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Comments to the Washington DC National Capital Planning Commission (NCPC) draft antenna guidelines

The Environmental Health Trust (EHT), a nonprofit research and policy organization dedicated to identifying and reducing environmental health hazards, wishes to express serious reservations about the proposed grounds for widespread rollout of 5G.
As past experiences with tobacco and asbestos demonstrate, the consequences are grave when governments fail to restrict and reduce environment pollutants that research proves cause harmful effects to populations.
Overwhelming evidence supports EHT's concerns that rollout of 5G will cause exposure to cancer-causing levels of radiation. In light of this evidence and consistent with public health concepts of preventing harm by reducing exposure to suspected and known carcinogens, EHT opposes placing wireless antennas on city utility poles, streetlights, and in close proximity to city workers, children, and families.

Governments are halting 5G until their health authorities have reviewed the state of science and impacts to environmental and human health. More than 150 cities in Italy, and a growing number of municipalities in Switzerland, Ireland and the United Kingdom have passed resolutions halting 5G until safety can be assured.[1]

Several cities in the United States have passed ordinances to restrict wireless antennas installation in residential neighborhoods[2]. For example San Diego County California has a 300 foot setback for schools and in Palo Altos California the installation of small cells on public utility easements in residential neighborhoods is prohibited, there is a 500 foot setback for small cells near multi-family residences in commercial districts and a 500 ft setback for schools[3]. The State of New Hampshire passed HB522[4] creating a Commission to investigate the environmental and human health risks of 5G[5] and Oregon passed SB 283[6] instructing the state health authority to investigate the independence science on the health impacts of radiofrequency radiation with a focus on children's school exposures.
Furthermore, EHT urges more testing on the impact of Millimeter Wave (MMW)-range radiation on humans, fauna, and flora before 5G becomes a commercially viable network.

Comments related to the draft of Antenna Submission Guidelines

[1] Environmental Health Trust, INTERNATIONAL ACTIONS TO HALT & DELAY 5G
[2] https://ehtrust.org/usa-city-ordinances-to-limit-and-control-wireless-facilities-small-cells-in-rights-of-ways/
[3] https://www.losaltosca.gov/sites/default/files/fileattachments/city_council/page/48421/resolution_no._2019-35.pdf
[4] https://trackbill.com/bill/new-hampshire-house-bill-522-establishing-a-commission-to-study-the-environmental-and-health-effects-of-evolving-5g-technology/1630657/?fbclid=IwAR28psMtRFU7mBGMmA8SKxoS0AIkf8LzcQR7e7vO_MiifUzs0N4GfUNcLC4
[5] http://www.gencourt.state.nh.us/statstudcomm/committees/1474/documents.html
[6] SB 283 https://olis.leg.state.or.us/liz/2019R1/Downloads/MeasureDocument/SB283

The draft guidelines only say of health "Sponsoring agencies must provide a certification that proposed antennas are in compliance with radio frequency (RF) radiation emission guidelines established by the Federal Communications Commission (FCC) and the Occupational Safety and Health Administration (OSHA). If other emission sources are nearby, the cumulative effect of the additional proposed antenna must also follow the FCC guidelines."

We recommend a halt to the roll-out of the fifth generation, 5G, for telecommunication and for the expansion of wireless networks until hazards for human health and the environment of these new frequencies and the densification of networks have been fully investigated by scientists independent from industry. 5G paired with densification of 4G antennas will substantially increase environmental exposure to radiofrequency electromagnetic fields. We also recommend federally developed safety limits based on empirical scientific studies that have thoroughly investigated long term effects to humans, animals, insects, trees and the environment. Federal safety limits should be based on adequate data from animal and human research, not based on assumptions.

Growing evidence indicates that wireless radiation and the frequencies used in 5G can seriously impact wildlife. For example, research shows that 5G radiofrequency radiation could affect the capacity of bees and other insects to pollinate crops. Studies also indicate that this radiation can alter animal navigation, disturb honeybee colonies, damage trees and impact other plants. Published reviews on 5G, millimeter waves and wireless radiation (even from decades ago) have cataloged a host of harmful impacts, including increased temperature, altered gene expression, faster cell growth, inflammatory and metabolic processes, damage to the eyes and cellular stress, memory problems, sperm damage, genetic damage, behavior issues and brain damage.

Recommendations Regarding RF Monitoring

These guidelines do not specify where the points of RF monitoring are to be. For example, usually when RF measurements are done, the engineer chooses the locations. Often they take measurements on the ground but not in the building with line of sight to the antennas, a location where some of the highest RF levels can be. Also, certification usually means measurements were computed but are not actual real measurements.

- Recommendation: Measurements be taken inside buildings at locations closest to the antennas, near windows. Measurements should take place on the roof as well.
- Recommendations: If Antennas are mounted on buildings measurements should take place in windows close to the antennas and also in directions further away, those that will be in the plume of the radiofrequency radiation beam.
- Recommendations: Measurements should be repeated on a yearly basis.
- Recommendations: Measurements should not be from simulation but from real measurements. Peak levels should be noted.

Additional issues with RF Monitoring

Not possible to accurately simulate real life exposures in the real world.
5G antennas will be a part of the new networks placed on telecommunications equipment in the City. This will mean different antenna technology and measurements could be challenging. The European Parliament has issued several reports on the matter pointing out that measuring exposure from these systems is a challenge.

- European Parliament Briefing Effects of 5G wireless communication on human health, (EHT PDF)
    - According to the 2019 study '5G deployment: State of Play in Europe, USA and Asia' prepared for the European Parliament, long-term technology research is essential. 'One key problem is the unusual propagation phenomena, especially controlling and measuring radio frequency EMF exposure with Multiple Input Multiple Output (MIMO) at millimetre wave frequencies for the handset and the base station. The technology presents challenges to the current level of expertise (based on previous generations of mobile cellular radio engineering) both for suppliers and standards organisations who must incorporate the specifications in future 5G standards'. The study states that the main problem seems to be that it is not currently possible to accurately simulate or measure 5G emissions in the real world.

Recommendations Regarding Environmental Review

Companies wishing to construct new small cell wireless facilities must complete an Environmental Assessment or certify that the proposed facility is categorically excluded from review. Construction cannot proceed without such documentation. Anyone wishing to construct a facility that uses an FCC license must submit an Environmental Assessment to the FCC or certification that the facility is categorically excluded.

On August 9, the U.S. Court of Appeals for the District of Columbia Circuit unanimously denied the FCC order[7] that would have exempted 800,000 or more small cell construction (cell antenna facilities) from historic-preservation review under the National Historic Preservation Act (NHPA) and environmental review under the National Environmental Policy Act (NEPA). The overturned FCC order had let carriers deploy small-cell equipment on non-tribal lands without any federally required reviews.

Radio Frequency can Impact Trees and Plants.

Recommendation: The NCPC should consider how these facilities will impact the areas trees and plants.

We want to bring your attention to the growing body of literature showing the impacts on trees and plants. Here again, experimental literature has found that rhizomes, nitrification and other critical

7 https://www.cadc.uscourts.gov/internet/opinions.nsf/4001BED4E8A6A29685258451005085C7/$file/18-1129-1801375.pdf

processes to plant growth and health are affected by cell phone like radiation under controlled conditions. There have been over one hundred studies that have shown this and most recently a field study[8] that showed under controlled conditions, trees that are closer to cell phone towers start to die more readily; and this can be seen if one looks at the branches of the trees closest to the antennae of the cell phone tower with the fake tree at the Stilson parking lot off Hwy 390.

Please note these published studies:

- A field monitoring study spanning 9 years involving over 100 trees (Waldmann-Selsam 2016)[9] found trees sustained significantly more damage on the side of the tree facing the antenna, leaving the entire tree system prone to degradation over time. Documentation of tree damage from base stations is made visible in the Report "Tree Damage Caused by Mobile phone base stations" (Breunig, 2017).[10]
- A study on Aspen trees near Lyons, Colorado entitled "Adverse Influence of Radio Frequency Background on Trembling Aspen Seedlings " published in the International Journal of Forestry found adverse effects on growth rate and fall anthocyanin production concluding that, "results of this preliminary experiment indicate that the RF background may be adversely affecting leaf and shoot growth and inhibiting fall production of anthocyanins associated with leaf senescence in trembling aspen seedlings. These effects suggest that exposure to the RF background may be an underlying factor in the recent rapid decline of aspen populations. Further studies are underway to test this hypothesis in a more rigorous way."[11]
- An analysis of 45 peer-reviewed scientific publications (1996-2016) on changes in plants due to the non-thermal RF-EMF effects from mobile phone radiation entitled "Weak radiofrequency radiation exposure from mobile phone radiation on plants concludes, "Our analysis demonstrates that the data from a substantial amount of the studies on RF-EMFs from mobile phones show physiological and/or morphological effects (89.9%, $p < 0.001$). Additionally, our analysis of the results from these reported studies demonstrates that the maize, roselle, pea, fenugreek, duckweeds, tomato, onions and mungbean plants seem to be very sensitive to RF-EMFs. Our findings also suggest that plants seem to be more responsive to certain frequencies…"[12]

Radiofrequency Can Impact Wildlife

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[8] Cornelia Waldmann-Selsam, Alfonso Balmori-de la Puente, Helmut Breunig, Alfonso Balmori, Radiofrequency radiation injures trees around mobile phone base stations, Science of The Total Environment, Volume 572, 2016, Pages 554-569, ISSN 0048-9697, doi.org/10.1016/j.scitotenv.2016.08.045.

[9] Cornelia Waldmann-Selsam, Alfonso Balmori-de la Puente, Helmut Breunig, Alfonso Balmori, Radiofrequency radiation injures trees around mobile phone base stations, *Science of The Total Environment*, Volume 572, 2016, Pages 554-569, ISSN 0048-9697, doi.org/10.1016/j.scitotenv.2016.08.045.

[10] Breunig, Helmut,Tree damage caused by mobile phone base stations An observation guide, 2017.

[11] Katie Haggerty, "Adverse Influence of Radio Frequency Background on Trembling Aspen Seedlings: Preliminary Observations," *International Journal of Forestry Research*, vol. 2010, Article ID 836278, 7 pages, 2010. doi.org/10.1155/2010/836278.

[12] Malka N. Halgamuge (2017) Review: Weak radiofrequency radiation exposure from mobile phone radiation on plants, *Electromagnetic Biology and Medicine*, 36:2, 213-235, DOI: 10.1080/15368378.2016.1220389.

- "A review of the ecological effects of RF-EMF" 2013 review of 113 published studies found in 65% of the studies (50% of the animal studies and about 75% of the plant studies) RF-EMF had a significant effect on birds, insects, other vertebrates, other organisms and plants (Cucurachi 2013). The review paper cites development and reproduction in birds and insects as the most strongly affected endpoints.[13]
- A 2012 Review "Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – A Review" on 919 research papers found 593 showed impacts, 180 showed no impacts, and 196 were inconclusive studies."[14]
- Studies on bees have found behavioral effects (Kumar 2011[15], Favre 2011[16]), disrupted navigation Goldsworthy 2009[17], Sainudeen 2011[18], Kimmel et al. 2007[19]), decreasing egg-laying rate (Sharma and Kumar, 2010[20]) and reduced colony strength after RF exposures (Sharma and Kumar, 2010, Harst et al. 2006).
- A study focusing on RF from cellular antennas found increased sperm abnormalities in mice exposed to RF from GSM antennas (Otitoloju 2010).[21]
- "Exposure of Insects to Radio-Frequency Electromagnetic Fields from 2 to 120 GHz" published in Scientific Reports is the first study to investigate how insects (including the Western honeybee) absorb the higher frequencies (2 GHz to 120 GHz) to be used in the 4G/5G rollout. The scientific simulations showed increases in absorbed power between 3% to 370% when the insects were exposed to the frequencies. Researchers concluded, "This could lead to changes in insect behavior, physiology, and morphology over time…."[22]
- Researchers published a study on frogs in Electromagnetic Biology and Medicine exposing eggs and tadpoles to electromagnetic radiation from cell phone antennas for two months, from the egg phase until an advanced phase of tadpole and found low coordination of movements, an asynchronous growth, resulting in both big and small tadpoles, and a high mortality rate. The authors conclude, "these results indicate that radiation emitted by phone masts in a real situation may affect the development and may cause an increase in mortality of exposed tadpoles."[23]

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[13] S. Cucurachi, W.L.M. Tamis, M.G. Vijver, W.J.G.M. Peijnenburg, J.F.B. Bolte, G.R. de Snoo, A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF), Environment International, Volume 51, 2013, Pages 116-140, ISSN 0160-4120, doi.org/10.1016/j.envint.2012.10.009.

[14] S Sivani*, D Sudarsanam, Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – a review, Biology and Medicine, 4 (4): 202–216, 2012.

[15] Kumar, N. R., Sangwan, S., & Badotra, P. (2011). Exposure to cell phone radiations produces biochemical changes in worker honey bees. *Toxicology international*, *18*(1), 70–72. doi:10.4103/0971-6580.75869.

[16] Favre, D. Apidologie, Mobile phone-induced honeybee worker piping, (2011) 42: 270. doi.org/10.1007/s13592-011-0016-x.

[17] Dr. Andrew Goldsworthy, The Birds, the Bees and Electromagnetic Pollution, May 2009.

[18] Sainudeen Sahib.S, Electromagnetic Radiation (EMR) Clashes with Honey Bees, *International Journal of Environmental Sciences*, Volume 1, No 5, 2011.

[19] Kimmel, Stefan, et. al, Electromagnetic Radiation: Influences on Honeybees (Apis mellifera), 2007.

[20] Ved Parkash Sharma, Neelima R. Kumar, Changes in honeybee behaviour and biology under the influence of cellphone radiations, *Current Science*, Vol. 98, No. 10, 25 May 2010.

[21] Otitoloju, A.A., Obe, I.A., Adewale, O.A. et al., Preliminary study on the induction of sperm head abnormalities in mice, Mus musculus, exposed to radiofrequency radiations from global system for mobile communication base stations. Bull Environ Contam Toxicol (2010) 84: 51. doi.org/10.1007/s00128-009-9894-2.

[22] Thielens, A., Bell, D., Mortimore, D. B., Greco, M. K., Martens, L., & Joseph, W. (2018). Exposure of Insects to Radio-Frequency Electromagnetic Fields from 2 to 120 GHz. *Scientific Reports*, *8*(1), 3924. https://doi.org/10.1038/s41598-018-22271-3.

[23] Balmori A. Mobile phone mast effects on common frog (Rana temporaria) tadpoles: the city turned into a laboratory. Electromagn Biol Med. 2010 Jun;29(1-2) 31-35. doi:10.3109/15368371003685363. PMID: 20560769.

A 2018 study published in Annals of Telecommunications found increased RF-EMF exposure from small cell LTE networks in two urban cities in France and the Netherlands. Researchers measured the RF-EMF from LTE (Long-Term Evolution) MC (macro cells meaning large cell towers) and SC networks (low-powered small cell base stations) and found that the small cell networks increased the radio emissions from base stations (called downlink) by a factor of 7–46 while decreasing the radio emissions from user equipment exposure (called) by a factor of 5–17. So while the devices themselves could emit less radiation, the cell antennas will increase the levels from cell antennas (Mazloum et al., 2019). This study shows the increased exposures would be involuntary. We can turn our phones off, but we cannot turn off the antennas in the neighborhood.

An Australian study published in the Journal of Exposure Science & Environmental Epidemiology also found that children in kindergartens with nearby antenna installations had nearly three-and-a-half times higher RF exposures than children with installations further away by more than 300 meters (Bhatt et al., 2016).

A 2018 multi-country study published in Environment International measured RF in several countries. It found that cell phone tower radiation is the dominant contributor to RF exposure in most outdoor areas; exposure in urban areas was higher and that exposure has drastically increased. As an example, the measurements the researchers took in Los Angeles, USA were 70 times higher than the US EPA estimate 40 years ago (Sagar et al., 2018).

As an example of how rapidly RF is increasing from wireless antennas, a 2014 published study from Environmental Research looked at RF in three European cities and found in just one year (between April 2011 and March 2012) that the total RF-EMF exposure levels in all outdoor areas in combination increased by 57.1% in Basel, by 20.1% in Ghent and by 38.2% in Brussels. “Exposure increase was most consistently observed in outdoor areas due to emissions from mobile phone base stations” (Urbinello et al., 2014).

Another study, published in Environment International, looked at 529 children in Denmark, the Netherlands, Slovenia, Switzerland and Spain who wore meters around the waist or carried in a backpack during the day and placed close to the bed at night. Researchers found “the largest contributors to total personal environmental RF-EMF exposure were downlink (meaning from cell tower base stations) and broadcast” (Birks et al., 2018).

“Adverse Health Effects of 5G Mobile Networking Technology Under Real Life Conditions” published in Toxicology Letters identifies the wide-spectrum of adverse health effects of non-ionizing non-visible radiation and concludes that 5 G mobile networking technology will affect not only the skin and eyes, but will have adverse systemic effects as well. They state that 5G will increase the cell tower densities by an

order of magnitude. The researchers conclude that in aggregate, for the high frequency (radiofrequency-RF) part of the spectrum, currently published reviews show that RF radiation below the FCC guidelines can result in: carcinogenicity (brain tumors/glioma, breast cancer, acoustic neuromas, leukemia, parotid gland tumors), genotoxicity (DNA damage, DNA repair inhibition, chromatin structure), mutagenicity, teratogenicity, neurodegenerative diseases (Alzheimer's Disease, Amyotrophic Lateral Sclerosis), neurobehavioral problems, autism, reproductive problems, pregnancy outcomes, excessive reactive oxygen species/oxidative stress, inflammation, apoptosis, blood-brain barrier disruption, pineal gland/melatonin production, sleep disturbance, headache, irritability, fatigue, concentration difficulties, depression, dizziness, tinnitus, burning and flushed skin, digestive disturbance, tremor, cardiac irregularities, adverse impacts on the neural, circulatory, immune, endocrine, and skeletal systems" and "from this perspective, RF is a highly pervasive cause of disease" (Kostoff et al., 2020).

Information from NRDC 5G Coming to Your Neighborhood?
Q: What are the current FCC standards and are they adequate?
A: The FCC has set limits for radio frequency emissions, with specific limits for occupational exposure and general population exposure. These limits are found in the FCC's regulations at 47 C.F.R. § 1.1301.
Unfortunately, the FCC has not updated its guidelines since 1996. Based on 30-year-old studies, today's FCC limits are still primarily designed to protect against high intensity, acute short-term exposures that could result in gross tissue heating effects. Since then, extensive research has raised concerns about other serious health effects below the thresholds set by the FCC. Scientific studies have also raised concern about harm to the wildlife and plant life around us. The FCC initiated a review of its limits in 2013, but failed to address the concerns raised by numerous commentsincluding hundreds of peer-reviewed studies. On December 4, the FCC issued an order ending its inquiry into the adequacy of its radio frequency exposure limits without changing the limits.
Q: What can local governments do?
A: Local governments can condition approval for new 5G cell construction upon compliance with federal requirements for environmental review. While a local government cannot add new requirements for environmental review, it can require proof that the necessary federal review has been done. Given the mounting evidence that the FCC's radio frequency limits are inadequate, such federal review should include an evaluation of the adequacy of these limits.

Q: What are the requirements for environmental review of new wireless infrastructure?

A: The National Environmental Policy Act (NEPA) requires an analysis of environmental impacts of major federal actions. Such actions include various types of federal approvals including for pipelines, oil and gas wells, dams and wireless infrastructure. If the impacts might be significant, the agency must prepare an Environmental Impact Statement. If an agency is unsure whether the impacts may be significant, it can prepare a shorter Environmental Assessment.

Based on the Environmental Assessment, the agency will either move forward to prepare an EIS or instead prepare a Finding of No Significant Impact (FONSI). The only way to avoid an EA or an EIS is if the action qualifies for a categorical exclusion. While some new cell construction may qualify for a categorical exclusion (CE), the FCC has identified circumstances where a CE does not apply. For more information on the difference between an EIS and an EA, as well as information on the use and limits

of categorical exclusions, see The Citizen's Guide to the National Environmental Policy Act prepared by the White House Council on Environmental Quality.

Anyone wishing to construct a facility that uses an FCC license must submit an Environmental Assessment to the FCC or certification that the facility is categorically excluded. 47 C.F.R. § 1.1307. An Environmental Assessment is required if the proposed construction:

- Will be in a wilderness area or wildlife preserve (generally on federal land);
- Might affect threatened and endangered species or their habitat (Endangered Species Act);
- Might affect properties included or eligible for inclusion in the National Register of Historic Places or Indian religious and cultural sites;
- Will be in a flood plain;
- Will involve "significant changes in surface features" during construction (e.g., wetlands, water diversion, deforestation);
- Will be taller than 450 feet and so might affect migratory birds;
- Involves high intensity lighting in a residential area; or
- Would cause radio frequency emission exposure in excess of FCC-established limits.

A company seeking to build a wireless facility that falls into any of the above categories must obtain a Finding of No Significant Impact before building. "Building without following the requirements at 47 CFR 1.1301-1.1319 can constitute a violation of FCC rules and subject the constructing party to potential enforcement action," the FCC said in its fact sheet on this topic.

