Better RF Health Science Requires Better RF Exposure Measurement

Nudgr response to the HHS Request for Information on Electromagnetic Fields (EMFs), Radiofrequency (RF) Radiation, and Wireless Radiation Exposure

Docket: HHS-OASH-2026-0397 (FR Doc. 2026-19252)

Submitted by: Nudgr, on behalf of the organization

Contacts: Mitch Marchand, BSc. EE, Co-founder; Stephanie Kerst, BA, Co-founder

Contact: https://nudgr.co, nudgrteam@gmail.com

Basis of this submission: peer-reviewed research, U.S. government reports (NTP, FCC), manufacturer technical specifications, industry and insurance-sector publications, and field observations from well over 1,000 on-site EMF assessments.

Section 1.

Responds to RFI Question 4.

1.1 The shared goal

HHS has set out to evaluate the state of the science, compare standards, identify critical research gaps, and develop practical recommendations for policymakers, families, schools, and communities [1,27]. The RFI notes that the scientific literature is extensive, technically complex, and not always easy for decision-makers to interpret. The Secretary put it plainly: wireless technologies are part of daily life, and the science must keep pace [27].

Science usually advances from observation. Practitioners notice a pattern, test it, form a hypothesis, and researchers then test that hypothesis rigorously. Many practitioners measuring RF in homes are asking the same question HHS is asking: *what, if any, biological effects, positive or negative, follow from the exposures people actually live with?* We welcome that HHS is asking it at the federal level. From the front line, the main obstacle to answering it is clear: the exposure itself is rarely measured well enough to test.

1.2 Field observations

Basis: field observations from well over 1,000 on-site assessments. These concern *exposure patterns*, not health outcomes, and are offered as hypothesis-generating, not as evidence of effect.

- **Occupants are often unaware of their main RF sources.** Examples include Wi-Fi access points and mesh nodes, cordless phone base stations, smart-home hubs, smart meters, wearables, neighboring networks, and devices that keep transmitting while “idle.”
- **Exposure is highly variable in space and time.** Levels differ between rooms, between positions within a room, and across day and night. Devices sync, update, and beacon on their own schedules, including overnight.
- **Much of the signal is intermittent and sporadic.** Short, intermittent transmissions are common. Instruments that average over seconds, or report a single reading, can understate peaks and miss short events.
- **A spot measurement is a snapshot, not a record.** A daytime assessment describes a room at one moment. It cannot reconstruct 3 a.m. across a month of nights.
- **Changes are hard to verify.** When a household moves or disables a device, confirming the actual change over time requires logging that most instruments cannot do unattended, silently, and with documented accuracy.

Standardized methods used. Practitioner assessments generally rely on spot measurements with broadband or frequency-selective handheld meters. These are useful for finding sources but not designed for longitudinal characterization.

Recommendation for research or surveillance. Develop and validate instrumentation for continuous, calibrated, unattended measurement in occupied homes, so field observations like these can become testable data (Section 3.4).

Section 2.

Each approach below has real value. The issue is what each one cannot see.

2.1 Laboratory studies isolate one signal

Controlled studies typically apply one modulated signal from one source for a set duration. That design is a strength for isolating effects, but it describes only part of real exposure. The 2024 WHO-commissioned systematic review of 41 human experimental studies states that experimental conditions differ substantially from real life in the duration, frequency, distance, and position of exposure, as well as co-exposure to other EMF sources [2].

What a phone study leaves out. In real use, the same phone may also be running Wi-Fi, Bluetooth, Ultra Wideband, and NFC. Around it are household Wi-Fi, other people's devices, broadcast AM/FM and TV, radar, and many licensed and unlicensed transmitters operating continuously.

