

Overview of the epidemiologic studies on the health effects of ELF electric and magnetic fields (ELF-EMF) published in the fourth quarter of 2024.

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1. Reviews and meta-analyses

1.1. Factsheet 'Exposure to electromagnetic fields (EMF) frequencies between 1Hz and 100 kHz'

European Directorate-General for Health and Food Safety (2024), Exposure to electromagnetic fields (EMF) frequencies between 1Hz and 100 kHz

Background: This factsheet explains the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) Opinion on the potential health effects of exposure to electromagnetic fields (EMF): Update with regard to frequencies between 1Hz and 100 kHz – May 2024.

Methods: While most people in Europe are exposed to ELF-EMF levels well below the safety limits recommended by the European Council, Developments in the use of new technologies, e.g., induction hobs and wireless charging, require updates to the assessment of how exposure to electromagnetic fields might impact our health, as well as the scientific guidelines that underpin restrictions and reference levels.

The SCHEER collected (systematic) reviews and meta-analyses published between 2015 and 2023 and summarized their findings.

Results: While scientific knowledge is increasing, there still remain gaps. The SCHEER summarised what is known:

- Leukemia & EMF: There is some evidence that exposure to extremely low-frequency EMF (such as from power lines) might slightly increase the risk of childhood leukaemia, but the evidence is not conclusive.
- Neurodegenerative Diseases: Studies suggest there is a possible link between workplace EMF exposure and diseases like ALS (Lou Gehrig's disease), but the evidence is still weak when it comes to conditions like Alzheimer's and dementia. No link can be established between EMF exposure and Parkinson's, or multiple sclerosis.
- Reproductive Health: Current research shows no association between EMF exposure and pregnancy or reproductive outcomes.

Conclusions: There is still a need for more research, especially using more consistent methods and models that reflect real-world exposure. For example, studies on how EMF affects things like melatonin, DNA, or oxidative stress are still in early stages. With the advent of diagnostic techniques for neurodegenerative diseases and the introduction of validated biomarkers for them, more clinical and epidemiological studies are required to investigate the association between EMF exposure and these diseases.

Comment: This factsheet is based on the Opinion on the potential health effects of exposure to electromagnetic fields (EMF): Update with regard to frequencies between 1Hz and 100 kHz – May 2024, which can be found here: https://health.ec.europa.eu/document/download/85ef39d5-49dc-4b5a-b875-54e578d1d2bc_en

2. Residential exposure

2.1. Magnetic fields from indoor transformer stations and risk of cancer in adults: a cohort study.

Juutilainen, J., Khan, M. W., Naarala, J., & Roivainen, P. (2024). Magnetic fields from indoor transformer stations and risk of cancer in adults: a cohort study. *Occupational and Environmental Medicine*, 81(11), 574–579.

Background: Previous 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.

Methods: 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, with apartments on the ground and first floor as those with increased exposure. Information on their cancer diagnoses was obtained from the Finnish Cancer Registry. Standardized Incidence Ratio (SIR) with 95% CI was calculated to investigate the association of MF exposure with overall cancer and specific cancers.

Results: 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.

Conclusions: Overall cancer risk was not affected by residential EMF exposure. The increased risk of digestive organ cancers among MF-exposed persons is a novel finding requiring confirmation in further studies.

3. Occupational exposure

3.1. 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.

Amila Madhushanka Weerasinghe, S. D. N. A. M., Liyanage, S., Rajitha Kawshalya, M. A. D., & Hong, S. C. (2024). 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. *International Journal of Occupational Safety and Ergonomics*, 1-8.

Background: This study investigates the potential health risks associated with exposure to extremely low frequency magnetic fields (ELF-EMF), focusing on the impact on sleep quality. The hypothesis

was that increased ELF-EMF exposure correlates with elevated blood pressure (BP), altered heart rate (HR) dynamics and poorer sleep quality among occupational workers in Korea.

