Bulletin de veille
Champs électromagnétiques
N°9 - Nov/Déc/Janvier 2024-25

Objectif : surveillance de la littérature scientifique concernant les impacts sur la santé humaine de l'exposition aux champs électromagnétiques

La validation des informations fournies (exactitude, fiabilité, pertinence par rapport aux principes de prévention, etc.) est du ressort des auteurs des articles signalés dans la veille. Les informations ne sont pas le reflet de la position de l'INRS.

Les liens mentionnés dans le bulletin donnent accès aux documents sous réserve d'un abonnement à la ressource.

Les bulletins de veille sont disponibles sur le portail documentaire de l'INRS. L'abonnement permet de recevoir une alerte mail lors de la publication d'un nouveau bulletin (bouton « M'abonner » disponible après connection à son compte).

Exposition professionnelle 1
Etudes épidémiologiques 6
Evaluation de l'exposition 8
Toxicité 13
Méthodes 22
Toxicité sur les animaux 29
Actualité, société et mesures de prévention 33

Exposition professionnelle

Radiation information, protection and awareness of healthcare professionals in terms of occupational health and safety: a two-center survey study,
Çetin, M. E., Akbas, M. M., Bayram, N., Candemir, M. and Aras, S., *Journal of Radiological Protection*, Dec 2024, Vol. 44, no. 4.

The objective of this study was to assess the level of knowledge, protection and awareness of radiation among healthcare professionals. A total of 413 healthcare professionals from two major training and research hospitals in Istanbul took part in the study. The sample consisted of 26.6%

physicians and 73.4% other healthcare professionals. There was considerable variation in the knowledge of radiation content in imaging techniques, with correct response rates of 89.3% for Computed Tomography, 80.1% for digital x-ray, and 52.8% for Magnetic Resonance Imaging. While 69.5% of respondents provided correct answers to questions regarding radiation protection principles, 64.4% demonstrated a lack of sufficient knowledge in this area. It is noteworthy that 48.4% of respondents incorrectly identified the medical imaging technique to which the public is most exposed. It was concluded that further training on radiation-related issues should be provided at the university level and through in-service training for healthcare professionals. https://doi.org/10.1088/1361-6498/ad8204

Determination of EMF exposure in arc welding by introducing improved numerical anatomic body simulation,
Egerland, S. A., Schranz, B. and Langeder, H., *Welding in the World*, 2024 Nov 2024.

Electric and magnetic field (EMF) phenomena arise where applying manual arc welding equipment. Consequently, using such systems may cause adverse effects to welding personnel. Models available quantitatively to assess EMF impacts in welding consistently show underestimation of exposure, mainly due to simplified boundary conditions implemented to facilitate modelling application. For arc welding, this paper introduces a novel approach, namely the implementation of Induction Factors based on anatomical body models in realistic welding postures and welding current parameters to improve the EMF assessment quality. Moreover, it is shown in how far especially advanced MIG/MAG and TIG welding variants, for example also involving additional hardware, may cause exposure values close to the limits defined in currently existing standards. Results, both found in practical process application and numerical simulation, are presented and discussed. Employing the developed calculation approach is capable of compensating for inaccuracies yet identified with models still recommended by regulatory or professional bodies. Users are provided with comprehensive information to help practically evaluate EMF exposure. https://doi.org/10.1007/s40194-024-01871-w

Breast cancer: Could we consider it as an occupational exposure disease?,
Favier, A., Mathelin, C., Gonzalez, M. and Uzan, C., *Gynecologie Obstetrique Fertilite & Senologie*, Nov 2024, Vol. 52, no. 11, p. 627-632.

Objective. - Breast cancer is the leading cancer in women in terms of incidence and mortality. The literature currently identifies several risk factors, some modifiable and others not. Because of its multifactorial nature, the combination of factors either increases or reduces the risk of cancer. Since 2004, the first commission's rapport of the French National Environmental Health Plan has recognized the significant impact of occupational exposure on the development of breast cancer. However, neither primary nor secondary preventive measures have yet been implemented in work environment. Method. - Based on available literature, we reviewed current knowledge of breast cancer risk factors associated with occupational exposure. Results. - The risk factors identified were ionizing radiation, magnetic fields, certain endocrine disruptors, ethylene oxide and night shift work. Conclusion. - Recognition of breast cancer as an occupational disease is complicated. In some cases, however, it may be possible, particularly in cases of multifactorial exposure. This work should help to raise awareness among employers and reinforce preventive measures in the workplace. (c) 2024 Published by Elsevier Masson SAS. https://doi.org/10.1016/j.gofs.2024.07.001

Assessment and Management of Risks from Occupational Exposure to Electromagnetic Fields (0 Hz to 300 GHz): A Compass to Keep the Right Course Through European and Italian Regulations,
Filosa, L. and Lopresto, V., *Safety*, Dec 2024, Vol. 10, no. 4.

This paper outlines the specific provisions of Italian legislation regarding workers' exposure to electromagnetic fields (EMFs) from 0 Hz to 300 GHz compared to the minimum health and safety requirements set in European Directive 2013/35/EU. In particular, the path to be followed to assess and manage occupational exposure to EMFs is outlined in relation to the distinction between 'professional' and 'non-professional' exposure of workers, as well as to the precautionary limits regarding exposures from power lines (50 Hz) and broadcast and telecommunication fixed systems (100 kHz-300 GHz) established by Italian regulations. The reasons underlying such an approach-mainly relying on the intent to reconcile scientific evidence with risk perception in public opinion-are analysed and discussed with the aim of increasing the knowledge of national regulatory provisions on occupational risk assessment, which may be more stringent than the requirements envisaged by international guidelines and community regulations. https://doi.org/10.3390/safety10040104

Electromagnetic compatibility of active cardiovascular implants to occupational magnetic field environments: impact of the field direction,
Hammen, L., Pichon, L., Le Bihan, Y., Bensetti, M. and Fleury, G., *Comptes Rendus Physique*, 2024, Vol. 25.

Active Implantable Medical Devices (AIMD) are nowadays a part of everyday life, with for example more than one million pacemakers (PMs) implanted each year worldwide. Like every electronic devices they are sensitive to electromagnetic interferences but the consequences are potentially severe. A large number of publications deals with electromagnetic compatibility (EMC) with common equipment but only a few concern industrial sources. Furthermore, the field encountered at workplace is potentially higher. Taking these into account, a new test method to assess the EMC of AIMDs against occupational magnetic field sources was developed. It is based on an experimental approach using a specific test bench able to generate a controlled magnetic field in all space directions up to the high occupational exposure limits between 50 Hz and 3 kHz. To do this, three Helmholtz coil systems are combined on three orthogonal space directions. This specificity makes it possible to take into account the high variability of the operator's position compared to the industrial source. In this paper, the study focused on the impact of the magnetic field direction on the PM's functioning with bipolar leads, as is the case for the vast majority of devices implanted nowadays. It appears that the magnetic field direction has an impact on the PM's functioning and is consequently a relevant parameter for evaluating their EMC. These observations led us to the hypothesis that the lead in bipolar mode is more sensitive to electric field than magnetic field. This assumption remains to be confirmed by further studies. https://doi.org/10.5802/crphys.187

Solutions to Reduce Electromagnetic Interference Inside Anesthesia and Intensive Care Units
Roman, M. G., Adochiei, I. R. and Adochiei, F. C. (2023). 11th International Conference on E-Health and Bioengineering (EHB), Univ Med & Pharmacy Iasi, Fac Med Bioengn, Bucharest, ROMANIA.
The field of interference and electromagnetic compatibility (EMC) in medical devices requires the use of measuring instruments and controlled environments for accurate measurements - a practice that is not currently feasible in Romanian hospitals. Our proposed study method offers a simpler approach to identifying susceptible surfaces and implementing electromagnetic shielding solutions. By characterizing these environments, we can take proactive steps to reduce occupational exposure for staff and mitigate electromagnetic interferences in the Anesthesia and Intensive Care Unit. Specifically, our study aims to identify solutions to minimize such interferences and protect healthcare personnel from prolonged exposure to wireless transmitters. We have applied this method to a scenario within the Emergency Clinical County Hospital "Sf. Spiridon", Iasi, in the Anesthesia and Intensive Care ward. https://doi.org/10.1007/978-3-031-62502-2_43

Ingested Magnets Found Inadvertently During Elective Magnetic Resonance Imaging,
Sawyer, J. R., Relland, L. M., Hagele, M. S. and Tobias, J. D., *Journal of Medical Cases*, Nov 2024, Vol. 15, no. 11, p. 319-323.

In the presence of a strong magnetic field such as for magnetic resonance imaging (MRI), ferromagnetic objects may become a source of patient or healthcare provider injury. To prevent such problems, careful screening of patients and healthcare workers is mandatory prior to MRI to identify contraindications to MRI including the presence of external or internal ferromagnetic products. We present a 2-year, 11-month-old child who presented for MRI to evaluate a potential vertebral anomaly. During initial scanning and image acquisition, image distortion was noted which was subsequently determined to be the result of ingested magnetic objects. The basic principles of MRI are discussed, safety pathways to prevent patient and practitioner risk related to ferromagnetic objects presented, and previous reports of patient-related adverse effects from internal ferromagnetic devices reviewed. https://doi.org/10.14740/jmc4280

Action potential threshold variability for different electrostimulation models and its potential impact on occupational exposure limit values,
Soyka, F., Tarnaud, T., Alteköster, C., Schoeters, R., Plovie, T., Joseph, W. and Tanghe, E., *Bioelectromagnetics*, Jan 2025, Vol. 46, no. 1.

Occupational exposure limit values (ELVs) for body internal electric fields can be derived from thresholds for action potential generation. These thresholds can be calculated with electrostimulation models. The spatially extended nonlinear node model (SENN) is often used to determine such thresholds. Important parameters of these models are the membrane channel dynamics describing the ionic transmembrane currents as well as the temperature at which the models operate. This work compares action potential thresholds for five different membrane channel dynamics used with the SENN model. Furthermore, two more detailed double-cable models by Gaines et al. (MRG-Sensory and MRG-Motor) are also considered in this work. Thresholds calculated with the SENN model and the MRG models are compared for frequencies between 1 Hz and 100 kHz and temperatures at 22 degrees C and 37 degrees C. Results show that MRG thresholds are lower than SENN thresholds. Deriving alternative ELVs from these thresholds shows that the alternative ELVs can change significantly with different ion channel dynamics (up to a factor of 22). Using the double cable model could lead to approximately ten times lower alternative exposure limit values. On the contrary, using the SENN model with different membrane channel dynamics could also lead to higher alternative exposure limit values. Therefore, future exposure guidelines should take the influence of different electrostimulation models into account when deriving ELVs. https://doi.org/10.1002/bem.22529

Protection of population and workers with cardiac implantable stimulators from 5G exposure. Part I: mobile terminal exposure,
Vivarelli, C., Calcagnini, G., Censi, F., Pavoncello, S., Franci, D., Burriesci, G. and Mattei, E., *European Physical Journal Plus*, Jan 2025, Vol. 140, no. 1.

The study investigates the potential risks of electromagnetic interference (EMI) from 5G signals on cardiac implantable electronic devices (CIED). Given the increasing prevalence of these devices and the widespread adoption of 5G technology, it is crucial to ensure the radiation protection of both workers and general population based on scientific evidence. The research introduces a novel measurement setup able to reproduce the actual signals adopted by 5G providers, focusing on the uplink scenario where the CIED is in proximity to a mobile terminal. The study tested the pacing, sensing, and high-voltage therapy delivery of five implantable defibrillators from major

manufacturers under controlled and worst-case conditions, at signal power levels beyond those generated by commercial 5G devices (8 W at 700 MHz and 2 W at 3600 MHz). Results showed that the interfering signal generated according to the actual 5G protocol, adhering to the timing and frequency constraints adopted by 5G service providers, did not cause any EMI events in any of the 60 tests conducted. This research demonstrates that 5G mobile terminals do not pose significant risks to PM/ICD wearers and provides important data, enhancing the current understanding of the EMI impact of 5G technology on critical medical devices. https://doi.org/10.1140/epjp/s13360-024-05945-y

Impact of exposure to extremely low-frequency magnetic fields on blood pressure, heart rate variation and disturbance to quality of sleep on industrial workers in Korea,
Weerasinghe, S., Liyanage, S., Kawshalya, M. and Hong, S. C., *International Journal of Occupational Safety and Ergonomics*, 2024 Nov 2024.

Objectives. This study investigates the potential health risks associated with exposure to extremely low-frequency magnetic fields (ELF-MFs), focusing on the impact on sleep quality. The hypothesis is that increasing ELF-MF exposure will correlate with elevated blood pressure (BP), altered heart rate (HR) dynamics and poorer sleep quality among occupational workers in Korea. Methods. The study involved 85 participants. Assessment of ELF-MF exposure was carried out continuously for 24 h in the two groups. Measurements of BP parameters, HR and sleep quality were conducted accordingly. Results. The study found significant ELF-MF exposure levels in both working and sleeping times for industrial factory workers (0.19 +/- 0.38 and 0.17 +/- 0.23 mu T, p < 0.05). Long-term exposure among industrial workers may contribute to a significant difference in systolic blood pressure (SBP) (125.61 +/- 9.60 mm Hg, p < 0.05). Additionally, a significant difference in deep sleep analysis was observed between the high-exposure and low-exposure groups (67.13 +/- 31.15 min, p < 0.05). Conclusion. The hypothesis was confirmed, indicating possible effects of high ELF-MF exposure on SBP and deep sleep. However, further research on long-term exposure and its association with sleep quality disturbances is needed for validation. https://doi.org/10.1080/10803548.2024.2413816

Evaluation of EMF Exposure From Distributed MIMO Antennas for 6G in an Industrial Indoor Environment,
Zhekov, S. S. and Xu, B., *Ieee Transactions on Electromagnetic Compatibility*, 2024 Oct 2024.

Distributed multi-input multioutput (D-MIMO) is one of the promising technology components for the 6G mobile communication systems. In this article, electromagnetic field (EMF) exposure from D-MIMO deployment scenarios in an industrial indoor environment is evaluated using a hybrid simulation approach, based on ray-tracing and full-wave simulations, for downlink transmission at 3.5 GHz. For comparison, EMF exposure from a massive MIMO (mMIMO) deployment scenario is also assessed in the same environment. Both single-user equal gain transmission precoding and multiuser centralized zero forcing precoding schemes are considered. EMF exposure is assessed with the metrics of incident power density, local specific absorption rate (SAR), and whole-body average SAR. The dependence of the exposure on the number of simultaneously served users and number of distributed radio units is investigated. The simulated exposure at the ground level is well below the limits specified in the international EMF exposure guidelines considering realistic output power levels for both D-MIMO and mMIMO scenarios. It is observed that the 95th and 99th percentiles of the assessed EMF exposure levels from D-MIMO are lower than those from the mMIMO deployment under the same condition. However, a trend is not observed for the median exposure levels. https://doi.org/10.1109/temc.2024.3474038

Electromagnetic compatibility study of trackside antenna array miniaturization in the subway tunnel,
Zhou, W. Y., Xu, J. J., Lu, M. and Li, Y. X., *Physica Scripta*, Dec 2024, Vol. 99, no. 12.