2.2 The existing evidence is mixed

- **Symptoms (human experiments).** The same WHO-commissioned review found no or small, non-significant effects of acute RF exposure below regulatory limits on self-reported symptoms [2]. It also noted that most participants were young and healthy, and that the data did not allow assessment beyond acute exposure or in elderly or chronically ill people.
- **Neurophysiology.** A 2025 meta-analysis found evidence of an effect in one resting-state EEG circumstance, with too much heterogeneity or risk of bias to combine most other comparisons [11]. Earlier double-blind studies reported sleep EEG changes without consistent changes in sleep architecture [12].
- **Animal toxicology.** NTP's two-year studies reported clear evidence of carcinogenic activity (malignant heart schwannomas) in male rats at 900 MHz, at whole-body SARs of 1.5 to 6 W/kg, with equivocal findings in other groups [3].
- **Everyday exposure cohorts.** A prospective cohort of 955 adults found no consistent relationship between modeled or measured everyday RF exposure and later sleep quality; its bedroom sub-study showed objective home exposure data is possible but difficult to collect [10].

Controlled studies isolate a signal but lose realism. Field studies gain realism but lose measurement control. Neither currently characterizes the multi-source, time-varying exposure of daily life.

2.3 The largest knowledge gap is on the exposure side

Many studies characterize exposure through fixed laboratory signals, questionnaires, modeled estimates, or instruments with known limits in sampling, calibration, orientation, body shielding, and duty-cycle response [7-9]. Evaluating current or future standards, and testing whether exposure-reduction techniques work, both require knowing what people are actually exposed to, over time, in real settings.

2.4 Instruments were built for compliance

Most RF instrumentation answers a compliance question: is exposure below limits set to prevent heating or nerve stimulation? [4,5] Health research needs a different answer: what are people actually exposed to, continuously, at the far lower levels typical of homes, and how does it change over time?

Instrument class	What it does well	What it misses for real-world health research
Compliance and occupational meters	Verify exposure against thermal and stimulation limits; broad frequency coverage	Sensitivity floors set for compliance rather than everyday levels; averaging windows too long for short bursts; not designed for weeks of unattended logging
Spectrum analyzers	Identify individual signals and frequencies	Sweeping instruments can miss events outside the band being measured at that instant; costly, complex, generally require an operator
Personal exposimeters	Log exposure on the person over time	Limited by band coverage, sampling interval (often seconds), orientation, and body shielding [7]
Consumer broadband meters	Low cost; fast response; useful for finding sources	Generally lack traceable calibration, documented uncertainty, and unattended research-grade logging
Modeling and proxies	Scalable to large populations	Do not measure actual exposure; poorly capture indoor sources and temporal variation

Other methods include fixed environmental monitors, device and network logs, and computational dosimetry. A peer-reviewed instrument review concluded that sound epidemiology still requires accurate dosimetry; measurement uncertainty arises from calibration, anisotropy, body interaction, detection limits, sampling, modulation response, and multi-signal response [7,9]. Exposure also varies substantially across people, places, and time [8].

2.5 The signal environment has grown far more complex

	Original iPhone (2007)	iPhone 18 Pro (2026)
Cellular	GSM/EDGE, 4 bands (850/900/1800/1900 MHz) [19]	5G NR sub-6 GHz, 5G NR mmWave, LTE, UMTS, GSM: 69 band designations listed for model A3472 [18]
Cellular MIMO	None	4x4 MIMO (5G and LTE) [18]
Wi-Fi	802.11b/g, 2.4 GHz [19]	Wi-Fi 7 (802.11be), 2x2 MIMO [18]
Bluetooth	Bluetooth 2.0 + EDR [19]	Bluetooth 6 [18]
Other radios	None	Ultra Wideband (second generation), Thread, NFC, satellite messaging and SOS [18]
Approximate frequency span	~0.8 to 2.5 GHz	~0.6 to 40 GHz (includes mmWave bands n258, n260, n261) [18]

Note: this comparison shows growth in signal complexity, not in exposure level, dose, or risk. A band designation is a supported configuration, not a separate transmitter.

Technology notes: The evidence on cumulative exposure patterns is limited largely because cumulative real-world exposure is rarely measured.

