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Scientific Evidence on Weak Electromagnetic Fields, Cellular Responses, and Exposure Assessment

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In response to: HHS Request for Information on Electromagnetic Fields (EMFs), Radiofrequency (RF) Radiation, and Wireless Radiation Exposure (Federal Register, Sept. 21, 2026).

1. Perspective and principal findings (Questions 2 and 18)

I submit this comment as an electrical engineer and bioelectromagnetics researcher. My collaborators and I have investigated electromagnetic-field interactions across static, extremely low-frequency, MHz radiofrequency, and 900 MHz exposures, with attention to field characterization, cellular signaling, and biological feedback. This research provides a foundation for identifying informative exposure variables, mechanistic endpoints, and priorities for federal RF/EMF research.

Across these studies, a recurring observation is that biological responses depend on the complete exposure condition—not simply a single measure of incident power. Relevant variables include magnetic flux density and orientation, induced electric field, carrier frequency, modulation and exposure duration, together with the physiological state of the exposed cells. These factors deserve systematic inclusion in the scientific evidence used to inform exposure assessment and future standards. [1–10]

2. Evidence from controlled biological experiments (Questions 5, 12, and 18)

Static magnetic fields and everyday electrical environments

Static magnetic fields are a persistent component of the environment, beginning with the approximately 25–65 μT geomagnetic field and local variations associated with electrical equipment, magnetic materials, and built environments. In a controlled study of HT-1080 human fibrosarcoma cells, we exposed cultures for four days to static fields between 0.5 and 600 μT, compared with a 45 μT control. Cell growth increased by 23% and 28% at 300 and 400 μT, respectively, and decreased by approximately 9% at 0.5 and 600 μT. The direction of the applied field also influenced growth. Additional changes occurred in mitochondrial calcium, membrane potential, intracellular pH, hydrogen peroxide, superoxide, and nitric oxide. These findings support consideration of local DC/background fields and field orientation when characterizing exposures in laboratories, workplaces, and spaces containing everyday electronics. [5]

Weak fields at extremely low frequencies

A more recent controlled study applied 12–33 Hz magnetic fields of 10 μT on a 45 μT static background for four days. Near 16.5 Hz, changing frequency by 0.5 Hz or amplitude by approximately 250 nT could reverse the direction of the growth response; reversing the static-field direction also reversed the response. Concurrent changes in mitochondrial superoxide, calcium, and membrane potential establish a practical research agenda for low-frequency waveform control and response-time measurements. [10]

900 MHz RF exposure and human cell behavior

At a frequency directly relevant to wireless communication, a study of human neutrophils exposed in vitro to a 900 MHz field of approximately 0.4 V/m reported altered chemotaxis, including a change in migration direction and an increase in maximum migration speed of approximately 50% relative to the highest speed observed in the corresponding temperature-only experiments. The estimated RF-associated temperature change was less than one microdegree, and the reported average cellular response time was approximately 2.5 minutes. This study motivates research using functional cellular endpoints and well-characterized fields at wireless-relevant carrier frequencies. [1]

RF carrier frequency, modulation, and background static fields

In HT-1080 cells exposed for four days, our 2023 Scientific Reports investigation varied RF magnetic-field amplitude from 1 nT to 1.5 μT, carrier frequency from 1.8 to 7.2 MHz, and background static field from 10 to 300 μT. Cell growth, intracellular pH, hydrogen peroxide, peroxynitrite, membrane potential, and mitochondrial calcium were assessed. Growth responses were frequency dependent, with a prominent response near 4 MHz. Critically, 50 kHz modulation produced a stronger cell-growth response than the corresponding unmodulated RF condition. This directly supports studying carrier frequency and modulation together rather than treating RF signals with equal average field strength as biologically interchangeable. [7]

The same study measured both field components with calibrated probes. At applied RF magnetic flux densities of 1 nT, 20 nT, and 1.5 μT, the measured electric fields in the medium were 0.056, 1.128, and 84.68 V/m, respectively. Recording electric and magnetic components alongside the waveform is essential to interpreting field–cell interactions and reproducing exposure conditions. [7]

Different responses in cancer cells and normal fibroblasts

Our Biomolecules study compared HT-1080 fibrosarcoma cells with primary human dermal fibroblasts during four-day exposures to 20 nT RF fields across 3–5 MHz. The two cell types showed distinctly different patterns: at approximately 4.2 MHz, oxidative-stress-associated fluorescence increased in HT-1080 cells, whereas it decreased in dermal fibroblasts. Mitochondrial mass increased substantially in HT-1080 cells near 4.2 MHz, while changes in fibroblasts were smaller. HT-1080 growth also reached a minimum near that frequency. The study used magnetic shielding, controlled static fields, magnetic-field calibration, and characterization of the accompanying electric field (reported below 10 V/m). Such comparative designs can help identify cell-state-dependent response pathways. [8]