Even when these conditions do not apply, the public can request and the FCC can order environmental review. "

Q: What was the effect of NRDC's lawsuit against the FCC regarding the siting of small cell wireless construction?
A: In March 2018, the FCC issued an order that attempted to eliminate environmental review requirements for small cell wireless facilities. NRDC challenged this order in court along with various other groups including the 19 Indian nations, the National Trust for Historic Preservation and the National Association of Tribal Historic Preservation Officers. While some of the construction might be called "small," it can include new cell towers.
In August 2019, the U.S. Court of the Appeals for the District of Columbia struck down the FCC's elimination of review under NEPA and the National Historic Preservation Act. No one appealed the decision to the U.S. Supreme Court. As a result, companies must comply with the environmental review requirements (listed above) that existed prior to the FCC's order attempting to eliminate them. As a result, companies wishing to construct new small cell wireless facilities must complete an Environmental Assessment or certify that the proposed facility is categorically excluded from review. Construction cannot proceed without such documentation.

Please Read more at NRDC 5G Coming to Your Neighborhood?

The draft guidelines say "Describe natural resources on or near the project area, and the project's anticipated effect on these natural resources such as endangered and threatened species, and migratory birds, etc"

EHT Recommendation: The Commission should ensure a proper review of the environmental impacts to birds, bees, trees and wildlife has been completed before moving forward. The FCC should have done an environmental impact statement before allowing the deployment of 5G. Perhaps the Commission could write to the FCC regarding this issue as well.

No US Environmental Agency Has Reviewed Effects on Birds, Bees, Trees or Wildlife

There is not a single health/safety/environmental agency investigating, researching or monitoring impacts to birds, bees trees and wildlife. Please see my attached letter from Lee Ann B. Veal Director, Radiation Protection Division Office of Radiation and Indoor Air, EPA confirmed that they do not have a funded mandate for radiofrequency matters and no research review has been done since the 80s- a review that did not include an understanding of impacts to birds and insects.

Regulatory limits for exposure to radiofrequency radiation have never been developed for birds, bees, trees and wildlife. This is why the U.S. Department of the Interior sent a letter to the National Telecommunications and Information Administration in 2014[24] reviewing several research studies showing harm to birds and concluding that "The electromagnetic radiation standards used by the Federal Communications Commission (FCC) continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable today".

A now retired US Fish and Wildlife Service wildlife biologist, former lead on on telecommunications impacts, Dr. Albert Manville, has written to the FCC on impacts to birds and higher frequencies to be used in 5G and authored numerous publications detailing research showing harm to birds[25][26][27]. "Now as a private wildlife consultant and part-time adjunct professor for Johns Hopkins University, I also continue to study the impacts of radiation on human health, welfare and safety, including impacts from millimeter-wide radiation frequencies on humans from 5G. The race to implement 5G and the push by FCC to approve the related 5G license frequencies to industry are very troubling and downright dangerous."

He has testified[28] about the impacts of cell towers on birds that, The the entire thermal model and all FCC categorical exclusions for all the devices we see today, rests on the incorrect assumption that low-level nonionizing nonthermal radiation cannot cause DNA breaks because it is so low power the evidence to the contrary is clear and growing laboratory animals and wildlife."

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[24] Washington DC, Veenendaal ME. Department of Interior Letter. *United States Department of the Interior OFFICE OF THE SECRETARY*.
[25] ECFS Filing Detail. https://www.fcc.gov/ecfs/filing/1060315601199. Accessed July 8, 2020.
[26] Albert M. Manville Ph.D. Former U.S. Fish and Wildlife Service Senior Biologist. Memorandum on the Bird and Wildlife Impacts of Non-ionizing Radiation. Environmental Health Trust. Accessed July 8, 2020.
[27] Manville AM. *Collisions, Electrocutions, and Next Steps-Manville BIRD STRIKES AND ELECTROCUTIONS AT POWER LINES, COMMUNICATION TOWERS, AND WIND TURBINES: STATE OF THE ART AND STATE OF THE SCIENCE B NEXT STEPS TOWARD MITIGATION 1*.; 2002.
[28] Manville AM. IPCWB. Declaration of: Albert M. Manville, II, PhD, C.W.B.. Published 2018. Accessed July 8, 2020.

Most recently Manville wrote the US FDA regarding the FDA statements of "safety" in regards to cell phone radiation that, "as a certified wildlife biologist and Ph.D. environmental scientist who has studied the impacts of radiation on migratory birds, other wildlife, and humans since the late 1990s, the statement credited to the FDA is preposterous, without any scientific credibility, and at a minimum deserves a retraction by the FDA.There currently are well over 500 scientific, peer-reviewed papers addressing impacts of non-ionizing, non-thermal radiation on laboratory animals — many of the studies directly applicable to human health and safety.[29]"

Birds will clearly come to rest on Washington DC antennas and there is no RF limit set for ensuring birds are not harmed. The same issue goes for bees and insects that can fly close to the antennas.

According to the European Parliament Briefing "Effects of 5G wireless communication on human health" 5G could have biological impacts requiring an evaluation.

- "Consequently, the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER), replacing the former Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), indicated a preliminary estimate of the importance of 5G as high, in a statement in December 2018. Furthermore, it evaluates the scale, urgency and interactions (with ecosystems and species) of possible hazard as high. It suggested that there could be biological consequences from a 5G environment, due to the fact that there is a lack of 'evidence to inform the development of exposure guidelines to 5G technology'."

Actions in Washington DC and the USA regarding 5G and small cell deployment.

- The Sierra Club of California has passed a resolution on 5G and the Washington DC Sierra Club testified in opposition to the 5G small cell rollout because of impacts to trees.

- In the United States the state of New Hampshire has a 5G Bill HB 522 that asks, "Why have 1,000s of peer-reviewed studies, including the recently published U.S. Toxicology Program 16-year $30 million study, that are showing a wide range of statistically significant DNA damage, brain and heart tumors, infertility, and so many other ailments, being ignored by the Federal Communication Commission (FCC)?" and, "Why have more than 220 of the worlds leading scientists signed an appeal to the WHO and the United Nations to protect public health from wireless radiation and nothing has been done?"
- The Washington DC Advisory 3/4G Committee passed a resolution "Opposing Small Cell Wireless and 5G Technology Without Studies Confirming Safety". Washington DC 2EAdvisory Council passed a resolution asking to minimize 5G small cells and require radiofrequency

[29] FDA Letter by Albert Manville PhD, retired Senior Wildlife Biologist, Division of Migratory Bird Management, U.S. Fish & Wildlife Service, Wash. DC HQ Office (17 years); Senior Lecturer, Johns Hopkins University

radiation measurements stating that "ANC 2E's entire community will be subjected to involuntary radio frequency exposure and this exposure may have negative effects for people with radio frequency emission disabilities or sensitivities. "

In 2019 US Doctors and Experts wrote President Trump calling for a halt to 5G.

"We join with the thousands of doctors, scientists and health care providers worldwide who have recently issued appeals for urgent action on 5G to protect public health. The rapidly growing list includes the International EMF Scientist Appeal, Appeal to the European Union, Belgium Doctors Appeal, Canadian Doctors, Cyprus Medical Association, Physicians of Turin, Italy, the German Doctors Appeal, International Appeal to Stop 5G on Earth and Space and the International Society of Doctors for the Environment.
We call for a moratorium on 5G and any further wireless antenna densification until potential hazards for human health and the environment have been fully investigated by scientists independent from the wireless industry." –December 11, 2019, US Doctors and Experts National 5G Resolution

Hundreds of doctors and scientists are calling to halt 5G. In addition environmental groups are opposed to 5G due to the impact to trees, bees and birds.

- In Italy, over 500 municipalities have passed resolutions to halt 5G.
- In Ireland Six County Councils have voted to halt 5G: Clare, Roscommon, Leitrim, Wicklow, County Laois and Sligo County Councils
- Switzerland refused to weaken their radiofrequency radiation limits to deploy 5G.
- In Turkey over 47.000 people signed a petition regarding a lawsuit 5G and health.
- In Greece, the Kalamata City Council decided not to continue the 5G pilot program after a three hour debate. News coverage: "The city council decided to suspend 5G in Kalamata"
- The International Society of Doctors for Environment issued a Declaration to Halt 5G in 2018. The environmental organization BUND is also calling for to stop 5G in Hamburg.
- Easton Connecticut and Farragut Tennessee have passed resolutions to halt 5G. Crown Castle withdrew applications after Western Springs Illinois sent this letter.

WHY 5G IS HARMFUL
The World Health Organization and International Agency for Research on Cancer (WHO/IARC) classified RF-EMF as a Group 2B Possible Carcinogen in 2011[30]. Several experts who have worked with the WHO/IARC since then have concluded that the weight of current peer-reviewed evidence supports the conclusion that RF-EMF should be regarded as a human carcinogen.
Published peer-reviewed science already indicates that the wireless technologies of 2G, 3G, and 4G — in use today with our cell phones, computers, and wearable tech — create radiofrequency exposures that clearly pose a serious health risk to humans, animals, and the environment.
The human health effects associated with wireless exposures include impaired reproduction, increased incidence of brain cancer, DNA breaks, oxidative stress and immune dysfunction, altered brain development, sleep changes, hyperactivity, and memory and cognitive problems.

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[30] Bann, Robert, et al. Carcinogenicity of Radiofrequency Electromagnetic Fields, *The Lancet*, VOLUME 12, ISSUE 7, pp. 624-626.

The following are a few of the studies on the impacts of radiofrequency radiation on humans, flora, and fauna. This is only a small sample of the body of research that has been published on this subject:

- Scientists at the University of Exeter found that mobile phone exposure was associated with reduced sperm motility and viability.[31]
- Doctors at Yale University's Department of Obstetrics, Gynecology and Reproductive Services found that mice exposed to cell phone radiofrequency exposure in-utero were hyperactive and had impaired memory, and that behavioral changes were due to altered neuronal developmental programming during gestation.[32]
- Scientists at Mizoram University in Aizawl, India, found that people living closer to cellular antennas had higher radiation levels in their homes as well as several significant changes in their blood predictive of cancer development.[33]
- Scientists looking at ecological effects of RF-EMF found that 70 percent of 113 studies it reviewed concluded that RF-EMF had a significant effect on birds, insects, other vertebrates, organisms, and plants. Development and reproduction in birds and insects were the most strongly affected.[34]
- The University of Lagos Department of Zoology looked at RF from antennas and found increased sperm abnormalities in mice exposed to RF from Global System for Mobile Communications (GSM) antennas.[35]
- Studies on bees have found behavioral effects,[3637] disrupted navigation,[383940] decreasing egg laying rate,[41] and reduced colony strength.[4243]
- A review published in the International Journal of Environmental Health[44] cites research that shows that higher frequencies can alter gene expression, promote cellular proliferation and synthesis of proteins linked with oxidative stress, inflammatory and metabolic processes, could generate ocular damages, affect neuro-muscular dynamics.

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[31] Adams, Jessica A., et al. "Effect of mobile telephones on sperm quality: a systematic review and meta-analysis." *Environment International,* 70, 2014, pp. 106-112.

[32] Aldad, T.S., et al. "Fetal Radiofrequency Radiation Exposure From 800-1900 MHz-Rated Cellular Telephones Affects Neurodevelopment and Behavior in Mice." *Scientific Reports,* vol. 2, no. 312, 2012.

[33] Zothansiama, et. al. Impact of radiofrequency radiation on DNA damage and antioxidants in peripheral blood lymphocytes of humans residing in the vicinity of mobile phone base station, *Electromagnetic Biology and Medicine*, 36(1):1-11 · August 2017

[34] Cucurachi. S, et al. A review of the ecological effects of RF-EMF, *Environment International*, 51, 2013, Pages 116-140.

[35] Otitoloju, A.A., Obe, I.A., Adewale, O.A. et al. Bull Environ Contam Toxicol (2010) 84: 51. https://doi.org/10.1007/s00128-009-9894-2

[36] Kumar, N. R., Sangwan, S., & Badotra, P. (2011). Exposure to cell phone radiations produces biochemical changes in worker honey bees. *Toxicology international*, *18*(1), 70–72. doi:10.4103/0971-6580.75869

[37] Favre, D. (2011). Mobile phone-induced honeybee worker piping. *Apidologie*, *42*(3), 270–279. https://doi.org/10.1007/s13592-011-0016-x

[38] Andrew Goldsworthy BSc PhD, Letter - The Birds, the Bees and Electromagnetic Pollution, May 2009

[39] Sainudeen Sahib.S, Electromagnetic Radiation (EMR) Clashes with Honey Bees, INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 1, No 5, 2011, Research article ISSN 0976 – 4402

[40] Kimmel et al., Electromagnetic Radiation: Influences on Honeybees (Apis mellifera), 2007

[41] Sharma, vp, & Kumar, N. R. (2010). Changes in honey bee behaviour and biology under the influence of cell phone radiations. *Current Science*, *98*, 1376–1378.

[42] IBID

[43] Harst et al., Can Electromagnetic Exposure Cause a Change in Behaviour? Studying Possible Non-Thermal Influences on Honey Bees – An Approach within the Framework of Educational Informatics, 2006.

[44] Di Ciaula, A. Towards 5G communication systems: Are there health implications? *Int J Hyg Environ Health*. 2018 Apr;221(3):367-375.

- A review of studies published in Environmental Research[45] documents a range of adverse effects reported in the published literature from cancer to bacteria growth changes to DNA damage.
- Research has found a high level of damage to trees from antenna radiation. For example, a nine-year field monitoring study[46] of exposures to 2G, 3G and 4G involving over 100 trees found trees sustained more damage on the side of the tree facing the antenna.

CORPORATE ACKNOWLEDGEMENT OF THE DANGERS

Insurers, investment firms, and telecom companies themselves are aware of the potential risks caused by 5G, and have warned their shareholders of the potential financial costs they may incur if — really, when — additional studies confirm the relationship of mobile networks to health damages due to RF.

For instance, investment trust company Crown Castle's 2019 10-K Annual Report[47] states:

"If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues.

The potential connection between radio frequency emissions and certain negative health effects, including some forms of cancer, has been the subject of substantial study by the scientific community in recent years. We cannot guarantee that claims relating to radio frequency emissions will not arise in the future or that the results of such studies will not be adverse to us. ... If a connection between radio frequency emissions and possible negative health effects were established, our operations, costs, or revenues may be materially and adversely affected. We currently do not maintain any significant insurance with respect to these matters."

Wireless companies from AT&T[48] to Nokia to T-Mobile to Verizon Wireless have issued similar warnings[49] to their own shareholders. These disclosures show that the manufacturers of the 5G network cannot assure safety.

Insurors Rank 5G, Wireless and Electromagnetic Radiation as "High Risk"

A 2019 Report by Swiss Re Institute[50] considers the risks so great to the insurance industry that it advises against writing any policies to cover damages that might arise. It classifies 5G mobile networks as an "off-the-leash" risk, meaning a high-impact emerging risk that will affect property and casualty claims in more than three years' time.

The report states:

- "Existing concerns regarding potential negative health effects from electromagnetic fields (EMF) are only likely to increase. An uptick in liability claims could be a potential long-term consequence."
- "As the biological effects of EMF in general and 5G in particular are still being debated, potential claims for health impairments may come with a long latency."

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[45] Russell, Cindy L. 5G wireless telecommunications expansion: Public health and environmental implications, *Environmental Research* (165) 2018, pp 484-495

[46] Waldmann-Selsam, C., Balmori-de la Puente, A., Breunig, H., & Balmori, A. (2016). Radiofrequency radiation injures trees around mobile phone base stations. *Science of The Total Environment*, *572*, 554–569.

[47] Crown Castle, 10-K Annual Report, 2019

[48] AT&T 2016 Annual Report

[49] EHTrust.org, Corporate Company Investor Warnings In Annual Reports 10k Filings Cell Phone Radiation Risks

[50] Swiss Re Institute, New Emerging Risk Insights, 2019

A Business Insurance analysis[51] also examined mass tort exposures that may have the potential to cause major difficulties for commercial policyholders and their insurers. It includes workers' overexposure to radio frequency waves from rooftop wireless transmitters as a potential future claim and states that research "has shown biological effects from lower-level 'nonthermal' exposure, and people exposed at lower levels have reported headache, dizziness, nausea, mood disorders, mental slowing, and memory loss."

Most insurance plans do not cover electromagnetic fields (EMF) and have very clear "electromagnetic field exclusions." According to CFC Underwriting LTD[52] in London, the UK agent for Lloyd's:

"The Electromagnetic Fields Exclusion (Exclusion 32) is a General Insurance Exclusion and is applied across the market as standard. The purpose of the exclusion is to exclude cover for illnesses caused by continuous long-term non-ionizing radiation exposure i.e. through mobile phone usage."

Even AT&T Mobile Insurance[53] excludes loss from pollutants. Their policy states, "Pollutants" means:

Any solid, liquid, gaseous, or thermal irritant or contaminant including smoke, vapor, soot, fumes, acid, alkalis, chemicals, artificially produced electric fields, magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non- ionizing radiation and waste."

In order for insurance companies to cover EMFs, policyholders often have to purchase additional "Pollution Liability"[54] or "Policy Enhancement" coverage.

If insurance companies will not insure EMFs and telecommunications firms consider EMFs a "pollutant" bad enough to warn its shareholders of the potential financial costs, how can governments allow such an environmental impact without also warning their citizens?

HOW SCIENCE CAN INFORM PUBLIC POLICY

The scientific evidence currently available indicates humans should drastically reduce, not increase, their daily wireless exposures.

The Environmental Research review[55] concludes that "a moratorium on the deployment of 5G is warranted" and "the addition of this added high frequency 5G radiation to an already complex mix of lower frequencies, will contribute to a negative public health outcome both from both physical and mental health perspectives."

In September 2017, more than 180 experts sent a declaration[56] to the European Union calling for a moratorium on 5G expansion citing potential neurological impacts, infertility, and cancer. The Declaration states,

"We, the undersigned, more than 180 scientists and doctors from 35 nations, recommend a moratorium on the roll-out of the fifth generation, 5G, for telecommunication until potential hazards for human health and the environment have been fully investigated by scientists independent from industry."

This appeal has now been signed onto by over 269 scientists and medical doctors.

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[51] BusinessInsurance.com, "The Next Asbestos: Five emerging risks that could shift the liability landscape," May 13, 2011.

[52] CFC Underwriting, LTD, Electromagnetic Field Insurance Policy Exclusion

[53] AT &T Mobile Insurance Policy, 2014, p. 4

[54] Beacon Hilll Associates, The GL Form and Pollution Exclusions, May 2016

[55] Russell, Cindy L. 5G wireless telecommunications expansion: Public health and environmental implications, Environmental Research (165) 2018, pp 484-495

[56] EHTrust.org, Scientists And Doctors Demand Moratorium On 5G Warning Of Health Effects, Sept. 13, 2017

In 2019, the European Parliament issued a report[57] which states that increased exposure to radiation frequencies "may result not only from the use of much higher frequencies in 5G but also from the potential for the aggregation of different signals, their dynamic nature, and the complex interference effects that may result, especially in dense urban areas."

The report notes that it "is not possible to accurately simulate or measure 5G emissions in the real world" and adds "5G radio emission fields are quite different to those of previous generations because of their complex beamformed transmissions in both directions – from base station to handset and for the return. Although fields are highly focused by beams, they vary rapidly with time and movement and so are unpredictable, as the signal levels and patterns interact as a closed loop system. This has yet to be mapped reliably for real situations, outside the laboratory."

Why roll out 5G if the potentially devastating effects have not been mapped out with any reliability? Is the benefit of 5G worth the consequences?

EHT's answer is no. In light of studies showing ample evidence of the biological impact of RF, it is imperative that a new infrastructure and 5G not be introduced widely into commerce at this time.

Policy that fast tracks the ability to deploy 5G technology will ensure the widespread exposure of millions to an agent that growing numbers of scientists and nations consider a serious health threat.

Nations need to consider critically the impact of unprecedented increased wireless exposures to the population. EHT is gratified by efforts to slow the rollout of 5G that are already in place in nations, including France, Israel, and Switzerland.

CONCLUSION

For a new 5G network to fulfill its promise of creating ultra-fast speeds and massive capacities for millions of people, thousands of new and often large cellular antennas will need to be sited in neighborhoods within meters of homes and bedrooms to connect the Internet of Things with 5G technology.

This means close proximity of humans to high-level RF-EMF, which can cause significant and widespread health damages.

Before introducing and additional and new untested wireless technology into the environment, it is necessary to:

- model exposures to infants, children and pregnant women;
- conduct experimental tests on exposures' impacts on wildlife; and
- evaluate impacts on human systems through in vitro and in vivo toxicology

The assumption that all wireless technology is safe has been shown to be incorrect. EHT strongly opposes the widespread installation of new wireless antennas and 5G infrastructure until more testing has been done and joins hundreds of scientific experts from around the world to urge nations to support safer technology instead of wireless 5th generation.

Letter From the EPA

--------- Forwarded message ---------

From: Veal, Lee<Veal.Lee@epa.gov>

Date: Wed, Jul 8, 2020 at 11:32 AM

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[57] 5G Deployment: State of Play in Europe, USA, and Asia

Subject: RE: Letter with specific Questions Related to the FDA review and to the EPA, CDC, NIOSH and FDA Jurisdiction on EMFs
To: Theodora Scarato <Theodora.Scarato@ehtrust.org>

Dear Director Scarato;

Thank you for sending us your questions and references regarding radiofrequency (RF) radiation. Up through the mid-1990s, EPA did study non-ionizing radiation. The Telecommunications Act of 1996 directs the Federal Communications Commission (FCC) to establish rules regarding RF exposure, while the U.S. Food and Drug Administration (FDA) sets standards for electronic devices that emit non-ionizing or ionizing radiation. EPA does not have a funded mandate for radiofrequency matters, nor do we have a dedicated subject matter expert in radiofrequency exposure. The EPA defers to other agencies possessing a defined role regarding RF. Although your questions are outside our current area of responsibilities, we have provided a response to each one as you requested.