- **a. 5G:** new bands up to about 40 GHz in U.S. devices, beamforming, and wider channels; beamformed exposure varies with location, usage, and network load.
- **b. 6G:** likely to extend spectrum and signal complexity further; measurement capability should exist before deployment, not after.
- **c. Wi-Fi:** expanded from one 2.4 GHz band to 2.4, 5, and 6 GHz, with wider channels and multiple spatial streams.
- **d. Satellite communications:** now built into consumer phones [18].
- **e. IoT; g. smart homes and appliances:** many small transmitters that beacon or report intermittently; in our experience, among the sources occupants are least aware of.
- **f. Wearables:** transmitters worn continuously on the body.
- **h. Smart cities; i. autonomous vehicles:** greater infrastructure density and vehicle-to-infrastructure links.
- **j. Wireless medical devices:** both a source and a potentially susceptible device class.
- **k. Smart meters:** intermittent, short transmissions that time-averaged readings describe poorly.
- **Ultra Wideband (not listed by HHS):** very wide channels (about 499.2 MHz in the IEEE 802.15.4 UWB channel plan) with short pulses at very low spectral power density [26]; a distinct signal type, and wide bandwidth does not imply high exposure.

2.6 Proximity is a weak proxy

- **a. Proximity to homes, schools, workplaces:** in our experience, distance to the nearest tower is a poor proxy for indoor exposure; antenna patterns, building materials, and indoor sources often dominate.
- **b. Cumulative neighborhood exposure; c. antenna density; d. small cells:** denser networks with more, smaller, closer transmitters increase spatial variability, which requires measurement where people spend time, over time.
- **e. Livestock:** outside our expertise; the same measurement requirements apply.

2.7 Environmental research and the risk-transfer view

What published research has reported. The Oceania Radiofrequency Scientific Advisory Association (ORSAA) maintains the ORSAA Database on Electromagnetic Bioeffects, a categorized database of published studies on biological effects of EMF [20]. Entries include studies of honey bees (enzyme activity, stress-related gene

expression, pollination service), night-migratory songbirds (disruption of magnetic compass orientation), earthworms, ticks, insects, fish, and plants (seedling growth, oxidative stress, and in some studies growth promotion).

Limits of this evidence. Inclusion in a database does not establish that a reported effect is reproducible or harmful. Designs and exposure conditions vary widely; some reported effects are stimulatory or beneficial; and study counts are not measures of risk or dose. Environmental studies also face the same exposure problem: laboratory exposures are often single-source, and there is little baseline data on the real-world RF environment wildlife and plants experience.

A risk-transfer perspective. The insurance industry offers another view, not as a medical authority, but as a specialist in uncertain, long-term liability.

- **Lloyd's (2010)** examined EMF from mobile phones as an emerging risk, noted there were no definitive conclusions on harm, and considered potential insurance consequences if a causal link were established, including comparison with asbestos [21a].
- **Swiss Re SONAR (2013)** listed "unforeseen consequences of electromagnetic fields" as an emerging risk with high potential impact and a time frame of more than 10 years [21b].
- **Swiss Re SONAR (2019)** identified the spread of 5G as an emerging risk and stated that concerns about potential negative health effects from EMF were likely to increase [21c].

These assessments are not evidence that EMF exposure causes illness. They show how risk specialists manage scientific uncertainty and long-tail claims. That is the same uncertainty better measurement would help resolve.

2.8 Research moves slower than technology

Date	Research milestone	Technology milestone
May 1999	FDA nominates cell phone RF for NTP study [3]	2G networks dominant
2010 onward		4G LTE deployed nationally (e.g., Verizon 4G launch 2010) [14]
Aug 2012		AT&T announces end of its 2G GSM network [13]
2016		Verizon begins announcing 3G CDMA retirement, initially for 2019 [14]
Jul 2016		FCC opens millimeter-wave bands (28, 37, 39 GHz) for 5G, first country to do so [16]
Jan 1, 2017		AT&T 2G GSM network shut down [13]
Dec 2017		First 3GPP 5G NR standard completed [17]
Mar 2018	NTP peer review of draft reports [3]	
Oct 1, 2018		Verizon launches 28 GHz mmWave 5G Home [17]
Nov 2018	**NTP final reports released, testing GSM and CDMA signals like those used in 2G and 3G phones** [3]	
End of 2018		AT&T mobile 5G at 39 GHz in parts of 12 cities [17]
Feb 2019		AT&T discloses plan to shut down 3G by Feb 2022 [15]
2022		U.S. 3G networks retired (AT&T Feb, T-Mobile/Sprint Mar and Jul, Verizon Dec 31) [15]

About 19 years passed from nomination to final reports. When the results arrived, the largest U.S. GSM carrier had already switched off 2G, 3G retirement was announced, 4G had dominated for years, and millimeter-wave 5G had launched one month earlier. Research that characterizes exposure only through fixed laboratory signals will always describe the previous generation.