Methods: Participants were invited by posting recruitment notices in worker support centers, after which 85 participants volunteered. Participants were categorized into two groups based on their occupational sector. Industrial factory workers were considered to have a high exposure level, while a general group ('sham exposure group') comprised agricultural workers, service workers, office workers, and individuals in academic categories.

Assessment of ELF-EMF exposure was carried out continuously for 24 h in the two groups.

Measurements of BP and HR were measured four times per day, with the mean value of the readings used for analysis. Sleep quality was measured by wearable devices (i.e. Apple Watch).

Results: Of the 85 participants, 28 were female, and 57 were male. The study found significant higher ELF-MF exposure levels for the industrial factory workers, both during working and sleeping times ($p < 0.05$). Industrial factory workers also demonstrated a higher systolic blood pressure than the general group (127.91 ± 8.78 vs. 123.27 ± 9.94 mmHg, $p < 0.05$). Additionally, a significant difference in deep sleep analysis was observed between the high-exposure and low-exposure groups (58.12 ± 28.95 vs. 75.93 ± 31.02 min, $p < 0.05$).

Conclusions: The hypothesis was confirmed, indicating possible effects of high ELF-EMF exposure on SBP and deep sleep. The higher exposure of industrial workers during sleep may be linked to their housing situation, where workers often sleep in factory-adjacent dormitories. However, further research, specifically long-term research, on significant ELF-EMF exposure and its association with sleep quality disturbances is needed for validation.

3.2. Analysis of Low Frequency Electromagnetic Fields Onboard Vessels with Electric Propulsion with Operating Voltage 11 kV.

Barudov, E., Ivanova, M., & Doneva, M. (2024). Analysis of Low Frequency Electromagnetic Fields Onboard Vessels with Electric Propulsion with Operating Voltage 11 kV. *2024 16th Electrical Engineering Faculty Conference (BulEF)*, 1–5.

Background: The aim of this study was to examine the 60 Hz electromagnetic fields produced by specific components of the electrical equipment aboard a passenger ship with electric propulsion drives, operating at a voltage of 11 kV. This with the overall aim to evaluate the work conditions of the technical staff involved in the maintenance of the considered equipment.

Methods: The study was conducted on a passenger ship equipped with two electric propulsion systems, each powered by a pair of high-voltage transformers (11000/1500 V, 60 Hz). ELF-EMF measurements were carried out for the main generator, the main engine, the engine room transformer, the 11kV electric motor, and cable trays. Measurements were done 20 to 120 cm away from the equipment's enclosure.

Results: The highest levels of electrical and magnetic fields were observed at a distance of 20 cm from the cable trays ($E=25$ V/m, $B=34,8$ μ T). All measured generated EMF were below the permissible values regarding occupation health and safety.

Conclusions: The levels of ELF-EMF generated by the parts of the electrical equipment onboard a passenger ship at certain load of the generators were measured for assessment of the occupational

health and safety of the technical personnel. The results showed that the values of the electric field intensity E and magnetic induction B were far below the European permissible values. However, it is possible certain situations (e.g. full ahead or emergency modes) can induce excessive ELF-EMF, highlighting the importance of protective measures for workers in these situations.

Comment: This study was published in the conference book of the 16th Electrical Engineering Faculty Conference, and was not peer reviewed. Future peer review of this study may influence the conclusions. However, as it contains measurement data of equipment with a well described methodology, the results may be of interest to occupational researchers, and the decision was made to include the study in this report.

3.3. Exposure assessment and cytogenetic biomonitoring study of workers occupationally exposed to extremely low-frequency magnetic fields.

Nguyen, H., Vandewalle, G., Mertens, B., Collard, J. F., Hinsenkamp, M., Verschaeve, L., Feipel, V., Magne, I., Souques, M., Beauvois, V., & Ledent, M. (2024). Exposure assessment and cytogenetic biomonitoring study of workers occupationally exposed to extremely low-frequency magnetic fields. *Bioelectromagnetics*, 45(6), 260–280.