1. What is your response to these scientists' statements regarding the FDA report and the call to retract it?

   EPA Response: The EPA does not have a funded mandate for radiofrequency matters, has not conducted a review of the FDA report you cited or the scientists' statements, and therefore has no response to it.

2. To the FDA- What consultants were hired for the FDA review and report on cell phone radiation?

   EPA Response: This is not an EPA matter. Please refer this question to the FDA.

3. What US agency has reviewed the research on cell phone radiation and brain damage? I ask this because the FDA only has looked at selected studies on cancer. If your agency has not, please simply state you have not.

   EPA Response: EPA's last review was in the 1984 document Biological Effects of Radiofrequency Radiation (EPA 600/8-83-026F). The EPA does not currently have a funded mandate for radiofrequency matters.

4. What US agency has reviewed the research on damage to memory by cell phone radiation? If so, when and send a link to the review.

   EPA Response: EPA's last review was in the 1984 document Biological Effects of

Radiofrequency Radiation (EPA 600/8-83-026F). The EPA does not currently have a funded mandate for radiofrequency matters.

5. What US agency has reviewed the research on damage to trees from cell phone radiation? If so, when was it issued and send a link to the review.Note this study showing damage from long term exposure to cell antennas.

   EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and we are not aware of any EPA reviews that have been conducted on this topic. We do not know if any other US agencies have reviewed it.

6. What US agency has reviewed the research on impacts to birds and bees? If so, when and send a link to the review. I will note the latest research showingpossible impacts to bees from higher frequencies to be used in 5G.

   EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and we are not aware of any EPA reviews that have been conducted on this topic. We do not know if any other US agencies have reviewed it.

7. What is a safe level of radiofrequency radiation? I ask this because the FDA and FCC both state they do not need to test cell phones at body contact and it is proven that phones will create exposure that are higher than FCC limits when phones are tested in these positions.

   The Telecommunications Act of 1996 directs the FCC to establish rules regarding radiofrequency (RF) exposure.The U.S. Food and Drug Administration (FDA) sets standards for electronic devices that emit non-ionizing or ionizing radiation. The EPA defers to these regulatory authorities for the establishment of safe levels of radiofrequency radiation.

8. The FDA and FCC have been provided with information and published data showing the fact that cell phones create cell phone radiation exposures that violate FCC limits. What agency has the job of ensuring accountability that the American public is not exposed to RF radiation that exceeds FCC limits. The FCC has test protocols that say body contact tests are not needed. The FDA refers to the FCC. Yet the fact is that cell phones exceed FCC limits when tested in body contact positions. Are the FCC limits legitimate? These FCC limits are being violated. Who is the responsible agency that will ensure Americans are protected? The FCC says their rules are not being violated as their rules allow for a space between the phone or device and the body? The FDA says there is a safety factor so there is no need for them to act (and will not state what the safety factor for a cell phone is) . YET government limits are being exceeded. Are agencies fine with limits being violated? If so please explain at what level of cell phone radiation a federal agency will step in? If so, which agency has jurisdiction? (March 12, 2019 Publication on Om Gandhi's paper on radiation emissions violating FCC limits 11 times and August 21, 2019 Chicago Tribune cell phone testing data released)

EPA Response: The Telecommunications Act of 1996 directs the FCC to establish rules regarding radiofrequency (RF) exposure. The U.S. Food and Drug Administration (FDA) sets standards for electronic devices that emit non-ionizing or ionizing radiation. The EPA does not have a funded mandate for radiofrequency matters, and the questions you raise are outside of EPA's areas of responsibilities and current expertise. Please refer this question to FCC and FDA.

9. The National Toxicology Program states clear evidence of cancer was found and the FDA disputes this because it was just an animal study. However birds fly and nest on cell antennas mounted on towers, bees fly in front of antennas and family pets (dogs, cats) will sit directly on or near Wi-Fi routers and smart speakers despite the fact that the manuals state humans should be at a minimum of 20 cm from wireless devices (far more from antennas of towers). What about the impact to these animals? What is the US government doing to ensure safety for wildlife and family pets?

EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and the questions you raise are outside of EPA's area of responsibility and current expertise. We defer to FDA to provide a response regarding their findings.

10. Please send me the staff member of your respective agency who is on the Interagency Radiofrequency Workgroup as I have repeatedly tried to get this information and it is never provided to me.

EPA Response: The Radiofrequency Interagency Work Group (RFIAWG) is an informal forum for exchange of information and the group does not meet to set, or advise on, policy, rulemaking or guidance. The group has not met in more than two years.

11. The FDA only reviewed selected studies on cancer until 2018. Most recently, the American Cancer Society funded radiation inpeople with genetic susceptibilities. The National Toxicology Program published research showing DNA damage. Will the FDA be updating it's review with these studies? If not, then what agency is accountable to American public to ensure humans are not harmed?

EPA Response: The questions you raise are outside of EPA's areas of responsibilities and current expertise. Please direct questions about FDA activities to FDA.

12. What agency ensures safety related to extremely low frequency (ELF-EMF) electromagnetic fields- also non ionizing? Currently we have no federal limit, no federal guidelines and confirmed associations with cancer and many other health effects. Kaiser Permanente researchers have published several studies linking pregnant women's exposure to magnetic field electromagnetic fields to not only increased miscarriage and but also increased ADHD, obesity and asthma in the

woman's prenatally exposed children. A recent large scale study again found associations with cancer. Please clarify which US agency has jurisdiction over ELF-EMF exposures?

EPA Response: There are no U.S. Federal standards limiting residential or occupational exposure to electric and magnetic fields (EMF) from power lines. The EPA does not have a funded mandate for radiofrequency matters.

13. When it comes to cell phone radiation SAR thresholds, what is your understanding of the "safety factor" in place?

EPA Response: EPA last commented on FCC proposals for SAR limits in the 1996FCC 96-236. The Telecommunications Act of 1996 directs the FCC to establish rules regarding radiofrequency (RF) exposure.The U.S. Food and Drug Administration (FDA) sets standards for electronic devices that emit non-ionizing or ionizing radiation. The EPA defers to these regulatory authorities for the establishment of safe levels of radiofrequency radiation.

Sincere regards,
Lee Ann B. Veal
Director, Radiation Protection Division
Office of Radiation and Indoor Air
www.epa.gov/radiation

From:Theodora Scarato <Theodora.Scarato@ehtrust.org>
Sent:Friday, June 05, 2020 5:27 PM

Subject:Letter with specific Questions Related to the FDA review and to the EPA, CDC, NIOSH and FDA Jurisdiction on EMFs

Dear Honorable Leadership and Scientists of the FDA, EPA, CDC, Health and Human Services, National Cancer Institute and Department of Labor;

I would respectfully ask the following questions for each of your agencies- the CDC, FDA, HHS, FDA, EPA, NIOSH, Department of Labor to answer promptly.

1. What is your response to these scientists statements regarding the FDA report and the call to retract it?
2. To the FDA- What consultants were hired for the FDA review and report on cell phone radiation?
3. What US agency has reviewed the research on cell phone radiation and brain damage? I ask this because the FDA only has looked at selected studies on cancer. If your agency has not, please simply state you have not.
4. What US agency has reviewed the research on damage to memory by cell phone radiation? If so, when and send a link to the review.

5. What US agency has reviewed the research on damage to trees from cell phone radiation? If so, when was it issued and send a link to the review.Note this study showing damage from long term exposure to cell antennas.
6. What US agency has reviewed the research on impacts to birds and bees? If so, when and send a link to the review. I will note the latest research showingpossible impacts to bees from higher frequencies to be used in 5G.
7. What is a safe level of radiofrequency radiation? I ask this because the FDA and FCC both state they do not need to test cell phones at body contact and it is proven that phones will create exposure that are higher than FCC limits when phones are tested in these positions.
8. The FDA and FCC have been provided with information and published data showing the fact that cell phones create cell phone radiation exposures that violate FCC limits. What agency has the job of ensuring accountability that the American public is not exposed to RF radiation that exceeds FCC limits. The FCC has test protocols that say body contact tests are not needed. The FDA refers to the FCC. Yet the fact is that cell phones exceed FCC limits when tested in body contact positions. Are the FCC limits legitimate? These FCC limits are being violated. Who is the responsible agency that will ensure Americans are protected? The FCC says their rules are not being violated as their rules allow for a space between the phone or device and the body? The FDA says there is a safety factor so there is no need for them to act (and will not state what the safety factor for a cell phone is) . YET government limits are being exceeded. Are agencies fine with limits being violated? If so please explain at what level of cell phone radiation a federal agency will step in? If so, which agency has jurisdiction?
(March 12, 2019 Publication on Om Gandhi's paper on radiation emissions violating FCC limits 11 times and August 21, 2019 Chicago Tribune cell phone testing data released)
9. The National Toxicology Program states clear evidence of cancer was found and the FDA disputes this because it was just an animal study. However birds fly and nest on cell antennas mounted on towers, bees fly in front of antennas and family pets (dogs, cats) will sit directly on or near Wi-Fi routers and smart speakers despite the fact that the manuals state humans should be at a minimum of 20 cm from wireless devices (far more from antennas of towers). What about the impact to these animals? What is the US government doing to ensure safety for wildlife and family pets?
10. Please send me the staff member of your respective agency who is on the Interagency Radiofrequency Workgroup as I have repeatedly tried to get this information and it is never provided to me.
11. The FDA only reviewed selected studies on cancer until 2018. Most recently, the American Cancer Society funded Yale study linked Thyroid cancer to cell phone radiationin people with genetic susceptibilities. The National Toxicology Program published research showing DNA damage. Will the FDA be updating it's review with these studies? If not, then what agency is accountable to American public to ensure humans are not harmed?
11. What agency ensures safety related to extremely low frequency (ELF-EMF) electromagnetic fields-also non ionizing? Currently we have no federal limit, no federal guidelines and confirmed associations with cancer and many other health effects. Kaiser Permanente researchers have published several studies linking pregnant women's exposure to magnetic field electromagnetic fields to not only increased miscarriage and but also increased ADHD, obesity and asthma in the woman's prenatally exposed children. A recent large scale study again found associations with cancer. Please clarify which US agency has jurisdiction over ELF-EMF exposures?

12. When it comes to cell phone radiation SAR thresholds, what is your understanding of the "safety factor" in place?

I am writing to all of you so each of your agencies can provide me with the answers from your respective agencies. Usually one agency sends me to the other agency but I do not receive an answer. Everyone points the finger at the other but no one has an answer. Please answer my questions numbered one through ten numbered so we have clarity in the response.

Please see the letter from multiple scientists below. I also attached a sampling of recent pertinent science.

Theodora Scarato
Executive Director
Environmental Health Trust

Jeffrey Shuren, MD, JD,
Director of the FDA's Center for Devices and Radiological Health
Food and Drug Administration
10903 New Hampshire Ave
Silver Spring, MD 20993-0002
December 17, 2018

Questions RE: FDA's Rejection of the Cancer Association Found in the National Toxicology Program Radiofrequency Cell Phone Research Studies

Dear Dr. Jeffrey Shuren;

As you are aware, the National Toxicology Program (NTP)/National Institute of Environmental Health Sciences (NIEHS) released their final reports on their $30 million animal study on long-term exposure to wireless radiofrequency electromagnetic (RF-EMF) radiation. They found statistically significant increases in DNA damage, heart damage, malignant glioma tumors of the brain, and malignant schwannomas of the heart. The increased incidence of heart tumors was considered by the expert peer-reviewers and staff of the NTP to demonstrate "clear evidence of carcinogenic activity" of modulated cell phone radiofrequency radiation. Similarly, studies by the Ramazzini Institute of RF-EMF at levels below FCC limits (Falcioni, 2018) found increases in malignant schwannomas of the heart in exposed rats.

Importantly, these animal study findings support published case control studies in humans which found increases in tumors of the same types—schwannomas and gliomas. In 2011, RF-EMF was classified as a Group 2B possible carcinogen by the World Health Organization's International Agency for Research on Cancer based on published research that found tumor increases in humans using cell phones long term. Now, in 2018, these animal studies substantially strengthen the scientific evidence that RF-EMF causes

cancer, and scientists have concluded that there is now sufficient evidence to classify RF-EMF as a human carcinogen (Hardell and Carlberg, 2017, Peleg et al., 2018, Miller et al., 2018).

However, in response to the NTP final reports, the FDA stated, "After reviewing the study, we disagree, however, with the conclusions of their final report regarding 'clear evidence' of carcinogenic activity in rodents exposed to radiofrequency energy."

We ask these questions to the FDA:

1. Are there technical comments by the FDA that substantiate the FDA's conclusions that NTP's study did not find "clear evidence" of carcinogenicity for RF-EMF. Please provide copies.

2. Specifically what are the FDA's conclusions regarding the schwannomas of the heart in male rats, the brain gliomas in the male rats, the DNA damage, and the cardiomyopathy of the heart?

3. The FDA states, "Based on our ongoing evaluation of this issue, the totality of the available scientific evidence continues to not support adverse health effects in humans caused by exposures at or under the current radiofrequency energy exposure limits." Please provide the documentation of the FDA's "ongoing evaluation." We respectfully request that you indicate the specific review process through which such an evaluation was undertaken and share with us the FDA evaluation, which we expect is in a report with citations for the research that was analyzed.

4. The FDA stated of the March 2018 peer review, "The FDA was not a participant in that process, but was invited to observe the panel discussions, which included an assessment of the study methods and data by a panel of 15 peer reviewers to determine the basis of evidence for the final report." However, two FDA officials came to the National Toxicology Program's peer review of the study and had an opportunity to speak and offer comments. Yet the FDA did not provide official comments on the NTP study at that time. FDA scientists did agree with the design of the NTP studies, which were presented to the Radiofrequency Interagency work group in 2003. Did the FDA ever share their disagreements or concerns with the NTP at any time—before and/or after the peer review? If so, please provide the comments of the FDA to the NTP.

5. The FDA nominated cell phone radiation emitted from wireless communication devices to the NTP in 1999 and specifically stated that "animal experiments are crucial because meaningful data will not be available from epidemiological studies for many years due to the long latency period between exposure to a carcinogen and the diagnosis of a tumor" and that such studies would "provide the basis to assess the risk to human health."

Did the FDA inform the NIEHS/NTP at any time over the last 20 years since this nomination that animal research would not be sufficient to determine risk to public health from cell phone radiation? Further, please clarify if it is now the FDA's position that animal research is no longer relevant to human health? If this is the case, will animal studies no longer be used to assess cancer risks from food contaminants,

and how does the FDA propose to treat pharmacological testing of animals in support of pharmaceutical registration processes?

6. The FDA states, “We believe the existing safety limits for cell phones remain acceptable for protecting the public health.” However, the FCC limits on allowable radiofrequency exposures are based on the assumption that only thermal RF levels can cause harm. The NTP studies were carefully controlled to minimize any potential thermal effects of RF on exposed animals, yet cancers and other adverse health effects were found at these nonthermal levels. Please provide the FDA’s scientific documentation that evaluates the current FCC limits in light of the NTP and Ramazzini studies to understand how the FDA can state FCC limits are adequate to protect human health.

7. Kindly provide copies of FDA-submitted recommendations, reports, or opinions to the FCC regarding the radiofrequency human exposure exposure limits and policies. This could be either to the FCC Dockets 13-84, 03-137 or directly to the Commission.

8. Will the FDA be performing a quantitative risk assessment? If so, please provide a timeline. If not, please explain how and why that decision was made.

Sincerely,

Ron Melnick, PhD
Senior Toxicologist and Director of Special Programs in the Environmental Toxicology Program at the National Institute of Environmental Health Sciences (NIEHS), National Institutes of Health, now retired.

Anthony B. Miller, MD, FACE
Professor Emeritus Dalla Lana School of Public Health
University of Toronto

Lennart Hardell, MD, PhD
Department of Oncology
University Hospital
SE-701 85 Örebro, Sweden (retired)
Cancer Research Foundation
Örebro, Sweden

Devra Davis, PhD, MPH
President and Founder Environmental Health Trust
Visiting Professor of Medicine
Hebrew University Hadassah Medical Center

David O. Carpenter, MD
Director, Institute for Health and the Environment
A Collaborating Centre of the World Health Organization

University at Albany

Theodora Scarato MSW
Executive Director, Environmental Health Trust

L. Lloyd Morgan
Senior Research Fellow, Environmental Health Trust

Letters which have been sent to the FDA include:

- Letter calling for a retraction signed by several scientists.
- Click here for a PDF of all letters and statements.
- Ronald Melnick PhD's letter to the FDA on the National Toxicology Program study
- Albert Manville PhD, retired Senior Wildlife Biologist, Division of Migratory Bird Management, U.S. Fish & Wildlife Service, Wash. DC HQ Office (17 years); Senior Lecturer, Johns Hopkins University
- Prof. Tom Butler of the University College in Cork, Ireland's letter to the FDA
- Igor Belyaev, PhD, Dr. Sc. Head, Department of Radiobiology of the Cancer Research Institute, Biomedical Research Center of the Slovak Academy of Science letter to the FDA
- Paul Heroux PhD, McGill University
- Alfonso Balmori, BSc statement to the FDA

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Building science and radiofrequency radiation: What makes smart and healthy buildings

Frank M. Clegg[a,*], Margaret Sears[b], Margaret Friesen[c], Theodora Scarato[d], Rob Metzinger[e], Cindy Russell[f], Alex Stadtner[g], Anthony B. Miller[h]

[a] Canadians for Safe Technology; Business Advisory Board, Environmental Health Trust; Canadians for Safe Technology, PO Box 33, Maple Grove Village Postal Outlet, Oakville, ON L6J 7P5, Canada
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[c] Canadians for Safe Technology; Environmental Health Association of Manitoba, 43 Rutgers Bay, Winnipeg, MB R3T 3C9, Canada
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ABSTRACT

Radiofrequency radiation (RFR), used for wireless communications and "smart" building technologies, including the "Internet of Things," is increasing rapidly. As both RFR exposures and scientific evidence of harmful effects increase apace, it is timely to heed calls to include low RFR levels as a performance indicator for the health, safety and well-being of occupants and the environment.

Adverse biochemical and biological effects at commonly experienced RFR levels indicate that exposure guidelines for the U.S., Canada and other countries are inadequate to protect public health and the environment.

Some industry liability insurance providers do not offer coverage against adverse health effects from radiation emitted by wireless technologies, and insurance authorities deem potential liability as "high." Internationally, governments have enacted laws, and medical and public health authorities have issued recommendations, to reduce and limit exposure to RFR.

There is an urgent need to implement strategies for no- or low-RFR emitting technologies, and shielding, in building design and retrofitting. These strategies include installing wired (not wireless) Internet networks, corded rather than cordless phones, and cable or wired connections in building systems (e.g., mechanical, lighting, security). Building science can profit from decades of work to institute performance parameters, operationalizing prudent guidelines and best practices. The goal is to achieve RFR exposures that are ALARA, "As Low As Reasonably Achievable."

We also challenge the business case of wireless systems, because wired or cabled connections are faster, more reliable and secure, emit substantially less RFR, and consume less energy in a sector with rapidly escalating greenhouse gas emissions.

1. Introduction

Radiofrequency radiation (RFR) exposures are increasing rapidly with wireless technologies, but rarely are the terms "building science" and "RFR" used in the same sentence. Building science attends to the physical performance of buildings, the comfort, health, safety of occupants, and the larger natural and built environment [1]. "Science" includes physics and the electromagnetic spectrum, including RFR.

Building science considers the building *as a system* and devises effective solutions for design concerns. The primary system elements include: the building enclosure (building envelope); inhabitants (humans, animals, and/or plants); building services (electrical/mechanical/

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electronic systems); site, with its landscape and services infrastructure; and external environment (landscape, weather and micro-climate) [1]. To achieve a well-performing building, all these elements must be harmonized.

Historically, awareness of indoor environmental quality heightened with novel materials following World War II, and was bolstered with improved air-tightness during the energy crisis of the 1980s. Minimizing chemical off-gassing of composite materials, maintenance products and mold is advised to optimize indoor air quality and occupants' health [2]. Similarly, magnetic and electrical fields and currents with early electrical applications are also associated with adverse health effects. Assiduous adherence to electrical codes and best practices, and isolation of potentially problematic equipment, are among measures to address ongoing power-frequency, "dirty power" and ground current concerns [3,4].

Today engineers, architects, planners and others are challenged to keep abreast of research and policies that address potential harm from wireless technology. This paper builds on long-standing recommendations to expand the typical scope of building science to consider RFR [3,4]. It briefly describes RFR in the electromagnetic spectrum, use of wireless technology in "smart" buildings, and summarizes peer-reviewed, scientific research regarding biological effects on human and environmental health. Key reasons as to why action should be taken include potential liability risks when technology is not implemented safely. International measures and guidelines for lower RFR exposure are highlighted. Finally, practices are outlined and recommendations made to minimize the impact of RFR on public and environmental health in the design, construction and maintenance of safer, modern buildings.

Internationally, a broad range of standards and policies limit magnetic and electric fields over a broad range of frequencies, including RFR [5]. It is beyond the scope of this paper to address the full electromagnetic spectrum.

2. Radiofrequency radiation explained

2.1. The electromagnetic spectrum

The electromagnetic spectrum (Fig. 1) is a continuum ranging from low to high frequencies, associated with the longest to shortest wavelengths, respectively [6,7]. A distinction is made between high frequency non-ionizing versus higher frequency ionizing radiation that has enough energy to displace electrons and "ionize" atoms and molecules. Ionizing radiation includes ultraviolet light, X-rays and gamma rays. Below these frequencies, non-ionizing radiation includes visible and infrared light, and frequencies for wireless communications and radar. Lower frequencies are used to broadcast commercial radio and television, while alternating currents at 50 or 60 cycles per second or Hertz (Hz) are in power lines and building wiring.