Section 3.

3.1 The principle

Measure the exposure people actually live with, continuously and with documented accuracy, before trying to answer what it does.

- It is neutral: it strengthens research whether future studies find positive, negative, or null associations.
- It is practical: it builds on existing metrology (JCGM 100, ISO/IEC 17025, IEEE Std 1309) [22-24].
- It keeps pace: continuous real-world measurement characterizes new technologies as they deploy.

3.2 How it relates to existing frameworks

- **ICNIRP (2020), 100 kHz to 300 GHz** [5]: basic restrictions designed to protect against tissue heating and, at lower frequencies, nerve stimulation.
- **FCC exposure rules and OET Bulletin 65** [6]: U.S. limits rest on protection against thermal effects.
- **NTP's own framing:** exposure guidelines were based on protection from acute injury from thermal effects, and definitive human data on long-term effects would take many years [4].
- **IARC (2011):** RF electromagnetic fields classified as "possibly carcinogenic to humans" (Group 2B) [25], noted for completeness, not to argue a conclusion.

Changes that would improve assessment, disclosure, and regulation. Evaluating whether current frameworks are adequate for long-term, low-level, multi-source exposure depends on data that mostly does not exist yet. We recommend that federal health agencies treat real-world exposure characterization as a research priority in its own right; support methods that capture the characteristics in 3.3, not only time-averaged power; and require documented uncertainty and calibration traceability for exposure data in federally funded health research.

3.3 What should be measured

Yes, a classification system should account for exposure characteristics, and it should be designed around what can be measured:

- operating frequency and frequency range;
- power density and electric-field strength (instantaneous and time-averaged);
- occupied bandwidth;
- modulation and pulse characteristics;
- duty cycle, burst length, and repetition interval;
- frequency hopping;
- beamforming and antenna state;
- simultaneous exposure to multiple frequencies and sources;
- duration, cumulative exposure, distance, and proximity to the body.

We do not claim each parameter has established biological importance. **If they are not measured, researchers cannot determine whether they matter.**

3.4 The capabilities instruments need

1. **Broad frequency coverage** spanning the major bands in current consumer and infrastructure use.
2. **Documented, low detection floor and wide dynamic range**, so everyday levels are measured rather than recorded as "below detection."
3. **Fast time response**, so short and intermittent transmissions are captured rather than averaged away.
4. **Simultaneous (non-scanning) measurement across bands**, so events in one band are not missed while another is measured.
5. **Continuous, unattended operation for days to weeks.**
6. **Independent, traceable calibration** with uncertainty evaluated under recognized metrology practice [22-24].

7. **Accurate timestamps** for alignment with physiological and health data, such as 30-second sleep epochs.
8. **Suitability for blinded studies:** silent, dark, no display of exposure to participants, and no intentional transmitter of its own.
9. **Interval statistics that preserve both peak and average**, without presupposing which is biologically relevant.
10. **Open, documented data formats and metadata** (instrument, firmware, calibration, clock correction) so data can be audited, compared, and pooled.

These requirements do not presuppose a biological mechanism. They make the question testable.

3.5 Why this matters for sensitive populations

- **a. Children; b. pregnant women; c. older adults; f. people with preexisting conditions:** the WHO-commissioned review noted most participants were young and healthy, and data did not allow assessment in elderly or chronically ill people [2]. Research in these groups needs measurement suited to where they spend time (homes, schools, care facilities).
- **d. Implanted medical devices:** electromagnetic compatibility is an established concern; real-world, multi-source exposure data would support FDA's device-safety work.
- **e. Workers with elevated occupational exposure:** continuous logging would improve occupational exposure records.
- **g. Other:** for individuals who attribute symptoms to EMF exposure, objective, blinded measurement is especially important because it separates perceived from actual exposure [2].

