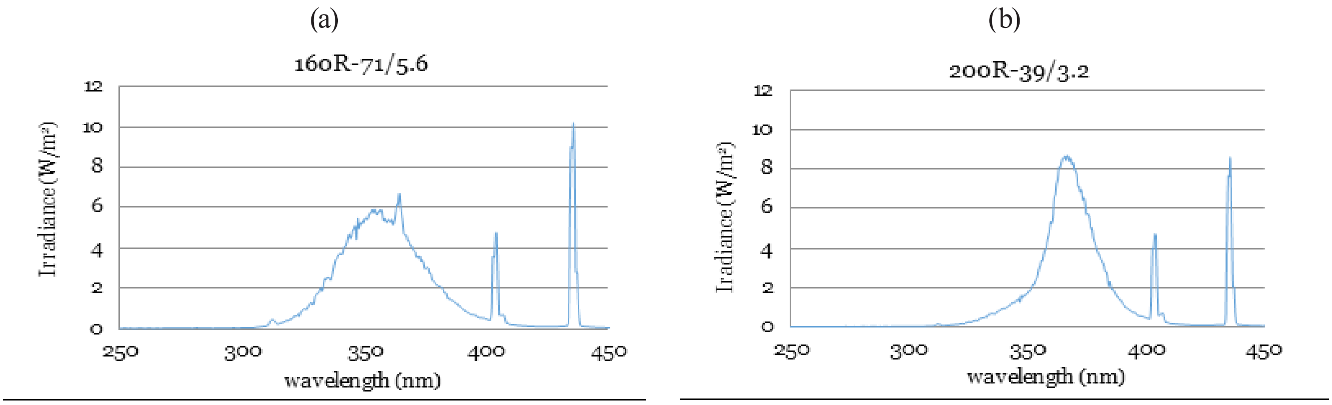
***Figure 7.*** *UVI distribution among sunbeds*




Representative UV emission spectra from the sunbeds are presented in the diagrams of Figure 8. The spectra were recorded using the Sola-Check handheld single monochromator spectrophotometer. Emissions were recorded mainly in the UVA range and far less in the UVBC range. Visible radiation was also emitted, violet and blue light mainly, as the characteristic peaks in the spectrum reveal. Differences in the emission spectra can be detected in the irradiance, depending on the power of the lamps.

**Figure 8.**

*UVR emission spectra of representative sunbed lamps: a. 160R-71/5.6, b. 200R-39/3.2.*




## 4. CONCLUSIONS

According to the irradiance measurements results from artificial tanning devices in various premises throughout Greece, performed during the period from October 2013 to April 2014, the effective irradiance exceeded the 0.3 W/m2 limit set by the EN ELOT 60335-2-27:2010 technical standard in two out of three sunbeds measured. Moreover irradiance in the UVC range was detected in one sunbed, whose measured value exceeded the 0.003 W/m2 limit by four times approximately. Transforming the results in terms of UV Index, it came out that 79% of the sunbeds emitted extreme UV radiation. Similar investigations performed in other European countries reached almost the same results. P. Tierney et al. measured 402 sunbeds throughout England and showed that 90% of the sunbeds emitted levels of UV radiation that exceeded the 0.3 W/m2 limit [13]. In Italy, S. Facta et al. measured the effective irradiance from 94 sunbeds and revealed that the 0.3 W/m2 effective irradiance limit was not respected by the 88% of the devices [14].

Classification of the sunbeds according to the criteria set by the EN ELOT 60335-2-27:2010 technical standard, showed that the majority of the sunbeds (76%) was either UV type 4 (24 % of the sunbeds measured), category in which only the UV emitting devices intended for medical use are included, or they couldn't be classified at all as they emitted higher radiation than the criteria predicted by the standard (52 % of the sunbeds measured). Moreover, the percentage of effective irradiance in the UVBC range was dominant even in those cases where the total effective irradiance was below the 0.3 W/m2 limit. In the same direction, S. Facta et al. reported that 38% of the examined sunbeds emitted too high UV radiation that they couldn't fall into any UV type [14]. According to the results of the measurements performed during the present action, only 21% of the sunbeds could be characterized as UV type 3 device. Nilsen et al. also showed that only 23% of the 194 sunbeds measured during a similar investigation in Norway emitted UV radiation below the UV type 3 limit [15].