RFR is sent wirelessly from a transceiver (e.g., Wi-Fi router) to another transceiver (e.g., computer) and vice versa. The RFR frequency range covered in guidelines and standards is generally from 3 kHz to 300 GHz and includes the microwave (MW) range. The terms RFR and MW are sometimes used interchangeably. Uses of frequency ranges overlap, so there are no precise boundaries for any particular technology. Information is encoded in the modulation (superimposed higher frequency irregularities) on a radiofrequency carrier wave. While the frequency of the carrier wave is stated in the manufacturer's specifications for various devices, the actual human exposure includes these overlain or superimposed signals [6]. Modern devices utilize multiple carrier frequencies.

Devices that receive and emit RFR include personal items that communicate wirelessly such as: cordless and mobile phones; computers, laptops, tablets and peripheral equipment; monitors (e.g., for babies, or medical purposes); toys, video game and entertainment systems; virtual reality headsets; GPS systems; and Bluetooth-enabled "wearables" such as for personal fitness. RFR-emitting equipment that may be installed in buildings includes: wireless routers and associated mesh networks; "smart" utility metering; identification and security systems; cell boosters; power transfer/battery charging stations; and the "Internet of Things" (IoT) such as building systems (e.g., heating, ventilation and lighting), and appliance monitoring and control.[1] These devices are designed to use a number of presently used plus new radiofrequency bands, from 600 MHz to GHz frequencies. Fifth generation or 5G frequencies that are being licensed by the U.S. Federal Communications Commission (FCC) will include lower frequencies used for television, through higher frequencies into the millimeter wavelength range (above 30 GHz) [9]. Higher frequencies provide greater bandwidth, albeit with shorter range and poorer penetration of structures and vegetation; these are discussed in Section 3.1.

Microwave ovens and other RFR-emitting devices (e.g., Wi-Fi and cell phones) rely on similar frequencies, but the power and signal characteristics are different. Ovens heat with 1000 Watts (W) of continuous-wave radiation, whereas wireless devices are lower power; for example a cell phone is a two-way microwave radio, using on average less than 1 W of modulated radiation. Wireless communications signals, however, are in short bursts, that are biologically active, independent of the carrier frequency [10,11]. Another key feature of anthropogenic electromagnetic radiation is polarization; i.e., that the waves may be in one plane [12].

2.2. Regulatory history of RFR in the United States

In the U.S., the FCC authorizes and licenses devices, transmitters and facilities that generate RFR [13]. The U.S. does not have federally developed safety limits, as the Environmental Protection Agency never developed biologically based limits. The current FCC RFR exposure limits were adopted in 1996 based on recommendations from the National Council on Radiation Protection and Measurements (NCRP) [14], the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers, Inc. (IEEE); specifically *IEEE C95.1–1991* and *ANSI/IEEE C95.1–1992*. None of these institutes have expertise in public health or biology. The FCC RFR exposure guidelines have not been substantially revised since 1996.

Presently, frequency bands between 9 kHz and 275 GHz have been allocated for various communications uses by the FCC [15].

2.3. RFR guidelines

The FCC RFR limits for public exposure reference three metrics: 1) the "Specific Absorption Rate" (SAR) is the rate at which RF energy is absorbed by human tissue; 2) power density, the rate of deposition of energy per unit area, is a function of the electrical and magnetic fields, at a particular frequency; and 3) the electrical field strength [7]. SAR limits apply to wireless wearable devices, cell phones and other items held close to the body. Power density limits apply to exposures at a distance, such as from cellular antennas and Wi-Fi.

2.3.1. Specific Absorption Rate (SAR)

The FCC and other governments' agencies require that all wireless devices such as cell phones or computers comply with SAR limits when the device is operating at its maximum power, before being placed on the market.

SAR is a measure of RFR energy dose to parts of the body closest to antennas, in the "near field," such as from the personal use of wireless devices. SAR is usually expressed in units of Watts per kilogram (W/kg) or milliwatts per gram (mW/g). The SAR for a given power density varies according to equipment details, the frequency and modulation,

[1] IoT is the comprehensive plan to connect billions of physical devices around the world to the Internet, collecting and sharing data.

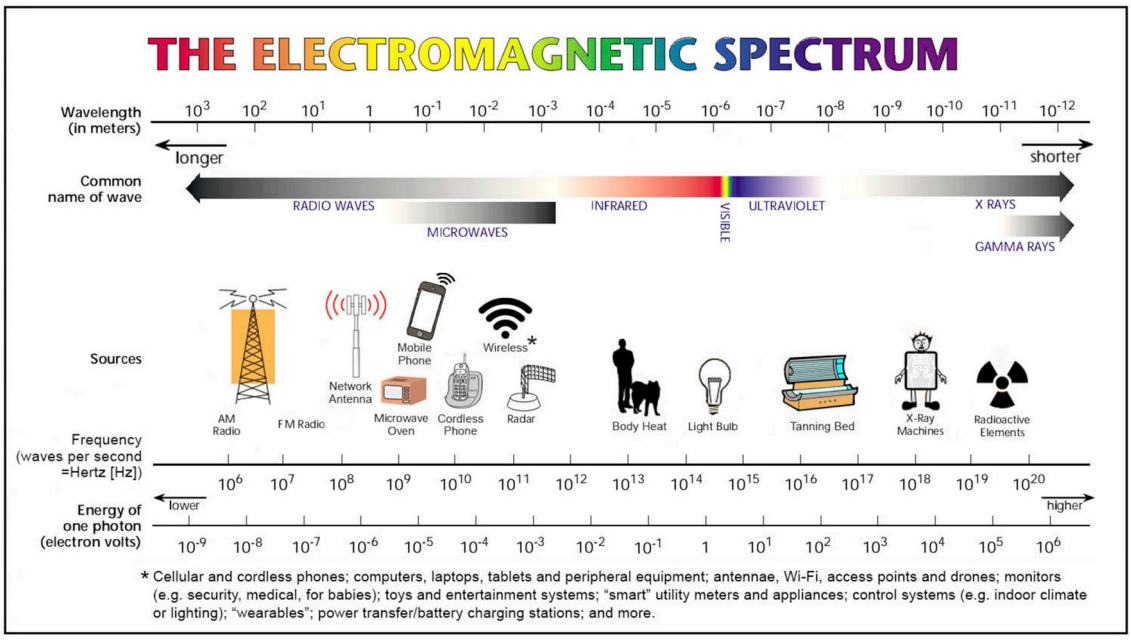

Fig. 1. The Electromagnetic spectrum (presented with permission) [8].

and the absorptive and reflective properties of the body or structure being exposed [7].

The FCC promulgated both public and occupational SAR limits. For the general public (commercial devices), the SAR limits for the head and the body are 1.6 W/kg averaged over a 1 g cube of tissue, and 4 W/kg averaged over a 10 g cube of tissue for ears, hands, feet, wrists and ankles [16]. Workers may be exposed to higher levels; occupational SAR limits are double those for the general public in the U.S., and five-fold greater for workers in "controlled environments" in Canada [17] as well as the many countries relying upon International Commission on Non-ionizing Radiation Protection (ICNIRP) guidelines [18].

Researchers have long criticized the SAR as an inadequate metric as it is measured in a mannequin – a liquid-filled phantom [19]. This does not capture the complex characteristics and interactions of living tissues' electromagnetic properties, or of RFR signals (e.g., the wave perturbations necessary to transmit information may cause additional biological impacts) [20]. FCC SAR limits and the measured SAR levels can be found in the manufacturer's instructions that come with every commercially sold wireless device, or on the manufacturer's website.

SAR testing protocols do not require cell phones and devices to be tested touching the body/skin or in novel configurations such as for virtual reality, despite the fact that this is the way they are often carried and used today [20,21,22]. Some cell phones are tested at as much as 25 mm separation distance. The national agency regulating radio-frequency radiation in France (ANFR) tested 450 cell phones in various configurations. The SAR exceeded the standard for 90% of the models that were tested as if they were contacting the body [23,24]. More than a dozen models were withdrawn from the market or had software updates to reduce RFR emissions.

2.3.2. Power density

Power density measurements address compliance in buildings or outdoor environments, such as when concerns are raised about RFR exposures from a nearby cell tower or from the Wireless Local Area Network (WLAN) system in a school. The FCC exposure limits range from 0.4 to 1.0 mW/cm^2 (4000 to 10,000 mW/m^2) [16] for commonly used frequencies.

Power density may be expressed as milliWatts or microWatts per square centimeter (mW/cm^2 or μW/cm^2), or milliWatts per square meter (mW/m^2).

For comparison, 1 mW/cm^2 = 1000 μW/cm^2 = 10,000 mW/m^2.

2.3.3. Electric field

"Electromagnetic" refers to both electrical and magnetic fields (EMF). Limits are established for electric fields, reported as volts per meter (V/m). Electric fields are commonly measured and reported during surveys of radiofrequency exposures, to characterize electromagnetic fields (EMF) across a broad range of frequencies [7].

2.3.4. Exposure attenuation

RFR reductions are generally reported as decibels. This is a non-linear, logarithmic scale, such that a signal that is 10 dB lower than another, is one tenth the signal strength of the comparator [25].

3. Information technologies and building science

Indoor environmental quality (IEQ) in more highly developed countries has advanced in terms of thermal comfort, air quality and construction for environmental performance (e.g., insulation), for example with guidance and classifications by The World Green Building Council [26] or Leadership in Energy and Environmental Design (LEED) [27]. These factors translate into familiar physical sensations of warmth, fresh air and comfort, versus cold drafts and stuffy air. Over the past decades, understanding of the modern sources of lower frequencies and now RFR within and surrounding building assemblies, and effects on inhabitants and surroundings, has gained recognition [3,28].

3.1. Developing technologies

Beyond Wi-Fi, a recent trend is the integration of wireless controls for lighting and heating/ventilation, as well as wireless security and audio/visual technology systems in buildings. "Smart buildings," with "smart systems" and "smart appliances" allow users to monitor and to control many interconnected mechanical and electronic systems via computers or "smart phones." Utility providers are utilizing "smart meters" for electricity, gas and water to transmit usage data electronically using RFR. Wireless charging stations for many items, from electronic devices to vehicles, may be additional sources of EMF.

Plans for the burgeoning IoT and 5th Generation (5G) wireless services are to transport large volumes of data quickly (e.g., for videos).

The proposed evolution of the “smart city” will imbue entire buildings and neighborhoods with higher levels of currently used frequencies, as well as the higher frequencies into millimeter wavelengths, which carriers plan to use in 5G [29]. A European Parliament report "5G Deployment: State of Play in Europe, USA, and Asia" explains how 5G radio emissions are different from those of previous generations because of their complex, highly focused, beam-formed transmissions, and that “it is not possible to accurately simulate or measure 5G emissions in the real world” [30].

Environments with very low RFR exposures can be achieved by choosing wired and fiber-optic cable connections, to buildings and throughout buildings. In fact, RFR is not only unnecessary for a “smart building;” wireless options will not match the bandwidth or reliability of fiber-optic or other cable options (“wired”) [31]. Wired options are faster and more secure, and require much less energy to operate [29,32], making them safer for human and environmental health.

4. Adverse health effects of RFR

4.1. Introduction

In many countries, guidelines and standards to protect the public from adverse effects of radiofrequency radiation (RFR) are based on an assumption that harm results only from excessive heating of tissue (thermal effects); however, numerous scientific publications document that RFR affects living organisms at exposures within regulatory parameters, at “non-thermal” levels.

“Microwave assisted chemistry” accelerates particular chemical reactions with low levels of RFR [33,34], and has been commercialized [33,35]. In living systems, the acceleration of some chemical reactions would cause molecular damage, chemical imbalances and dysfunction, and is consistent with observations of significant effects in humans, animals, plants and isolated cells.

Effects observed in studies of humans exposed to non-thermal levels of RFR include: cancer; early childhood developmental problems; brain, sperm and DNA damage; as well as electromagnetic hypersensitivity.

4.2. Cancer

4.2.1. RFR classified as a possible human carcinogen

The adequacy of RFR regulatory limits was challenged in 2011 when an expert panel convened by the International Agency for Research on Cancer (IARC) of the World Health Organization classified RFR (100 MHz–300 GHz) as a Group 2B, *possible* human carcinogen, largely based on the human epidemiological evidence of increased risk of glioma [36,37], a type of brain cancer. This classification includes wireless frequencies from all types of RFR-emitting devices, including Wi-Fi. In 2019, an IARC advisory group recommended reassessment of the 2011 classification, in light of recent animal research [38].

4.2.2. Subsequent evidence supports upgrading the IARC classification

In 2018, Miller et al. concluded that as a result of human epidemiology, and animal studies published following the IARC 2011 panel meeting, RFR should be categorized as a Group 1 *known* human carcinogen [39]. Hardell and Carlberg came to the same conclusion [40]. Tobacco smoke and asbestos are in Group 1.

The main human evidence for this proposed classification upgrade is a large French epidemiological study [41], as well as a meta-analysis of pooled case-controlled studies in Sweden [42]. In addition, a 2018 Israeli occupational exposure study concluded that overall the evidence “make[s] a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)” [43]. A case series also reports breast cancers associated with carrying a cell phone in the bra [44].

Canadian data (2001–2004) showed evidence of doubled risk of developing glioma for adults who used cell phones for 558 lifetime hours or more [45]. Consistent with the increasing use of cell phones, there was a statistically significant increase in incidence of primary malignant brain and central nervous system tumors in children and adolescents in the U.S. between 2000 and 2010 [46], and brain tumors subsequently became the most common malignancy in children and adolescents, with disease shifting to more aggressive gliomas [47].

Further supporting evidence came from three recent RFR rodent studies. The first two studies reported higher incidence of cancers in male rats exposed to RFR: 1) a $30 million study by the U.S. National Toxicology Program (NTP) of the National Institutes of Environmental Health Sciences (NIEHS), studied radiation simulating RFR intensity from cell phones [48]; and 2) a study by the Italian Ramazzini Institute [49] that was conducted at lower intensities (below FCC limits) designed to mimic radiation from cell towers. The tumors found in these large-scale studies were of the same histotype as in some human epidemiological cell phone studies.

A third large study demonstrated increased initiation and acceleration of tumor growth with RFR when the exposure was in conjunction with a cancer-causing chemical [50], replicating findings of a 2010 study [51].

4.3. Early life stages

During their rapid development, the embryo, fetus, infant and child are more vulnerable to many environmental insults, and impacts are potentially lifelong. Various life stages have different vulnerabilities

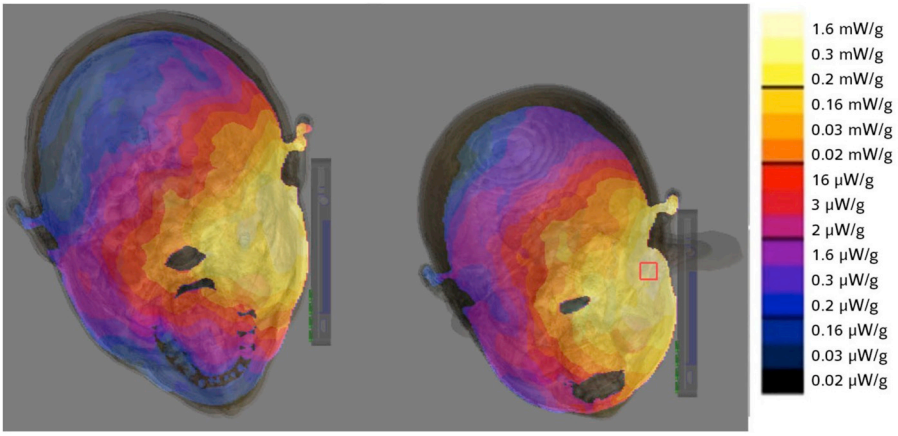

Fig. 2. Specific Absorption Rate (SAR) in adult and child (age 6 years) male heads with phone in talk position. The scale is 50 dB with 0 dB = 1.6 mW/kg. From work of Claudio Férnandez, 2018 [20] (used with permission of Environmental Health Trust).

and susceptibilities to RFR [52,53,54,55]. Modeling indicates that children absorb substantially higher RFR doses from cell phones, in deeper brain structures, than do adults (Fig. 2) [20]. Research has also found proportionately higher doses to tissues in children compared with adults, from wireless laptops and utility meters [56,57,58].

Research has linked exposure during pregnancy to adverse effects. The authors of a case-control study published in 2015 stated, "use of mobile phones can be related to early spontaneous abortions" [59]. Maternal mobile phone use during the first trimester of pregnancy may contribute to slowing or halting of embryonic development [60], possibly due to effects on membrane receptors in human amniotic cells [61]. A 2019 study of over 55,000 pregnant women and infants in four countries (Denmark, the Netherlands, Spain and Korea) linked maternal cell phone use during pregnancy with shorter pregnancy duration and increased risk for preterm birth [62].

Behavioral problems have been associated with prenatal and postnatal cell phone exposure. In five cohorts, Birks et al. found cell phone use by a pregnant woman to be associated with an increased risk for behavioral problems, particularly hyperactivity/inattention in her child [63], and Divan et al. reported behavioral problems in children up to seven years of age [64,65]. Studies of children and adolescents report possible associations of wireless technology use with addictions and depression [66], fatigue [67], altered baseline thyroid hormone levels [68], and poorer well-being [69,70]. Sage and Burgio discuss the damage from low levels of RFR to genetic material including DNA and nuclear structures in the cell, and potential mechanisms of child neurodevelopmental impairment [71].

A Yale University study found that when mice were exposed *in utero* to cell phone radiation, they had impaired memory and increased hyperactivity in adulthood [72].

Not only can RFR act along with carcinogens to promote tumor development [50], it also may synergize with toxic chemicals in other ways. For example, in a study of Attention Deficit Hyperactivity Disorder in children, ADHD was associated with mobile phone use for voice calls only in children who were also exposed to relatively high lead levels (lead is an established, potent neurotoxin) [73]. Further synergistic effects between RFR and various chemicals including nutrients (i.e., both beneficial and adverse) are described in a 2016 review by Kostoff and Lau [74].

4.4. Sperm

Three systematic reviews published from 2014 to 2016 [75,76,77] reported significant adverse effects on sperm quantity and quality, as well as DNA damage, from everyday RFR exposures. Animal studies reported testicular damage at 0.002 W/kg [78] and sperm damage at 0.024 W/kg SAR values [79].

4.5. Wi-Fi and other ambient RFR

Much of the RFR research reported thus far has focused on exposures to users of devices in close proximity (e.g., cell phones). More distant sources such as Wi-Fi access points or cell towers generally contribute less to exposures because RFR drops off quickly with distance from the source, following the "inverse square law" (levels are a quarter at twice the distance; one-ninth at three times the distance; etc.). Although exposure intensities from distant sources are usually low compared with devices in close proximity, simultaneous exposures are complex as devices connect to networks, people move around, and RFR may be reflected or absorbed by building materials, other surroundings, and inhabitants [80,81].

At any particular point in space and time, electromagnetic exposures are the sums of electrical and magnetic field vectors [7]. Of importance for health, effects (e.g., oxidative stress and consequences in tissues) may be cumulative over time, and these effects are modulated by other exposures to chemicals (nutrients as well as adverse substances) and other stressors [8]. 5G is to be deployed with multiple directional antennas, but future exposures are not well characterized [30], and less is known of future health outcomes from this technology.

In a comprehensive literature review, Pall states that "Wi-Fi causes oxidative stress, sperm/testicular damage, neuropsychiatric effects including EEG changes, apoptosis [cell death], cellular DNA damage, endocrine changes, and calcium overload," that the effects from continuous, long-term exposure may be cumulative, and that pulsed signals are more biologically active than a smooth carrier wave [82].

Impaired brain development and cognitive function, as well as addictive behaviors in children and adolescents are observed with exposure to RFR [71,81]. In a study of exposure to RFR in schools, 18 teachers wore "exposimeters" to continuously record exposures to a spectrum of RFR. Mean exposure levels varied widely according to activities in the classroom, but peak measures were up to 83,000 μW/m^2 [81]. The highest levels occurred when students were streaming video, and the lowest occurred when the teacher had a wired Internet connection in a classroom far from Wi-Fi access points and students' laptops were in airplane/flight mode [81].

Measurements of ambient RFR have been carried out in other settings, including a train station [80] and other Stockholm landmarks [83], and neighborhood surveys from a car [84]. Ambient measurements correlate moderately with personal monitoring.

In an extensive review, Dürrenberger et al. characterized RFR and emissions from infrastructure in micro-environments [85]. Exposures are typically underestimated, and experts, officials and citizens may be surprised at the differences among venues. These uncertainties make it statistically difficult to detect health effects, resulting in under-estimation of harms as well [86]. Although exposures generally meet government regulatory limits, they exceed precautionary recommendations [80]. Recent reviews of RFR assessments found higher levels in offices and public transportation [87,88].

Researchers in a Bavarian village followed a natural experiment over 18 months, when a central cell tower was installed [89]. They found dose-dependent dysregulation of stress hormones, according to peak RFR exposure measured at the doorstep [89].

Effects reported in RFR studies may be complex and non-monotonic (i.e., effects occur at lower exposure levels that do not manifest at higher levels) [48,50,90]. It is known that biological mechanisms are established whereby chemicals cause complex dose-responses, particularly for hormone-related effects (the endocrine system) [91,92].