Section 4.

4.1 The highest-priority research gap

Validated instrumentation and standardized methods for objective, longitudinal, real-world RF exposure measurement. A health study is only as useful as its exposure variable. Poor exposure characterization can hide genuine associations, create misleading ones, reduce statistical power, and make studies hard to reproduce or combine.

4.2 Recommended program

Element	Recommendation
Scope	(1) Instrument development against the capability list in 3.4; (2) independent calibration and validation with published uncertainty budgets; (3) an RF exposure common data standard (metadata, timestamps, calibration identifiers); (4) pilot deployments alongside existing sleep, cardiometabolic, or cohort studies
Vehicle	NIH small-business research programs (SBIR/STTR topic) and/or a targeted funding opportunity; FDA and NIST support for calibration and measurement methods; CDC/NIOSH input on surveillance and occupational use
Risk control	Milestone-gated awards: instruments must pass independent validation before use in health studies; validation protocols and data formats published
Deliverables	Validated instruments available to researchers; published verification protocols; open data standard; pilot datasets showing exposure can be aligned with health outcomes
Neutrality	Success is defined by measurement quality, not by any particular health finding

4.3 Agency roles

- **NIH (lead):** fund development and independent validation of real-world RF exposure instrumentation, including through SBIR/STTR and targeted funding opportunities; support exposure-assessment methodology and longitudinal studies that measure exposure objectively alongside sleep, cardiometabolic, and other outcomes; develop common data elements for RF exposure.
- **FDA:** contribute device-emission characterization expertise; support measurement methodology for RF-emitting consumer and medical devices; coordinate with standards bodies.
- **CDC (including NIOSH):** develop methodology for population-level and occupational exposure surveillance; integrate objective exposure measures into appropriate public-health datasets.

- **Cross-agency:** coordinate with measurement-science partners (for example, NIST) on calibration traceability; adopt a shared statement that validated, longitudinal, time-resolved real-world RF exposure measurement is research infrastructure for human health research.

4.4 Surveillance and data systems

The limiting factor across all approaches is the exposure variable. Without objective exposure data, registries, cohorts, and adverse-event reports can only relate outcomes to proxies.

- **a. Disease registries:** link to objective exposure measurement, even in sub-samples.
- **b. Occupational monitoring:** a proving ground for continuous logging methods.
- **c. Environmental monitoring:** fixed monitors miss indoor sources, which dominate much residential exposure in our experience.
- **d. Longitudinal cohort studies:** the highest-value use of improved instrumentation.
- **e. Biomonitoring:** interpretable only if exposure is measured with comparable time resolution.
- **f. Adverse event reporting:** far more informative when paired with measured exposure.
- **g. Disease or illness clusters:** need rapid, credible, deployable measurement.
- **h. Other:** an RF exposure common data standard so datasets can be compared and pooled.

Example synchronization model: RF timestamp → 30-second sleep epoch → actigraphy or polysomnography → heart-rate variability and other physiological metrics.

4.5 Public disclosure

Meaningful disclosure depends on measurement. Consumers, schools, and local governments benefit most from practical, verifiable information: which radios a device contains and whether each can be disabled independently; whether a device transmits when “idle,” and roughly how often; infrastructure locations and operating bands in plain language; and a clear explanation that compliance with a limit is not the same as a measurement of actual exposure in a specific home or classroom.

4.6 Additional recommendations

1. **Measure first, then conclude:** establish exposure-measurement capability before, or alongside, large new health studies.
2. **Require documented uncertainty:** exposure data in federally funded research should state instrument, calibration, frequency range, detection floor, time resolution, and uncertainty.
3. **Build for blinded research:** support instruments that do not reveal exposure to participants.
4. **Publish open data standards:** a common RF exposure format multiplies the value of every study.
5. **Keep pace with deployment:** fund measurement for new technologies (5G mmWave, 6G, satellite direct-to-device, dense IoT) as they deploy.
6. **Stay neutral on the answer:** success should be judged by the quality of the exposure data, not by any particular finding.

Section 5.