To improve the compatibility of the subway tunnel's electromagnetic environment and reduce the radiation impact of trackside antennas on subway workers. This paper proposes a miniaturized dual-band trackside antenna array by using metamaterial units. Its operation bandwidth is 2.33 similar to 2.56 GHz and 3.24 similar to 3.45 GHz, which could simultaneously satisfy the signal cover demands of the communications-based train control (CBTC) and the civil 5G wireless communication system. The proposed miniaturized antenna array has a maximum gain of 14.4 dBi and a maximum channel capacity of 13.9 bps Hz(-1) at a signal-to-noise ratio (SNR) of 20 dB, which can effectively improve the quality of wireless communication systems. The number of trackside antennas with a single operation frequency band is reduced, and the distance between the antennas is enlarged at the same time. Besides that, we analyze the radiation impact on the tunnel electromagnetic environment of the proposed trackside antenna array. In particular, the electromagnetic dose absorbed by the human model of a tunnel worker is quantized. The results show that the electric field strength in the tunnel reduces by 4.11% at least after antenna array miniaturization, and the specific absorption rate (SAR) absorbed by the worker model's trunk, skull, brain, heart, and liver is reduced by a maximum of 19.02%, 33.16%, 28.27%, 41.75%, and 74.54%, respectively, further lowering the human electromagnetic exposure risk. Therefore, a miniaturized trackside antenna array could reduce the interference from other radiation sources in the tunnel while providing a new idea for electromagnetic protection for subway workers. https://doi.org/10.1088/1402-4896/ad8b74

Etudes épidémiologiques

Magnetic fields from indoor transformer stations and risk of cancer in adults: a cohort study,
Juutilainen, J., Khan, M. W., Naarala, J. and Roivainen, P., *Occupational and Environmental Medicine*, Dec 2024, Vol. 81, no. 11, p. 574-579.

Studies assessing the association of adult cancers with extremely low frequency (ELF) magnetic fields (MF) have provided inconclusive results, probably affected by limitations such as low exposure levels, confounding and various forms of bias. This study investigated the association between residential ELF MF exposure and adult cancer using a design that avoids the main limitations of previous studies. Persons who have lived in buildings with indoor transformer stations during the period 1971-2016 formed the study cohort. Their MF exposure was assessed based on the location of their apartment in relation to the transformer room. Information on their cancer diagnoses was obtained from the Finnish Cancer Registry. SIR with 95% CI was calculated to investigate the association of MF exposure with overall cancer and specific cancers. The SIR for all primary sites was 1.01 (95% CI 0.93 to 1.09). An increased risk of digestive organ cancers was observed among the exposed persons, with a SIR of 1.23 (95% CI 1.03 to 1.46). The highest SIR was observed for gallbladder cancer (3.92, 95% CI 1.44 to 8.69). Increased risk of testicular cancer was observed among men exposed to MF during childhood, but this is likely to be due to confounding associated with living on the lowest floors. No other significant associations were observed for other primary cancer sites studied. Overall cancer risk was not affected by residential MF exposure. The increased risk of digestive organ cancers among MF-exposed persons is a novel finding requiring confirmation in further studies. https://doi.org/10.1136/oemed-2024-109466

Preliminary study on the impact of 900 MHz radiation on human sperm: An in vitro molecular approach,
Keskin, I., Karabulut, S., Kaplan, A. A., Alagöz, M., Akdeniz, M., Tüfekci, K. K., Davis, D. L. and Kaplan, S., *Reproductive Toxicology*, Dec 2024, Vol. 130.

The use of technologies that produce and emit electromagnetic fields (EMF) is growing exponentially worldwide. The biological effects of EMF-emitting equipment, such as mobile phones and other wireless devices, have been studied in the last decade using in vitro and in vivo methods. Infertility is a growing health problem, and nearly half of cases are because of male-factor. This study investigated the direct in vitro effects of 900 MHz radiation exposure on sperm parameters, genetic status, apoptotic markers, and the PI3K/AKT signaling pathway in healthy normozoospermic men. Semen samples were divided into four groups, two control (30 min and 1 h) and two EMF exposure (30 min and 1 h). Sperm parameters (motility, progressive motility, acrosomal index, morphology), genetic status (DNA fragmentation and chromatin integrity), apoptotic markers (cytokine-c and caspase-3 expression) and the PI3K/AKT signaling pathway (phosphoinoitide 3-kinase-PI3K- and phosphorylated AKT- p-AKT-) were analysed. Sperm motility were significantly reduced in 30 min EMF exposure while a significant increase in the expression of p-AKT were observed in 1 h EMF exposure group. An increased vacuolisation, acrosomal defect, extension of subacrosomal space, uncondensed chromatin structure, apoptotic signs and disrupted axoneme were observed in both EMF groups which were not observed in the control group. Other sperm parameters (morphology and acrosomal index), genetic status, apoptotic markers and the PI3K expression rates had no significant change. https://doi.org/10.1016/j.reprotox.2024.108744

Impact of non-ionising radiation of male fertility: a systematic review,
Motchidlover, L., Sari-Minodier, I., Sunyach, C., Metzler-Guillemain, C. and Perrin, J., *French Journal of Urology*, Jan 2025, Vol. 35, no. 1.

Exposure to non-ionizing radiation has become inevitable because people cannot escape sources of electromagnetic fields, such as Wi-Fi or cell phones. Among the mechanisms mentioned, the energy emitted by this non-ionizing radiation could cause heating which would have harmful effects on semen quality. The objective of our study was to carry out a systematic review of the literature concerning the impact of exposure to non-ionizing radiation from mobile phones (or other sources) on sperm parameters. We selected 12 studies: the majority of in vivo studies in humans and in vitro studies in animals report a significant impact on sperm count, mobility and vitality. Mobility and vitality seem to be the parameters most regularly impacted by exposure to non-ionizing radiation. Additional studies are necessary to complete this study in order to deepen knowledge with new generations of mobile phones which can raise health concerns. (c) 2024 Elsevier Masson SAS. All rights are reserved, including those for text and data mining, AI training, and similar technologies. https://doi.org/10.1016/j.fjurol.2024.102800

Systematic Review of Exposure Studies to Radiofrequency Electromagnetic Fields: Spot Measurements and Mixed Methodologies,
Ramirez-Vazquez, R., Escobar, I., Arribas, E. and Vandenbosch, G. a. E., *Applied Sciences-Basel*, Dec 2024, Vol. 14, no. 23.

This work presents a review and evaluation of studies measuring exposure to Radiofrequency Electromagnetic Fields (RF-EMF). The review meets the basic quality criteria and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines after the eligibility criteria of the PECO (Population, Exposure, Comparator, and Outcome) methodology and the instrument Critical Appraisal Skills Programme Espanol (CASPe). A total of 86 papers published

between 1 January 1998 and 31 December 2023 are included: 61 studies with spot measurements and 25 studies with mixed methodologies (spot measurements, personal measurements with volunteers or with a trained researcher and prediction models) are highlighted. Forty-three percent of the studies use Spectrum Analyzers in the spot measurements, mainly the Narda SRM-3006, followed by the Narda SRM-3000, highlighting the introduction and use of Sensors for this kind of study. The minimum mean value was measured in Palestine at 0.0600 mu W/m2, and the maximum mean value was measured in Norway at 200,000 mu W/m2. The RF-EMF exposure levels measured in the different microenvironments are minimal and far from the maximum levels established by the ICNIRP guidelines. https://doi.org/10.3390/app142311161

Quantitative assessment of thermal effects on the auricle region caused by mobile phones operating in different modes,
Rok, T., Kacprzyk, A., Rokita, E., Kantor, D. and Taton, G., *Aims Biophysics*, 2024, Vol. 11, no. 4, p. 427-444.

To analyze thermal effects caused by mobile phones on the human auricle region, we performed an experiment with controlled exposure to mobile phones operating in different modes for a group of 40 men. Temperature changes were measured with the use of infrared thermography. Thermograms were taken before and after a standardized 15-minute phone call when the mobile phone was placed lightly against the skin surface in the auricle region. The measurements were performed in three modes: OFF, ON, and FLIGHT. Statistically significant differences (p = 0.03) were observed between the experimental temperature increase of the auricle region in OFF mode (average temperature rise = 1.1 degrees C +/- 0.2 degrees C) and in ON mode (average temperature rise = 1.9 degrees C +/- 0.3 degrees C), while between FLIGHT (average temperature rise = 1.4 degrees C +/- 0.2 degrees C) and ON modes, no statistical differences were observed (p = 0.20). Based on thermographic measurements and the model of heat transfer between the ear and the phone, it was shown that the human ear is the largest heat source in the system and that the increase in skin temperature is mainly caused by the handheld mobile phone restricting heat dissipation from the skin surface. https://doi.org/10.3934/biophy.2024023

Evaluation de l'exposition

Electromagnetic intensity investigation of emitted non-ionizing radiation from base transcriptive stations in the urban region of southern Iran,
Abbasi, F., Badeenezhad, A., Abouee, E., Shademanpour, Z., Janghorban, F., Janatshoar, H., Naserpour, M. and Mohammadpour, A., *International Journal of Environmental Health Research*, 2024 Dec 2024.

Their monitoring in urban regions is essential for policymakers and the population. In this study, the electromagnetic intensity (EMI) was measured around 30 stations of base transcriptive stations (BTS) at both distances lower than 20m and higher than 200m using real-time equipment SMP2-dual in summer and winter. Results have shown that EMI in summer (range: 2-6500 mW/m2) was more than in winter (1.5-5000), and the intensity of about 93% of samples exceeded WHO standards. EMI has consistently decreased with the increasing distance from BTS. There was a negative correlation between the temperature and EMI in summer and humidity and EMI for both distances. The mapping of EMI depicted the highest value of EMI across the central region from south to eastern north at a distance lower than 20 m in winter. The clustering of the EMI in this region was influenced by the geographical location of BTS.
https://doi.org/10.1080/09603123.2024.2435484

Extraction of Concealed Features From RF-EMF Monitoring at Kindergartens and Schools, Djuric, N., Kljajic, D., Pasquino, N., Otasevic, V. and Djuric, S., *Ieee Access*, 2024, Vol. 12, p. 183429-183443.

Modern electromagnetic field (EMF) monitoring networks, such as the Serbian EMF RATEL network, are based on continuous EMF monitoring and offer daily observation of EMF levels in areas where people can reside for many hours a day and, consequently, experience an increased sensitivity to EMF exposure. Areas of particular importance are residential locations, kindergartens, schools, hospitals, and children's playgrounds. Such areas require daily, comprehensive EMF monitoring and compliance checking with the prescribed reference levels. The whole process must be followed by transparent presentation of measurement results, to increase public confidence in the EMF monitoring. However, any additional information on EMF behavior, beyond elementary field strength measurements, is welcome. Therefore, this paper presents an innovative EMF data analysis of monitoring results, utilizing a time-averaging approach applied to acquired EMF data. The analysis is performed on a case study of EMF-sensitive areas in the Serbian city of Novi Sad, i.e., two kindergartens and an elementary school, revealing some of the concealed features in the behavior of the EMFs exposure in those areas, through a comparative evaluation.
https://doi.org/10.1109/access.2024.3512001

Analysis of the Electric Field Strength Emitted by Wireless Devices Operating at 868.3 MHz in the Vicinity of the Human Body
Enghes, A., Bordianu, A., Cazacu, E. and Ieee (2023). International Symposium on Fundamentals of Electrical Engineering (ISFEE), Bucharest, ROMANIA.
The aim of this article is to investigate the impact of the electric field emitted by an antenna operating at a frequency of 868.3 MHz on the human body. The operating frequency falls within the radiofrequency range and was chosen due to its widespread use in various wireless communication systems, such as smart building and security systems. This simulation was conducted using the COMSOL Multiphysics software and was performed in the Radio Frequency, Electromagnetic Waves, Frequency Domain (EMW). The elements that compose this simulation are: the human body, the signal-emitting antenna and the enclosure. Within the simulation, it has been observed that the equipment operating at the 868.3 MHz frequency emits a low electric field strength near the human body, that has a nonhazardous impact under safe conditions.
https://doi.org/10.1109/isfee60884.2023.10637120

Safety Assessment of Electromagnetic Exposure to Arcing in Electrified Railway Bow Networks, Liang, J. Y., Shi, L., Wang, F. C., Zhao, Y. Y., Liu, Y. Z., Meimeijiao and Li, X. R., *Ieee Access*, 2024, Vol. 12, p. 143352-143377.

With the rapid advancement of electrified high-speed railways, electromagnetic exposure within train carriages has become a subject of growing concern. To evaluate the electromagnetic safety of passengers during bow network arcing events, this study utilizes numerical simulation tools to model the train's traction power supply system and simulate the voltage fluctuations in the contact network during arcing events. The simulations reveal a maximum voltage fluctuation of 30 kV. Subsequently, a three-dimensional electromagnetic environment model of passengers in the CR400AF-type train compartments is constructed using specialized simulation software. The study focuses on analyzing the magnetic field strength, electric field strength, and current density distribution, specifically in the brain region of passengers. The results indicate that the maximum values of magnetic induction, induced electric field strength, and induced current density in the passengers' brains are 7.55 mu T, 0.90 mV/m, and 831.2 mu A/m(2), respectively-values that are

well below the exposure limits set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for industrial-frequency electromagnetic fields. Additionally, the study demonstrates that the intermediate-frequency magnetic field generated by the contact network fluctuations due to bow network arcing is effectively shielded by the aluminum alloy body of the train, further mitigating the risk of electromagnetic exposure. These findings suggest that electromagnetic field (EMF) exposure in CR400AF rolling stock caused by contact network fluctuations during bow network arcing does not pose a significant health risk to passengers, providing valuable insights for the assessment of EMF safety in high-speed rail systems. https://doi.org/10.1109/access.2024.3471174

The Assessment of the Influence of Low-Frequency Electromagnetic Fields Originated from the Power Infrastructure on Humans' Health,
Litzbarski, L. S., Olesz, M., Redlarski, G., Tojza, P. M., Zak, A., Gifuni, E., Cieslikowska, Z. and Czaplinski, M., *Applied Sciences-Basel*, Nov 2024, Vol. 14, no. 21.

The objective of this study is to assess the impact of low-frequency electromagnetic fields (LF EMFs) generated by power infrastructure on the nearby environment. Measurements of electric (E) and magnetic (H) field intensities were conducted around high-voltage power lines, transformer stations and facilities related to them. Numerical simulations were also performed to model the distribution of the field values around real buildings in close proximity to power delivery systems. Given the ongoing scientific debate regarding the effects of EMFs on living organisms, the current analysis was based on the existing standards-particularly ICNIRP 2010 guidelines, which set the maximum allowable E and magnetic induction (B) values at 5 kV/m and 200 mu T, respectively. Stricter national regulations were also examined, such as Poland's 1 kV/m E limit in residential areas and Belgium's 10 mu T limit for B. The results showed that while most cases complied with ICNIRP 2010 standards, certain stricter local regulations were exceeded. Specifically, 9 of 14 cases exceeded Poland's E limits, and 8 failed to meet Belgium's B requirements. Only in one place-a warehouse near 110 kV power lines (in a critical case)-the ICNIRP limit B was exceeded. These findings underscore the variability in regulatory standards and highlight the need for localized assessments of EMF exposure. https://doi.org/10.3390/app14219668

Extremely low frequency magnetic fields (ELF-MF) in Switzerland: From exposure monitoring to daily exposure scenarios,
Loizeau, N., Haas, D., Zahner, M., Stephan, C., Schindler, J., Gugler, M., Fröhlich, J., Ziegler, T. and Röösli, M., *Environment International*, Dec 2024, Vol. 194.