Background: Human cytogenetic biomonitoring (HCB) has long been used to evaluate the potential effects of work environments on the DNA integrity of workers. However, HCB studies on the genotoxic effects of occupational exposure to extremely low-frequency electromagnetic fields (ELF-EMF) were limited by the quality of the exposure assessment. More specifically, concerns were raised regarding the method of exposure assessment, the selection of exposure metrics, and the definition of exposure group.

Methods: In this study, genotoxic effects of occupational exposure to ELF-MFs were assessed on peripheral blood lymphocytes of 88 workers from the electrical sector using the comet and cytokinesis-block micronucleus assay, considering workers' actual exposure measured over three consecutive days. Different methods were applied to define exposure groups.

Results: Overall, the summarized ELF-MF data indicated a low exposure level in the whole study population. It also showed that relying solely on job titles might misclassify 12 workers into exposure groups. The authors propose combining hierarchical agglomerative clustering on personal exposure data and job titles to define exposure groups.

Conclusions: The final results showed that occupational MF exposure did not significantly induce more genetic damage. Other factors such as age or past smoking rather than ELF-MF exposure could affect the cytogenetic test outcomes.

Comment: As mentioned in the manuscript, this study is part of the BBEMG project, which is also responsible for the publication of these reports.

4. Exposure Assessment

4.1. Extremely low frequency magnetic fields (ELF-EMF) 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., & Rösli, M. (2024). Extremely low frequency magnetic fields (ELF-MF) in Switzerland: From exposure monitoring to daily exposure scenarios. *Environment International*, 194.

Background: While ELF-EMF is classified as ‘possibly carcinogenic’, potential adverse health outcomes have been observed with long-term exposure. Concurrently, comprehensive exposure-assessment of the general population remains limited. This study characterizes the ELF-EMF exposure in numerous Swiss environments and introduces a novel environmental exposure matrix (EEM) for estimating time weighted average (TWA) ELF-EMF exposure.

Methods: Magnetic flux density levels (μT) 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). The authors collected ELF-EMF exposure 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).

Results: Over all environments, the highest ELF-EMF exposure levels were measured in train stations (median: $0.48 \mu\text{T}$), trains (median: $0.40 \mu\text{T}$), and in living rooms near ($<200 \text{ m}$) highest voltage lines of 220 kV and 380 kV (median: $0.37 \mu\text{T}$). ELF-EMF 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: $0.2 \mu\text{T}$).

Additionally the authors derived an environmental exposure matrix and modelled 27 daily time-weighted average ELF-EMF exposure scenarios by combining typical time spent at home, work and transport environments. The highest daily TWA exposure corresponds to a scenario in which a person lives near high voltage lines, works on trains, and commutes by train (mean \pm SD: $0.82 \pm 1.18 \mu\text{T}$). The lowest daily TWA exposure corresponds to a scenario with a person who is not exposed to an environmental source at home, works in educational places, and commutes by car (mean \pm SD: $0.09 \pm 0.10 \mu\text{T}$).

Conclusions: This exposure monitoring study presents a comprehensive overview of ELF-EMF exposure in Switzerland between 2022 and 2024 through real-world measurements in numerous public areas, transport, and homes. The authors derived an environmental exposure matrix for ELF-EMF suitable for agent-based exposure modelling, which may support public communication and future epidemiological research.

5. Leukaemia Studies

5.1. Maternal use of hormonal contraception and risk of childhood leukemia: A Scandinavian population-based cohort study.

Hemmingsen, C. H., Kjaer, S. K., Hjorth, S., Nörby, U., Broe, A., Pottegård, A., Bénévent, J., Schmiegelow, K., Skovlund, C. W., Leinonen, M. K., Nordeng, H., Mørch, L. S., & Hargreave, M. (2024). Maternal use of hormonal contraception and risk of childhood leukemia: A Scandinavian population-based cohort study. *European Journal of Cancer*, 215, 115168.