Antioxidant activity, mitochondrial superoxide, and both field components

In Antioxidants (2024), HT-1080 cells were exposed for four days to 20 nT RF magnetic fields in the 2–5 MHz range against a 45 μT static field. Measurements included superoxide dismutase (SOD), glutathione (GSH), peroxidase, mitochondrial superoxide, cell viability, and confluence. Responses varied by frequency: 4–4.5 MHz exposures were associated with increased antioxidant defenses and reduced mitochondrial superoxide, while other frequencies showed different redox patterns. At 4 MHz, mean cell confluence increased from 60.25 ± 9.01% in controls to 73.12 ± 7.93% in the exposed group ($p = 0.00017$; 16 samples across two independent experiments). The 20 nT RF condition was associated with a measured electric field of 1.128 V/m, and measured temperature changes were less than 0.2 °C. These paired biological and exposure measurements offer a useful template for detailed dosimetry and outcome reporting. [9]

3. Mechanistic interpretation: radical pairs, time delays, and feedback (Questions 12 and 16)

Biological redox pathways include radical intermediates and molecular systems with unpaired electrons. Spin-dependent radical-pair reactions, hyperfine interactions, and Zeeman interactions provide candidate pathways by which weak magnetic fields could affect chemical reaction yields. Electron-transport proteins and mitochondrial redox chemistry are relevant targets for experimental discrimination among proposed mechanisms. [3, 6–10]

Biological systems also contain coupled feedback loops and finite response times. Our 2018 work with Kandala discussed how delayed feedback can generate frequency-dependent and time-dependent responses, while Barnes and Greenebaum (2018) examined how radical-pair pathways interact with feedback and repair processes to yield increases, decreases, or minimal net change in measured endpoints. These concepts suggest measuring transient responses, recovery, exposure timing, and repeated stimulation rather than relying exclusively on a single terminal measurement. [2, 3]

4. Improving exposure measurement and interpretation (Questions 5, 7, and 8)

For both experimental and real-world RF/EMF evaluations, I recommend documenting the following elements as a common minimum dataset:

- Field specification: carrier frequency and bandwidth; electric-field strength (V/m); magnetic-field strength or flux density (A/m or T); static-background field vector and orientation; spatial uniformity; and the location of the measurement.
- Waveform specification: continuous-wave or modulated operation; modulation type and frequency; duty cycle, pulse parameters, spectral components, and exposure timing.
- Exposure and dosimetry: calibrated instrumentation, induced fields at the sample or tissue, estimated absorption where applicable, temperature, duration, duty cycle, and cumulative/repeated-exposure profiles.
- Biological context: cell type and physiological state, time of measurement, sham and environmental controls, independent replication, and orthogonal assessments of oxidative stress, mitochondrial function, membrane potential, and functional outcomes.

A central lesson of these studies is that equal nominal transmitter settings or average power can produce meaningfully different biological exposure conditions. Full measurement of both electric and magnetic field components, including the background static field, helps distinguish frequency-dependent cell responses from differences introduced by the exposure apparatus. [5, 7–10]

5. Federal research and exposure-guideline priorities (Questions 5, 16, and 17)

In 2020, Barnes and Greenebaum outlined research needs and proposed an approach for considering long-term weak-field exposures alongside existing short-term exposure guidelines. Barnes and Freeman (2022) further analyzed biological feedback, weak-field responses, exposure guidelines, and the role of thermal and nonthermal interaction pathways. These publications provide a framework for connecting experimental results with evidence-based guideline development. [4, 6]

I recommend that HHS, FDA, NIH, and CDC support a coordinated program organized around four priorities:

- Multifrequency replication: reproduce carefully selected response patterns at static, extremely low, MHz, and wireless-relevant GHz frequencies, using several independent laboratories and consistent measurement protocols.
- Waveform and feedback studies: test continuous-wave versus modulated signals, frequency steps, amplitude variation, orientation, onset and recovery, exposure duration, and chronic or repeated exposures.
- Biological specificity and causal pathways: compare primary normal cells with disease-derived cells; use multiple oxidative and mitochondrial endpoints together with targeted mechanistic perturbations to identify the reaction pathways responsible for observed responses.
- Guideline-relevant dosimetry: pair experimentally observed response thresholds with calibrated electric and magnetic fields, induced fields, absorption estimates, and explicit long-term exposure profiles, to create datasets usable by standards-setting bodies.

I encourage HHS to make these measurement and study-design elements priorities in its evidence review and future solicitations. Better linkage between electromagnetic waveform characteristics, cellular state, functional biological endpoints, and rigorous replication will strengthen the basis for interpreting RF/EMF exposures across devices, environments, and populations.

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