Exposure to extremely low frequency magnetic fields (ELF-MF) is ubiquitous in our daily environment. This study aims to provide a comprehensive overview of the ambient ELF-MF exposure in Switzerland and presents a novel environmental exposure matrix for exposure assessment and risk communication. Magnetic flux density levels (mu T) were measured using a portable exposimeter carried in a backpack for the main ELF sources: railway power (16.7 Hz), domestic power (50 Hz), and tram ripple current (300 Hz). We collected ELF-MF levels between 2022 and 2024 in various environments representative of the Swiss population: 300 outdoor areas (e.g. city centres, residential areas), 245 public spaces (e.g. train stations, schools), 348 transport journeys (e.g. train, cars), and in 59 homes (e.g. bedrooms, living rooms). Over all environments, the highest ELF-MF exposure levels were measured in train stations (median: 0.48 mu T), trains (median: 0.40 mu T), and in living rooms near (<200 m) highest voltage lines of 220 kV and 380 kV (median: 0.37 <mu>T). ELF-MF median levels measured two years apart showed high Pearson correlation coefficients in the same 150 outdoor areas (r = 0.88) and 86 public spaces (r = 0.87), without any significant changes. All measurements are well below the Swiss ambient regulatory limit based on the ICNIRP 1998

guidelines (median: 0.2 %). Finally, we derived an environmental exposure matrix and modelled 27 daily time-weighted average ELF-MF exposure scenarios by combining typical time spent at home, work and transport environments. People who do not live near highest voltage lines or work in highly exposed environments are typically exposed to less than 0.3 mu T on average, while those who do are likely to exceed this level. This novel environmental exposure matrix is a useful tool for public communication and agent-based exposure modelling for future epidemiological research. https://doi.org/10.1016/j.envint.2024.109181

RF Exposure Assessment by Drone-Based Technology,
Paniagua-Sánchez, J. M., Marabel-Calderón, C., García-Cobos, F. J., Gordillo-Guerrero, A., Rufo-Pérez, M. and Jiménez-Barco, A., *Applied Sciences-Basel*, Nov 2024, Vol. 14, no. 22.

There is growing international interest in assessing population exposure to radiofrequency electromagnetic fields, especially those generated by mobile-phone base stations. The work presented here is an experimental study in which we assess exposure to radiofrequency electromagnetic fields in a university environment, where there is a site with mobile-phone antennas and where a large number of people live on a daily basis. The data were collected with a personal exposure meter in two samplings, one walking at ground level and the other using an aerial vehicle at a height higher than the buildings. The geo-referenced electric-field data were subjected to a process in which a theoretical model was adjusted to the experimental variograms, and heat maps were obtained using kriging interpolation. The research carried out is of great relevance, since it provides detailed measurements of the electromagnetic radiation levels both at ground level and at significant heights, using innovative methodologies such as the use of drones. Furthermore, the results obtained allow for contextualizing the exposures in relation to international safety limits, highlighting the importance of rigorous monitoring in everyday environments. https://doi.org/10.3390/app142210203

Average Local EMF Exposure and Power Consumption of a RIS-assisted WET System
Rosabal, O. M., López, O. A., Montejo-Sánchez, S., Souza, R. D., Alves, H., Latva-Aho, M. and Ieee (2024). 19th International Symposium on Wireless Communication Systems (ISWCS), Rio de Janeiro, BRAZIL.
Energy beamforming is fundamental to overcome the coverage limitations of radio frequency (RF) wireless energy transfer. Indeed, multi-antenna energy transmitters, also known as power beacons (PBs), can leverage spatial degrees of freedom to boost energy efficiency, motivating large-antenna array implementations. However, practical implementations based on traditional analog, digital, and hybrid analog-digital architectures are difficult to scale when the number of antennas increases because of the increasing number of power-hungry RF chains and the lossy and complex interconnection networks that carry the signal to the antenna array. In this work, we studied a costeffective single RF chain PB architecture embedding a reflecting intelligent surface and a single antenna feeder. Herein, we model the PB's average power consumption and obtain a closed-form approximation for the point-to-point charging scenario where the device position varies randomly. Moreover, we estimate the local electromagnetic field radiation (EMF) exposure in the device's vicinity by leveraging a Monte Carlo integration method. Our results show the increasing trend of the PB's average power consumption as the operating frequency increases, as well as the power savings obtained by increasing the directivity of the radiating elements. Moreover, we show the optimal position of the feeder for different operating frequencies and antennas' boresight gain. We also illustrate that EMF exposure decreases with the increased operating frequency and the measuring distance from the device. https://doi.org/10.1109/iswcs61526.2024.10639138

Evaluation of the Actual EMF Exposure from Extreme Massive MIMO Base Stations around 10 GHz using Channel Modelling
Rybakowski, M., Bechta, K., Grangeat, C., Kabacik, P. and Ieee (2024). 25th International Microwave and Radar Conference (MIKON), Wroclaw, POLAND.
Massive MIMO is a key 5G technology and will be even more important for future generations of cellular standards such as 6G. The system performance improvements offered by this technology and the possibility to develop larger antenna arrays for new frequency bands pave the way to the future deployments of extremely large multi-antenna systems. This paper provides an analysis of the actual EMF exposure levels from extreme massive MIMO active antenna array systems that are targeted for 6G mobile networks in the 7-15 GHz frequency range. Various antenna array dimensions have been investigated, from a 12x8 array of 192 antenna elements to a 24x16 array with 796 antenna elements. Modelling studies have been performed at 10 GHz. The actual maximum approach has been implemented as recommended in IEC 62232:2022. The modelling results provide a range of power reduction factors (FPR) from -7.1 dB to -10.7 dB with increasing antenna array size. https://ieeexplore.ieee.org/document/10633966

ELECTROMAGNETIC FIELD EXPOSURE IN THE PUBLIC SPACE OF THE SLOVAKIAN CITY,
Trnka, M., Gálik, P., Králová, E. and Vazan, R., *Komunikacie - Vedecke Listy Zilinskej Univerzity V Ziline*, 2023, Vol. 25, no. 1.

The main objective of our research was to map the exposure to electromagnetic smog in the frequented space of shopping centres in the city of Bratislava and to compare our results to the actual hygienic limits. The measurements of the low- and high-frequency electromagnetic fields were performed at different places in shopping centres. Our results did not exceed the Slovak current limits in any of the measurements. However, almost all of them markedly exceed new permitted limits according to EUROPAEM. Based on our results, stricter limits in many European countries and increasing evidence on possible harmfulness of long-term exposures to artificial electromagnetic fields, preventive carefulness can be recommended- to support the research in this field, to prepare professional public education and possibly to prepare the stricter Slovak exposure limits. https://doi.org/10.26552/com.C.2023.011

Exploring RF-EMF levels in Swiss microenvironments: An evaluation of environmental and auto-induced downlink and uplink exposure in the era of 5G,
Veludo, A. F., Stroobandt, B., Van Bladel, H., Sandoval-Diez, N., Guxens, M., Joseph, W. and Röösli, M., *Environmental Research*, Feb 2025, Vol. 266.

The advancement of cellular networks requires updating measurement protocols to better study radiofrequency electromagnetic field (RF-EMF) exposure emitted from devices and base stations. This paper aims to present a novel activity-based microenvironmental survey protocol to measure environmental, auto-induced downlink (DL), and uplink (UL) RF-EMF exposure in the era of 5G. We present results when applying the protocol in Switzerland. Five study areas with different degrees of urbanization were selected, in which microenvironments were defined to assess RF-EMF exposure in the population. Three scenarios of data transmission were performed using a user equipment in flight mode (non-user), inducing DL traffic (max DL), or UL traffic (max UL). The exposimeter ExpoM-RF 4, continuously measuring 35 frequency bands ranging from broadcasting to Wi-Fi sources, was carried in a backpack and placed 30 cm apart from the user equipment. The highest median RF-EMF levels during the non-user scenario were measured in an urban business area (1.02 mW/m2). Here, DL and broadcasting bands contributed the most to total RF-EMF levels. Compared to the non-user scenario, exposure levels increased substantially during max DL due to the 5G band at 3.5 GHz with 50% of the median levels between 3.20 and 12.13 mW/m2, mostly in urban areas. Note that the

time-division nature of this band prevents distinguishing between exposure contribution from DL beamforming or UL signals emitted at this frequency. The highest levels were measured during max UL, especially in rural microenvironments, with 50% of the median levels between 12.08 and 37.50 mW/m2. Mobile UL 2.1 GHz band was the primary contributor to exposure during this scenario. The protocol was successfully applied in Switzerland and used in nine additional countries. Inducing DL and UL traffic resulted in a substantial increase in exposure, whereas environmental exposure levels remained similar to previous studies. This data is important for epidemiological research and risk communication/management. https://doi.org/10.1016/j.envres.2024.120550

RF Exposure Assessment in ITS-5.9 GHz V2X Connectivity and Vehicle Wireless Technologies: A Numerical and Experimental Approach,
Yang, Y. Z., Masini, B. M., Vermeeren, G., Van Den Akker, D., Aerts, S., Verloock, L., Chiaramello, E., Bonato, M., Wiart, J., Tognola, G. and Joseph, W., *Ieee Access*, 2024, Vol. 12, p. 186002-186021.

As Vehicle-to-Everything (V2X) communication technologies gain prominence, ensuring human safety from radiofrequency (RF) electromagnetic fields (EMF) becomes paramount. This study critically examines human RF exposure in the context of ITS-5.9 GHz V2X connectivity, employing a combination of numerical dosimetry simulations and targeted experimental measurements. The focus extends across Road-Side Units (RSUs), On-Board Units (OBUs), and, notably, the advanced vehicular technologies within a Tesla Model S, which includes Bluetooth, Long Term Evolution (LTE) modules, and millimeter-wave (mmWave) radar systems. Key findings indicate that RF exposure levels for RSUs and OBUs, as well as from Tesla's integrated technologies, consistently remain below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure guidelines by a significant margin. Specifically, the maximum exposure level around RSUs was observed to be 10 times lower than ICNIRP reference level, and Tesla's mmWave radar exposure did not exceed 0.29 W/m2, well below the threshold of 10 W/m2 set for the general public. This comprehensive analysis not only corroborates the effectiveness of numerical dosimetry in accurately predicting RF exposure but also underscores the compliance of current V2X communication technologies with exposure guidelines, thereby facilitating the protective advancement of intelligent transportation systems against potential health risks. https://doi.org/10.1109/access.2024.3435566

Toxicité

Confronting stem cells with surface-modified magnetic nanoparticles and low-frequency pulsed electromagnetic field,
Bayramli-Öner, B., Lalegül-Ülker, O., Sezer, S., Elçin, A. E. and Elçin, Y. M., *Emergent Materials*, 2025 Jan 2025.

The combined use of Low Frequency-Pulsed Electromagnetic Field (LF-PEMF) and magnetic nanoparticles (MNPs) represents an innovative approach for biomedical applications in recent years. Also, the surface properties of MNPs play a crucial role in understanding how they will interact with biological systems and determining their suitability for the intended applications. The aim of this study was to evaluate the interactions of MNPs with different surface charges with adipose-derived mesenchymal stem cells (AD-MSCs) under LF-PEMF stimulation. Intracellular localization and in vitro cytotoxicity of surface-modified MNPs were examined through their interaction with AD-MSCs. Calcium and histochemical analysis were performed to investigate the synergistic effect of LF-PEMF. It was determined that application of MNPs (50 mu g/mL) with LF-PEMF (1.3 mT, 15 Hz) did not demonstrate a cytotoxic effect on AD-MSCs. The surface modification of MNPs ensured a homogeneous distribution within cells, with cationic nanoparticles being predominantly localized around the nucleus, while anionic nanoparticles were dispersed in the cytoplasm. Furthermore, LF-

PEMF exposure influenced cell morphology, leading to increased cytoplasmic extensions, particularly in cells interacting with silica-coated MNPs. These results shed light on the importance of how the surface properties of MNPs interact with cells under LF-PEMF stimulation and pave the way for future studies. https://doi.org/10.1007/s42247-025-00997-x

Does radiofrequency radiation impact sleep? A double-blind, randomised, placebo-controlled, crossover pilot study,
Bijlsma, N., Conduit, R., Kennedy, G. and Cohen, M., *Frontiers in Public Health*, Oct 2024, Vol. 12.

The most common source of Radiofrequency Electromagnetic Field (RF-EMF) exposures during sleep includes digital devices, yet there are no studies investigating the impact of multi-night exposure to electromagnetic fields emitted from a baby monitor on sleep under real-world conditions in healthy adults. Given the rise in the number of people reporting to be sensitive to manmade electromagnetic fields, the ubiquitous use of Wi-Fi enabled digital devices and the lack of real-world data, we investigated the effect of 2.45 GHz radiofrequency exposure during sleep on subjective sleep quality, and objective sleep measures, heart rate variability and actigraphy in healthy adults. This pilot study was a 4-week randomised, double-blind, crossover trial of 12 healthy adults. After a one-week run-in period, participants were randomised to exposure from either an active or inactive (sham) baby monitor for 7 nights and then crossed over to the alternate intervention after a one-week washout period. Subjective and objective assessments of sleep included the Pittsburgh Insomnia Rating Scale (PIRS-20), electroencephalography (EEG), actigraphy and heart rate variability (HRV) derived from electrocardiogram. Sleep quality was reduced significantly ($p < 0.05$) and clinically meaningful during RF-EMF exposure compared to sham-exposure as indicated by the PIRS-20 scores. Furthermore, at higher frequencies (gamma, beta and theta bands), EEG power density significantly increased during the Non-Rapid Eye Movement sleep ($p < 0.05$). No statistically significant differences in HRV or actigraphy were detected. Our findings suggest that exposure to a 2.45 GHz radiofrequency device (baby monitor) may impact sleep in some people under real-world conditions however further large-scale real-world investigations with specified dosimetry are required to confirm these findings. https://doi.org/10.3389/fpubh.2024.1481537

Health Aspects of Millimeter-Wave Exposures in 5G and Beyond: Millimeter Waves and Health,
Foster, K. R., Chou, C. K. and Omar, A., *Ieee Microwave Magazine*, Jan 2025, Vol. 26, no. 1, p. 70-82.

This article reviews, at a nontechnical level, the issue of potential health effects of millimeter wave exposure (30-300 GHz) as well as 5G NR exposure in the high band (presently, 24.25-52.6 GHz). MM-wave energy is chiefly absorbed in the top layers of skin. The established hazards from such energy are associated with excessive heating of tissue, including thermal damage to skin and the eye, and thermal pain. Present exposure limits to mm-waves in IEEE Standard C95.1-2019 and ICNIRP (2020) Guidelines are based on numerical modeling of tissue heating and on a limited number of human and animal studies, and appear to be quite conservative with respect to thermal hazards. The existence of many mm-wave bioeffects studies, many reporting biological effects of exposure over a wide range of frequencies and exposure levels but with high risk of bias and other limitations, introduces significant uncertainty in assessing the health effects literature. Health agencies have not identified hazards of 5G high band and mm-wave exposure at "nonthermal" levels below current exposure limits, but all recommend further research. The present authors suggest several lines of needed research, and point to the need to improve the quality of future bioeffects studies. https://doi.org/10.1109/mmm.2024.3474419

Influence of Electrostatic Field on Optical Rotation of D-Glucose Solution: Experimental Research for Electric Field-Induced Biological Effect,
Guo, Q. L., Gou, D. Z., Zhao, C. X., Ma, Y., Chen, C. J. and Zhu, J. X., *Molecules*, Oct 2024, Vol. 29, no. 20.