The results of the measurements performed in sunbeds at solaria businesses throughout Greece are rather alarming as they reveal non compliance with the limits set by the EN ELOT 60335-2-27:2010 technical standard. This finding enhances the necessity of continuing and expanding the measurements of UV emissions from artificial tanning devices in Greece. Analysis of the results revealed also the need to develop a code of practice for the artificial tanning services and to design an educational course for the personnel working in this field, but most of all the need to develop national legislation regarding sunbeds and solarium services in Greece, given that no relevant legislation currently exists.

## ACKNOWLEDGMENT

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# LEGISLATION ON HUMAN HEALTH PROTECTION ON USING SOLARIA

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*ABSTRACT*

*Artificial tanning sunbeds are popular for cosmetic purposes for several decades. In 2010 UV radiation, encompassing UVC, UVB and UVA; solar radiation and use of UV-emitting tanning devices are recognized as carcinogenic to humans and included in the list of carcinogens as Group 1 by IARC. The proven biological effects of UV radiation and the wide use of sunbeds by the general public, especially by adolescents necessitate implementation of legislation to prevent and/or reduce the harmful health effects. The major problem with this type of source is that many people consider intensive sunbathing / solarium exposure as normal and sun tan is seen as a symbol of good health, prosperity and attractiveness.*

*The first European standard for this particular group of UV sources was developed by the IEC in 1985. Since then, many countries and organizations have developed opinions, manuals, recommendations to public authorities and general public that reflect new scientific evidence about the harmful effects of UV radiation. Human health protection on using solaria requires specific approaches, namely setting of technical requirements and control of the sources, requirements for training and education of indoor exposure consultants, providing adequate information to the general public, not permitting advertising of beneficial effects and use of solaria by sensitive populations. The report presents various aspects laid down in the legislation for the human health protection on using solaria. Here, special attention is paid on the Bulgarian opinion to such legislation.*

***Key words:*** *tanning, solaria, health risk, legislation, requirements.*

Tanning beds are popular for cosmetic tanning for several decades. From the 40s to the 60s of the last century UV exposure from mercury lamp was popular in northern Europe and North America. The ultraviolet spectrum of the mercury lamp consisted of about 20% UVC and 30-50% UVB radiation. In some cases, mercury lamps were covered with glass, which is a way for limiting the emissions in UVB and UVC ranges somewhat depending on the thickness of the glass. Exposure to these lamps was of short duration, but could lead to erythema and burning. These lamps have been used mainly for exposure of children in order to cause vitamin D synthesis, and for adults tanning. They were banned in most of the countries around 1980. Fluorescent tubes emitting UV radiation for tanning are produced by the 60s of last century. Before requirements setting it was possible the predominant part of the spectrum of these devices to be in UVB range. In the 80s and 90s with increasing concerns about the carcinogenetic potential of UVB, the yield of fluorescent lamps with low pressure shifts to UVA. Nowadays, sunbeds emit UVA and UVB radiation. In general, sunbeds mainly emit UVA radiation, because it is thought to be the least damaging of the UV radiation spectrum. However in recent years, sunbeds have been manufactured that produce higher levels of UVB to mimic the solar spectrum and speed the tanning process. At present the spectral characteristics of the tanning devices vary significantly.

After numerous epidemiological studies in recent decades consensus among epidemiologists has reached that malignant skin melanoma is connected to exposure to solar radiation and the main risks are associated with episodes of sunburn and high levels of solar radiation in childhood. The results of studies on carcinogenic effects warrant the IARC to categorize solar radiation as Group 1: “carcinogenic for humans” and UVA, UVB and UVC as group 2A “probably carcinogenic for humans” [7]. After reviewing the scientific evidence and reporting of studies conducted since 2006 [6], in 2011 in the group 1 except for solar radiation are categorized UV radiation, encompassing UVC, UVB and UVA and the use of UV devices for tanning [8].

Earlier, in its press release IARC concluded that there is no positive effect from the use of artificial UV radiation for tanning [9].

UVA, UVB and UVC radiation are also included in the list of «known human carcinogens» in the 10th report on the carcinogenesis of the National Toxicology Program of the United States.

Since 2003, WHO recommends not using artificial UV radiation for cosmetic purposes and encourages each country to introduce their own legislation regarding the legalization and use of tanning beds.