4.6. Electromagnetic hypersensitivity (EHS)

As with other environmental exposures, some people are more susceptible (sensitive or intolerant) and overtly affected by RFR. Electromagnetic hypersensitivity (EHS) is also commonly termed electrical sensitivity, electrohypersensitivity, idiopathic environmental intolerance, or (historically) microwave sickness.

Common symptoms of EHS include headaches, cognitive difficulties, sleep problems, dizziness, depression, fatigue, skin rashes, tinnitus and flu-like symptoms [93,94]. Adverse reactions to wireless devices range from mild and readily reversible to severe and disabling, and individuals must greatly reduce their exposures to sources of electromagnetic radiation [95,96,97].

Surveys conducted in several countries at times ranging from 1998 to 2007 estimated that approximately three to thirteen percent or more of the population experience symptoms of EHS [98–101].

As well as being difficult to manage in the modern world, EHS is typically unexpected. The theory that EHS is merely a "nocebo" response – that it results from suggestion and worry over possible effects of electronic devices – is the opposite of experience. In a study of 40 people, their EHS was only recognized following a period of illness and self-experimentation [102]. Further research has confirmed that lived experience is not consistent with the nocebo hypothesis [103].

EHS is recognized as a disability and is accommodated in the U.S.

under the *Americans With Disabilities Act* [104]. Sweden recognizes EHS as a functional impairment [99]. In Canada, the condition is included under environmental sensitivities [97,105]. Legal cases for compensation, disability pensions and accommodation in various countries are discussed in Section 6.

Physicians' organizations' research, experiences, practices and statements over the years were summarized by the European Academy of Environmental Medicine (EUROPAEM) in 2016 [4]. Sensitivities vary among individuals, and symptoms may also occur with exposures outside the RFR range. The consensus of the *EUROPAEM EMF Guideline* is that the most important action for treatment and management of EHS is reduction and avoidance of pertinent exposures in locations where significant amounts of time are spent, especially in sleeping areas. Other recommended measures include a suite of healthy lifestyle measures such as nutrition, stress reduction and measures to avoid toxicants, as well as to reduce levels of toxicants sequestered in the body [4].

4.7. Rigorous systematic review of the scientific evidence, for public health, policy and regulation

As evidenced here, contributions of RFR to adverse effects on public health may be substantial [106,107]. Public policy, and safety guidelines and standards, should be based on all of the best available scientific evidence; however, there has never been a systematic review conducted according to international best practices [108] of the RFR evidence, upon which to base exposure guidelines.

Influence of biases and conflicts of interest has been documented as a serious concern for international authoritative bodies such as the World Health Organization-International Electromagnetic Fields (EMF) Project, and the International Commission on Non-Ionizing Radiation Protection [109–111]. The same is true for the national authorities in Australia [112], Canada [113–115], the European Commission [116], the United Kingdom [117] and the U.S [118]. Bias in original scientific studies is evident in that studies funded by industry are less likely to identify adverse effects than those that are independently funded, and even less likely to conclude that adverse effects exist [119–121].

An important step towards resolution of the adequacy of guidelines and standards to protect public health, as well as policy and practical responses for individuals who experience EHS, would be a thorough systematic literature review conducted by independent, knowledgeable specialists. This would examine all of the RFR literature dating back to the identification of health concerns with the development and deployment of radar during World War II, including the studies in the 1971 review by Dr. Zorach Glaser [122].

Key features of this type of review include that all steps and findings must be transparent, such as bibliographic search methods, study selection, data extraction and meta-analyses, quality assessment and the weight of evidence analysis [108].

5. Environmental impacts of cell tower and radiofrequency radiation

Built and natural environments are interconnected. Biological systems are integrated, complex and operate using minute electrical charges combined with precise chemical signals. These mediate complex functions such as development, reproduction and cognition. Recent research has demonstrated adverse effects of radiofrequency radiation (RFR) on environments and wildlife, including birds, amphibians, insects, fish, mammals and plants [123–125]. For example, trees near cell towers can become visibly unhealthy on the side facing a cellular antenna, and can die prematurely [126].

A diverse array of species depends upon the Earth's low-level magnetic field to navigate for migration, homing, breeding, foraging and survival. RFR can have significant long-term impacts on the natural environment via disruption of normal positioning and orientation abilities as well as other complex cellular and biologic processes. Incremental effects may be only slowly recognized as species and ecosystems decline.

Small deposits of the iron-containing mineral magnetite act as magnetoreceptors to sense the Earth's magnetic field in a variety of organisms, including bacteria, insects, fish, birds and mammals [127–129].

Some bird species are strongly influenced by the low-intensity magnetic fields of the Earth for directional reference. Newer studies suggest that light-dependent cryptochrome photo receptors in birds' eyes are also sensitive to magnetic forces, and communicate with the brain [130,131].

RFR can interfere directly with magnetoreception in birds, disabling their avian magnetic compass [132]. A series of double-blinded studies replicated over several years demonstrated that migratory European robins lost their ability to orient and navigate in a city with high background "electromagnetic noise" and broadband frequencies [133]. Effects can be complex, as illustrated by findings that some birds can be more sensitive to weak broadband than to stronger fields [134,135].

Bees use magnetite crystals in their abdomens for navigation [136]. This sensory modality can be disrupted by electromagnetic fields, causing a loss of colony strength [137–140]. Scientists are increasingly concerned about the impacts of wireless radiation on the worldwide decline of domestic bees and colony collapse disorder [141,142]. Other insects are also adversely affected by RFR [142–145].

Review articles indicate that the weight of evidence is that RFR acts as an environmental toxin with ecosystem-wide harm from increasing ambient RFR emitted by cell towers and other RFR infrastructure [146–152].

6. Liability

Some industry liability insurance providers do not provide coverage against adverse health effects from RFR. Lawsuits for RFR health-related conditions are underway, and some have been successful in different countries.

6.1. Insurance industry and liability related to radiofrequency radiation

Insurers have declined to provide coverage to wireless product manufacturers and U.S. mobile operators for health damages from their products and networks since the early 2000s [153]. Insurers often exclude or limit coverage for the risk from electromagnetic fields (EMFs) posed by commercial general liability policies, decline policyholders in the wireless industry, and only provide coverage via pollution liability policy enhancements.

Insurance authorities also address the risks of electromagnetic fields. In 2014, the Swiss RE report *New emerging risk insights* listed the potential impact of the "Unforeseen consequences of electromagnetic fields" as "High" and examined further incremental risk associated with smart cities [154]. In its 2019 update, Swiss Re identified the top two emerging risks to be "digital technology's clash with legacy hardware, and potential threats from the spread of 5G mobile networks" [155].

In 2010, the Emerging Risk Team of Lloyds issued a white paper [156] indicating that the potential risks to insurers from health damage claims associated with cell phones and wireless radiation are comparable to those posed by asbestos. The 2013 Lloyds Risk Index lists "harmful effects of new technology" as an increasing environmental risk [157].

Some corporate insurance policies feature a general exclusion section that explicitly prohibits liability for injury or property damages from electromagnetic fields. This is considered to be a standard across the North American insurance industry [158].

Insurance company policies will often define electromagnetic radiation as a "pollutant." According to the AT&T Mobile 2012 Insurance policy, "Pollutants" mean: "Any … artificially produced electric fields,

magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non-ionizing radiation and waste." [159]. Policy enhancements can be purchased to cover environmental pollutants, which include EMFs [160,161].

The Austrian Worker's Compensation Board (AUVA) commissioned the Vienna Medical University to research effects of cell phone radiation on the brain, immune system, DNA and proteins, and published a series of reports that present the research evidence and conclude by recommending precautions to reduce exposure [162,163].

6.2. Summary of 10 K reports

Publicly traded companies issue annual 10-K reports to the U.S. Securities and Exchange Commission, summarizing the company's financial performance and status. Mobile operator reports identify potential liabilities for health damages from exposure to wireless devices as a risk, and provide no assurances that their products or equipment will be safe in future years.

Crown Castle states in their 2017 Annual Report [164], "If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues."

Verizon's 2017 Annual Report [165] states, "… our wireless business also faces personal injury and wrongful death lawsuits relating to alleged health effects of wireless phones or radio frequency transmitters. We may incur significant expenses in defending these lawsuits. In addition, we may be required to pay significant awards or settlements."

6.3. Lawsuits related to electromagnetic fields

In the U.S., the first cell phone cancer case was filed in 1992 and was followed by a series of cases that were either settled by confidential resolutions or dismissed due to lack of evidence or lack of authority of the court [166]. At the time of writing, there are thirteen active consolidated cases with defendants alleging their brain cancers were from cell phone use [167]. In 2017, Italy's highest court recognized a causal link between development of a brain tumor and cell phone use, and awarded social security payments [168].

Internationally there are several lawsuits related to cell phones and cancer and disability from EMF exposures. For example, Australian [169] and Spanish [170] courts have awarded disability to workers claiming sensitivity to electromagnetic radiation.

In January 2019, an Italian court ordered the government to launch a campaign to advise the public of the health risks from mobile and cordless phones [171].

7. International actions to limit public exposure to RFR

Some international governments have passed legislation (Table 1), and health and environmental authorities in numerous countries, regions and cities have issued recommendations (Table 2) to reduce exposure of the public to radiofrequency radiation (RFR). Measures frequently focus on children's vulnerabilities [172], identifying "sensitive areas" with stricter exposure limits where the young sleep, play and learn.

5G, the next generation of wireless technology, will utilize frequencies presently in use, plus higher frequency millimeter waves not previously used for commercial telecommunications. Regional governments, such as the Cantons of Geneva, Vaud and Neuchâtel in Switzerland, are issuing decrees calling for moratoriums on the rollout of 5G technology until the health effects are better understood [173–175].

7.1. Regional U.S. Guidelines and recommendations to limit RFR exposure in schools

In addition to national policies to reduce children's EMF exposures, several authorities in the U.S. have issued guidelines for schools. In 2014, the Collaborative for High Performance Schools (CHPS) [189], the leading organization for healthy schools in the U.S., first published recommendations to minimize exposure to both Extremely Low Frequency (ELF) magnetic fields and RFR. Criteria for "Low-EMF Best Practices" include:

- providing a wired local area network (LAN) for Internet access throughout the school;
- disabling all wireless transmitters on all devices;
- ensuring that all laptops or notebooks have an Ethernet port and a single physical switch to disable all wireless radios;
- providing easily accessible hard-wired phones for teacher and student use;
- prohibiting the installation or use of DECT cordless phones; and
- prohibiting the use of cell phones and other personal electronic devices in instructional areas.

In 2016, the New Jersey Educational Association [190] and the Maryland Children's Environmental Health and Protection Advisory Council (CEHPAC) [191] also issued recommendations to reduce RFR in school classrooms, including, "if a new classroom is to be built, or electrical work is to be carried out in an existing classroom, network cables can be added at the same time, providing wired network access with minimal extra cost and time."

Measures to reduce exposures regarding personal devices are listed in the Appendix.

8. Recommendations for the building industry

Rapidly evolving technology is resulting in an evolution of building systems, moving to integration of air quality control, power management, surveillance and access, communications and data management, etc. in "smart" buildings. Although wireless "Internet of Things" may be popularized as central to "smart" infrastructure and conveniences, key features can readily be physically connected non-wirelessly. Sinopoli detailed essential elements of design, construction (installation of cables/wiring), integration and operation of networked systems to improve indoor environments and function, and achieve efficiencies in indoor spaces [192].

Electromagnetic interference is another reason to minimize radiofrequency radiation RFR [193]. It can degrade operation of wireless systems (e.g., Wi-Fi), and sensitive electronic equipment (wired or wireless) such as for entertainment recording or medical applications. Addition of cell towers in proximity to unshielded areas (indoors or outdoors) can also cause signal interruptions and static. In the extreme, wireless systems can be shut down by malicious attack with strong signals "drowning out" signals on designated frequencies.

Health care policies have evolved to protect operation of essential equipment. Mobile phones were initially forbidden in hospitals due to risks of interference with operation of sensitive equipment. Based on limited study, it is now recommended that wireless devices be kept at a distance from sensitive equipment (e.g., in intensive care units [ICUs]) [194]. Today, wireless access for patients and the public is often provided in hospitals, and wireless devices are common in healthcare [195]. There is no evidence of clinical benefit, and reviews did not investigate potential clinical harms [195].

For any systems that are not "wired," architects, builders, owners and inhabitants all must operate within constraints of regulated RFR exposure levels. RFR exposure limits vary among jurisdictions, with the highest permitted personal exposures in the U.S.A. and Japan. Many countries adhere to the International Commission on Non-Ionizing

Table 1
Examples of national legislation limiting RFR.

Year	Country and Reference	Legislation
2016	French Polynesia [176]	Banned marketing of cell phones to children. Prohibited wireless in nursery schools.
2015	France [177]	Banned Wi-Fi from nursery schools. Decreed that in schools Wi-Fi be turned off as default, unless the teacher uses it for specific instruction. Wi-Fi hotspots must be labeled.
2014	Korea [178]	Mandated SAR labeling on cell phones and portable devices. Public health recommendations to reduce exposure to cell phone radiation.
2013	Belgium [179]	Banned marketing of cell phones to children below age 14. Phones designed for children below age 7 years are prohibited from sale.
2012	India [180]	Limited RF-EMF exposure levels from cell antennas to 1/10th of International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. Required SAR labeling on phones.
2012	Greece [181]	Forbade installation of mobile phone base stations on the premises of schools, kindergartens, hospitals or eldercare facilities.
2010	France [182]	Required that cell phones be sold with a headset and recommendation to limit exposure to the head. Cell phone advertising aimed at children below age 14 years was banned.

Radiation Protection (ICNIRP) recommended guidelines for power flux density, electrical fields and SAR for various frequencies [196]. Exposure limits range widely, for example in terms of power density at 900 MHz, as summarized in Fig. 3.

8.1. Building guidelines for lower electromagnetic field (EMF) exposures

Green building standards for occupants' health put great emphasis on indoor air quality, and the electromagnetic characteristics of the indoor environment are beginning to gain more widespread attention. This is exemplified by the aforementioned CHPS "Low-EMF Best Practices" in the U.S [189].

In Austria, Germany and Switzerland, however, electromagnetic fields and radiation exposures have long been a green building consideration. In Germany, the first precautionary exposure guideline for sleeping areas (SBM-2015) [28] was issued by Baubiologie Maes in cooperation with the Institute of Building Biology and Sustainability (IBN) in 1992. Based on thousands of electromagnetic assessments, radiofrequency radiation (RFR) levels in the bedroom below 0.1 $\mu W/m^2$ are considered "no anomaly." RFR levels above 1000 $\mu W/m^2$ (1 mW/m^2) are considered an "extreme anomaly."

The Total Quality Building Assessment Tool (TQB) is a widely used green building rating system [199], addressing a broader range of parameters than the Leadership in Energy and Environmental Design (LEED) rating system [27]. Since its inception in 2001 the TQB tool has included low-intensity EMFs and radiation – both low-frequency alternating magnetic fields and RFR. The TQB awards points in the planning and final testing stages for low levels of RFR.

The European Academy for Environmental Medicine (EUROPAEM) EUROPEAM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses [4] details recommendations for precautionary threshold electromagnetic exposure levels, including for RFR.

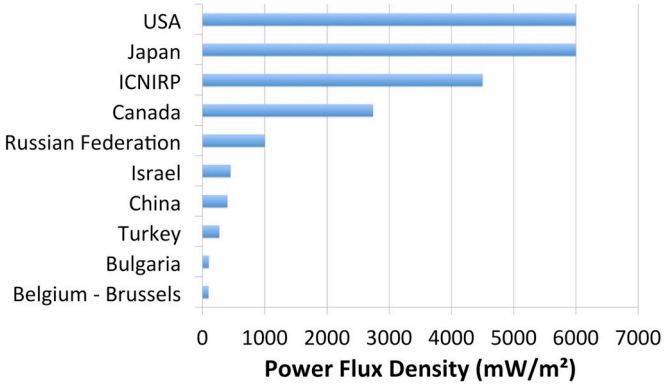

Fig. 3. International RFR power flux density exposure limits at 900 MHz [197,198].

To put these recommendations into context, the precautionary thresholds fall somewhere between the low natural background level and official exposure limits (Fig. 3). For comparison, Table 3 summarizes prudent, precautionary recommendations of European specialists.

The guiding principle of "as low as reasonably achievable" (ALARA) was introduced as early as the 1950s to protect against ionizing radiation [200] and holds true for many toxicants to the present day [91], including RFR [201]. RFR levels in indoor environments can be minimized by integrating the principal of ALARA (minimize emissions and exposures, maximize distance and use protection) [202] into selection of the building location, design and materials, as well as choices of electrical, monitoring, control, surveillance and other systems and services.

Table 2
Examples of national policies, public health advice and medical organization recommendations.

Year	Organization and Reference	Advice and Recommendations
2017	Athens Medical Association [183]	Sixteen recommendations to reduce human exposure to wireless radiation
2016	France - National Decree [184]	Reduced EMF exposure of workers, especially pregnant women
2016	US - American Academy of Pediatrics [185]	Ten recommendations to reduce exposure to cell phone radiation
2015	Cyprus National Committee on Environment and Child Health [186]	Public service videos and brochures for families about how to reduce cell phone and wireless exposure
2009, 2015	Finland - Radiation and Nuclear Safety Authority [187]	Recommendations to reduce RFR exposure, especially of children
2011	Parliamentary Assembly, Council of Europe [188]	"The potential dangers of electromagnetic fields and their effect on the environment" recommends As Low As Reasonably Achievable (ALARA), awareness, precautionary approaches, transparency, research, etc.
2010	France - National Public Health Agency [182]	An awareness campaign about ways to reduce RFR exposure

Table 3
Precautionary guidance RFR exposure levels [4,199].

		Exposure to 900–1800 MHz RFR (mW/m^2)
TQB Tool	Planning stage	
	10 points (best)	≤ 1
	5 points	≤ 3
	0 points	> 3
	Final stage	
	10 points	$S \leq 0.01$
	8 points	$0.01\ mW/m^2 < S \leq 0.1$
	6 points	$0.1\ mW/m^2 < S \leq 1$
	4 points	$1\ mW/m^2 < S \leq 3$
	0 points	> 3
EUROPAEM 9001800 MHz		
	Daytime	0.1
	During sleep	0.01
	Sensitive Populations	0.001
Natural Background		0.000000001

8.2. Strategies to eliminate or minimize RFR exposures from sources within buildings

As exemplified in section 8.1, engineers, architects, designers and planners have a unique opportunity to create healthier living, learning and work environments by reducing use of wireless technologies and thereby reducing levels of RFR. Although it is simpler, preferable and less expensive to implement RFR-free options during the initial design and construction stages, existing buildings represent many opportunities for improvements.

8.2.1. Connect necessary technologies with cables

An important first step to minimize levels of RFR within buildings is to eliminate indoor sources of RFR, and to connect all technologies via wire or fiber cable ("wired").

Consider alternative approaches to wireless technology. Recommendations include:

- Neighborhood infrastructure with cable access for high-speed, wired telephone and Internet;
- Within buildings use cables, preferably shielded, in Local Area Networks (LAN) to provide wired access points for all networking and data transmission, including wired connections for modems, routers, Internet and media; lighting, heating, ventilation, air conditioning (HVAC), thermostats and humidistats; surveillance and security systems; fire detection and response (e.g., sprinklers); pool equipment such as pump and treatment controls, etc.;
- Install easily accessible wired (not cordless) phones and prohibit installation and use of cordless phones;
- Throughout the building, provide connections to hardwired CAT6 or CAT7 Ethernet cables, preferably shielded, to service devices such as computers, tablets and other devices. Use wired peripherals and accessories. Ensure that all wireless features are turned off or disabled;
- Install wired RJ11 phone jacks for corded and landline telephones; and
- Use analog, non-transmitting utility (water, electricity, gas) meter options, that do not transmit data wirelessly.

8.3. Strategies to minimize the RFR exposures from external sources

8.3.1. Building location and landscaping

To achieve very low RFR levels, new buildings may be located in a low-RFR environment, for example at a distance from cell towers, radio and TV broadcast towers, and radar sites (e.g., airports). Evaluate the proposed location with professional grade RFR equipment to determine ambient RFR levels and sources. Sites in valleys may be at least partially protected from regional sources of RFR by surrounding hills, as may underground structures by intervening earth that absorbs RFR, depending upon composition and moisture level [203]. Conductivity and permittivity of soil increases with moisture content [204]; MW radiation is strongly absorbed by water.

Vegetation, with its significant water content, will absorb some RFR. While foliage of tall deciduous or evergreen trees may present challenges to wireless service providers, absorption of RFR from nearby antennas may also harm vegetation [126].

8.3.2. Building materials and shielding

RFR may be either reflected or absorbed by building materials, and there is a continuum of how opaque building elements are to RFR [204]. Shielding with highly absorbing or conductive materials can be very effective to reduce RFR originating from outdoors sources [205].

Many building materials such as wood and wallboard are largely transparent to present day RF signals, but research is intensifying on RFR-absorbing materials and fabrics that contain metals or carbon based substances (e.g., nanotubes) [206,207]. Construction materials are less effective barriers to RFR in the MHz and lower GHz frequency ranges, as currently used for cell phones, than for higher GHz frequencies planned for 5th generation (5G) technologies [208].

Absorption rather than reflection offers clear advantages for protection from RFR, and considerable relevant research has been devoted to materials that absorb radar [205]. Thick layers of dense building materials such as concrete offer some potential to absorb RFR and thereby reduce levels, particularly in the GHz range. Early research indicating high attenuation [209] was not precisely replicated with drier samples.