At present, the effects of environmental electromagnetic irradiation on the metabolism of organisms have attracted extensive attention, but the mechanism is still not clear. D-glucose plays an important role in the metabolism of organisms. In this work, the change in the optical rotation of D-glucose solution under an electrostatic field is measured experimentally, so as to explain the mechanism of the electric field-induced biological effect. The experimental results show that the electrostatic field can alter the optical rotation of D-glucose solution at different temperatures. Under the different strengths of electrostatic field, the specific rotation of D-glucose solution increases at different temperatures; the maximum increase can reach 2.07%, but the effect of temperature and electric field strength on the rotation increment is nonlinear and very complex. Further, it turns out that the proportion of alpha-D-glucose in solution increases by up to 3.25% under the electrostatic field, while the proportion of beta-D-glucose decreases by as much as 1.75%. The experimental study confirms that electrostatic field can change the proportion of two conformation molecules (alpha and beta-D-glucose) in D-glucose solution, which can provide a novel explanation for the mechanism of the electric field-induced biological effect.
https://doi.org/10.3390/molecules29204898

Estimating the Perception Threshold of Electrostimulation and Heating for Radiofrequency Contact Current,
Kodera, S., Kimura, S., Uehara, S., Yuasa, A., Ushizawa, K., Otaka, Y. and Hirata, A., *Ieee Transactions on Electromagnetic Compatibility*, 2024 Nov 2024.

Radiofrequency contact current occurs when a human touches objects with different electrical potentials. For emerging wireless power transfer systems, this type of exposure is potentially more restrictive than direct exposure. The limits for contact current are prescribed in the international guidelines for human protection from electromagnetic fields, but its rationale is limited compared with that for direct field exposure. In this article, the perceptional threshold for electrostimulation and heating was evaluated based on computational dosimetry from 10 kHz to 10 MHz. First, the time course of the temperature rise was calculated until each subject perceived the contact current. Second, the perception of current was estimated considering the nerve activation modeling. The computationally estimated current threshold for nerve activation was consistent with the measured data at 100 kHz and increased linearly with increasing frequency, which was contrary to the measured threshold for perception above 300 kHz. By contrast, the estimated perceptual temperature increase was smaller at 100 kHz than at 300 kHz and above. These results indicate that the transient frequency of the threshold for stimulation and heating lies between 100 and 300 kHz, supporting the transition frequency of contact current in the international guidelines.
https://doi.org/10.1109/temc.2024.3483168

Biological issue of electromagnetic fields and waves
Koyama, S.: 2024. WIRELESS POWER TRANSFER TECHNOLOGIES, 2 EDITION
Chapitre d'ouvrage Pages 273-294
https://shop.theiet.org/wireless-power-transfer-technologies-2nd-edition

The effects of radiofrequency electromagnetic field exposure on biomarkers of oxidative stress in vivo and in vitro : A systematic review of experimental studies,
Meyer, F., Bitsch, A., Forman, H. J., Fragoulis, A., Ghezzi, P., Henschenmacher, B., Kellner, R., Kuhne, J., Ludwig, T., Sachno, D., Schmid, G., Tsaioun, K., Verbeek, J. and Wright, R., *Environment International*, Dec 2024, Vol. 194.

Background: Oxidative stress is thought to be related to many diseases. Furthermore, it is hypothesized that radiofrequency electromagnetic fields (RF-EMF) may induce excessive oxidative stress in various cell types and thereby have the potential to compromise human and animal health. The objective of this systematic review (SR) is to summarize and evaluate the literature on the relation between the exposure to RF-EMF in the frequency range from 100 kHz to 300 GHz and biomarkers of oxidative stress. Methods: The SR framework was developed following the guidelines established in the WHO Handbook for Guideline Development and NTP/OHAT's Handbook for Conducting a Literature-Based Health Assessment. We used the latter handbook's methodology for implementing the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach for environmental health assessments. We searched the following databases up until June 30, 2023: PubMed, Embase, Web of Science Core Collection, Scopus, and the EMF-Portal. The reference lists of included studies and retrieved review articles were also manually searched. We rated Risk of Bias (RoB) using the OHAT RoB Rating Tool and assessed publication bias using funnel plots of included studies. We assessed the certainty of the evidence (high, moderate, low, or very low) for an association between RF-EMF and oxidative stress using an adapted version of the GRADE framework. Data were extracted according to a predefined set of forms developed in DistillerSR. Data were analysed after grouping them first as in vitro or in vivo and then according to outcome category, species category, and exposed tissue. We synthesized study results using a random effects meta-analysis when study characteristics were judged sufficiently similar to be combined and heterogeneity (I2) was lower than 75 %, otherwise we describe the findings narratively. Results: Fifty-six (56) studies, 45 in vivo and 11 in vitro, in which cells (in vitro) or animals (in vivo) were exposed to frequencies in the range 800-2450 MHz, were included in the systematic review after eliminating 12,353 publications because they did not meet the criteria defined in the published protocol (Henschenmacher et al., 2022). Of 56 studies 52 studies with 169 individual results were included in the meta-analysis. Together, these studies examined six human in vitro samples and fifty animal samples, including rodents (mice, rats, hamsters, and guinea pigs, (n = 46)) and rabbits (n = 4). RF-EMF were predominantly applied as continuous wave exposures in these studies. The outcome biomarkers for modified proteins and amino acids were measured in n = 30 studies, for oxidized DNA bases in n = 26 studies, for oxidized lipids in n = 3 studies and hydrogen peroxide production in 2 studies. Outcomes were mostly measured in the brain (n = 22), liver (n = 9), cells (n = 9), blood (n = 6), and testis (n = 2). RoB in studies was high, mainly due to biases in exposure and outcome assessment. In vivo studies: Brain: The effect on biomarkers for oxidized DNA bases in the rodent brain (five studies, n = 98) had an inconsistent effect, varying from a large decrease with a standardized mean difference (SMD) of-3.40 (95 % CI [-5.15,-1.64]) to a large increase with an SMD of 2.2 (95 % CI [0.78, 3.62]). In the brain of rabbits (two studies, n = 44), the effect sizes also varied, from an SMD of-1.06 (95 % CI [-2.13, 0.00]) to an SMD of 5.94 (95 % CI [3.14, 8.73]). The effect on biomarkers for modified proteins and amino acids in the rodent brain (15 studies, n = 328) also varied from a large decrease with an SMD of-6.11 (95% CI [-8.16,-4.06]) to a large increase with an SMD of 5.33 (95 % CI [2.49, 8.17]). The effect on biomarkers for oxidized lipids in the brain of rodents (one study, n = 56) also varied from a large decrease with SMD =-4.10 (95 % CI [-5.48,-2.73]) to SMD = 1.27 (95 % CI [0.45, 2.10]). Liver: The effect on biomarkers for oxidized DNA bases in the rodent liver (two studies, n = 26) was inconsistent with effect sizes in both directions: SMD =-0.71 (95 % CI [-1.80, 0.38]) and SMD = 1.56 (95 % CI [0.19, 2.92]). The effect on biomarkers for oxidized DNA bases in the rabbits' liver (two studies, n = 60) was medium with a pooled SMD of 0.39(95% CI

[-0.79, 1.56]). Biomarkers for modified proteins and amino acids in the liver of rodents (six studies, n = 159) increased with a pooled SMD of 0.55(95% CI [0.06, 1.05]). Blood: The effect of RF-EMF on biomarkers for oxidized DNA bases in rodent blood (four studies, n = 104) was inconsistent, with SMDs ranging from-1.14 (95 % CI [-2.23,-0.06]) to 1.71 (95 % CI [-0.10, 3.53]). RF-EMF had no effect on biomarkers for modified proteins and amino acids in rodent blood (three studies, n = 40), with a pooled SMD of-0.08 (95 % CI [-1.32, 1.16]). There was a large increase in biomarkers for oxidized DNA bases in rodent plasma (two studies, n = 38) with a pooled SMD of 2.25 (95 % CI [1.27, 3.24]). Gonads: There was an increase in biomarkers for oxidized DNA bases in the rodent testis (two studies, n = 24) with a pooled SMD of 1.60 (95% CI [0.62, 2.59]). The effect of RF-EMF on biomarkers for modified proteins and amino acids in the ovary of rodents (two studies, n = 52) was inconsistent with a medium effect, SMD = 0.24 (95 % CI [-0.74, 1.23])) and a large effect (SMD = 2.08 (95% CI [1.22, 2.94])). Thymus: RF-EMF increased biomarkers for modified proteins and amino acids in the thymus of rodents (one study, n = 42) considerably with a pooled SMD of 6.16 (95 % CI [3.55, 8.76]). Cells: RF-EMF increased oxidized DNA bases in rodent cells with SMD of 2.49 (95% CI [1.30, 3.67]) (one study, n = 27). There was a medium effect in oxidized lipids (one study, n = 18) but not statistically significant with SMD = 0.34 (95 % CI [-0.62, 1.29]). In vitro studies: In in vitro studies in human cells (three studies, n = 110), there were inconsistent increases in biomarkers for oxidized DNA bases, where the SMDs varied between 0.01 (95% CI [-0.59, 0.62]) and 7.12 (95% CI [0.06, 14.18]) in 4 results (2 of them statistically significant). In rodent cells (three studies, n = 24), there was a not statistically significant large effect in biomarkers for oxidized DNA bases with SMD = 2.07 (95 % CI [-1.38, 5.52]). The RF-EMF biomarkers for modified proteins and amino acids in human cells (one study, n = 18) showed a large effect with SMD = 1.07 (95 % CI [-0.05, 2.19]). In rodent cells (two studies, n = 24) a medium effect of SMD = 0.56 (95 % CI [-0.29, 1.41]) was observed. Discussion: The evidence on the relation between the exposure to RF-EMF and biomarkers of oxidative stress was of very low certainty, because a majority of the included studies were rated with a high RoB level and provided high heterogeneity. This is due to inaccurate measurements of exposure and/or of measurement of oxidative stress biomarkers and missing information on the blinding of research personnel to exposure conditions or outcome measurements. There may be no or an inconsistent effect of RF-EMF on biomarkers of oxidative stress in the brain, liver, blood, plasma and serum, and in the female reproductive system in animal experiments but the evidence is of very low certainty. There may be an increase in biomarkers of oxidative stress in testes, serum and thymus of rodents but the evidence is of very low certainty. Future studies should improve experimental designs and characterization of exposure systems as well as the use of validated biomarker measurements with positive controls. Other: This review was partially funded by the World Health Organization. The protocol for this review is registered in PROSPERO (https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021235573) and published in Environment International (https://doi.org/10.1016/j.envint.20 21.106932) (Henschenmacher et al., 2022). https://doi.org/10.1016/j.envint.2024.108940

Static Magnetic Field Exposure Causes Small Cell Cycle Disruptions and Changes in Reactive Oxygen Species Levels in Ionizing Radiation Exposed Human Neuroblastoma Cells, Nieminen, V., Seppälä, J., Virén, T., Juutilainen, J., Naarala, J. and Luukkonen, J., *Bioelectromagnetics*, Jan 2025, Vol. 46, no. 1.

Although static magnetic fields (SMFs) have been reported to induce only minimal biological effects, it has been proposed that they may alter the effects of other agents, such as ionizing radiation. We sham-exposed or exposed human SH-SY5Y neuroblastoma cells to 0.5-, 1.5-, 2.5-, or 3.5-mT SMFs for 24 h either before or after irradiation at 0, 0.4 or 2.0 Gy. After the exposures, cell cycle distribution (subG1 for apoptosis), reactive oxygen species (ROS) levels, caspase-3 activity, and clonogenic survival were assayed. Increase of G0/G1 and decrease of S phase cells was observed in samples

exposed to a 3.5-mT SMF after irradiation. The same exposure schedule with a 1.5-mT SMF was associated with an increase of S phase cells, and an increase in ROS levels. Conversely, a decrease in ROS levels was observed in cells exposed to a 2.5-mT SMF before ionizing radiation. No cell cycle changes were observed with SMF exposures before irradiation. Caspase-3 activity or clonogenic survival was not affected by SMF exposures, irrespective of the exposure schedule. In conclusion, small changes in cell cycle distribution and ROS levels were observed in SH-SY5Y cells exposed to SMFs, with more prominent effects observed when SMF exposure was applied after irradiation. Our results suggest that SMF-induced effects show no linear dependency on magnetic flux density below 5 mT. Notably, SMF exposures did not significantly potentiate the effects of ionizing radiation but rather caused an independent additive effect. Bioelectromagnetics. 00:00-00, 2024.
https://doi.org/10.1002/bem.22538

Exploring Non-Thermal Mechanisms of Biological Reactions to Extremely Low-Frequency Magnetic Field Exposure,
Radil, R., Carnecka, L., Judakova, Z., Pobocikova, I., Bajtos, M. and Janousek, L., *Applied Sciences-Basel*, Oct 2024, Vol. 14, no. 20.

The increasing evidence regarding biological effects of exposure to an extremely low frequency magnetic field is of utmost interest not only to the scientific community, but also to legislative bodies and the public. However, the research in this field is full of controversial and inconsistent results, originated from a lack of widely acceptable physical mechanisms that could sufficiently describe the principle of such a field's action. This experimental study addresses and points to possible sources of ambiguities via investigation of the ion parametric resonance mechanism at 50 Hz frequency. The chosen methodology incorporates exposure of the Saccharomyces cerevisiae yeast strain based on an established exposure protocol with special attention to the measurement of an applied time-varying magnetic field corresponding to the ion parametric resonance requirements. Subsequently, the differences in cell growth as a reaction to changes in magnetic flux density are evaluated and statistically analyzed. It is found that fluctuations in the magnetic field within the exposure setup need to be addressed properly, since this could have an impact on replication of the experiments and reliability of the results. Furthermore, comparison of two independently performed sets of 10 experiments showed statistically significant effects even in conditions that did not fulfill the requirements of the resonance theory, putting the validity and practical application of the ion parametric resonance model into question.
https://doi.org/10.3390/app14209409

Temperature and state-dependent electrical conductivity of soft biological tissue at hyperthermic temperatures,
Ran, J. R. and Ostoja-Starzewski, M., *International Journal of Hyperthermia*, Dec 2024, Vol. 41, no. 1.

Objective: We present a physics-based, temperature and state-dependent electrical conductivity model for soft biological tissue under thermal therapies with a quantified damage parameter that represents the state of soft biological tissue (degree of denaturation). Most existing models consider electrical conductivity to be only temperature-dependent and evaluate tissue damage during post-processing after temperature calculation. Our model allows tissue damage to be coupled into the thermal model for a more accurate description of both RF ablation and electrosurgery. Methods: We model the denaturation process with an Arrhenius-type differential equation for chemical kinetics and a modified Stogryn equation for electrical conductivity under state transition. We present experimental data from two types of heating procedures at 128 kHz to validate and showcase the capability of our model. Results: Our model is able to capture the change in electrical conductivity during heating, cooling, and reheating procedures, which distinguishes different states

and shows the irreversibility of denaturation. The model also accurately captures tissue change during slow cooking at a constant temperature, highlighting a state dependence. Conclusion: By incorporating state dependence into the model for electrical properties, we are able to capture the denaturation process more accurately and distinguish different degrees of damage. Our model allows the modeling of procedures involving repeated heating or cooling, which is impossible for models without a state dependence. While being able to adapt to patient-specific needs, the model can be used to improve planning and control in future robot-assisted surgeries to reduce unnecessary damage. https://doi.org/10.1080/02656736.2024.2422509

Genotoxicity of radiofrequency electromagnetic fields on mammalian cells in vitro: A systematic review with narrative synthesis,
Romeo, S., Sannino, A., Scarfi, M. R., Lagorio, S. and Zeni, O., *Environment International*, Nov 2024, Vol. 193.