Background: Maternal hormonal contraception use has been associated with childhood leukemia risk. However, studies are few and often based on self-reported information.

Methods: Using registry data from Denmark, Norway, and Sweden, the authors identified 3,183,316 children (born 1996–2018) and followed them from birth until leukemia diagnosis, censoring (death, emigration, other cancer, 20th birthday) or study closure (December 31st, 2017, 2018, or 2020). They estimated hazard ratios (HRs) and 95 % confidence intervals (CIs) for childhood leukemia (any, lymphoid and non-lymphoid) associated with maternal recent use (≤ 3 months before or during pregnancy) or previous use (before recent use) of hormonal contraception overall and by type, compared to no use.

Results: During 29,455,528 person-years, 1701 children developed leukemia (no use: 518, previous use: 974, recent use: 209). Maternal recent use of hormonal contraception was associated with an increased leukemia risk in children (HR 1.22, 95 % CI 1.04–1.44; incidence rate per 1,000,000 person-years [IR] 65), compared to no use (IR 53). The association was strongest for non-lymphoid leukemia (HR 1.69, 95 % CI 1.20–2.37) and mainly driven by the oral combined products, both for any leukemia (HR 1.29, 95 % CI 1.05–1.59) and non-lymphoid leukemia (HR 1.75, 95 % CI 1.17–2.62). Additionally, non-lymphoid leukemia was associated with recent use of the non-oral progestin-only products (HR 2.10, 95 % CI 1.28–3.44).

Conclusions: Although the absolute risk was low, maternal hormonal contraception use up to or during pregnancy was associated with an increased childhood leukemia risk, particularly non-lymphoid leukemia, and mainly driven by oral combined and non-oral progestin-only products.

5.2. A municipality-specific analysis to investigate persistent increased incidence rates of childhood leukaemia near the nuclear power plant of Krümmel in Germany.

Gianicolo, E., Russo, A., di Staso, R., Ronckers, C. M., Schmidtman, I., Wollschläger, D., & Blettner, M. (2024). A municipality-specific analysis to investigate persistent increased incidence rates of childhood leukaemia near the nuclear power plant of Krümmel in Germany. *European Journal of Epidemiology*.

Background: Increased incidence rates for childhood leukaemia have been reported in municipalities close to the nuclear power plant (NPP) Krümmel (Geesthacht, Germany). Methodological challenges arise when analyzing this association at ecological level. They include the use of an appropriate

reference population, unstable estimates of standardized incidence ratios (SIRs), and the potential role of prevailing winds. The aim of this study is to address these challenges.

Methods: The German Childhood Cancer Registry provided data on leukaemia in children under 15 years (2004–2019). The German Federal Statistical Office provided the population data. The study region included all municipalities with $\geq 75\%$ surface area within 50 kms from the Krümmel NPP. SIRs were calculated using national and regional reference rates. Smoothed incidence relative rates (IRRs) were calculated and mapped to check for potential patterns associated with prevailing winds.

Results: Overall 356 cases of childhood leukaemia were observed in the study region (321 municipalities) during 2004–2019. SIRs based on national reference rates show nearly no difference to those calculated using the regional rates as reference. Increased SIR and IRR were observed in Geesthacht (observed-cases=8; SIR=2.29; 95% confidence interval: 0.99–4.51. IRR=1.80; 95% credibility interval: 0.88–2.79). The analysis of the IRR map does not show patterns associated with prevailing winds.

Conclusions: Using a regional population as the reference, the authors found evidence that there may still be an increased risk for childhood leukaemia in Geesthacht. However, IRR estimates are uncertain and credibility intervals are compatible with the absence of elevated risk. The persistent evidence of risk of childhood leukaemia in Geesthacht warrants further epidemiological surveillance.

5.3. Association Between Perinatal Factors and Childhood Lymphoma—A Pooled Analysis of the ESCALE and ESTELLE Studies (SFCE).