The proven biological effects of UV radiation and the wide use of sunbeds by the general public, especially by adolescents necessitate implementation of legislation to prevent and/or reduce the harmful health effects.

***The major problem with this type of source is that many people consider intensive sunbathing / solarium exposure as normal and sun tan is seen as a symbol of good health, prosperity and attractiveness.***

The first European standard for this particular group of UV sources was developed by the IEC in 1985. Since then, many countries and organizations have developed opinions, manuals, and recommendations to public authorities and general public that reflect new scientific evidence about the harmful effects of UV radiation. In the EU countries the basic legal document that is used to determine the technical requirements to sources, and basic instructions for consumers is EN 60 335-2-27 [4].

In its 3d edition standard states how the appliances shall be categorized and labeled with UV type based on the measured erythemal CIE-weighted effective integrated irradiance (W/m²) below and above 320 nm. According this document each device could be assigned to one of the following types:

- ***UV Type -1*** appliance: device with UV source, in which the biological effect is caused by the radiation with wavelength > 320nm, and could be characterized with relatively high effective irradiance in the range 320–400 nm.
- ***UV Type -2*** appliance: device with UV source, in which the biological effect is caused by the radiation with wavelength above or under 320 nm, and could be characterized with relatively high effective irradiance in the range 320–400 nm.
- ***UV Type -3*** appliance: device with UV source, in which the biological effect is caused by the radiation with wavelength above and under 320 nm and could be characterized with limited irradiance in the whole UV range.
- ***UV Type -4*** appliance: devices with UV source in which the biological effect is caused by the radiation with wavelength < 320 nm.

***Table 1.*** *UV types of appliances depending on their effective irradiance according to EN 60 335-2-27.*

| **UV type appliance** | **Effective irradiance, $W.m^{-2}$** | |
|---|---|---|
| | 250 nm < λ <320 nm | 320 nm < λ < 400 nm |
| **1** | < 0.005 | ≥ 0.15 |
| **2** | 0.0005 до 0.15 | ≥ 0.15 |
| **3** | < 0.15 | < 0.15 |
| **4** | ≥ 0.15 | < 0.15 |

Type 1 and type 2 appliances should be used only under supervision of appropriately trained persons. Type 3 appliances may be used by unskilled persons. Type 4 appliances are intended to be used following medical advice.

The standard requires checking of the compliance to include assessment of the possibility the UV type to be altered by changes in the lamps, electrical components, or lamp covers; influence of lamp ageing and performing measurements at distance of 30 cm. It specifies requirements for the user instructions and cases when UV exposure should be discouraged. Requirements for UV radiation dose for the first session (≤ 100 J.m-2), and annual dose (15 kJ.m-2 (150 SED)) are introduced as well. Sunbeds should be provided with protective goggles which transmission in the UV range should not exceed that shown on Table No. 2.

***Table 2.*** *Required transmission of UV radiation for goggles*

| Wavelenght, λ | Maximal transmission, % |
|---|---|
| 250 < λ ≤ 320 | 0.1 |
| 320 < λ ≤ 400 | 1.0 |
| 400 < λ ≤ 450 | 5.0 |

In some countries such as Belgium, Germany, Norway, France, Sweden and others standard is adopted as the general requirements regarding tanning devices, but additional regulations are developed that concern their licensing and restrictions on their use. Presented classification of UV appliances according to the spectrum of the radiation and the effective irradiance allows some national authorities to exclude particular types of devices of their markets in order to protect the health and safety of the consumers. This is the case in France and the Scandinavian countries, where only devices UV type -1 and UV type -3 are allowed.

Several international organizations have adopted clear positions regarding the use of UV sources for tanning. All they consider that exposure to artificial sources of UV radiation should be avoided. Most of them define the cases when UV exposure should be discouraged, as follows [4, 10, 11, 12, 13, 14, 15, 16]:

- persons under the age of 18 years;
- persons who tend to freckle;
- persons with a natural red hair color;
- persons having abnormal discolored patches on the skin;
- persons having more than 16 moles (2 mm or more in diameter);
- persons having any atypical moles (atypical moles are defined as asymmetrical moles larger than 5 mm in diameter with variable pigmentation and irregular borders; in case of doubt, seek medical advice);
- persons suffering from sunburn;
- persons not able to tan at all or not able to tan without burning when exposed to the sun;
- persons that burn easily when exposed to the sun;
- persons having a history of frequent severe sunburn during childhood;
- persons suffering from or previously suffering from skin cancer or predisposed to skin cancer;
- persons having a first-degree relative with a history of melanoma;
- persons under doctor's care for diseases that involve photosensitivity;
- persons receiving photosensitizing medications.