Background: Over the last decades, great concern has been raised about possible adverse effects to human health due to exposures to radiofrequency electromagnetic fields (RF-EMF, 100 kHz - 300 GHz) emitted by wireless communication technologies. In 2011 the International Agency for Research on Cancer classified RF-EMF as possibly carcinogenic to humans, highlighting that the evidence was weak and far from conclusive. Updated systematic reviews of the scientific literature on this topic are lacking, especially for mechanistic studies. Objectives: To perform a systematic review of the scientific literature on genotoxic effects induced by RF-EMF in in vitro experimental models. The overall aim is to assess the confidence and level of evidence of the induced effects in mammalian cell cultures. Methods: Full details regarding the eligibility criteria, information sources, and methods developed to assess risk of bias in the included study, are reported in our published protocol (Romeo et al. 2021). The databases NCBI PubMed, Web of Science, and EMF-Portal were used as information sources (last searched on 31st December 2022). In developing the systematic review, we followed the guidelines provided by the National Toxicology Program-Office of Health Assessment and Translation (NTP-OHAT), adapted to the evaluation of in vitro studies. A narrative synthesis of the body of evidence was performed by tabulating data classified according to meaningful groups (endpoints) and sub-groups (exposure parameters). This report, abstract included, conforms to the PRISMA 2020 (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines. Results: Out of 7750 unique records identified, 159 articles were eligible for inclusion. From the extracted data, we identified 1111 experiments (defined as independent specific combinations of diverse biological and electromagnetic parameters). The large majority (80%) of experiments reviewed did not show statistically significant genotoxic effects of RF-EMF exposures, and most "positive" studies were rated as of moderate to low quality, with negative ratings in the key bias domains. A qualitative evidence appraisal was conducted at the endpoint level, and then integrated across endpoints. Discussion: To the best of our knowledge, this is the first systematic review of the scientific literature on genotoxic effects in mammalian cell cultures in relation to RF-EMF exposure, which confirms and strengthens conclusions from previous syntheses of this specific topic thanks to the use of transparently reported methods, pre-defined inclusion criteria, and formal assessment of susceptibility to bias. Limitations of the evidence included the frequent reporting of findings in graphical display only, and the large heterogeneity of experimental data, which precluded a meta-analysis. Conclusions: In the assessment restricted to studies reporting a significant effect of the exposure on the outcome, we reached an overall assessment of "low" confidence in the evidence that RF-EMF induce genotoxic effects in mammalian cells. However, 80% of experiments reviewed showed no effect of RF exposure on the large majority of endpoints, especially the irreversible ones, independently of the exposure features, level, and duration (moderate evidence of no effect). Therefore, we conclude that the analysis of the papers included in this review, although only qualitative, suggests that RF exposure does not increase the

occurrence of genotoxic effects in vitro. Framework and funding: This systematic review addresses one of the evidence streams considered in a larger systematic review of the scientific literature on the potential carcinogenicity of RF-EMF, performed by scientists
https://doi.org/10.1016/j.envint.2024.109104

Fifty-hertz magnetic fields induce DNA damage through activating mPTP associated mitochondrial permeability transition in senescent human fetal lung fibroblasts,
Sun, C., Wang, S. Y., Zhang, J., Zhou, X. Q., Zhu, T. J. and Mao, G. X., *Biophysical Chemistry*, Mar 2025, Vol. 318.

With the rapid development and using of electromagnetic technology, artificial electromagnetic fields (EMFs) have become an emerging environmental factor in our daily life. Extremely-low-frequency (ELF) magnetic fields (MFs), generally generated by power lines and various electric equipment, is one of the most common EMFs in the environment which were concerned for the potential impact on human health. Base on limited evidence, ELFMFs have been classified as possible carcinogen to human by International Agency for Research on Cancer (IARC), but the mechanisms have not been fully elucidated. Senescent cells are a group of special cells, characterized by cell cycle arrest, senescence-associated secretory phenotype (SASP), accumulation of macromolecular damage, and metabolic disturbance, play important role in fetal development, tissue aging, and even carcinogenesis. Thus, EMFs may promote carcinogenesis by affecting senescent cells, however, there are few studies. In this study, we found that exposure to 50 Hz MFs at 1.0 mT for 24 h could induce significant DNA damage in senescent but not non-senescent human fetal lung fibroblast suggested that senescent cells are more sensitive to 50 Hz MFs on DNA damage, and further results revealed that reactive oxygen species (ROS) generation mediated by mitochondrial permeability transition pore (mPTP) activation play critical role in this process. Our results indicated that cellular senescence can lead to cell sensitivity to the DNA damage effect of 50 Hz MFs, however, whether this play important role in mediating the carcinogenesis of EMFs await further study. https://doi.org/10.1016/j.bpc.2024.107367

Study of Electromagnetic Radiation From High-Speed Train Voice and Data Antennae on the Health of Pacemaker Wearers,
Tian, R., Wu, H. and Lu, M., *International Journal of Rf and Microwave Computer-Aided Engineering*, Oct 2024, Vol. 2024.

In China, high-speed trains have become a major means of transportation for the masses. When the passengers wearing pacemakers travel on high-speed trains, electromagnetic environment in the carriage where the GSM-R voice and data antennae are located should be concerned. In this work, a real-size carriage monopole antennae simulating voice and data antennae as high-frequency radiation sources and wearing pacemaker passenger' models were established to study the electromagnetic exposure of the passenger at different conditions. The results showed that when the passenger faced the voice antenna, he suffered much greater electromagnetic radiation than when his back in turned from it. The electric field strength, average SAR, and temperature rise of the heart when facing the antenna were 27.3 V/m, 0.0102 W/kg, and 0.0016 degrees C, respectively. Meanwhile, the temperature rise of the pacemaker was 0.001 degrees C. We also obtained the values of electromagnetic dose for the whole body. All data were below the limits of the ICNIRP guidelines. These results indicate that the electromagnetic fields generated by the GSM-R voice and data antennae do not harm the health of passengers wearing pacemaker.
https://doi.org/10.1155/2024/2690885

Neurobiological effects and mechanisms of magnetic fields: a review from 2000 to 2023, Wang, X. J., Ye, Y. M., Zuo, H. Y. and Li, Y., *Bmc Public Health*, Nov 2024, Vol. 24, no. 1.

Magnetic fields are widely used in medical diagnostics because of their superior non-invasive properties. In addition, with the widespread use of magnetic fields in transportation and other areas, their potential hazards to human health and the assessment of their safety have attracted considerable attention. The effects of magnetic fields on living organisms have a long history. The biological effects of magnetic field exposure in mice and rats depend on the magnetic field strength, exposure time, and direction; depending on these and potentially other factors, magnetic fields can cause a series of neurobiological effects. We reviewed global research on the neurobiological effects of magnetic fields from recent years to provide an overview and insights into the underlying mechanisms. This review focuses on the biological effects of static and dynamic magnetic fields of different frequencies and intensities on animals and nerve cells and their mechanisms of action. https://doi.org/10.1186/s12889-024-18987-9

Study of the Inhibition of Schumann Resonance-inspired Electromagnetic Field on Cancer Cell Proliferation, Yan, X. Q., Liu, X. L., Zhang, S. J., Liu, Z. N. and Ren, L. Q., *Journal of Bionic Engineering*, Jan 2025, Vol. 22, no. 1, p. 341-353.

Organisms on Earth evolve and coexist with natural Electromagnetic Fields (EMFs). Although many reports have suggested the potential anti-neoplastic effects of EMFs with specific parameters, the studies on the influence of natural EMFs on cancers are still rare. Herein, an EMF emitter has been developed to investigate the effects of the extremely-low frequency SR-mimicking EMF (SREMF) on cancer and normal cell proliferation. The numerical simulation has revealed that the emitter with specific parameters is able to enhance EMF intensity and uniformity on the designated plane above the emitter. More importantly, honeycomb-like emitter array can generate a stronger EMF intensity on the 20 mm plane above the array. Cell colony formation assays have demonstrated that SREMF generated by the honeycomb-like emitter array can significantly inhibit Hela cell proliferation in a cell-density-dependent manner. The morphological changes of SREMF-exposed Hela cells suggest that the anti-proliferative effect of SREMF may be caused by apoptosis induction. In contrast, no detrimental effect is observed for SREMF-treated normal cells, which probably can be explained by the evolutionary adaptation. Hence, this work can not only contribute to understanding the impact of natural EMF on creatures, but also afford a novel strategy to personalized cancer prevention and treatment. https://doi.org/10.1007/s42235-024-00624-1

Effects of Static and Low-Frequency Magnetic Fields on Gene Expression, Zablotskii, V., Gorobets, O., Gorobets, S. and Polyakova, T., *Journal of Magnetic Resonance Imaging*, 2025 Jan 2025.

Substantial research over the past two decades has established that magnetic fields affect fundamental cellular processes, including gene expression. However, since biological cells and subcellular components exhibit diamagnetic behavior and are therefore subjected to very small magnetic forces that cannot directly compete with the viscoelastic and bioelectric intracellular forces responsible for cellular machinery functions, it becomes challenging to understand cell-magnetic field interactions and to reveal the mechanisms through which these interactions differentially influence gene expression in cells. The limited understanding of the molecular mechanisms underlying biomagnetic effects has hindered progress in developing effective therapeutic applications of magnetic fields. This review examines the expanding body of literature on genetic events during static and low-frequency magnetic field exposure, focusing particularly on

how changes in gene expression interact with cellular machinery. To address this, we conducted a systematic review utilizing extensive search strategies across multiple databases. We explore the intracellular mechanisms through which transcription functions may be modified by a magnetic field in contexts where other cellular signaling pathways are also activated by the field. This review summarizes key findings in the field, outlines the connections between magnetic fields and gene expression changes, identifies critical gaps in current knowledge, and proposes directions for future research. https://doi.org/10.1002/jmri.29726

Méthodes

The Influence of Harmonic Content on the RMS Value of Electromagnetic Fields Emitted by Overhead Power Lines,
Bendík, J., Cenky, M. and Eleschova, Z., *Modelling*, Dec 2024, Vol. 5, no. 4, p. 1519-1531.

This paper investigates the influence of harmonic content on the root mean square value of electromagnetic fields emitted by overhead power lines. The paper presents a methodology to assess the intensity of electric field and magnetic flux density, incorporating both fundamental frequencies and harmonics. The results of our calculations indicate that harmonic distortion in current waveforms can significantly increase the RMS value of magnetic flux density but its effect on electric field intensity is minimal. Additionally, our findings highlight a potential increase in induced voltages on buried or overhead steel pipelines in the vicinity of OPLs, which could pose risks such as pipeline damage and increased corrosion. This underscores the importance of considering harmonic content in EMF exposure evaluations to address both health risks and potential infrastructure impacts comprehensively. Effective harmonic management and rigorous infrastructure monitoring are essential to prevent potential hazards and ensure the reliability of protective systems.
https://doi.org/10.3390/modelling5040079

Revealing the Imperceptible Network : Numerical Studies on the Impact of Electromagnetism on the Human Brain
Bouali, L., Bouali, K. A. and Ieee (2024). IEEE 7th International Conference on Advanced Technologies, Signal and Image Processing (ATSIP), Sousse, TUNISIA.
Recent advancements in radiofrequency electromagnetic field communication have raised questions about their potential impact on biological tissues, particularly the human brain. Our study aims to numerically examine the influence of these electromagnetic fields on the human brain. For this purpose, we used a numerical modeling approach that integrates the human brain as the internal medium and a cell phone as the external source of radiofrequency. The methodology is based on Maxwell's equations and the finite element method to discretize our model, complemented by boundary integral techniques. Our results show the behavior and intensity of the electric and magnetic fields inside the brain as a function of distance. Furthermore, we aim to understand their influence on the action potential, which is in the millivolt range, with frequencies between 0.1 and 100 Hz. https://doi.org/10.1109/atsip62566.2024.10638880

Effect of the Conductivity Variations on Computed Electric Field Induced in Learning-Based Models,
Diao, Y. L., Rashed, E. A., Giaccone, L., Laakso, I., Li, C. S., Scorretti, R. and Hirata, A., *Ieee Access*, 2024, Vol. 12, p. 188454-188464.

Anatomical human models are extensively utilized for assessing induced electric fields due to low-frequency (LF) electromagnetic exposure. One difficulty in the LF dosimetry is that the results are often affected by numerical artifacts, which are attributable to the abrupt change at tissue

interfaces for the segmented human models with discrete tissue conductivities. To overcome this difficulty, head models with continuous conductivities have been recently developed using deep learning networks, which directly map magnetic resonance images to volume conductivity without segmentation. To validate the effectiveness of this novel modeling method for electromagnetic dosimetry, a working group was established by the IEEE International Committee on Electromagnetic Safety Technical Committee 95 Subcommittee 6. The group's initial study focused on intercomparison of computed fields using learning-based models across several laboratories. This paper extends the analysis considering the effect of conductivity variations on the computed electric field induced in learning-based continuous models and segmented discrete models. Six international research groups participated in this joint study. It is found that the electric field strengths decrease in grey matter (GM) and increase in white matter (WM) as GM conductivity increases. Electric field strengths in both GM and WM decrease as WM conductivity increases. The variation ranges of electric field strength, due to varying conductivity values, show comparability between discrete and continuous models. For the intercomparison, the highest relative differences (RDs) are 15.9% and 6.7% for the 100th and 99th percentile values of the induced electric fields for the discrete models, respectively, and 10.1% and 3.8% for the continuous models. The RDs for computations using the scalar-potential finite-difference method with different solvers are below 1.2%.
https://doi.org/10.1109/access.2024.3514710

Modeling RF-EMF at Sports Events: User Density Impact,
Engiz, B. K., Kurnaz, C., Cheema, A. A. and Rehman, M. U., *Ieee Access*, 2024, Vol. 12, p. 163492-163506.