Picture the field five years from now, if measurement comes first:

- A researcher places a calibrated, silent instrument beside a study participant and aligns every RF value with 30-second sleep epochs or other health data, traceable to the instrument, calibration, and clock that produced it.
- Standards reviews draw on measured real-world exposure, not only on laboratory signals and proxies.
- Parents, schools, and clinicians get answers grounded in data from the places people actually live, learn, and sleep.
- New technologies such as 6G are characterized as they deploy, not two decades later.
- Findings are trusted whichever way they point, because the exposure record behind them is credible.

HHS has said its science must keep pace with wireless technology [27]. That begins with treating real-world RF exposure measurement as research infrastructure. We urge HHS to make it a stated federal priority and to fund it.

Respectfully submitted,

Mitch Marchand, BSc. EE, Co-founder, Nudgr

Stephanie Kerst BA, Co-founder, Nudgr

References

1. U.S. Department of Health and Human Services. Request for Information on Electromagnetic Fields (EMFs), Radiofrequency (RF) Radiation, and Wireless Radiation Exposure. FR Doc. 2026-19252; Docket HHS-OASH-2026-0397. https://public-inspection.federalregister.gov/2026-19252.pdf
2. Bosch-Capblanch X, Esu E, Oringanje CM, et al. The effects of radiofrequency electromagnetic fields exposure on human self-reported symptoms: a systematic review of human experimental studies. Environ Int. 2024;187:108612. doi:10.1016/j.envint.2024.108612. https://www.sciencedirect.com/science/article/pii/S0160412024001983 (Abstract: Discussion, “Limitations of evidence”; full text: Section 4.2.)
3. National Toxicology Program. Cell Phone Radio Frequency Radiation (research overview; nominated May 1999; Technical Reports TR-595 and TR-596, November 2018). https://ntp.niehs.nih.gov/research/topics/cellphones ; TR-595 abstract: https://ntp.niehs.nih.gov/publications/reports/tr/tr595 ; Peer review record: https://www.ncbi.nlm.nih.gov/books/NBK564521/
4. Wyde M. Nomination, NTP’s considerations for toxicological evaluation of RFR exposure in rodents, and background on exposure system selection. NTP Technical Report Peer-Review Meeting, March 26-28, 2018. https://ntp.niehs.nih.gov/ntp/about_ntp/trpanel/2018/march/presentations/02wyde_nomination_508.pdf
5. International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Health Phys. 2020;118(5):483-524. doi:10.1097/HP.0000000000001210
6. Federal Communications Commission, Office of Engineering and Technology. OET Bulletin 65, Edition 97-01: Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields. August 1997.
7. Bolte JFB. Lessons learnt on biases and uncertainties in personal exposure measurement surveys of radiofrequency electromagnetic fields with exposimeters. Environ Int. 2016;94:724-735. doi:10.1016/j.envint.2016.06.023
8. Frei P, Mohler E, Neubauer G, et al. Temporal and spatial variability of personal exposure to radio frequency electromagnetic fields. Environ Res. 2009;109(6):779-785. doi:10.1016/j.envres.2009.04.015
9. Bhatt CR, Henderson S, Brzozek C, Benke G. Instruments to measure environmental and personal radiofrequency-electromagnetic field exposures: an update. Phys Eng Sci Med. 2022;45(3):687-704. doi:10.1007/s13246-022-01146-y
10. Mohler E, Frei P, Fröhlich J, Braun-Fahrländer C, Röösli M; QUALIFEX Team. Exposure to radiofrequency electromagnetic fields and sleep quality: a prospective cohort study. PLoS One. 2012;7(5):e37455. doi:10.1371/journal.pone.0037455
11. Prins AC, Baas K, van der Meer JN, Jacobs M, Nederveen AJ. The effect of mobile phone electromagnetic fields on the human resting state wake EEG and event-related potential: a systematic review and meta-analysis. Bioelectromagnetics. 2025;46(1):e22531. doi:10.1002/bem.22531
12. Loughran SP, Wood AW, Barton JM, et al. The effect of electromagnetic fields emitted by mobile phones on human sleep. Neuroreport. 2005;16(17):1973-1976; Regel SJ, Tinguely G, Schuderer J, et al. Pulsed radio-frequency electromagnetic fields: dose-dependent effects on sleep, the sleep EEG and cognitive performance. J Sleep Res. 2007;16(3):253-258.
13. Fierce Network. “AT&T confirms it shut down its 2G network Jan. 1.” January 17, 2017 (notes AT&T first announced in August 2012). https://www.fierce-network.com/wireless/at-t-confirms-it-shut-down-its-2g-network-jan-1

