Summaries and assessments of selected studies

Between end of October 2024 and end of January 2025, 105 new publications were identified, three of which were discussed in depth by BERENIS. All three were deemed particularly relevant based on the selection criteria. Their summaries and assessments are outlined below.

1) Experimental animal and cell studies

Effects of extremely low frequency magnetic fields on mature cells (Sun et al. *2025)*

In this *in vitro* study, the authors hypothesized that aged (senescent) cells react more sensitively to 24-hour exposure to a 50 Hz ELF-MF (1 mT, sinusoidal wave) than freshly isolated human lung fibroblasts. Unlike cancer cells, cultures of primary cells have a limited lifespan, with the proliferation potential of the cells decreasing with age, in conjunction with physiological and molecular changes. This biological phenomenon is known as senescence. In 'young' cell cultures, the authors found that 50 Hz ELF-MF exposure had no effect or even caused a slight reduction of DNA damage (comet assay and a biomarker for DNA double-strand breaks). In contrast, senescent cells with more than 50 divisions showed not only elevated background levels in the controls but responded to exposure with an increase in DNA damage. When triggering senescence by bleaching agent hydrogen peroxide (H_2O_2) a comparable effect was observed: the aged cells reacted to the 50 Hz magnetic field with more DNA damage. Furthermore, a slight increase in ROS and intracellular calcium concentration was observed after exposure of senescent cell cultures, but not of 'young' cell cultures. The authors attributed these effects to a faster release of calcium from the mitochondria through a specific membrane pore (mPTP). Pharmacological blocking of the pore prevented both exposure-related ROS production and DNA damage.

In terms of its experimental and technical execution, this is a sound cell study. However, conducting the sham exposures in a separate incubator introduces some uncertainties. The study provides interesting mechanistic insights and illustrates that the response to ELF-MF should not be considered in a generalized manner, but in relation to the condition and state of cells. Whether the findings from such a cell culture-based model of aging can be transferred to the normal ageing process in humans, however, has not been conclusively clarified and requires further investigation.

2) Measurement studies

Exposure measurements in Switzerland: extremely low frequency magnetic fields from environmental sources (Loizeau et al. *2024) and radiofrequency downlink and uplink exposures since the introduction of 5G (Veludo* et al. *2025)*

The two studies by Loizeau *et al.* (2024) and Veludo *et al.* (2025) investigated real-life exposure situations in Switzerland in defined environments (outdoor areas, public spaces and during traveling). The focus lay on typical scenarios for extremely low frequency magnetic fields (ELF-MF) from common environmental sources (Loizeau *et al.* 2024) and on downlink and uplink exposure since the introduction of 5G (Veludo *et al.* 2025).

The Loizeau study measured ELF-MF in 300 outdoor areas (urban, industrial and rural), 248 public spaces (train stations, shops, restaurants, schools, etc.), 348 journeys (by train, tram, bus, metro, cable car, and car), and in 59 homes (near high and medium-voltage power lines, railway lines, tram

lines, or transformer stations). An ExpoM-ELF measuring device was used, carried in the researchers' backpack in outdoor areas, public spaces and during traveling, or mounted on a tripod during home measurements. ELF-MF levels were found to be highest at train stations, in trains, and at tram stops, and lowest at airports, in cable cars, and in green areas. Homes near high voltage power lines clearly had the highest ELF-MF levels among the selected homes, followed by those near transformers, railway lines, and tram lines, all of which had elevated levels of ELF-MF compared to reference homes without such nearby sources. All measured exposures were well below Swiss ambient regulatory limits, but 2.9% of home measurements and 1.2% of educational locations, which are considered "places of sensitive use"[1], exceeded the Swiss precautionary limit of 1.0 µT for power lines. Even if multiple sources contribute to this exceedance, this limit applies to each installation separately. In most houses with measurements exceeding 1.0 µT, the exposure likely originates predominantly from nearby power lines, except in one house, where it was attributed to a heated waterbed, for which the precautionary limit does not apply. Furthermore, the precautionary limit may be exceeded if the operator demonstrates that all reasonable measures have been taken to minimize exposure.