To address the needs of tomorrow, Future Wireless Networks (FWNs) like 6G are anticipated to integrate terrestrial and non-terrestrial networks. Intelligent network coordination across several frequency bands, radio technologies, and end-user requirements are critical factors which will determine the success of such networks. However, there is a widespread concern about the growth in Radio Frequency Electromagnetic Fields (RF-EMF) exposure levels for end users from FWNs. It is critical to identify RF-EMF exposure levels and provide a framework for monitoring, managing, and optimization of RF-EMF levels. This study performs extensive band-selective RF-EMF measurements at two sporting events (a football and basketball match) in sub-6 GHz band. The data is collected every 6 seconds before and during the sporting events from different radio technologies using EME SPY evolution device. We provide a comprehensive analysis to understand exposure levels, contributions from different radio technologies and variations of total exposure levels over the sub-6 GHz band. In addition, RF-EMF levels are modelled using various statistical distributions and evaluated using the Anderson-Darling test. It is found that exposure levels increase in the range of 1.35-1.93 times compare to non-match day and Burr distribution provides the best fit to model RF-EMF exposure levels in both sporting events. https://doi.org/10.1109/access.2024.3491340

Challenges and opportunities from the out-of-band sensitivity of data loggers in a (quasi)autonomous evaluation of electromagnetic exposure
Gryz, K., Karpowicz, J., Zradzinski, P. and Ieee (2024). IEEE International Symposium on Measurements and Networking (M and N), Rome, ITALY.
The investigations examined the applicability of radiofrequency (RF) electromagnetic field (EMF) data loggers (DL), readily available on the market, for assessing worker exposure to the strong EMF (i.e. near its sources) in the microenvironment where strong and complex (in the frequency domain) exposure may exist - at frequencies within the DL's declared measurement frequency band and outside of it (outof-band frequency), e.g. exposure to RF and also 50 Hz (out-ofband) EMF. The results of laboratory tests and field studies show that, based on: (i) the real RF-DL metrological parameters (including its out-of-band sensitivity) and (ii) the frequency pattern of EMF in a

microenvironment under question, as anticipated from previous tests, a possible false detection that it is a highly RF-exposed environment may be reinterpreted into the relevant evaluating of exposure to the out-of-band frequency EMF component. Using the approach of three-step exposure evaluation (including: (1) laboratory tests on the out-of-band sensitivity of available RF-DL; (2) environmental tests of real frequency pattern of exposure in the microenvironment under question; (3) expert-assisted interpretation of the results of RF-DL measurements), may technically allow the extension of the frequency range of workers' EMF exposure (beyond measurement frequency ranges declared for DLs available on the market), which may be (quasi)autonomously monitored in a real working environment with respect to its timing and level.
https://doi.org/10.1109/mn60932.2024.10615926

Metamaterial Slabs for Electric Vehicle Wireless Charging Application,
Jeebklum, P. and Sumpavakup, C., *Ieee Access*, 2024, Vol. 12, p. 156717-156729.

Design and development of a wireless charging system with metamaterial slabs for electric vehicles (EV) based on the Society of Automotive Engineers (SAE) standard is proposed in this paper. The objective is to study the effect of the metamaterial slab on wireless charging efficiency. The wireless charging system was set with a distance between the coils of 0.15 m and a resonant frequency of 81.64 kHz. The symmetrical metamaterial slab (SM) and the edge metamaterial slab (EM) were designed. The experiment varied the placement position of the metamaterial slab in four cases. The efficiency of the wireless power transfer system without the metamaterial slab (WOM) was the highest at 75.78% with the coils aligned. The position at which the coils are in alignment has the maximum efficiency. The efficiency tends to decrease when the coil is more misalignment. The EM over the receiver coil (EMR) results in a maximum efficiency of 75.87% at a 0.10 m misalignment. The EMR provides an efficiency that is 8.00% higher than the WOM at a misalignment of 0.20 m. The metamaterial slab is important in increasing the efficiency when the misalignment occurs. In addition, the metamaterial slab shields the magnetic fields over the receiver coil. The magnetic field of the WOM had an average value of 0.0216 mT. Therefore, the magnetic fields of the system are within safe exposure levels according to the International Commission for Non-Ionization Radiation Protection (ICNIRP) guidelines which are 0.1 mT for occupational exposure and 0.027 mT for general public exposure, respectively. The placement of metamaterial slabs can significantly impact the efficiency and safety of wireless power transfer systems.
https://doi.org/10.1109/access.2024.3485180

Effect of Cotton and Wool Fabrics on the Accuracy of Electromagnetic Dosimetry Analysis Due to Millimeter Wave Exposures,
Kaburcuk, F., *Applied Computational Electromagnetics Society Journal*, Aug 2024, Vol. 39, no. 8, p. 733-741.

- With the development of wireless communication, satellite, and radar technologies operated at millimeter wave (MMW) frequency range, it is essential to consider the adverse health effects of the radiated electromagnetic (EM) fields at MMW frequency. In most EM dosimetry analyses for the human body models, bare human models have been considered. However, the presence of fabrics such as cotton and wool on the human body can affect the accuracy of the EM dosimetry analysis. At the MMW frequency range, the effect of fabrics on EM dosimetry analysis in a human body model has not been extensively investigated using the finite-difference time-domain (FDTD) method. In this study, the effects of fabrics on the human body on the power transmission coefficient, specific absorption rate, absorbed power density, and heating factor due to EM MMW exposure are investigated using the FDTD method. Numerical results show that the thickness of the fabrics and

air gap introduced between the fabrics and the skin surface significantly affects the accuracy of EM dosimetry analysis at the frequency range 1-100 GHz. https://doi.org/10.13052/2024.Aces.J.390809

Effect of skin thickness on electromagnetic dosimetry analysis of a human body model up to 100 GHz,
Kaburcuk, F., *International Journal of Microwave and Wireless Technologies*, 2024 Nov 2024.

The accuracy of electromagnetic (EM) exposure assessments depends mainly on the resolution of a voxel human body model. The resolution of the conventional human body model is limited to a few millimeters. In the millimeter wave (mmWave) frequency range, EM waves are absorbed by the superficial tissues in the human body. Therefore, resolution and skin thickness of the human body model are important for accuracy of the EM wave exposure metrics recommended by international human safety guidelines. Realistic thickness modeling of the skin tissue on the human body may provide greater accuracy in the EM exposure assessment, especially at mmWave frequency range. In this paper, effects of the skin thickness on the EM exposure metrics in one-dimensional multi-layered models obtained from different regions of the body model are investigated using the dispersive algorithm based on the finite-difference time-domain method over the frequency range from 1 to 100 GHz. Furthermore, effects of eyelid tissue in a human eye on the EM exposure metrics are studied over the frequency range. The EM exposure metrics such as absorbed power density, heating factor, and power transmission coefficient are calculated up to 100 GHz to evaluate the limits of EM wave exposure. https://doi.org/10.1017/s1759078724000977

Monitoring the time-variability of electromagnetic exposure due to mobile radio communication emissions using narrow-bandwidths data loggers
Karpowicz, J., Miclaus, S. and Ieee (2024). IEEE International Symposium on Measurements and Networking (M and N), Rome, ITALY.
Analyzing measurements performed by equipment, differing in sensitivity and sample recording rates, belongs to key problems in long duration monitoring of electromagnetic exposure. Parameters of descriptive statistics, Weibull distribution and Poincare maps, were applied to the relevant databases of electric field strength values recorded simultaneously in the same microenvironment (in fast train cars, with dominating exposure from travelers' terminals for mobile communication, i.e. GSM 900 and LTE 1800 up link emissions) by three types of data loggers operating at various sample recording rates. Analyzed case of exposure to uplink emissions significantly differs from down link cases in the majority of environmental studies. The combination of used analytical tools provided comprehensive parameterizing and comparing the results from various data loggers, which were found to be insignificantly different (over particular range of percentiles) when measurements were performed in the same microenvironment. It confirmed reliability of used equipment for comparative monitoring electromagnetic exposure (despite differences in sensitivity and recording rate). The study's methodology and findings provide a solid foundation for ongoing research and monitoring efforts into better understanding of electromagnetic exposure in specific microenvironments and required monitoring strategies. https://doi.org/10.1109/mn60932.2024.10615726

AI-based optimization of EM radiation estimates from GSM base stations using traffic data,
Lal, R., Singh, R. K., Nishad, D. K. and Khalid, S., *Discover Applied Sciences*, Nov 2024, Vol. 6, no. 12.

The fast expansion of mobile networks has sparked worries regarding base station EM radiation's health impacts. Traffic load is commonly ignored when evaluating EM radiation levels using maximum power output. This study proposes utilizing AI and ML on real network traffic data to optimize GSM base station EM radiation estimations. We obtained EM radiation measurements and

traffic data from selecting GSM base stations by location and configuration. To predict EM radiation levels, traffic patterns were used to train linear regression, random forests, and neural networks. Base stations were clustered by radiation profile using unsupervised learning. Considering regulatory restrictions and measurement feasibility, an optimization methodology was created to minimize EM radiation estimate inaccuracy. The results show better prediction accuracy than power-based estimations and high generalisability across base station types. Site-specific factors influenced daily EM radiation patterns after clustering. EM radiation levels can be monitored using traffic data and the optimized AI/ML model. This research helps telecom operators and regulators analyze EM radiation more accurately and efficiently. Future projects should include 5G and small cell network extensions and intelligent city platform integration. The suggested method develops data-driven, AI-powered Public Safety and mobile network trust solutions.
https://doi.org/10.1007/s42452-024-06395-y

A comparison of measurement methodologies for the assessment of E-field level radiated by 5G NR base station,
Milanovic, J. and Katalinic-Mucalo, A., *Wireless Networks*, 2024 Nov 2024.

This paper presents the comparison of two measurement methods mostly used for the 5G NR base station radiation assessment, namely channel-power method and code-selective method. The methods were assessed and compared based on results of the 5G NR E-field measurement campaign conducted in a real-life scenario and under realistic conditions. The results have shown that the channel-power method gives optimistic E-field measurement results, meaning lower levels of E-field radiation. Contrary, the code-selective method gives pessimistic results regarding radiated E-field level, which is expected since it obtains the theoretical maximum radiation of the base station. Therefore, it is not straightforward to choose between the methods, especially considering their practical applicability. This paper addresses advantages and disadvantages of both proposed methods and provides some first-hand insights and recommendations for the 5G NR E-field measurements. https://doi.org/10.1007/s11276-024-03865-4

A Closed RF Wave-Applicator to Study the Biological Effects of Mobile Communication Systems
Miri, S. M., Mohammadpour-Aghdam, K. and Ieee (2024). 32nd International Conference on Electrical Engineering (ICEE), Tehran, IRAN.
According to the growing trend in using cellular communication systems and frequent and longtime usage of mobile devices by everybody, studying biological effects of the electromagnetic waves which propagate from these cell-phones is critical and social request. First estimation is that this effect is proportional to the field intensity, frequency and duration of exposure. This paper presents a closed RF wave-applicator, providing a uniform electromagnetic field in a closed area to expose the under-study biological tissue in 3G and 4G cellular frequency bands that is 1920-1980 MHz for uplink and 2110-2170 MHz for downlink. To generate desired amplitude of electric field with suitable uniformity in a specific region, a rectangular waveguide with a square cross-section is proposed. Also, a specified shape of printed probes is designed to couple the power from input coaxial cables to the waveguide to cover the mentioned bandwidth. A testing tube containing distilled water is placed in the middle of the wave-applicator and the whole structure is simulated. S-parameters and electric field amplitude are presented in both cases of absence and presence of testing sample and finally, the performance of the structure is investigated through a Vector Network Analyzer and measured results are presented.
https://doi.org/10.1109/icee63041.2024.10667929

Electrotextile-Based Flexible Electromagnetic Skin for Wearables and Remote Monitoring, Rizzo, R., Ruello, G., Massa, R., Zhadobov, M. and Sacco, G., *Ieee Journal of Microwaves*, Jan 2025, Vol. 5, no. 1, p. 23-33.

This paper presents a flexible electrotextile-based solid skin-equivalent phantom operating in the millimeter-wave (mmW) range. The phantom reproduces the reflection coefficient at the air/skin interface in the 55-65 GHz band. It is composed of a layer of carbon powder mixed with silicone and backed with an electrotextile. Its thickness is optimized to approach the target reflection coefficient of the human skin. For the angles of incidence from 0(degrees) to 60 (degrees) the maximum relative error in respect to the target value is 2.6% for the magnitude and 13% for the phase when considering impinging transverse electric (TE) and transverse magnetic (TM) polarized plane wave. To experimentally validate the phantom, its scattering properties are measured in the 55-65 GHz range using a free-space transmission/reflection system. A good agreement between the numerical and experimental results is demonstrated, exhibiting a relative error within 1.9% for the magnitude of the reflection coefficient in the 55-65 GHz range at normal incidence. Such phantoms may be used in a wide range of body-centric mmW applications, including remote sensing and medical applications. https://doi.org/10.1109/jmw.2024.3504846

TEM Cell With a High-Transparency Aperture for Homogeneous Microwave Absorption and Real-Time Viewing of Thermoelastic Expansion of Tissue, Roper, C. J., Hagness, S. C. and Ma, C., *Ieee Journal of Electromagnetics Rf and Microwaves in Medicine and Biology*, 2024 Nov 2024.

In this study we simulate and evaluate a transverse electromagnetic cell (TEM) for dosimetry applications in the UHF band with design modifications to allow real-time monitoring of tissue expansion due to microwave pulse absorption. We introduce an aperture for high-speed microscope-based imaging inside the waveguide and use simulations to assess the aperture' s impact on power absorption homogeneity and dosage level in tissue samples positioned at the site of the aperture. We consider both transparent, non-conductive borosilicate and semi-transparent, conductive indium tin oxide-coated glass plates covering the aperture. Our simulation results indicate a borosilicate covering provides optimal power absorption homogeneity when the tissue sample is smaller in diameter than the aperture. Analysis of the simulation results enabled us to construct an optimized TEM cell with a borosilicate-glass-covered aperture and experimentally verify that it maximizes dosage in the tissue sample. This modified TEM cell is expected to be an essential component in an experimental platform for observing and recording the macroscopic, dynamic thermoelastic expansion of tissue induced by pulsed microwave exposure. https://doi.org/10.1109/jerm.2024.3493623

Safety Assessment of Gender-specific Human Electromagnetic Exposure with Aortic Valve Stents for EV-WPT, Tan, T. H., Jiang, T., Wu, Y. Y., Zhu, Y. and Chi, Y. D., *Applied Computational Electromagnetics Society Journal*, Aug 2024, Vol. 39, no. 8, p. 742-753.

- Electric vehicle wireless power transfer brings additional electromagnetic exposure (EME) risks to the human body, especially those with metal implants. This paper focuses on the safety assessment of human EME with aortic valve stents (AVS), and establishes electromagnetic simulation models for different genders of humans, AVS, and electric vehicle-wireless power transfer (EV-WPT) systems. The transmission power of the EV-WPT system is 11 kW. Considering the uncertainty of the EV-WPT system and AVS in practical use, an efficient deep neural network method is proposed to evaluate the EME safety to different genders of humans. Using the standard limits of the International

Committee on Non-Ionizing Radiation Protection (ICNIRP) as the judgment standard, comparing human EME under static conditions, it is demonstrated that AVS can change the distribution of induced electric fields in the human body and increase the risk of human EME. Moreover, the probability of male human EME exceeding the standard limits is 22.78% higher than that of female human. https://doi.org/10.13052/2024.Aces.J.390810

An Alternative Approach for Evaluating Induced and Contact Currents for Compliance with Their Exposure Limits (100 kHz to 110 MHz) in IEEE Std C95.1-2019,
Tell, R. A. and Kavet, R., *Health Physics*, Feb 2025, Vol. 128, no. 2, p. 156-166.