Conductive materials must be used with care and caution because reflections may result in unanticipated exposures. Totally enclosing a space with reflective materials (e.g., metal) results in a "Faraday cage." Radiation from sources within the "cage" reflects from one surface to another and this can result in higher local levels than would be the case if RFR was transmitted or absorbed by structural materials and furnishings.

To shield against incoming RFR from cell antennas, Wi-Fi networks and radio broadcast towers, shielding may be integrated across the entire building envelope or selected rooms or zones of a building.

Low-E windows coated with a transparent layer of metal oxides (developed to reflect infrared to retain heat in buildings and reflect ultraviolet light from the outdoors) and metals reflect RFR. Exterior shielding may be achieved with metal cladding/roofing, metal window and door frames, metal or metal-clad doors, low-E windows, metal screens, RF window film, and fine metal mesh or radiant barrier foil integrated into the building envelope. Further options indoors include high quality carbon-based shielding paints or fine metal mesh, and RF-shielding drapes/sheers. Conductive shielding materials including paint must be electrically connected and properly grounded.

It is essential to recognize that within shielded spaces, devices must have all wireless functions turned off. Poor network connections for cell phones will result in stronger RFR signals from the device itself, with potentially four-fold higher exposure to the user [210], and reflections from metal shielding may result in yet higher exposures. Thus, prominent explanatory safety notices are necessary to ensure that all cell phones are "off," set to "airplane mode," or are left outside of the low-RFR shielded zone. Options to meet occupants' needs include provision of accessible corded landline telephones to which cell phone calls can be forwarded, and provision of wired connections for devices.

Whatever options are used to achieve low RFR levels, it is necessary to verify final results with measurements using an RFR meter. RFR from equipment and exterior sources, along with reflections, and interactions with conductive infrastructure can result in complex, unanticipated patterns of electromagnetic fields, including hotspots [193,208]. Periodic checks are necessary to ensure that additional equipment,

furnishings or modifications, indoors or outdoors have not increased RFR levels.

Each make and model of RFR meter or measurement instrumentation has different specifications. To confirm the effectiveness of an RFR meter, obtain a third-party calibration report from a certified testing facility.

8.3.3. Partial RFR-Reduction measures for internet connectivity in buildings

In homes, schools, and workplaces, the installation and exclusive use of wired Internet access and electronic communication among devices mitigates the RFR emissions from internal network systems.

During any time that a wireless function is enabled, on stationary or mobile equipment, routine signals to maintain connections will expose building occupants to RFR, whether or not the device is actually being used.

In situations where decision makers decide not to hardwire a building immediately and instead continue with wireless connectivity, some partial measures may partially reduce unnecessary exposure. Importantly, these partial reduction steps do not equate with complete RFR mitigation, do not ensure safety for occupants, and do not reduce liability.

Recommendations include:

- Connect routers to a power source using a timer, to power off when not routinely in use, such as at bedtime;
- Wireless routers and access points should have an easily accessible switch to turn them off when not in use;
- Choose routers that can accommodate wired input, equipped with an accessible on/off switch for wireless features, and use a wired connection to a wired modem, to provide Internet connection when the wireless function is turned off;
- Avoid modems that also act as public “hot spots;”
- Do not install wireless access points near bedrooms or other highly or frequently occupied spaces;
- Clearly label wireless access points and areas where wireless antennas are in use;
- Use wired connections for HVAC monitoring and control, lighting, security and other fixed monitors and controllers;
- For improved security and lower carbon footprint, as well as reduced RFR, access data and controllers via a wired connection;
- If a wired analogue utility meter is not an option, mount the wireless meter at a distance, shield appropriately and direct signals to where they are read. Locate wireless meters away from high-use areas, particularly bedrooms; and
- If the building is mostly shielded, but has an unshielded zone for wireless device use, ensure that there is signage informing people: 1) of the RFR exposures along with wireless access (and alternatives onsite); and 2) the need to have all wireless functions turned off in shielded zones.

Implementation of partial measures will continue to expose occupants to RFR at levels associated with adverse effects. Measures such as turning off wireless features when not in use still result in RFR exposures, are not ALARA, and ideally will only be used in the interim while wiring plans are being developed and implemented.

8.4. Sensitive and vulnerable individuals

All of the above and more may need to be implemented to reduce RFR adequately in indoor and outdoor environments, to accommodate sensitive individuals. This will often require engaging an EMF expert, because the behavior of electromagnetic fields, currents and radiation is complex and difficult to predict. Sensitive individuals must be consulted throughout the duration of any renovation or building project, because individuals may react differently to various electromagnetic exposures. These individuals may also be sensitive to indoor air quality, so they must be involved in selection of materials for construction or retrofitting [2].

8.5. Challenging the business case of wireless systems

Not only are multiple risks invoked by choices of wireless instead of wired technology, there are many advantages to wired solutions.

Wireless networks [29,211]:

- continue to be about 100 times slower than wired systems;
- are unreliable, and more prone to both latency and delay issues;
- consume significant amounts of energy – more than wired – and are not sustainable;
- increase the points of vulnerability; and
- increase the security and privacy risks to personal and business data.

Some companies are cautioning that deployment of wireless 5G and beyond will be hampered by current regulatory power density exposure limits [212,213].

9. Discussion and conclusion

The breadth of peer-reviewed scientific research demonstrating biological effects of radiofrequency radiation (RFR) below current guidelines and standards highlights the need to further develop and codify pertinent building technology standards and guidance. Public health risks, accessibility needs, industrial liability and international precautionary actions indicate that RFR is an important performance parameter in building science.

Parallel with rapid innovation in wireless technologies, and the increasing RFR both inside and outside building structures, building science must also innovate to include alternative, physically connected technologies and systems. This is important to achieve accessibility and a building's success. Ensuring that the health and safety of occupants are not compromised requires those in the building science professions to develop and apply needs and means assessments, as well as best practices for methods and models for communications, with RFR wireless technology as a less-preferred option.

Research and knowledge transfer are needed to develop, publish, and encourage compliance with explicit directions for the integration of wired communications technologies in the design, planning, engineering, construction, operation and life cycle of a building.

Building science has embraced ecology and sustainability as core tenets in building performance. Currently, modern technologies minimizing RFR exposures offer an under-addressed opportunity for “smart” buildings also to be healthy – for their occupants, and for natural and built environments.

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Appendix

General Safety Tips to Reduce Radiofrequency Radiation (RFR) Exposure from Personal Devices

- Keep cell phones away from the head and body, and keep wireless devices at a distance, and off of laps.
- Make only short or essential calls on cell phones.
- Use text messaging instead of voice calls whenever possible.
- As much as possible power off phones and personal digital devices, or set on airplane mode with Wi-Fi, Bluetooth, Data, Mobile Hotspot and Location off.
- Avoid sleeping next to cell phones or wireless devices; power them

off at night. If a cell phone must be used as an alarm clock, turn the phone to airplane mode, or use a separate battery-powered clock.
- Keep non-prescription electronics out of bedrooms. If you depend upon medical devices with wireless functions, check how often they may be set to “airplane mode,” and ask your health care provider about adequate alternatives that do not emit RFR.
- Avoid charging phones and devices near beds.
- Use a corded (not cordless) home phone (wired [not wireless] VoIP or landline) whenever possible, especially for long voice calls.
- Pre-download videos and music rather than streaming.
- Minimize the number of apps running on wireless devices.
- Choose wired Internet connections instead of wireless systems, whenever possible. Provide wired Internet connections for others.
- If Wi-Fi cannot be entirely eliminated, put the Wi-Fi router on a timer to turn off when not needed (especially while sleeping).
- When digital devices are connected with wired Internet connections, turn off the Data, Wi-Fi and Bluetooth (in device settings) and turn off the Wi-Fi on the router.
- Request wired options and provide them to others, such as for computers, laptops, tablets, printers, gaming consoles and handsets, mouse, keyboards, video cameras, speakers, headphones, microphones and other accessories.

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ABSTRACT

Radiofrequency radiations (RFRs) emitted by mobile phone base stations have raised concerns on its adverse impact on humans residing in the vicinity of mobile phone base stations. Therefore, the present study was envisaged to evaluate the effect of RFR on the DNA damage and antioxidant status in cultured human peripheral blood lymphocytes (HPBLs) of individuals residing in the vicinity of mobile phone base stations and comparing it with healthy controls. The study groups matched for various demographic data including age, gender, dietary pattern, smoking habit, alcohol consumption, duration of mobile phone use and average daily mobile phone use. The RF power density of the exposed individuals was significantly higher ($p < 0.0001$) when compared to the control group. The HPBLs were cultured and the DNA damage was assessed by cytokinesis blocked micronucleus (MN) assay in the binucleate lymphocytes. The analyses of data from the exposed group ($n = 40$), residing within a perimeter of 80 m of mobile base stations, showed significantly ($p < 0.0001$) higher frequency of micronuclei when compared to the control group, residing 300 m away from the mobile base station/s. The analysis of various antioxidants in the plasma of exposed individuals revealed a significant attrition in glutathione (GSH) concentration ($p < 0.01$), activities of catalase (CAT) ($p < 0.001$) and superoxide dismutase (SOD) ($p < 0.001$) and rise in lipid peroxidation (LOO) when compared to controls. Multiple linear regression analyses revealed a significant association among reduced GSH concentration ($p < 0.05$), CAT ($p < 0.001$) and SOD ($p < 0.001$) activities and elevated MN frequency ($p < 0.001$) and LOO ($p < 0.001$) with increasing RF power density.

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Introduction

The mobile phone base stations are one of the essential parts of mobile telecommunication as they transmit the signals in the form of radiofrequency radiations (RFRs) that are received by the mobile phones, acting as a two-way radio, i.e. transceiver (Kwan-Hoong, 2005), generally operating in the frequency range of 900 MHz to 1.9 GHz (Levitt and Lai, 2010). The ever-increasing subscription of mobile phones has led to a phenomenal increase in the mobile phone base stations required to cater to the needs of increasing demand of the mobile subscribers. For decades, there has been an increasing concern on the possible adverse effects of RFR on humans living near mobile phone base stations despite the fact that RFR spectrum are of low frequency (ARPANSA, 2011). There has been a link between the RFR exposures and several human health disorders including cancer, diabetes, cardiovascular and neurological diseases (Bortkiewicz et al., 2004; Eger et al., 2004; Havas, 2013; Lerchl et al., 2015; Wolf and Wolf, 2004). The International Agency for Research on Cancer (IARC, 2011) has classified RFR as a possible carcinogen to humans (group 2B), based on the increased risk for glioma, a malignant type of brain cancer associated with wireless phone use (Hardell et al., 2013).

RFR may change the fidelity of DNA as the increased incidence of cancer has been reported among those residing near mobile phone base stations (Abdel-Rassonl et al., 2007; Bortkiewicz et al., 2004; Cherry, 2000; Eger et al., 2004; Hardell et al., 1999; Hutter et al., 2006; Wolf and Wolf, 2004). RFR emitted from mobile base stations is also reported to increase the DNA strand breaks in lymphocytes of mobile phone users and individuals residing in the vicinity of a mobile base station/s (Gandhi and Anita, 2005; Gandhi et al., 2014). Exposure of human fibroblasts and rat granulosa cells to RFR (1800 MHz, SAR 1.2 or 2 W/kg) has been reported to induce DNA single- and double-strands breaks (Diem et al., 2005). Irreversible DNA damage was also reported in cultured human lens epithelial cells exposed to microwave generated by mobile phones (Sun et al., 2006). The adverse health effects of RFR are still debatable as many studies indicated above have found a positive correlation between the DNA

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damage and RFR exposure; however, several studies reported no significant effect of RFR on DNA strand breaks and micronuclei formation in different study systems (Li et al., 2001; Tice et al., 2002; McNamee et al., 2003; Maes et al., 2006). The potential genotoxicity of RFR emitted by mobile phone base stations can be determined by micronucleus (MN) assay, which is an effective tool to evaluate the genotoxic or clastogenic effects of physical and chemical agents. This technique has also been used to quantify the frequencies of radiation-induced MN in human peripheral blood lymphocytes (HPBLs) (Fenech and Morley, 1985; Jagetia and Venkatesha, 2005; Prosser et al., 1988; Yildirim et al., 2010).

Besides its effect on DNA damage and association of cancer in individuals living near mobile phone base station, the deep penetration of RFR within the living cells may cause overproduction of free radicals particularly reactive oxygen species (ROS), thereby inducing adverse effects in living cells (Yakymenko et al., 2015). ROS amount is also reported to increase during infections, exercise, exposure to pollutants, UV light, ionizing radiations, etc. (Kunwar and Priyadarsini, 2011). Uncontrolled generations of ROS can lead to their accumulation causing oxidative stress in the cells. Any chronic exposure to conditions that increase the oxidative stress leads to an increased risk of cancer, and elevated levels of cancer have been demonstrated in populations with increased residential exposure to RFR (Dart et al., 2013; IARC, 2011). The change in the activities of antioxidants such as glutathione (GSH), superoxide dismutase (SOD) and catalase (CAT) may be regarded as an indicator of increased oxidative stress (Kerman and Senol, 2012). Since lipid peroxidation (LOO) is a free-radical oxidation product of polysaturated fatty acids, detection and measurement of LOO is the evidence which is frequently cited to support the involvement of free-radical reactions in toxicity and disease progression (Gutteridge, 1995). The increasing use of mobile phones and installation of more mobile base stations stimulated us to obtain an insight into the genotoxic effects of RFR using MN assay and alteration in the antioxidant status in the PBLs of the individuals residing in the vicinity of the mobile phone base stations.

Methods

Chemicals

RPMI-1640 medium, phytohemagglutinin, acridine orange, bovine serum albumin (BSA), GSH reduced, nicotinamide adenosine dinucleotide (NADH), nitrobluetetrazolium (NBT) and *n*-butanol were purchased from HiMedia laboratories Pvt Ltd. (Mumbai, Maharashtra, India). Methanol, acetic acid, Folin–Ciocalteu reagent, potassium tartarate, hydrogen peroxide (H_2O_2), trichloroacetic acid (TCA), hydrochloric acid (HCl) and potassium chloride (KCl) were purchased from MERCK (Mumbai, Maharashtra, India). Cytochalasin B, thiobarbaturic acid (TBA) and phenazinemethosulphate (PMS) were purchased from Sigma Aldrich Chemical Co (Bangalore, Karnataka, India) and 5,5′-dithio-2-nitrobenzoic acid (DTNB) was procured from Tokyo Chemical Industry (Tokyo, Japan).

Power density measurement from mobile phone base stations

Six mobile phone base stations, operating in the frequency range of 900 MHz ($N = 2$) and1800 MHz ($N = 4$), erected in the thickly populated areas of Aizawl city were selected for the present study. Both dish and sectored antennas of each base station are arranged equilaterally that provide 360° network coverage. The power output of all the base stations is 20 W, with their primary beam emitting radiation at an angle of 20°. Power density measurements (using HF-60105V4, Germany) were carried out in the bedroom of each participant where they spent most of the time and hence have the longest constant level of electromagnetic field exposure. Power density measurement was carried out three times (morning, midday and evening), and the average was calculated for each residence around each base station. The main purpose of the measurement of power density was to ensure that RFR emission from each site did not exceed the safe public limits and to determine any difference in power density between selected households that were close to (within 80 m) and far (>300 m) from the mobile phone base stations. The safety limits for public exposure from mobile phone base stations are 0.45 W/m^2 for 900 MHz and 0.92 W/m^2 for 1800 MHz frequency as per Department of Telecommunications, Ministry of Communications, Government of India, New Delhi guidelines (DoT, 2012).

Selection of subjects

The study was carried out in Aizawl city (23°43′37.58′′N and 92°43′3.49′′E), Mizoram, India, during 2015 and 2016. Since the city is located in the hilly region, some residences are located horizontally with the top of the towers from which RFR are emitted, making it possible to get an exposure at a short distance of 1–20 m, despite being erected on the rooftop or in the ground. A minimum of two individuals were sampled from each household and at least five individuals were sampled around each mobile base station. Individuals sampled around each base station were matched for their age and gender (Table 1). The exposed group consisted of 40 healthy

Table 1. Composition of base stations and the demographic characteristics of the exposed group.

	Components				Gender of volunteers	
Base station	Disc antenna	Sectored antenna	Power density (mW/m^2)	Average age (years) of volunteers	Male	Female
1	3	10	3.90–6.52	28.8	3	4
2	6	10	5.12–7.32	30.0	3	3
3	3	9	2.80–6.55	28.2	4	4
4	11	6	3.58–7.52	28.9	2	4
5	6	4	4.56–5.43	28.6	3	2
6	6	4	3.58–6.53	27.6	3	5

individuals who fulfilled the inclusion criteria of being above 18 years of age and residing in the vicinity of mobile phone base stations (within 80 m radius). The control group comprised of 40 healthy individuals matched for age and gender who had been living at least 300 m away from any mobile phone base stations. None of the participants have occupational exposure to RFR, and there were no electric transformer, high tension electric power line and radio and television transmitters close to (at least 500 m) their residences. Sampling was also done only from those residences who did not use microwave oven for cooking, Wifi devices and any other major source of electromagnetic field as they are known to cause adverse effects (Atasoy et al., 2013; Avendaño et al., 2012). The study was approved by the Human Ethics Committee, Mizoram University, Aizawl, India, and only those individuals who gave their voluntary written consent were included in the study.

Questionnaire used

A questionnaire was prepared to collect information on demographic data such as family and exposure histories, lifestyle such as smoking habit (≤10 cigarette in a day), alcohol consumption (three to four times a week) and dietary pattern, duration of stay near mobile phone base stations, duration of mobile phone use and average daily mobile phone use.

Blood sample collection and lymphocyte culture

The blood samples were collected by venipuncture from each volunteer of both groups in individual heparinized tubes. The lymphocyte culture was carried out according to the method described earlier (Jagetia et al., 2001). Briefly, the blood was allowed to sediment and the buffy coat containing nucleated cells was collected in individual sterile glass tubes. Usually 10^6 nucleated cells were inoculated into sterile glass tubes containing RPMI-1640 medium, supplemented with 10% fetal calf serum and phytohemagglutinin as the mitogen. The cells were allowed to grow for the next 44 h and cytochalasin B was added at a final concentration of 5 µg/ml to block the cytokinesis (Fenech and Morley, 1985). The cells were harvested at the end of 72 h after initiation of lymphocyte culture by centrifugation. The cell pellet was subjected to mild hypotonic treatment so as to retain the cell membrane and fixed in freshly prepared Carnoy's fixative (methanol: acetic acid, 3:1). The cell suspension was dropped onto precleaned coded slides to avoid observer's bias and stained with acridine orange. Usually a total of 1000 binucleate cells (BNCs) with well-preserved cytoplasm were scored from each individual using a fluorescence microscope (DM 2500, Leica MikrosystemeVertrieb GmbH, Wetzlar, Germany). Scoring of MN frequencies was performed based on the criteria of Fenech et al. (2003).

Biochemical estimations

The antioxidants were measured in the plasma of the study groups. Protein contents were measured by the method of Lowry et al. (1951) using BSA as the standard.

Glutathione

GSH contents were measured using the method given by Moron et al. (1979). Briefly, 80 µl of plasma was mixed with 900 µl of 0.02 M sodium phosphate buffer and 20 µl of 10 mM DTNB and incubated for 2 min at room temperature. The absorbance of the sample was read against blank at 412 nm in a UV-Visible spectrophotometer (SW 3.5.1.0. Biospectrometer, Eppendorf India Ltd., Chennai), and the GSH concentration was calculated from the standard curve and expressed in µmol/mg protein.

Superoxide dismutase

The SOD activity was measured by the method of Fried (1975). Briefly, 100 µl each of plasma and 186 µM PMS were mixed with 300 µl of 3 mM NBT and 200 µl of 780 µM NADH. The mixture was incubated for 90 s at 30°C and 1 ml of acetic acid and 4 ml of *n*-butanol were added to stop the reaction. The blank consisted of all the reagents, and distilled H_2O was added instead of plasma. The absorbance of test and blank was measured at 560 nm using a UV-VIS spectrophotometer, and the

enzyme activity has been expressed in units (1U = 50% inhibition of NBT reduction)/mg protein.

% inhibition = (OD of blank − OD of test/OD of blank) × 100
SOD unit = 1/50 × % inhibition.

Catalase

The CAT activity was determined using the modified protocol of Aebi (1984). Briefly, 200 µl of 3% H_2O_2 was mixed with 50 µl each of plasma and 150 µl of 50 mM phosphate buffer (pH 7.0). The absorbance was recorded at 240 nm in a UV-VIS spectrophotometer. The decomposition of H_2O_2 can be followed directly by the decrease in absorbance. The enzyme activity has been expressed in units/mg protein. The catalytic activity of CAT at a time interval of 15 s was calculated by the following formula,

$$K = 0.153\,(\log A_0/A_1)$$

where A_0 is the absorbance at 0 s and A_1 is the absorbance at 15 s.

Lipid peroxidation

The LOO was estimated by the method of Beuege and Aust (1978). Briefly, plasma was mixed with 10% TCA, 0.8% TBA and 0.025 N HCl in a 1:2 ratio. The mixture was boiled for 10 min in a boiling water bath. After centrifugation, the absorbance of the supernatant was recorded at 540 nm UV-VIS spectrophotometer.