Correlations between measurements taken in 2021-2022 and 2023-2024 at the same defined environments were moderate in public transport environments and high in most outdoor areas and public spaces, indicating stable ELF-MF exposure contrasts over time.

The researchers also developed an environmental exposure matrix to estimate typical exposures based on home location (near power or railway lines or without environmental sources), workplace (on a train, in an industrial area, or at a school), and commuting method (train, tram, car). The authors noted significant variability within the same types of defined environments, leading to potential exposure misclassification in epidemiological studies if such environmental exposure matrix were applied, even for cohorts with known daily activities.

The authors of the Veludo study measured environmental and self-induced RF-EMF levels in various settings, including urban, industrial, and rural outdoor areas as well as public spaces such as stations, shops and universities. An ExpoM-RF4 measurement device was carried in a backpack, recording RF-EMF levels for 35 different frequency bands. Three scenarios were measured: (1) a non-user scenario with the investigator's phone in flight mode to register only ambient RF-EMF levels; (2) a maximum downlink scenario, in which a file was repeatedly downloaded from a server, and (3) a maximum uplink scenario, in which a file was repeatedly uploaded to a server.

Average RF-EMF levels in the non-user and maximum downlink scenarios were higher in urban areas than in rural areas. In contrast, RF-EMF levels in the maximum uplink scenario were higher in rural areas, due to weaker signals from base stations resulting in higher phone output power.

In the non-user scenario, downlink frequency bands dominated. The new 5G time-division duplex (TDD) 3.5 GHz band was the main contributor to RF-EMF levels in the maximum downlink scenario, particularly in urban areas with a well-established 5G network. Dynamic beamforming occurred when the researchers "demanded" downlink service through the self-induced maximum downlink scenario. In the maximum uplink scenario, both the 2.1 GHz uplink band and the 5G TDD 3.5 GHz band contributed substantially to the exposure, though the 5G contribution was markedly lower in rural areas, due to greater distances from 5G services. The researchers note that with TDD technology, it is impossible to separate uplink (coming from the phone) and downlink (from the base station) contributions to the total RF-EMF level.

[1] with regard to the Swiss Ordinance on Protection against Non-Ionising Radiation (NISV)

3) Further information

Monitoring of non-ionising radiation in Switzerland

The SwissNIS project consortium has published its fourth annual report (in German). The report describes the measurements carried out in 2024 as part of the Swiss exposure monitoring programme for non-ionising radiation.[2]

European research cluster on Electromagnetic Fields and Health: policy brief

The European research cluster on Electromagnetic Fields and Health (CLUE-H) has published a policy brief on the use of different exposure metrics in the research about the health impacts of electromagnetic fields, explaining "why different exposure metrics are being used, what these quantities mean and why the different metrics help to achieve the respective policy and research objectives".[3]

ICNIRP statement regarding knowledge gaps

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has published a statement describing knowledge gaps relevant to the "ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (100 kHz TO 300 GHz)".[4]

References

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[2] SwissNIS (2025): Expositionsmessungen nichtionisierende Strahlung: Jahresbericht 2024 - Projektkonsortium SwissNIS. 18. Juli 2025. Bundesamt für Umwelt (BAFU). https://www.bafu.admin.ch/dam/bafu/de/dokumente/elektrosmog/externe-studien-berichte/expositionsmessungen-nichtionisierende-strahlung-jahresbericht-2024-projektkonsortium-swissnis.pdf.download.pdf/Jahresbericht_2024_-_NIS-Expositionsmessungen_(DE).pdf

[3] https://www.emf-health-cluster.eu/wp-content/uploads/2024/06/CLUE-H_First_Policy_Brief_DEF_approved.pdf

[4] https://doi.org/10.1097/hp.0000000000001944

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Additional information:

BERENIS - Swiss expert group on electromagnetic fields and non-ionising radiation

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List of abbreviations (pdf)