14. RCR Wireless. “RIP, 3G: Verizon’s shutdown wraps up 3G sunsets for US.” January 4, 2023. https://www.rcrwireless.com/20230104/featured/rip-3g-verizons-shutdown-wraps-up-3g-sunsets-for-us-national-carriers ; Verizon Business. 3G CDMA Network Retirement. https://www.verizon.com/business/support/services-and-apps/cdma-network-retire/

15. Federal Communications Commission. Plan Ahead for Phase Out of 3G Cellular Networks and Service. https://www.fcc.gov/consumers/guides/plan-ahead-phase-out-3g-cellular-networks-and-service ; IEEE ComSoc Technology Blog. “AT&T to shut down 3G network in 2022; Verizon at end of 2019.” February 22, 2019. https://techblog.comsoc.org/2019/02/22/att-to-shut-down-3g-network-in-2022-verizon-at-end-of-2019/

16. Federal Communications Commission. Fact Sheet: Spectrum Frontiers Rules. July 14, 2016. https://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0714/DOC-340310A1.pdf

17. Light Reading. “Verizon to Launch Fixed 5G Service on Oct. 1.” https://www.lightreading.com/5g/verizon-to-launch-fixed-5g-service-on-oct-1 ; Verizon announcement noting 3GPP 5G NR standard release in December 2017 (via 5Gstore, September 12, 2018). https://5gstore.com/blog/2018/09/12/verizon-announces-5g-home-internet-service-to-be-available-oct-1/ ; AT&T 5G in parts of 12 cities at end of 2018: see ref 15 (IEEE ComSoc).

18. Apple Inc. iPhone 18 Pro and iPhone 18 Pro Max: Technical Specifications. https://www.apple.com/iphone-18-pro/specs/

19. Apple Inc. iPhone (original): Technical Specifications. https://support.apple.com/en-us/112445

20. Oceania Radiofrequency Scientific Advisory Association (ORSAA). ORSAA Database on Electromagnetic Bioeffects (ODEB). https://www.orsaa.org/ (database: https://www.orsaa.org/orsaa-database.html)

21.

    (a) Lloyd’s Emerging Risks Team. Electromagnetic fields from mobile phones: recent developments. November 2010. https://www.lloyds.com/insights/risk-reports/emf ; (b) Swiss Re. Swiss Re SONAR 2013: Emerging risk insights. Zurich: Swiss Re; 2013; (c) Swiss Re Institute. SONAR 2019 press release. May 22, 2019. https://www.swissre.com/media/press-release/nr-20190522-sonar2019.html

22. Joint Committee for Guides in Metrology. JCGM 100:2008, Evaluation of measurement data: Guide to the expression of uncertainty in measurement.

23. ISO/IEC 17025:2017, General requirements for the competence of testing and calibration laboratories.

24. IEEE Std 1309-2013, IEEE Standard for Calibration of Electromagnetic Field Sensors and Probes (Excluding Antennas) from 9 kHz to 40 GHz.

25. Baan R, Grosse Y, Lauby-Secretan B, et al. Carcinogenicity of radiofrequency electromagnetic fields. Lancet Oncol. 2011;12(7):624-626. doi:10.1016/S1470-2045(11)70147-4

26. IEEE Std 802.15.4-2020, IEEE Standard for Low-Rate Wireless Networks (UWB PHY channel plan); IEEE Std 802.15.4z-2020, Amendment: Enhanced Ultra Wideband (UWB) Physical Layers and Associated Ranging Techniques.

27. U.S. Department of Health and Human Services. HHS Seeks Public Input on Electromagnetic Fields and Wireless Radiation (press release). September 17, 2026. https://www.hhs.gov/press-room/hhs-seeks-public-input-electromagnetic-fields-wireless-radiation.html