If, despite of the recommendations of these organizations, people decide to use tanning devices special measures have to be taken in order to minimize the risk.

In 2003, WHO published a document «Artificial tanning sunbeds: risks and guidance» [15] as a part of Intersun Program. This document is intended to inform customers of the tanning devices about the risks of UV radiation and to convince them not to subject themselves to multiple exposures to artificial UV and solar radiation (studies show that users of artificial sources of UV radiation are «addicted» to sunbaths as well), and draws particular attention to the prohibition of UV sessions for minors. Specific requirement in WHO recommendations is to require users of tanning devices to read the recommendations and to sign an informed consent form before each tanning session.

Over the years, the quality and safety in the use of tanning beds significantly improved, especially having in mind the fact that in 2010 effective irradiance in the new revision of EN 60335-2-27 is limited to 0,3 W/m² (it corresponds to 11 SED; UVI 12 described as "extreme") after SCCP/0949/05 Opinion on Biological effects of ultraviolet radiation relevant to health with particular reference to sun beds for cosmetic purposes [14]. On the other hand the safe use of professional tanning devices strongly depends on the way the service is provided. One of the key elements in ensuring the safe use of tanning by the general public is providing adequate information upon request of the service and setting ethical and professional rules under which these services are provided. For this purpose, the Technical Committee CEN / PC 412 «Solar tanning services» whose secretariat is supported by the Austrian Standards Institute (ASI) developed standard in three parts:

- EN 16489-1: 2014: Professional indoor sun exposure services - Part 1:Requirements for the provision of training [5]
- prEN 16489-2 Professional indoor sun exposure services - Part 2: Required qualification and competence of the indoor sun exposure consultant;
- prEN 16489-3 Professional indoor sun exposure services - Part 3: Requirements for the provision of services.

The ***aims*** of developed standards are as follows:

- to meet the needs of the European market of a clear regulation of the basic quality of beauty services;
- to provide a framework for effective management of the full range of services offered by professional beauty centers;
- to protect the health and safety of customers by introducing ethical and professional rules which prevent misleading advertising and use of hazardous for health beauty services.

The main aspects are: quality assurance; introducing of good practices in the field; information and customer service; maintenance of equipment; hygiene and materials' sterilization.

The content of the three parts of the standard is as follows:

***1. EN 16489-1 Professional indoor sun exposure services - Part 1: Requirements for the provision of training***

- Terms and definitions;
- Learning contents including theoretical training; general content; specific content; practical training – communication with the consumers; safe operation of UV tanning device; follow-up training;
- Assessment of knowledge and skills;
- Attestation;
- Quality assurance of the training course;

The document contains two annexes: The Fitzpatrick skin-type chart and A-deviations.

The first part of the standard EN 16489 [5] defines the main learning content of training intended for consultants specialized in providing professional solar services. The standard also defines the operational procedures for demonstrating and testing the competence of the consultants and requirements for follow-up training. Our opinion on this part of the standard is that it contains basic information required for training and assessment of competence of UV exposure consultants.

Our main remarks to the draft standard were related to unclear definition of professional groups that could act as consultants, and lack of required specific minimum education and competence.

In our opinion the person who is working as an indoor sun exposure consultant should have at least background competencies in the field of:

- Anatomy (mainly skin and eye);
- Physiology;
- Biophysics/biochemistry (mechanisms of tanning and production of vit. D);
- Health promotion;
- Hazard and risk;
- Risk assessment, etc.
- Examples: medical doctors, nurses, specialists in cosmetics, health physicists, kinesitherapists, rehabilitators, physiotherapists, etc.

Other major drawbacks are the lack of a few key elements in the learning content and competence related to the reduction of risk to customers, namely:

- Knowledge of groups at increased risk for which exposure to the procedures for obtaining tanning is contraindicated and as such should be limited / or not allowed at all;
- Precautions to be taken before exposure procedures in solarium;

We also believe that in tanning salons should not be declared positive effects of procedures for artificial tanning. In fact, UV radiation has positive effects on human health, which makes it necessary for the human health, but in general these positive effects can occur during normal human activities outdoors and for this purpose artificial sources are not necessary.