Msallem, E., Pacquement, H., Olivier, L., Brugières, L., Landman Parker, J., Garnier, N., Lambilliotte, A., Faure, L., Clavel, J., & Bonaventure, A. (2024). Association Between Perinatal Factors and Childhood Lymphoma—A Pooled Analysis of the ESCALE and ESTELLE Studies (SFCE). *Pediatric Blood and Cancer*.

Background: There is much interest in the perinatal period in relation to childhood cancer aetiology, with most studies focusing on childhood leukaemia. This work aimed to investigate the associations between pregnancy-related and perinatal factors and childhood lymphoma.

Methods: The authors conducted a pooled analysis of two French nationwide population-based case–control studies. Data on sociodemographic, perinatal and lifestyle factors were collected through maternal interviews. Odds ratios (OR) and 95% confidence intervals (CIs) were computed using adjusted logistic regression models, separately for non-Hodgkin lymphoma (NHL) and Hodgkin lymphoma (HL). Specific analyses also investigated Burkitt NHL and nodular sclerosis HL, the two most common histological types in children.

Results: The study included 305 NHL, 328 HL and 2415 controls. No associations were observed with gestational age, foetal growth indicators, folic acid supplementation, factors related to maternal fertility and reproductive history, or maternal smoking during pregnancy. Maternal coffee consumption during pregnancy was associated with NHL (>2 cups/day, OR = 1.5 [95% CI: 1.1–2.1]), with a dose–response relationship; while maternal alcohol consumption was associated with Burkitt NHL (OR = 1.5 [1.1–2.2]). Paternal smoking during preconception/pregnancy was associated with NHL (OR = 1.4 [1.1–1.8]). Breastfeeding (ever/never) was not significantly associated with NHL and HL, but an inverse log-linear trend was observed with the duration of breastfeeding for NHL ($p = 0.04$).

Conclusions: Maternal coffee and alcohol consumptions during pregnancy and paternal smoking during preconception/pregnancy might increase the risk of childhood NHL. While warranting replication, these findings could help to better understand the aetiology of childhood lymphoma.

5.4. Residential proximity to oil and gas developments and childhood cancer survival.

Hoang, T. T., Rathod, R. A., Rosales, O., Castellanos, M. I., Schraw, J. M., Burgess, E., Peckham-Gregory, E. C., Oluyomi, A. O., Scheurer, M. E., Hughes, A. E., & Lupo, P. J. (2024). Residential proximity to oil and gas developments and childhood cancer survival. *Cancer*.

Background: Environmental toxicants may impact survival in children with cancer, but the literature investigating these associations remains limited. Because oil and gas developments emit several hazardous air pollutants, the authors evaluated the relationship between residential proximity to oil or gas development and survival across 21 different pediatric cancers.

Methods: The Texas Cancer Registry had 29,730 children (≤ 19 years old) diagnosed with a primary cancer between 1995 to 2017. Geocoded data were available for 285,266 active oil or gas wells and 109,965 horizontal wells. The authors calculated whether each case lived within 1000 m (yes/no) from each type of oil or gas development. Survival analyses were conducted using Cox regression, adjusting for potential confounders.

Results: A total of 14.2% of cases lived within 1000 m of an oil or gas well or horizontal well. Living within 1000 m of an oil or gas well was associated with risk of mortality in cases with acute myeloid leukemia (AML) (adjusted hazard ratio [aHR], 1.36; 95% confidence interval [CI], 1.01–1.84) and hepatoblastoma (aHR, 2.13; 95% CI, 1.03–4.39). An inverse association was observed with Ewing sarcoma (aHR, 0.35; 95% CI, 0.13–0.95). No associations were observed with horizontal well. There was evidence of a dose-response effect in children with AML or hepatoblastoma and residential proximity to oil or gas wells. In general, the magnitude of association increased with decreasing distance and with higher number of wells across the three distances.

Conclusions: Residential proximity to oil or gas wells at diagnosis is associated with the risk of mortality in children with AML or hepatoblastoma.

6. References

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