The Institute of Electrical and Electronics Engineers establishes exposure reference levels (ERLs) for electric fields (E-fields) (0-300 GHz) and both induced (I-IND) and contact currents (I-SC) (<110 MHz) in its standard, IEEE Std C95.1 (TM)-2019 (IEEE C95.1). The "classical" scenarios addressed in IEEE C95.1 include a free-standing, grounded "reference" person (I-IND) or an ungrounded reference person in manual contact with an adjacent grounded conductor (I-SC), each exposed to a vertically oriented E-field driving the currents. The ERLs for current from 100 kHz to 110 MHz were established to limit heating in the finger (from touch), ankle (I-IND), and wrist (I-SC from grasp contact), specifying the 6-min average specific absorption rate (SAR, W kg(-1)) as the dosimetric reference limit (DRL); whole-body E-field ERLs are 30-min averages. The DRLs were established assuming a default "effective" local cross-section (9.5 cm(2)) and consistent with a composite tissue conductivity of similar to 0.5 S m(-1). A previous publication described the misalignment of the ERLs for E-fields with the ERLs for IIND (which extends to I-SC) and also proposed a ramped E-field ERL from 100 kHz to 30 MHz. For the frequency range 100 kHz to 110 MHz, this paper proposes temperature increase (Delta T) in ankle and wrist as the preferred effect metric associated with I-IND and I-SC; applying the E-field ERLs as surrogates for limits to these currents; and adopting the proposed ramp. The analysis of Delta T is based on the tissue mix in realistic anatomic depictions of ankle and wrist cross-sections; relevant tissue properties posted online; published tissue perfusion data; and anthropometric data on a large sample of male and female adults in the US military, allowing an estimate of effects over a range of body size. To evaluate Delta T versus frequency and time, the Penne bioheat equation was adapted with convective cooling from arterial blood as the lone cooling mechanism. The analysis revealed that I-INDs and I(SC)s induced by ERL-level E-fields produce SARs in excess of the local DRLs (in some cases far exceed). Calculations of time to Delta T of 5 degrees C, reflective of a potentially adverse (painful) response, resulted in worst-case times for effects in the ankle on the order of minutes but on the order of 10s of s in wrist. Thus, compliance with the E-field ERL, as assessed as a 30-min whole-body average is incompatible with the time course of potentially adverse effects in ankle and wrist from I-IND and I-SC, respectively. Further analysis of the relevant exposure/dose scenarios and consensus of stakeholders with a multi-disciplinary perspective will enable the development of a revised standard, practical from a compliance perspective and protective of all persons. https://doi.org/10.1097/hp.0000000000001902

Construction and Application of a Static Magnetic Field Exposure Apparatus for Biological Research in Aqueous Model Systems and Cell Culture,
Vuckovic, J., Gurhan, H., Gutierrez, B., Guerra, J., Kinsey, L. J., Nava, I., Fitzpatrick, A., Barnes, F. S., Tseng, K. A. and Beane, W. S., *Bio-Protocol*, Oct 2024, Vol. 14, no. 19.

With the growth of the quantum biology field, the study of magnetic field (MF) effects on biological processes and their potential therapeutic applications has attracted much attention. However, most biologists lack the experience needed to construct an MF exposure apparatus on their own, no consensus standard exists for exposure methods, and protocols for model organisms are sorely lacking. We aim to provide those interested in entering the field with the ability to investigate static

MF effects in their own research. This protocol covers how to design, build, calibrate, and operate a static MF exposure chamber (MagShield apparatus), with instructions on how to modify parameters to other specific needs. The MagShield apparatus is constructed of mu-metal (which blocks external MFs), allowing for the generation of experimentally controlled MFs via 3-axial Helmholtz coils. Precise manipulation of static field strengths across a physiologically relevant range is possible: nT hypomagnetic fields, mu T to < 1 mT weak MFs, and moderate MFs of several mT. An integrated mu-metal partition enables different control and experimental field strengths to run simultaneously. We demonstrate (with example results) how to use the MagShield apparatus with Xenopus, planarians, and fibroblast/fibrosarcoma cell lines, discussing the modifications needed for cell culture systems; however, the apparatus is easily adaptable to zebrafish, C. elegans, , and 3D organoids. The operational methodology provided ensures uniform and reproducible results, affording the means for rigorous examination of static MF effects. Thus, this protocol is a valuable resource for investigators seeking to explore the intricate interplay between MFs and living organisms. https://doi.org/10.21769/BioProtoc.5077

Prediction of Electromagnetic Field Exposure at 20-100 GHz for Clothed Human Body Using an Adaptively Reconfigurable Architecture Neural Network With Weight Analysis (RAWA-NN) Framework,
Yao, M., Wei, Z. H., Li, K., Pedersen, G. F. and Zhang, S., *Ieee Transactions on Antennas and Propagation*, Dec 2024, Vol. 72, no. 12, p. 9286-9300.

In the context of forthcoming sixth-generation (6G) wireless communication, the sub-terahertz and terahertz frequency spectrum are anticipated. At such high frequencies, electromagnetic field (EMF) exposure assessment becomes significantly challenging, requiring substantial computational resources. This article is the first to utilize machine learning (ML) to predict EMF exposure levels for the clothed human body at 20-100 GHz, including temperature rises and absorbed power density (APD) at the exposed skin surface. To predict the EMF exposure, a reconfigurable architecture neural network with weight analysis (RAWA-NN) framework is proposed. This framework is based on the deep neural network (DNN) integrating the proposed weights-analyzer module and optimization module. The proposed novel framework streamlines the training process and reduces training time, while simultaneously adaptively optimizes the hyperparameters (hidden layers and hidden sizes) without the necessity for manual intervention during training and optimization. The model was trained using 70% of forearm data, with the remaining data for testing. Data from other body parts, such as the abdomen and quadriceps, was used to validate the model generalization. Compared to conventional dosimetry analysis, relative difference (RD) across various parameters remains below 2.6% across various parameters, for the same body part of the forearm, and below 9.5% for other body parts. There is an approximate four orders of magnitude improvement in assessment speed. https://doi.org/10.1109/tap.2024.3474913

Toxicité sur les animaux

Hematological and thermographical changes in rat's model exposed to long-term RF modulated signals,
Aghaa, O. B. and Hameed, B. K., *Open Veterinary Journal*, 2024, Vol. 14, no. 11, p. 2837-2847.

Background: Long-term exposure to LTE signals at different frequencies has become a crucial problem in our daily life. Aim: The aim of the study to figure out the thermal influence of LTE signals (850 MHz, 1800 MHz, and 2600 MHz) on hematological values in rat's model during different

periods. Methods: Forty adult male rats were randomly distributed into four equal groups (control, 850 MHz, 1800 MHz, and 2600 MHz exposure groups). The rats were exposed for 2 hours per day over a period of up to 60 days using a radiofrequency generator. Results: The results showed that the different frequencies have different effects on both hematological and thermographical image analysis. Conclusion: The study findings demonstrate that these LTE frequencies have a detrimental effect on the rat model through thermal mechanisms. https://doi.org/10.5455/OVJ.2024.v14.i11.12

Effects of extremely low frequency magnetic fields on animal cancer and DNA damage: A systematic review and meta-analysis,
Brabant, C., Honvo, G., Demonceau, C., Tirelli, E., Léonard, F. and Bruyére, O., *Progress in Biophysics & Molecular Biology*, Mar 2025, Vol. 195, p. 137-156.

The objective of this systematic review and meta-analysis was to assess the carcinogenic effects of extremely low frequency magnetic fields (ELF-MF) by analyzing animal and comet assay studies. We have performed a global meta-analysis on all the animal studies on the relation between ELF-MF and cancer incidence and separate meta- analyses on the incidence of cancer, leukemia, lymphoma, breast cancer, brain cancer and DNA damage assessed with the comet assay. Of the 5145 references identified, 71 studies have been included in our systematic review and 22 studies in our meta-analyses. Our global meta-analysis indicated that ELF-MF exposure had no significant impact on the incidence of cancers in rodents (19 studies, OR = 1.10; 95% CI 0.91-1.32). However, our separate meta-analyses showed that ELF-MF increased the odds of developing leukemia in mice (4 studies, OR = 4.45; 95% CI 1.90-10.38) but not in rats. Our systematic review also suggests that ELF-MF can damage DNA in certain cell types like brain cells. Nevertheless, a meta-analysis on three comet assay studies indicated that ELF-MF did not increase DNA damage in neuroblastoma cells (SMD =-0.08; 95% CI-0.18-0.01). Overall, our results suggest that exposure to ELF-MF does not represent a major hazard for mammals and the carcinogenic effects of these magnetic fields could be limited to leukemia. https://doi.org/10.1016/j.pbiomolbio.2024.12.005

Extremely low-frequency electromagnetic fields targeting spleen modifies the populations of immunocytes in the spleen,
Chen, S. J., Wei, W., Wang, Z., Zhu, J. Z., Zhang, H. L., Wang, G. H., Guo, N., Li, J., Mu, Y. H., Zhang, N. M. and Li, Z. F., *Bioelectromagnetics*, Jan 2025, Vol. 46, no. 1.

Our study focused on investigating the bioeffects of extremely low-frequency electromagnetic fields (ELF-EMFs) on the immune function of the spleen. We designed an electromagnetic instrument that can locally target on spleen, the spleens of mice were locally exposed to the ELF-EMF (50 Hz, 30 mT) for 14 days (4 h/day). Parallelly, the isolated splenic T cells were exposed to ELF-EMF (50 Hz, 15 mT) for 2 h. After the exposure, the splenocyte showed a reduced apoptosis rate. Among the splenocytes, the CD4+ T cells and natural killer cells accumulated, the percentage of B cells decreased. In vitro study demonstrated that ELF-EMF induced the alteration of T cell subsets, showing an increased percentage of CD4+ T cells and a decreased percentage of CD8+ T cells. Within CD4+ T cells, the population of T helper (Th) 17 cells increased, and the population of regulatory T cells (Treg) cells decreased. The enrichment of the nuclear factor (NF)-kappa B pathway in the splenic T cells was found to be reduced after exposure to ELF-EMF. Our findings suggest that ELF-EMF regulated the immune function of the spleen by changing the proportion of immune cells in the spleen. Specifically, the differentiation of spleen T cells was induced by ELF-EMF toward Th17 cells and inhibited by ELF-EMF into Treg cells. The NF-kappa B signaling pathway probably accounts for the effects of ELF-EMF on the spleen T cells. https://doi.org/10.1002/bem.22532

Exposure to a 0.9-GHz electromagnetic field on postnatal days 21-45 may trigger the renin-angiotensin system in male rat: a histological and biochemical study,
Keles, A. I., Kaya, H., Keles, G., Erol, H. S., Mercantepe, T. and Odaci, E., *Journal of Molecular Histology*, Feb 2025, Vol. 56, no. 1.

The aim of this study was to examine the relationship between the renin-angiotensin system (RAS) and histological and biochemical changes occurring in the kidney tissue of male rats exposed to a 0.9 GHz electromagnetic field (EMF). Twelve male rats aged 21 days were randomly assigned to control (C-Gr) and EMF (EMF-Gr) groups. No procedure was performed on C-Gr, while the EMF-Gr rats were exposed to a 0.9 GHz EMF on postnatal days 21-45 (one hour a day for 25 days). Tissues were removed at the end of the experiment and evaluated using biochemical, and histopathological methods. Increased kidney tissue volume and weight and total body weight were determined in the group exposed to EMF. Lipid peroxidation, glutathione, catalase, and superoxide dismutase also increased in the kidney tissue of the EMF-Gr rats. Histopathological evaluation revealed cortical/medullary bleeding/obstruction and widespread fibrosis, dilatation, vacuolization, and degeneration in distal and proximal tubules, decreased and atypical parietal cells, and degeneration in epithelial cells. Additionally, dilated and degenerated glomeruli in the Malpighian body, Bowman's membrane degeneration and degeneration in the vascular pole, podocyte, pedicel and mesangial cells were also observed. As a result of exposure to EMF, oxidative stress, tissue volume and weight increased, and histopathological changes caused the formation of a pathway that triggers RAS in kidney tissues. In conclusion, long-term exposure to 0.9 GHz EMF can activate the renin-angiotensin system in the rat kidney, and we think that such activation may be associated with structural, histopathological, and biochemical changes occurring in renal tissue. https://doi.org/10.1007/s10735-024-10317-y

Effects of 1800 MHz and 2100 MHz mobile phone radiation on the blood-brain barrier of New Zealand rabbits,
Kizilçay, A. O., Tütüncü, B., Koçarslan, M. and Gözel, M. A., *Medical & Biological Engineering & Computing*, 2024 Nov 2024.

In this study, the impact of mobile phone radiation on blood-brain barrier (BBB) permeability was investigated. A total of 21 New Zealand rabbits were used for the experiments, divided into three groups, each consisting of 7 rabbits. One group served as the control, while the other two were exposed to electromagnetic radiation at frequencies of 1800 MHz with a distance of 14.5 cm and 2100 MHz with a distance of 17 cm, maintaining a constant power intensity of 15 dBm, for a duration equivalent to the current average daily conversation time of 38 min. The exposure was conducted under non-thermal conditions, with RF radiation levels approximately ten times lower than normal values. Evans blue (EB) dye was used as a marker to assess BBB permeability. EB binds to plasma proteins, and its presence in brain tissue indicates a disruption in BBB integrity, allowing for a quantitative evaluation of radiation-induced permeability changes. Left and right brain tissue samples were analyzed using trichloroacetic acid (TCA) and phosphate-buffered solution (PBS) solutions to measure EB amounts at 620 nm via spectrophotometry. After the experiments, BBB tissue samples were collected from the right and left brains of all rabbits in the three groups and subjected to a series of medical procedures. Samples from Group 1 were compared with those from Group 2 and Group 3 using statistical methods to determine if there were any significant differences. As a result, it was found that there was no statistically significant difference in the BBB of rabbits exposed to 1800 MHz radiation, whereas there was a statistically significant difference at a 95% confidence level in the BBB of rabbits exposed to 2100 MHz radiation. A decrease in EB values was observed upon the arithmetic examination of the BBB. https://doi.org/10.1007/s11517-024-03238-1

The extremely low-frequency electromagnetic field (50 Hz) can establish a new "set-point" for the activity of the locus coeruleus-noradrenergic (LC-NA) system in rat,
Klimek, A., Kletkiewicz, H., Siejka, A., Wyszkowska, J., Maliszewska, J., Klimiuk, M., Jankowska, M. and Rogalska, J., *Brain Research Bulletin*, Dec 2024, Vol. 219.

Exposure of organisms to extremely low-frequency electromagnetic field (ELF-EMF; 50 Hz) has been increasing in recent decades, which is connected with dynamic technological development. ELF-EMF is considered a stress factor and its effects on organisms are still being investigated. We aimed to determine its impact on the locus coeruleus-noradrenergic (LC-NA) system enabling adaptation to stressful conditions. For this purpose, we exposed rats to 50 Hz ELF-EMF of 1 and 7 mT, 1 h/day for 7 days. The procedure was repeated three times to examine the organism's adaptive capabilities. Subsequently, the concentration of adrenaline, noradrenaline and its metabolite MHPG as well as the expression of the beta 2-adrenergic receptor was assessed. After the end of each exposure, part of the animals were subjected to a behavioural test to assess the influence of repeated ELF-EMF exposure on stress response to subsequent stress factors. Our research proved that mechanisms underlying the effects of ELF-EMF on stress response include the LC-NA system. ELF-EMF of 1 mT induced adaptive changes in the NA-LC system. However, exposure to 7 mT caused increased activity of the stress system which resulted in sensitization to subsequent, heterotypic (different from the one previously acting) stress factor. As ELF-EMF of 7 mT caused a profound decrease in beta 2-AR level would strongly inhibit the potential for neuroplastic processes in the hippocampus. Moreover, rats exposed to ELF-EMF of 7 mT showed moderately increased anxiety-related behaviour. Disturbances in NA-LC transmission may underlie the development of some neurodegenerative and psychiatric diseases which indicates the possible involvement of ELF-EMF in the pathogenesis of these disorders. https://doi.org/10.1016/j.brainresbull.2024.111111

Effect of 2.45 GHz Microwave Radiation on the Inner Ear: A Histopathological Study on 2.45 GHz Microwave Radiation and Cochlea,
Tahir, E., Karadayi, A. A., Gürgen, S. G., Engiz, B. K. and Turgut, A., *Journal of International Advanced Otology*, Jan 2024, Vol. 20, no. 1, p. 35-42.