At the stage of discussion of the standard several countries including Bulgaria proposed to ban advertising of positive effects of UV radiation in tanning beds. This solution would be essential for the health of clients of tanning salon as often «positive» effects are used as a pretext for the use of sunbeds, particularly by persons at risk. Unfortunately, the proposal was not supported by the working group at the stage of consideration of the first part of the standard. The same proposal was submitted and in consideration of the other two parts of the standard by the delegations of several countries and the European Commission for Consumer Protection (ANEC), but did not get a majority vote.

The draft standard did not address training for safety of sun exposure consultants. By our proposal reference has been made to Directive 2006/25/EC [3].

Our opinion is that the defined period of 5 years for follow-up training is too extended and doesn't comply with other legislation.

The draft document did not include the cases when UV exposure should be discouraged and in our opinion it should be a major part of the theoretical training.

***2. prEN 16489-2 Professional indoor sun exposure services - Part 2: Required qualification and competence of the indoor sun exposure consultant***

Together with Part 1, this document contributes to awareness, safety and security of users of tanning devices by identifying necessary knowledge and competence of indoor exposure consultants. This second part of the standard prEN 16489 specifies the basic requirements concerning the knowledge, skills, competence and qualifications of consultants specialized in providing professional exposure services.

Our main remarks to the draft standard are associated with non-compliance of the basic knowledge and skills covered in the first part of the standard, but also there are the knowledge and skills that must be clearly outlined in this part of the standard.

Also believe that it should be clearly defined in a shorter period for the assessment of conformity with the requirements of Part 1 of EN 16489 or the period is in line with the national legislation of each country.

***3. prEN 16489-3 Professional indoor sun exposure services - Part 3: Requirements for the provision of services***

This third part of the standard prEN 16489 specifies the requirements related to the provision of services in indoor tanning facilities.

Our remarks to this part apply to adding a requirement to provide information about the harmful effects of UV radiation on the eye and the use of protective eyewear; specifying the period of prophylaxis of tanning devices. We also believe that in provided feedback to the studio documentation must contain all statements of the customers, not just complaints, but satisfaction and recommendations.

**Situation in our country**

In our country there is still no established policy regarding the protection of people using tanning devices. The standard EN 60335-2-27 [4] was introduced only with confirmation (not translated) which restricts its use to control the sunbeds in the country. Given the status of documents as standards as they are voluntary, it can be said that in practice, in our country there is no legal basis for the control of solar studios and other premises using tanning devices.

According to our information got from advertisements in Internet and other media, visits to solaria, sports and spa centers with tanning devices, they often encounter a description of health benefits, and reducing the harmful effects of the sun.

Operators provide general information about the adverse health effects, but do not exercise control in respect to duration of exposure. Most often, the duration of exposure is a matter of personal choice by the customer of the studio. There are studios, where the choice of the duration of exposure is based on the number of purchased coins, which are also used only depending on the customers' willingness.

**Our proposals for further activities in this field:**

- Development of a national legal document regulating the safety requirements for the use of tanning beds, including: requirements for tanning devices; electrical safety; requirements for periodical inspection of the level of radiation; requirements for medical surveillance; defining groups of people that should not be subjected to these procedures; Information for consumers; Training of consultants providing solar services.
- Provision of training for consultants providing indoor solar services;
- Establishment of control over the education and training of consultants providing indoor solar services
- Implementation of control of tanning premises by the health authorities and prohibition of ads claiming beneficial effects of artificial tanning;
- Establishing control respect of using tanning devices by persons under 18 years;
- Development a program for risk communication regarding the use ultraviolet radiation from the sun and artificial sources (tanning).

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NATIONAL CENTER OF PUBLIC HEALTH AND ANALYSES

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**SESSION 2.**
Measurement, exposure, modeling, dosimetry

**SESSION 3.**
Human exposure standards

**SESSION 4.**
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**SESSION 5.**
Medical Applications of EMF and UV

**ROUND TABLE**

**24** September, 2014 Wednesday

**SESSION 6.**
Occupational health and safety

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