Statistical analyses

The data are expressed as mean ± standard error of the mean. Student's "*t*" and Chi-square tests were used for comparison of demographic variables of the exposed and control groups. Pearson`s correlation analysis was performed to determine the relationship between power density and the distance of residences from the base stations. Mann Whitney *U* test was applied to determine the significance between the control and exposed group for MN frequencies. Student's "*t*" test was performed to determine the significance between the groups for antioxidants. Multiple linear regression analyses were carried out for the prediction of MN frequency and antioxidants status separately from the demographic characteristics. SPSS Ver.16.0 software (SPSS Inc, Chicago, IL, USA) was used for statistical analyses. A *p*-value of less than 0.05 was considered statistically significant.

Results

The demographic characteristics of both exposed and control groups are depicted in Table 2. The groups matched for most of the demographic data such as age, gender, dietary pattern, smoking habit, alcohol consumption, mobile phone usage, duration of mobile phone use and average daily mobile phone use (Table 2). A highly significant variation ($p < 0.0001$) was observed for the distance of household from the base station (40.10 ± 3.02 vs. 403.17 ± 7.98 in m) between exposed and control groups. The data of RF

Table 2. Demographic data of the exposed and control groups.

		Exposed group		Control group			*p*-value
Characteristics	Category	*N* (%)	M±SEM	*N* (%)	M±SEM	t/χ^2-value	(t/χ^2-value)
Age (years)	20–30	26 (65)	28.6 ± 0.85	29 (72.5)	28.6 ± 0.85	1.074/–	0.286/–
	31–40	14 (35)		11 (27.5)			
Gender	Male	18 (45)		21 (52.5)		–/0.450	–/0.502
	Female	22 (55)		19 (47.5)			
Diet	Vegetarian	5 (12.5)		7 (17.5)		–/0.392	–/0.531
	Nonvegetarian	35 (87.5)		33 (82.5)			
Smoking habit	Yes	16 (40)		14 (35)		–/0.213	–/0.644
	No	24 (60)		26 (65)			
Alcohol consumption	Yes	7 (17.5)		9 (22.5)		–/0.312	–/0.576
	No	33 (82.5)		31 (77.5)			
Mobile phone usage	User	37 (92.5)		35 (87.5)		–/0.556	–/0.456
	Nonuser	3 (7.5)		5 (12.5)			
Duration of mobile phone use (years)	≤5	9 (24.32)	6.32 ± 0.265	11 (31.42)	5.91 ± 0.296	1.032/–	0.306/–
	>5	28 (75.68)		24 (68.58)			
Daily mobile phone use (hours)	≤3	24 (64.86)	3.054 ± 0.229	25 (71.42)	2.800 ± 0.156	1.145/–	0.256/–
	>3	13 (35.13)		10 (28.58)			
Distance from the base station (m)	1–20	8 (20)	40.10 ± 3.02		403.17 ± 7.98	42.046/–	0.0001/–
	21–40	12 (30)					
	41–60	13 (32.5)					
	61–80	7 (17.5)					
Power density (mW/m^2)	Range	2.80–7.52	5.002 ± 0.182	0.014–0.065	0.035 ± 0.002	27.247/–	0.0001/–
Duration of residing near the base station (years)	5–10	33 (82.5)	7.85 ± 0.419	–	–	–	–
	11–15	7 (17.5)					

power density were collected from 23 houses, each of the exposed group staying within a perimeter of 80 m and those of control group staying at least 300 m away from mobile phone base stations. The RF power density of the exposed group (2.80–7.52 mW/m^2; average 5.002 ± 0.182 mW/m^2) was significantly higher ($p < 0.0001$) when compared to the control group (0.014–0.065 mW/m^2; average 0.035 ± 0.002 mW/m^2). The highest power density was recorded at a distance of 1–20 m (6.44 ± 0.31 mW/m^2), which is significantly higher ($p < 0.0001$) than those at a distance of 21–40 m (4.79 ± 0.33), 41–60 m (4.48 ± 0.22) and 61–80 m (4.61 ± 0.10). No significant variation was observed for the RFR power density among the distance ranges of 21–40 m, 41–60 m and 61–80 m (Table 1). Nevertheless, there was a highly significant negative correlation between distance from the base station and the power density ($r = -0.509$, $p < 0.0001$).

The MN frequency and LOO were significantly ($p < 0.0001$ for MN and LOO) higher in the exposed group as compared to that of control group, while antioxidants were significantly ($p < 0.01$ for GSH; $p < 0.001$ for CAT and SOD) lower for the exposed group compared to controls irrespective of their demographic characteristics (Tables 3 and 4). On consideration of the demographic characteristics, smokers had significantly higher MN frequency ($p < 0.001$) and LOO ($p < 0.01$) and significantly lower GSH ($p < 0.01$) and SOD ($p < 0.01$) than nonsmokers within each study group. Similarly, alcoholics compared to nonalcoholics had significantly higher MN frequency ($p < 0.01$) and significantly lower GSH ($p < 0.01$) within the exposed group and significantly higher MN frequency ($p < 0.001$) and LOO ($p < 0.01$) within the control group. The smokers of the exposed group had significantly higher MN frequency ($p < 0.001$) and LOO ($p < 0.01$) and significantly lower CAT ($p < 0.001$) and SOD ($p < 0.05$) activities than the smokers of control group. Alcoholic among exposed group also had significantly higher MN frequency ($p < 0.05$) and significantly lower GSH ($p < 0.05$) concentration and CAT ($p < 0.01$) and SOD ($p < 0.05$) activities than the alcoholic of control group. MN frequency and antioxidant status with LOO showed no significant variations between the ages, genders and dietary pattern within the exposed group. Among controls, males compared to females had significantly ($p < 0.05$) higher MN frequency (Table 3).

There was no significant variation in the MN frequency and antioxidant status between mobile phone user and nonuser of exposed group, while individuals who have been using mobile phone for more than 5 years had significantly higher MN frequency ($p < 0.01$) and lower GSH ($p < 0.05$) than those using for less than 5 years. Similarly, exposed group with average daily mobile phone use of above 3 h showed a higher MN frequency ($p < 0.05$) than those having the average daily use of less than 3 h (Table 4). Among the control group, features of mobile phone usage showed no variation in MN frequency and antioxidant status. Significantly lower levels of antioxidants ($p < 0.05$ for GSH; $p < 0.001$ for CAT; $p < 0.01$ for SOD) and higher

Table 3. Function of the demographic characteristics on MN frequencies and the antioxidant status of exposed and control groups.

				GSH	CAT	SOD	LOO	MN/1000 BNC
	Characteristics	Category	*N*	(M±SEM)	(M±SEM)	(M±SEM)	(M±SEM)	(M±SEM)
EXPOSED GROUP	Age (years)	20–30	26	4.604 ± 2.68**	0.022 ± 0.001***	1.832 ± 0.11***	0.646 ± 0.064***	38.15 ± 1.65**
		31–40	14	3.882 ± 2.09	0.021 ± 0.001***	1.791 ± 0.11**	0.755 ± 0.101*	43.71 ± 2.64**
		Total	40	4.351 ± 1.95**	0.021 ± 0.001***	1.823 ± 0.08***	0.677 ± 0.054***	40.10 ± 1.46***
	Gender	Male	18	4.209 ± 3.08*	0.020 ± 0.001***	1.802 ± 0.12**	0.667 ± 0.072**	40.77 ± 2.71*
		Female	22	4.467 ± 2.54	0.023 ± 0.001***	1.834 ± 0.11***	0.686 ± 0.080**	39.54 ± 1.51***
	Dietary pattern	Vegetarian	5	4.360 ± 4.26*	0.019 ± 0.001**	1.913 ± 0.18**	0.650 ± 0.040***	40.20 ± 2.87***
		Nonvegetarian	35	4.350 ± 2.17*	0.022 ± 0.001***	1.807 ± 0.09***	0.682 ± 0.053***	40.08 ± 1.63***
	Smoking habit	Yes	16	3.713 ± 2.28[a]	0.022 ± 0.001***	1.645 ± 0.11*	0.892 ± 0.102[a]**	46.50 ± 1.65[a]***
		No	24	4.777 ± 2.56**	0.021 ± 0.001***	1.932 ± 0.11***	0.535 ± 0.039**	35.83 ± 1.69***
	Alcohol consumption	Yes	7	3.394 ± 2.35[a]*	0.021 ± 0.001**	1.792 ± 0.22*	0.683 ± 0.119	49.71 ± 3.12[a]*
		No	33	4.554 ± 2.16*	0.022 ± 0.001***	1.823 ± 0.08***	0.676 ± 0.061**	38.27 ± 1.47***
CONTROL GROUP	Age (years)	20–30	29	5.380 ± 1.54	0.038 ± 0.001	2.534 ± 0.09	0.389 ± 0.037	31.89 ± 1.64
		31–40	11	4.023 ± 3.82	0.036 ± 0,002	2.492 ± 0.21	0.482 ± 0.062	35.09 ± 1.96
		Total	40	5.007 ± 1.79	0.037 ± 0.001	2.526 ± 0.09	0.415 ± 0.032	32.77 ± 1.31
	Gender	Male	21	5.067 ± 2.70	0.038 ± 0.002	2.434 ± 0.11	0.385 ± 0.049	35.23 ± 1.99[a]
		Female	19	4.940 ± 2.38	0.037 ± 0.001	2.622 ± 0.14	0.447 ± 0.040	30.05 ± 1.49
	Dietary pattern	Vegetarian	7	5.473 ± 2.53	0.039 ± 0.003	2.845 ± 0.17	0.378 ± 0.066	29.85 ± 1.95
		Nonvegetarian	33	4.908 ± 1.08	0.037 ± 0.001	2.453 ± 0.10	0.423 ± 0.038	33.39 ± 1.52
	Smoking habit	Yes	14	3.996 ± 2.66[a]	0.036 ± 0.002	2.181 ± 0.17[a]	0.522 ± 0.055[a]	39.78 ± 1.70[a]
		No	26	5.551 ± 1.53	0.040 ± 0.001	2.717 ± 0.08	0.356 ± 0.036	29.00 ± 1.30
	Alcohol consumption	Yes	9	4.416 ± 2.91	0.036 ± 0.002	2.212 ± 0.23	0.546 ± 0.073[a]	42.44 ± 2.29[a]
		No	31	5.178 ± 2.07	0.038 ± 0.001	2.616 ± 0.09	0.376 ± 0.033	29.96 ± 1.15

*Significant ($p \leq 0.05$) between the exposed and control groups.
**Highly significant ($p \leq 0.01$) between the exposed and control groups.
***Very highly significant ($p \leq 0.001$) between the exposed and control groups.
[a]Significant ($p \leq 0.05$) along the demographic characteristics within group.

Table 4. Function of mobile phone usage and residence near base stations on MN frequencies and antioxidants status on exposed and control groups.

				GSH	CAT	SOD	LOO	MN/1000 BNC
	Characteristics	Category	*N*	(M±SEM)	(M±SEM)	(M±SEM)	(M±SEM)	(M±SEM)
EXPOSED GROUP	Mobile phone usage	User	37	4.336 ± 2.07**	0.020 ± 0.002***	1.852 ± 0.08***	0.66 ± 0.051***	40.21 ± 1.55***
		Nonuser	3	4.534 ± 6.04	0.022 ± 0.001***	1.394 ± 0.10*	0.890 ± 0.205*	38.66± 1.37**
	Duration of mobile phone use (years)	≤5	9	5.006 ± 3.26[a]	0.023 ± 0.002**	1.834 ± 0.23**	0.673 ± 0.109*	34.77 ±3.23[a]
		>5	28	4.145 ± 2.24**	0.021 ± 0.001***	1.863 ± 0.08***	0.656 ± 0.058**	41.96 ±1.66***
	Daily mobile phone use (hours)	≤3	24	4.410 ± 1.26*	0.023 ± 0.001***	1.902 ± 0.11***	0.653 ± 0.068**	37.87 ±1.99[a*]
		>3	13	4.233 ± 1.73*	0.020 ± 0.001***	1.765 ± 0.13***	0.674 ± 0.073**	44.53 ±2.02***
	Distance from the base station (m)	1–20	8	3.884 ± 2.20**	0.018 ± 0.002***	1.654 ± 0.18***	0.720 ± 0.154**	43.00 ± 3.94**
		21–40	12	4.174 ± 3.72*	0.020 ± 0.001***	1.762 ± 0.13***	0.674 ± 0.106**	41.69 ± 2.49**
		41–60	13	4.692 ± 3.23	0.022 ± 0.001***	1.903 ± 0.15**	0.600 ± 0.069*	39.00 ± 1.24*
		61–80	7	4.631 ± 6.44	0.025 ± 0.002**	2.016 ± 0.17*	0.494 ± 0.084	36.71 ± 2.57
	Duration of residence near the base station (years)	5–10	33	4.406 ± 2.25*	0.024 ± 0.001***	1.872 ± 0.08**	0.642 ± 0.055***	40.03 ± 3.13**
		11–15	7	4.092 ± 2.54*	0.021 ± 0.001***	1.814 ± 0.12**	0.781 ± 0.170***	40.42 ± 1.66**
	Power density (mW/m^2)	≤4 mW/m^2	7	4.554 ± 2.22*	0.025 ± 0.002**	1.915 ± 0.16*	0.660 ± 0.122**	39.14 ±0.21*
		>4 mW/m^2	33	4.308 ± 2.32**	0.021 ± 0.001***	1.807 ± 0.09***	0.681 ± 0.061***	40.30 ± 1.59***
CONTROL GROUP	Mobile phone usage	User	35	5.145 ± 1.86	0.037 ± 0.001	2.550 ± 0.09	0.417 ± 0.035	32.28 ± 1.40
		Nonuser	5	4.038 ± 4.21	0.041 ± 0.004	2.282 ± 0.25	0.456 ± 0.022	31.80± 1.22
	Duration of mobile phone use (years)	≤5	11	5.528 ± 2.24	0.036 ± 0.003	2.553 ± 0.10	0.372 ± 0.062	31.09 ± 1.88
		>5	24	5.039 ± 2.31	0.037 ± 0.001	2.568 ± 0.13	0.438 ± 0.043	32.83 ± 1.87
	Daily mobile phone use (hours)	≤3	25	5.258 ± 1.99	0.038 ± 0.001	2.524 ± 0.11	0.436 ± 0.041	30.10± 2.46
		>3	10	5.027 ± 3.75	0.036 ± 0.001	2.655 ± 0.19	0.371 ± 0.070	33.16 ± 1.70

*Significant ($p \leq 0.05$) between the exposed and control groups.
**Highly significant ($p \leq 0.01$) between the exposed and control groups.
***Very highly significant ($p \leq 0.001$) between the exposed and control groups.
[a]Significant ($p \leq 0.05$) along the demographic characteristics within group.

MN frequency ($p < 0.001$) and LOO ($p < 0.001$) were observed in the exposed group residing in the vicinity of the base stations for 5–10 years and 11–15 years when compared to the control group. None of the parameters showed a significant variation among the exposed group residing for 5–10 years and 11–15 years in the vicinity of the base stations (Table 4).

As a function of distance from the base stations, MN frequency and LOO within the distance of 1–20 m ($p < 0.01$ for MN and LOO), 21–40 m ($p < 0.01$ for MN and LOO) and 41–60 m ($p < 0.05$ for MN and LOO) were significantly higher in the exposed group than that of the control group. There were no significant variation in MN frequency and LOO between the exposed group residing within 61–80 m away from mobile stations and the control group. GSH, CAT and SOD were significantly lower in the exposed group residing within a distance range of 1–20 m ($p < 0.01$ for GSH; $p < 0.001$ for CAT; $p < 0.001$ for SOD), 21–40 m ($p < 0.05$ for GSH; $p < 0.001$ for CAT; $p < 0.001$ for SOD), 41–60 m ($p < 0.001$ for CAT; $p < 0.01$ for SOD) and 61–80 m ($p < 0.01$ for CAT; $p < 0.05$ for SOD) than individuals residing at least 300 m away from the base stations. However, GSH contents did not differ between the exposed group residing between 41 and 80 m from the base stations and controls (Table 4). The individuals exposed to a power density of ≤4 mW/m^2 and >4 mW/m^2 showed a higher MN frequency ($p < 0.05$ for ≤4 mW/m^2; $p < 0.001$ for >4 mW/m^2) and LOO ($p < 0.01$ for ≤4 mW/m^2; $p < 0.001$ for >4 mW/m^2) and lower GSH ($p < 0.05$ for ≤4 mW/m^2; $p < 0.01$ for >4 mW/m^2), CAT ($p < 0.01$ for ≤4mW/m^2; $p < 0.001$ for >4 mW/m^2) and SOD ($p < 0.05$ for ≤4 mW/m^2; $p < 0.001$ for >4 mW/m^2) (Table 4).

Multiple linear regression analyses revealed a significant association with low GSH concentration and age ($p < 0.05$), smoking habit ($p < 0.001$), daily mobile phone use ($p < 0.05$) and increasing power density ($p < 0.05$). A similar association has been reported with reduced CAT activity with increasing power density ($p < 0.001$) and alleviated SOD activity with smoking habit ($p < 0.05$) and increasing power density ($p < 0.001$) (Table 5). The analyses also showed a significant relationship between higher MN frequency with smoking habit ($p < 0.001$) and increasing power density ($p < 0.001$) and higher LOO with smoking habit ($p < 0.001$), alcohol consumption ($p < 0.05$) and increasing power density ($p < 0.001$) (Table 5). The parameter of mobile phone usage was not included in the multiple linear regression analysis due to multicollinearity with the duration of mobile phone use and average daily mobile phone use. Similarly, distance from the base stations showed multicollinearity with power density in the preliminary analysis; therefore, the former is also excluded in the multiple linear regression analysis.

Discussion

Mobile phone base stations have become an integral part of telecommunication, which use RFR to transmit the signals. These electromagnetic waves are generated by

Table 5. Multiple linear regression in the exposed and control groups.

	Characteristics	Durbin–Watson	Model-*F*	*B*-value	*t*-value	*p*-value
GSH	Age	2.22	6.62***	−0.24	−2.10	**0.043**
	Gender			0.11	1.09	0.283
	Dietary pattern			−0.10	−0.99	0.328
	Smoking habit			0.44	−3.86	**0.001**
	Alcohol consumption			−0.06	−0.47	0.640
	Duration of mobile phone use			−0.09	−0.69	0.492
	Daily mobile phone use			0.22	2.06	**0.039**
	Power density			−0.18	−1.97	**0.041**
CAT	Age	2.10	11.19***	−0.09	−0.94	0.352
	Gender			0.03	0.29	0.774
	Dietary pattern			0.01	0.12	0.907
	Smoking habit			−0.01	−0.07	0.950
	Alcohol consumption			0.03	0.29	0.771
	Duration of mobile phone use			0.01	0.08	0.944
	Daily mobile phone use			−0.07	−0.77	0.447
	Power density			−0.72	−8.93	**0.001**
SOD	Age	2.23	4.94***	0.01	0.11	0.911
	Gender			0.00	0.01	0.993
	Dietary pattern			−0.12	−1.22	0.237
	Smoking habit			−0.32	−2.70	**0.012**
	Alcohol consumption			0.01	0.10	0.923
	Duration of mobile phone use			0.11	0.81	0.426
	Daily mobile phone use			−0.07	−0.61	0.551
	Power density			−0.46	−4.74	**0.001**
LOO	Age	1.82	6.53***	0.22	1.96	0.052
	Gender			−0.13	−1.30	0.208
	Dietary pattern			0.11	1.13	0.262
	Smoking habit			0.47	4.12	**0.001**
	Alcohol consumption			−0.15	−1.25	0.210
	Duration of mobile phone use			−0.01	−0.05	0.965
	Daily mobile phone use			0.02	0.15	0.886
	Power density			0.37	3.99	**0.001**
MN	Age	2.17	11.10***	0.09	0.87	0.390
	Gender			−0.05	−0.58	0.572
	Dietary pattern			0.03	0.38	0.718
	Smoking habit			0.44	4.41	**0.001**
	Alcohol consumption			0.28	2.62	**0.013**
	Duration of mobile phone use			−0.04	−0.34	0.733
	Daily mobile phone use			0.06	0.58	0.562
	Power density			0.36	4.45	**0.001**

Values in bold are significant ($p < 0.05$).

electric charges that are rapidly accelerated to and fro in the transmitting antenna. Although RFR are nonionizing electromagnetic radiations, yet there has been a great concern about their deleterious effects on the human body as it is assumed that RFR could produce some of the biological effects akin to those produced by ionizing radiations such as X or γ-rays. Because of its adverse health effects reported worldwide, the presence of mobile base stations in the residential areas could be an electromagnetic threat, which is silently creeping in the lives of residents staying near the mobile base stations. We have therefore attempted to obtain an insight into the adverse effects of RFR in the inhabitants residing in the vicinity (within 80 m) of mobile base stations emitting RFR for mobile connectivity.