BACKGROUND: The present study aims to determine the possible low dose-dependent adverse effects of 2.45 GHz microwave exposure and Wi-Fi frequency on the cochlea. METHODS: Twelve pregnant female rats (n = 12) and their male newborns were exposed to Wi-Fi frequencies with varying electric field values of 0.6, 1.9, 5, 10 V/m, and 15 V/m during the 21-day gestation period and 45 days after birth, except for the control group. Auditory brainstem response testing was performed before exposure and sacrification. After removal of the cochlea, histopathological examination was conducted by immunohistochemistry methods using caspase (cysteine-aspartic proteases, cysteine aspartates, or cysteine-dependent aspartate-directed proteases)-3, -9, and terminal deoxynucleotidyl transferase dUTP nick end labeling (TUNEL). Kruskal-Wallis and Wilcoxon tests and multivariate analysis of variance were used. RESULTS: Auditory brainstem response thresholds in postexposure tests increased statistically significantly at 5 V/m and above doses. When the number of apoptotic cells was compared in immunohistochemistry examination, significant differences were found at 10 V/m and 15 V/m doses (F-(5,F-15) = 23.203, P =.001; Pillai's trace = 1.912, eta(2) = 0.637). As the magnitude of the electric field increased, all histopathological indicators of apoptosis increased. The most significant effect was noted on caspase-9 staining (eta(2)c9 = 0.996), followed by caspase-3 (eta(2)c3 = 0.991), and TUNEL staining (eta(2)t = 0.801). Caspase-3, caspase-9, and TUNEL-stained cell densities increased directly by increasing the electric field and power values. CONCLUSION: Apoptosis and immune activity in the cochlea depend on the

electric field and power value. Even at low doses, the electromagnetic field in Wi-Fi frequency damages the inner ear and causes apoptosis. https://doi.org/10.5152/iao.2024.231142

Effects of extremely low-frequency (50 Hz) electromagnetic fields on vital organs of adult Wistar rats and viability of mouse fibroblast cells,
Tekam, C. K. S., Majumdar, S., Kumari, P., Prajapati, S. K., Sahi, A. K., Singh, R., Krishnamurthy, S. and Mahto, S. K., *Radiation Protection Dosimetry*, 2024 Dec 2024.

In recent years, scientific communities have been concerned about the potential health effects of periodic electromagnetic field exposure (<= 1 h/d). The objective of our study is to determine the impact of extremely low-frequency pulsed electromagnetic fields (ELF-PEMF) (1-3 mT, 50 Hz) on mouse fibroblast (red fluorescent protein (RFP)-L929) cells and adult Wistar rats to gain a comprehensive understanding of biological effects. We observed that RFP-L929 exhibits no significant changes in cell proliferation and morphology but mild elevation in aspartate aminotransferases, alanine aminotransferases, total bilirubin, serum creatinine, and creatine kinase-myocardial band levels in ELF-PEMF exposed groups under in vitro and in vivo conditions. However, the histological examination showed no significant alterations in tissue structure and morphologies. Our result suggests that 50-Hz ELF-PEMF exposure (1-3 mT, 50 Hz) with duration (<1 h/d) can trigger mild changes in biochemical parameters, but it is insufficient to induce any pathological alterations. https://doi.org/10.1093/rpd/ncae220

Effects of electromagnetic field emitted by a 90 kHz WPT system on the cognitive functions and neuronal excitation of mice,
Zhao, J., Ma, J., Wang, X. X. and Zhang, B. Q., *Electromagnetic Biology and Medicine*, Jan 2025, Vol. 44, no. 1, p. 1-16.

The advantages of Magnetic Coupling Resonant Wireless Power Transfer (MCR-WPT) technology include long transmission distance, high efficiency, and high power. Therefore, it shows great potential in the field of smart home. This study aims to explore the specific impacts on the cognitive functions and neuronal excitation of mice exposed to the electromagnetic fields (EMF) emitted by the MCR-WPT platform, thereby providing biological solid experimental evidence for developing Wireless Power Transfer (WPT) technology. The research employed a frequency of 90 kHz, which is suitable for wireless charging of household appliances. Mice were exposed to EMF emitted by the WPT biosafety experimental platform for various durations. And they were divided into four groups (control group, 2-week exposure group, 4-week exposure group, and 8-week exposure group). Upon completion of the exposure period, the study employed the Novel Object Recognition (NOR) test to evaluate the learning and memory capabilities of the animals. Following this, whole-cell patch-clamp experiments were conducted to record the action potentials (AP) and potassium currents. It was revealed by our observations that, in comparison to mice without electromagnetic exposure, long-term exposure to WPT-emitted EMF resulted in accelerated release of action potentials, inhibited the activation of Voltage-Gated Potassium Channels (VGKCs) current, accelerated the deactivation of K+ channel current, and thus significantly improved the excitability of neurons in the dentate gyrus (DG) of the hippocampus of mice, but did not significantly affect cognitive function. https://doi.org/10.1080/15368378.2024.2438607

Actualité, société et mesures de prévention

Gaps in Knowledge Relevant to the "ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (100 kHz TO 300 GHz)",
Health Physics, Feb 2025, Vol. 128, no. 2, p. 190-202.

In the last 30 y, observational as well as experimental studies have addressed possible health effects of exposure to radiofrequency electromagnetic fields (EMF) and investigated potential interaction mechanisms. The main goal of ICNIRP is to protect people and the environment from detrimental exposure to all forms of non-ionizing radiation (NIR), providing advice and guidance by developing and disseminating exposure guidelines based on the available scientific research on specific parts of the electromagnetic spectrum. During the development of International Commission on Non-Ionizing Radiation Protection's (ICNIRP's) 2020 radiofrequency EMF guidelines some gaps in the available data were identified. To encourage further research into knowledge gaps in research that would, if addressed, assist ICNIRP in further developing guidelines and setting revised recommendations on limiting exposure, data gaps that were identified during the development of the 2020 radiofrequency EMF guidelines, in conjunction with subsequent consideration of the literature, are described in this Statement. Note that this process and resultant recommendations were not intended to duplicate more traditional research agendas, whose focus is on extending knowledge in this area more generally but was tightly focused on identifying the highest data gap priorities for guidelines development more specifically. The result of this distinction is that the present data gap recommendations do not include some gaps in the literature that in principle could be relevant to radiofrequency EMF health, but which were excluded because either the link between exposure and endpoint, or the link between endpoint and health, was not supported sufficiently by the literature. The evaluation of these research areas identified the following data gaps: (1) Issues concerning relations between radiofrequency EMF exposure and heat-induced pain; (2) Clarification of the relation between whole-body exposure and core temperature rise from 100 kHz to 300 GHz, as a function of exposure duration and combined EMF exposures; (3) Adverse effect thresholds and thermal dosimetry for a range of ocular structures; (4) Pain thresholds for contact currents under a range of exposure scenarios, including associated dosimetry; and (5) A range of additional dosimetry studies to both support future research, and also to improve the application of radiofrequency EMF exposure restrictions in future guidelines.
https://doi.org/10.1097/hp.0000000000001944

Construction of heterojunction MXene/RGO/CoFe-LDH for electromagnetic wave absorption, Ding, G. X., Sun, C. F., Wang, M. Y., Hu, Y. X., Cheng, G. J. and Liu, J., *Materials Research Bulletin*, Jan 2025, Vol. 181.

The 2D nanomaterial has been widely used in the field of electromagnetic wave absorption because of its high specific surface area and special electrical properties. In this work, three 2D materials were integrated to form a unique ternary composite with Ti3C2Tx MXene as the substrate, RGO as the intercalator with additional components, and CoFe-LDH loaded on the MXene/RGO surface. The interfacial and dipole polarizations were notably enhanced due to the abundant formation of heterogeneous interfaces between the three 2D materials and their corresponding abundant functional groups and defects, and the space between the 2D lamellae enabled multiple reflections of electromagnetic waves. Compared with pure MXene, the MXene/RGO/CoFe-LDH composites exhibited excellent electromagnetic wave absorption performance due to the synergy of multiple loss mechanisms, resulting in the best reflection loss value of -58.9 dB at 13.12 GHz.
https://doi.org/10.1016/j.materresbull.2024.113121

A Durable Textile With Advanced Thermal Functions and Electromagnetic Shielding, Gao, D. G., Jia, Z. T., Lyu, B., Tang, L. T., Fu, Y. T. and Ma, J. Z., *Small*, Jan 2025, Vol. 21, no. 1.

In the face of increasingly variable cold climates and diverse individual temperature regulation demands, personal thermal management (PTM) textiles with electromagnetic shielding have

obtained significant attention. However, the PTM textiles face several challenges, including single heating mode, insufficient durability, and complex preparation processes. Herein, an all-day PTM textile Cotton@PDA/AgNPs (CPANS) with energy-free PRH, energy-saving solar heating, compensatory electrical heating, electromagnetic interference (EMI) shielding, and outstanding durability is fabricated by sequentially growing polydopamine (PDA) and silver nanoparticles (AgNPs) on the cotton fabric (CF). The CPANS exhibits low mid-infrared emissivity (36.6%) and high absorptivity (70.8%), which guarantees the energy-saving heating capability. Moreover, the conductivity of the CPANS is approximate to 11109 S m-1, enabling an electrical heating temperature of approximate to 177 degrees C under a low voltage of 1.1 V and superb EMI shielding effectiveness (approximate to 60 dB). The remarkable adhesive properties of the PDA ensure that the desired durability of the CPANS remains high even after rigorous physical treatments. This innovation shows enormous potential for wearable integrated garments in the future and offers a new ideal for PTM fabrics in the cold. https://doi.org/10.1002/smll.202407571

Wireless radiation and health: making the case for proteomics research of individual sensitivity, Leszczynski, D., *Frontiers in Public Health*, Jan 2025, Vol. 12.

The current deployment of the fifth generation of wireless communication technology (5G) has reignited the long-standing debate around the possibility of health effects from the radiation emitted by the existing wireless communication devices and networks and the new ones introduced by the 5G. The opposition of the part of society toward wireless communication technologies is caused by the uncertainty of whether this radiation affects humans as well as fauna and flora. Some of the population considers themselves sensitive to wireless radiation, the so-called electromagnetic hypersensitivity (EHS). Currently, the existence of EHS has not yet been proven scientifically. However, according to the definition of health of the World Health Organization (1) where "health is a state of complete physical, mental, and social wellbeing and not merely the absence of disease and infirmity", any person believing his/her health is affected or sensitive to wireless radiation experiences a health effect caused by the wireless radiation. According to the WHO definition of health, just a belief in having EHS and experiencing non-specific symptoms, physiological and/or psychological, is experiencing the health effects of wireless technology. Hence, it is correct to claim that wireless radiation causes health effects. The existence of individual sensitivity to wireless radiation has not been proven yet, or disproven because to date performed research is inadequate. Of course, it is challenging to prove things with science as an infinite number of potential confounders and covariates need to be considered. However, science should be used to evaluate the balance of probability whether a hypothesis is plausible. Hence, providing an absolute proof might be elusive. Most of the research on EHS was conducted using psychology methods, asking a person, who is concerned that wireless exposure might affect health of the wireless radiation exposure, how the person feels during the real or the sham exposure. Puzzlingly, the frequent observation that the self-declared EHS person can't feel the wireless radiation and can't recognize when the wireless transmitter emits radiation and when it is not transmitting, is considered ultimate proof that the form of individual sensitivity to wireless radiation called EHS is not caused by wireless radiation exposures. This is questionable as no person, sensitive or not, could feel the ionizing radiation or other non-ionizing radiation like ultraviolet in their environment. Thus, research on EHS and individual sensitivity to wireless radiation, in general, has generated scientifically subjective data, unreliable for public health recommendations or radiation safety limits. On the contrary, logically and per analogiam with other environmental factors, individual sensitivity to wireless radiation, which includes EHS, exists as indicated below, and should be studied using biochemical methods. https://doi.org/10.3389/fpubh.2024.1543818

Application of MEMS technology in anti-electromagnetic radiation maternity clothes: state of the art and future perspectives,
Luo, Y. C., Bai, Q. M. and Skrzypacz, P., *Frontiers in Physics*, Jan 2025, Vol. 12.

This review provides a comprehensive analysis of the application of Micro-Electro-Mechanical Systems (MEMS) technology in anti-electromagnetic radiation maternity wear. The review commences with an elaboration of the electromagnetic shielding principles of traditional materials and the principle of anti-electromagnetic radiation. Subsequently, the role of MEMS in maternity clothing is detailed, including the real-time monitoring of radiation via sensors, the enhancement of fabric shielding through electrospinning and material deposition, and the realization of intelligent functions such as micro-actuators and communication modules. Furthermore, the review considers the optimization of performance, taking into account factors such as electromagnetic shielding, air permeability and comfort. Furthermore, the article addresses the challenges of ensuring comfort and power supply. The article concludes by emphasizing the potential of MEMS in protecting pregnant women and fetuses and proposes future research directions, including an in-depth exploration of the working principles, technical specifications, and performance characteristics of key MEMS components (sensors and micro-actuators), as well as research on the combination and The combination of MEMS technology with existing anti-radiation technologies, such as traditional metal fiber fabrics and nanomaterials, has the potential to yield significant synergistic effects. Furthermore, an in-depth analysis of performance optimization, including durability and washing stability of maternity clothes, is essential. Additionally, the exploration of emerging technologies, such as bubble electrospinning in maternity clothes, could lead to innovative applications in this field. https://doi.org/10.3389/fphy.2024.1529899

Infrared Ultralow-Emissivity Polymeric Metafabric Conductors Enabling Remarkable Electromagnetic and Thermal Management,
Yu, R. Q., Wang, M. Y., Lu, W. F., Wang, J. S., Cao, Y. X., Yang, Y. Y., Wang, W. J. and Wang, J. F., *Advanced Functional Materials*, 2025 Jan 2025.

Infrared ultralow-emissivity fabric has garnered significant interest for applications in infrared stealth and personal thermal management. However, reconciling the competing demands of low emissivity, breathability, and mechanical strength poses a formidable challenge. Here, an air-permeable polymeric metafabric distinguished by a unique non-through-hole structure is presented. This design is achieved through the electroless plating of silver nanoparticles onto commercially available nylon fabric, supplemented by an intermediate layer of hot-processed nylon porous mesh. This metafabric demonstrates an ultralow emissivity of 0.044, an exceptional electrical conductivity of 51 315 S m-1, an impressive electromagnetic interference shielding efficiency of 78 dB, and a high tensile strength of 110 MPa. The emissivity, conductivity, and strength of the metafabric are among the highest values reported for infrared low-emissivity fabrics. The metafabric also exhibits an air permeability that conforms to Grade 2 of international standards. The metafabric facilitates personal precision heating across diverse environments through its integrated capabilities of passive radiative and active solar/Joule heating. Additionally, the metafabric displays antibacterial properties, flame retardancy, sweat absorption, quick-drying, and washability performance, thereby significantly enhancing its wearability. This high-performance, multifunctional, infrared ultralow-emissivity polymeric metafabric holds great promise for applications in infrared camouflage, electromagnetic protection, and personal thermal management.
https://doi.org/10.1002/adfm.202421347