The frequency of nonspecific health symptoms such as nausea, loss of appetite, visual disturbance, irritability and depression were found to be significantly higher in the population living close (within 100 m) to mobile phone base stations as compared to those living away from these stations (Santini et al., 2002, 2003). Besides the nonspecific health symptoms of fatigue, headache, dizziness and muscle pain self-reported by the volunteers in the earlier study (Pachuau et al., 2015), the present study showed a significant increase in MN frequency and decreased antioxidants among inhabitants residing close to the base station/s when compared to controls. A number of studies have reported an increase in the DNA damage/micronuclei in different study systems. The human PBLs exposed to RFR have shown an increased frequency of micronuclei earlier (d'Ambrosio et al., 2002; Garaj-Vrhovac et al., 1992; El-Abd and Eltoweissy, 2012; Tice et al., 2002; Zotti-Martelli et al., 2000). Various studies conducted in other systems have also revealed an increased micronuclei frequency after exposure to RFR (Balode, 1996; Busljeta et al., 2004; Gandhi and Singh, 2005; Trosic et al., 2002, 2004). Our results are in agreement with a recent study where buccal mucosa cells showed increased micronuclei in mobile phone users (Banerjee et al., 2016). However, some of the studies did not find any increase in the MN frequency after RFR exposure both *in vitro* and *in vivo* (Bisht et al., 2002; Scarfi et al., 2006; Vijayalaxmi et al., 1997, 1999, 2001; Zeni et al., 2003, 2008), and such reports emphasized on the lack of thermal effects from RFR

(Vijaylaxmi and Obe, 2004), whereas the observed effect in the present study may be due to the interaction of RFR with various cellular macromolecules by producing ROS. This contention is supported by the fact that RFR-exposed individuals showed increased LOO and alleviated GSH contents, CAT and SOD activities in the present study. A similar effect has been observed earlier in the CAT activity in the rats exposed to low level of RFR (Achudume et al., 2010). Also, RFR emitted from cell phones led to oxidative stress in human semen (Agarwal et al., 2009). RFR (2.45 GHz) has been reported to cause a significant increase in the LOO of exposed Wistar rats (Aweda et al., 2003). The present study also revealed the induction of LOO by RF radiation, which could possibly react with DNA and produce lesions in it. The increased LOO has been reported in the plasma of rats with a decline in GSH and other antioxidants earlier (Aydin and Akar, 2011).

The highest measured power density was 7.52 mW/m^2. Most of the measured values close to base stations (Table 1) are higher than that of the safe limits recommended by Bioinitive Report 2012 (0.5 mW/m^2), Salzburg resolution 2000 (1 mW/m^2) and EU (STOA) 2001 (0.1 mW/m^2). However, all the recorded values were well below the current ICNIRP safe level (4700 mW/m^2) and the current Indian Standard (450 mW/m^2). Although cigarette smoking increased the MN frequency and decreased the antioxidants, the statistical analysis also revealed a close correlation between the power density and MN frequency and antioxidant status. Thus, the effects of RF radiation cannot be ignored as unrepaired DNA damage and oxidative stress are associated with several diseases such as cancer and several age-related diseases (Bernstein et al., 2013; Dart et al., 2013). The persistence of low level of DNA damage could have negative effect on human health.

The exact mechanism of action of RFR in micronuclei induction and reduced antioxidant status is not apparent. The possible putative mechanism of generation of DNA damage may be the production of endogenous free radicals due to continuous exposure. RFR has been reported to produce different free radicals earlier (Avci et al., 2009; Burlaka et al., 2013; Barcal et al., 2014; Kazemi et al., 2015). Cells possess a number of compensatory mechanisms to deal with ROS and its effects. Among these are the induction of antioxidant proteins such as GSH, SOD and CAT. Enzymatic antioxidant systems function by direct or sequential removal of ROS, thereby terminating their activities. An imbalance between the oxidative forces and antioxidant defense systems causes oxidative injury, which has been implicated in various diseases, such as cancer, neurological disorders, atherosclerosis, diabetes, liver cirrhosis, asthma, hypertension and ischemia (Andreadis et al., 2003; Comhair et al., 2005; Dhalla et al., 2000; Finkel and Holbrook, 2000; Kasparova et al., 2005; Sayre et al., 2001; Sohal et al., 2002). Because of the significant decrease in endogenous antioxidants and increased LOO among the exposed group, the extra burden of free radicals is unlikely to get neutralized, and these surplus ROS may react with important cellular macromolecules including DNA forming either DNA adducts or stand breaks, which may be later expressed as micronuclei once the cell decides to divide. The decline in the antioxidant status may be also due to the suppressed activity of Nrf2 transcription factor which is involved in maintaining the antioxidant status in the cells.

The present study has reported that RFR increased the frequency of MN and LOO and reduced GSH contents, CAT and SOD activities in the plasma of the exposed individuals. The induction of MN may be due to the increase in free-radical production. The present study demonstrated that staying near the mobile base stations and continuous use of mobile phones damage the DNA, and it may have an adverse effect in the long run. The persistence of DNA unrepaired damage leads to genomic instability which may lead to several health disorders including the induction of cancer.

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Declaration of interest

The authors report no declarations of interest.

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Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – a review

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Abstract
This paper summarizes the effect of radio-frequency electromagnetic field (RF-EMF) from cell towers and wireless devices on the biosphere. Based on current available literature, it is justified to conclude that RF-EMF radiation exposure can change neurotransmitter functions, blood-brain barrier, morphology, electrophysiology, cellular metabolism, calcium efflux, and gene and protein expression in certain types of cells even at lower intensities. The biological consequences of such changes remain unclear. Short-term studies on the impacts of RF-EMF on frogs, honey bees, house sparrows, bats, and even humans are scarce and long-term studies are non-existent in India. Identification of the frequency, intensity, and duration of non-ionizing electromagnetic fields causing damage to the biosystem and ecosystem would evolve strategies for mitigation and would enable the proper use of wireless technologies to enjoy its immense benefits, while ensuring one's health and that of the environment.

Keywords: Radio-frequency electromagnetic field; cell phone tower; power density; SAR; non-ionizing radiation; non-thermal.

Introduction

There has been an unprecedented growth in the global communication industry in recent years which has resulted in a dramatic increase in the number of wireless devices. Mobile services were launched in India in 1995 and it is one of the fastest growing mobile telephony industries in the world. According to the Telecom Regulatory Authority of India (TRAI, 2012), the composition of telephone subscribers using wireless form of communication in urban area is 63.27% and rural area is 33.20%. By 2013, it is estimated that more than one billion people will be having cell phone connection in India. This has led to the mushrooming of supporting infrastructure in the form of cell towers which provide the link to and from the mobile phone. With no regulation on the placement of cell towers, they are being placed haphazardly closer to schools, creches, public playgrounds, on commercial buildings, hospitals, college campuses, and terraces of densely populated urban residential areas. Hence, the public is being exposed to continuous, low intensity radiations from these towers. Since the electromagnetic radiations, also known as electrosmog cannot be seen, smelt or felt, one would not realize their potential harm over long periods of exposure until they manifest in the form of biological disorders. Various studies have shown the ill-effects of radio-frequency electromagnetic field (RF-EMF) on bees, fruit flies, frogs, birds, bats, and humans, but the long-term studies of such exposures are inconclusive and scarce, and almost non-existent in India (MOEF, 2010; DoT, 2010). In 2011, International Agency for Research on Cancer (IARC), part of WHO, designated RF-EMF from cell phones as a "possible human carcinogen" Class 2B (WHO, 2011). Cancer, diabetes, asthma, infectious diseases, infertility, neurodegenerative disorders, and even suicides are on the rise in India. This invisible health hazard pollution (IHHP) is a relatively new environmental threat.

Electromagnetic radiation, in the form of waves of electric and magnetic energy, have been circulating together through space. The electromagnetic spectrum includes radio waves, microwaves, infrared rays, light rays, ultraviolet rays, X-rays, and gamma rays (ARPANSA, 2011;

FCC, 1999). The electromagnetic radiations are of two types, one being ionizing radiations such as X-rays and gamma rays, and the other being non-ionizing radiations such as electric and magnetic fields, radio waves, radio-frequency band which includes microwaves, infrared, ultraviolet, and visible radiation (Figure 1). The biological effects of RF-EMF at molecular level induce thermal and non-thermal damage, which may be due to dielectric heating leading to protein denaturation, polar molecular agitation, cellular response through molecular cascades and heat shock proteins, and changes in enzyme kinetics in cells (Instituto Edumed, 2010). The three major physical parameters of RF-EMF radiations is frequency, intensity, and exposure duration. Although the non-ionizing radiations are considered less dangerous than ionizing radiation, over-exposure can cause health hazards (FCC, 1999).

Electromagnetic Spectrum and RF-EMF Radiation

The RF-EMF radiations fall in the range of 10 MHz–300 GHz. Cell phone technology uses frequencies mainly between 800 MHz and 3 GHz and cell tower antenna uses a frequency of 900 or 1800 MHz, pulsed at low frequencies, generally known as microwaves (300 MHz–300 GHz).

Power Density and Specific Absorption Rate (SAR)

Variables used in the measurement of these radiations are power density, measured in watts per meter squared (W/m^2) and specific absorption rate (SAR). The term used to describe the absorption of RF-EMF radiation in the body is SAR, which is the rate of energy that is actually absorbed by a unit of tissue, expressed in watts per kilogram (W/kg) of tissue. The SAR measurements are averaged either over the whole body or over a small volume of tissue, typically between 1 and 10 g of tissue. SAR was set with the help of a phantom, known as specific anthropomorphic mannequin (SAM) derived from the size and dimensions of the 90th percentile large adult male reported in a 1988 US Army study who is 6 feet 2 inches and weighed 200 pounds (Davis, 2010). SAR is set at 1.6 W/kg averaged over 1 g of body tissue in the US and Canada and 2 W/kg averaged over 10 g of body tissue in countries adopting the ICNIRP guidelines. The SAR is used to quantify energy absorption to fields typically between 100 kHz and 10 GHz and encompasses radio-frequency radiation from devices such as cellular phones up through diagnostic magnetic resonance imaging (MRI). The biological effects depend on how much of the energy

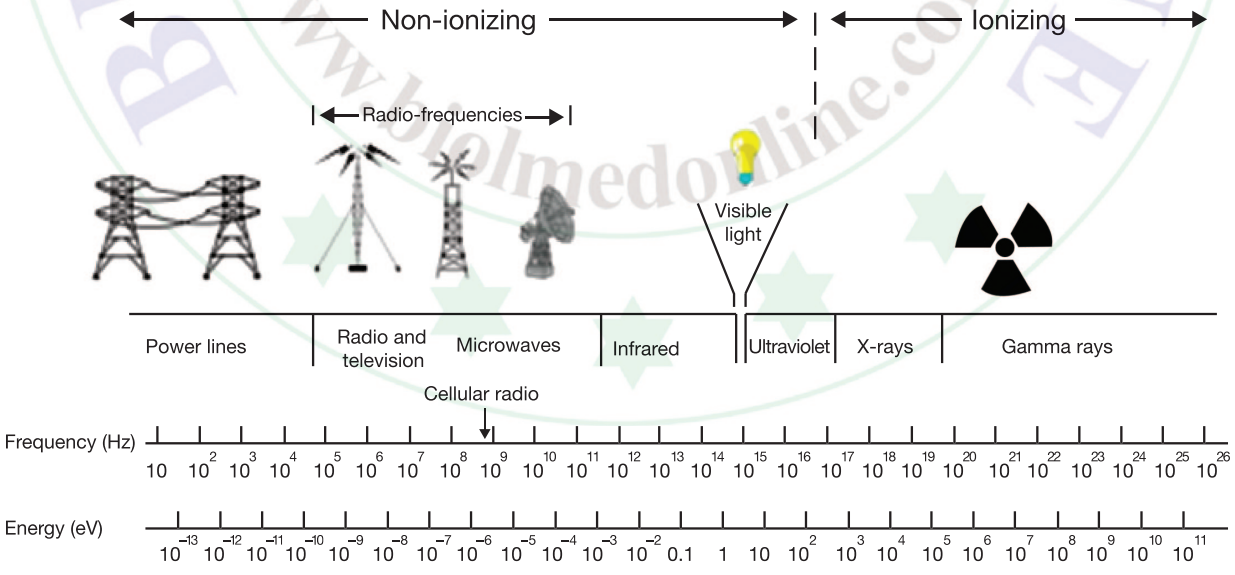

Figure 1: Electromagnetic spectrum from the Federal Communications Commission (FCC), OET Bulletin 56, 1999.

is absorbed in the body of a living organism, not just what exists in space. Absorption of RF-EMF radiations depend on frequency of transmission, power density, distance from the radiating source and the organism's size, shape, mineral, and water content. Exposure will be lower from towers under most circumstances than from cell phones because the transmitter is placed directly against the head during cell phone use whereas proximity to a cell tower will be an ambient exposure at a distance (Levitt and Lai, 2010). Exposure guidelines for RF protection had adopted the value of 4 W/kg averaged over the whole body (SARWB) as the threshold for the induction of adverse thermal effects associated with an increase of the body core temperature of about 1°C in animal experiments. This standard is set by International Commission on Non-ionizing Radiation Protection (ICNIRP), national Radiological Protection Board (NRPB), and Institute of Electrical and Electronics Engineers (IEEE) (Barnes and Greenebaum, 2007).

Cell Phones and Cell Tower Standards in India

India has adopted ICNIRP guidelines as the standard for safety limits of exposure to radio-frequency energy produced by mobile handsets for general public as follows: whole-body average SAR of 0.08 W/kg, localized SAR for head and trunk of 2 W/kg, and localized SAR for limbs 4 W/kg. The basic restrictions/proper limits for power density specified in ICNIRP guidelines for safe frequencies between 400 and 2000 MHz, adopted in India, for occupational exposure is 22.5 W/m^2, and general public is 4.5 W/m^2 for 900 MHz (ICNIRP, 1998).

Antennas of cell tower transmit in the frequency range of 869–890 MHz for CDMA, 935–960 MHz for GSM-900, 1805–1880 MHz for GSM-1800, and 2110–2170 MHz for 3G. Wi-Fi frequency range is 2.4 GHz, WiMAX is 2.5–3.3 GHz, and 4G LTE is 2.99 GHz. The antennas for cellular transmissions are typically located on towers mounted on terraces of houses, apartments or other elevated structures including rooftops and the sides of buildings, and also as a freestanding tower. Typical heights for cell towers are 50–200 feet. Sector antennas for 2G and 3G transmission, broader sector antennas for 4G transmission, and parabolic microwave antennas for point-to-point communications are used in urban and suburban areas (Table 1). There are different types of base stations used by operators in India and they include the macro cell, micro cell, or pico cell. Categorization is based on the purpose of the site rather than in terms of technical constraints such as radiated power or antenna height. In India, macro cellular base station provide the main infrastructure for a mobile phone network and their antennas are mounted at sufficient height to give them a clear view over the surrounding geographical area. The maximum power for individual macro cellular base station transmitter is 20 W. According to FCC (1999), depending on the cell tower height, the majority of cellular base stations in urban and suburban areas operate at an effective radiated power (ERP) of 100 W per channel or less. ERP is a quantity that takes into consideration transmitter power and antenna directivity. An ERP of 100 W corresponds to an actual radiated power of about 5–10 W, depending on the type of antenna used. In urban areas, an ERP of 10 W per channel (corresponding to a radiated power of 0.5–1 W) or less is commonly used. In India, cell tower sites transmit hundreds of watts of power with antenna gain of 50, so ERP sometimes equals 5000 W (Kumar, 2010).

For installation of mobile towers, the standing advisory committee on radio frequency

Table 1: Radio-frequency sources in India.

RF source	Operating frequency	Transmission powers	Numbers
AM towers	540–1600 kHz	100 KW	197 towers
FM towers	88–108 MHz	10 KW	503 towers
TV towers	180–220 MHz	40 KW	1201 towers
Cell towers	800, 900, 1800 MHz	20 W	5.4 lakh towers
Mobile phones	GSM-1800/CDMA GSM-900	1 W 2 W	800+ million
Wi-Fi	2.4–2.5 GHz	10–100 mW	Wi-Fi hot spots

allocations (SACFA) clearances are issued by the wireless monitoring organization, Department of Telecommunications (DoT), after getting no objection from defence and airport authority considering aviation hazards, obstruction to line of sight of existing/planned networks and interferences. In many metros in India, there is no restriction on the location of the towers leading to a situation of overlapping of towers, where even more than 30 cell towers can be seen within 1 km^2.

As mobile technology progresses, the data demands on mobile network increases, coupled with lower costs, their use has increased dramatically and the overall levels of exposure of the population as a whole has increased drastically. Table 2 gives the reference levels for general public exposure adopted by various countries and organizations.

Impacts on Biosystem and Ecosystem

Every living being is tuned into the earth's electromagnetism and uses it for various purposes. A natural mineral magnetite, which is found in living tissues, seems to play an important role. These magnetite crystals are found in bacteria, protozoa, teeth of sea mollusks, fish and sea mammals, eye and beak of birds, and in humans. They are also found in the ethmoid bone above the eye and sinuses and blood-brain barrier (Warnke, 2007). Migratory birds rarely get lost, but sometimes there are disruptions due to storms and magnetic disturbances caused by man (Kirschvink *et al.*, 2001). The traditional and most effective approach to study cause–effect relationships in biological sciences is by experimentation with cells and organisms. The areas of enquiry and experimentation of in vitro studies include genotoxicity, cancer-related gene and protein expression, cell proliferation and differentiation, and apoptosis and in vivo studies include thermal effects, animal behavior, brain biochemistry, neuropathology, teratogenicity, reproduction and development, immune function, blood-brain barrier, visual auditory systems and effects on genetic material, cell function, and biochemistry (Repacholi and Cardis, 2002). In human health studies, concerns have been expressed about the possible interactions of RF-EMF with several human organ systems such as nervous, circulatory, reproductive, and endocrine systems. In order to reveal the global effects of RF-EMF on gene and protein expression, transcriptomics,

Table 2: Reference levels for the general public.

Country/organization \ Standards	Power density (W/m^2)	
	900 MHz	1800 MHz
ICNIRP, 1998, adopted by India	4.5	9
FCC, 1999	6	10
IEEE, USA, 1999	6	12
Australia	2	2
Belgium	1.1	2.4
Italy	1	1
Israel	x	1
New Zealand	x	0.5
China	x	0.4
Russia	x	0.2
Hungary	0.1	0.1
Toronto Board of Health, Canada, 1999	0.06	0.1
Switzerland	0.04	0.1
France	x	0.1
Germany, ECOLOG, 1998	x	0.09
Austria's precautionary limit	0.001	0.001

and proteomics as high-throughput screening techniques (HTSTs), were eventually employed in EMF research with an intention to screen potential EMF responsive genes and/or proteins without any bias (Nylund and Leszczynski, 2004). The safety standards set by ICNIRP, adopted by India, has only taken into account the short-term effects and not against the biological effects from long-term, non-thermal, low-level microwave exposure from mobile phones, cell phone towers, and many other wireless devices.

Current Research

Various studies have shown that even at low levels of this radiation, there is evidence of damage to cell tissue and DNA, and it has been linked to brain tumors, cancer, suppressed immune function, neuroendocrine disruption, chronic fatigue syndrome, and depression (Rogers, 2002; Milham, 2010). Oncogenesis studies at molecular and cellular levels due to RF-EMF radiations are considered particularly important (Marino and Carrubba, 2009). Orientation, navigation, and homing are critical traits expressed by organisms ranging from bacteria through higher vertebrates. Across many species and groups of organisms, compelling evidence exists that the physical basis of this response is tiny crystals of single-domain magnetite (Fe_3O_4) (Kirschvink *et al.*, 2001). All magnetic field sensitivity in living organisms, including elasmobranch fishes, is the result of a highly evolved, finely-tuned sensory system based on single-domain, ferromagnetic crystals. Animals that depend on the natural electrical, magnetic, and electromagnetic fields for their orientation and navigation through earth's atmosphere are confused by the much stronger and constantly changing artificial fields created by technology and fail to navigate back to their home environments (Warnke, 2007).

Studies on Plants

Tops of trees tend to dry up when they directly face the cell tower antennas and they seem to be most vulnerable if they have their roots close to the water (Belyavskaya, 2004). They also have a gloomy and unhealthy appearance, possible growth delays, and a higher tendency to contract plagues and illnesses. According to Levitt (2010), trees, algae, and other vegetation may also be affected by RF-EMF. Some studies have found both growth stimulation and dieback. The browning of tree tops is often observed near cell towers, especially when water is near their root base. The tree tops are known as RF waveguides. In fact, military applications utilize this capability in trees for low-flying weapon systems. In an observational study, it was found that the output of most fruit-bearing trees reduced drastically from 100% to $<$5% after 2.5 years of cell tower installation in a farm facing four cell towers in Gurgaon–Delhi Toll Naka (Kumar and Kumar, 2009).

Studies on Insects

Monarch butterflies and locusts migrate great distances using their antennae to sense air currents and earths electromagnetic fields. Moths are drawn to light frequencies. Ants, with the help of their antennas are adept at electrical transmission and found to respond to frequencies as low as 9 MHz. Flying ants are very sensitive to electromagnetic fields (Warnke, 2007).

Bees have clusters of magnetite in the abdominal areas. Colony collapse disorder (CCD) was observed in beehives exposed to 900 MHz for 10 minutes, with sudden disappearance of a hive's inhabitants, leaving only queen, eggs, and a few immature workers behind. With navigational skills affected, worker bees stopped coming to the hives after 10 days and egg production in queen bees dropped drastically to 100 eggs/day compared to 350 eggs (Sharma and Kumar, 2010). Radiation affects the pollinators, honeybees, whose numbers have recently been declining due to CCD by 60% at US West Coast apiaries and 70% along the East Coast (Cane and Tepedino, 2001). CCD is being documented in Greece, Italy, Germany, Portugal, Spain, and Switzerland. Studies performed in Europe documented navigational disorientation, lower honey production, and decreased bee survivorship (Kimmel *et al.*, 2007). EMFs from telecommunication infrastructure interfere with bees' biological clocks that enable them to compensate properly for the sun's movements, as a result of which, may fly in the wrong direction when attempting to return to the hive (Rubin *et al.*, 2006). Bee colonies irradiated with digital enhanced cordless communications (DECT) phones and mobile handsets had a dramatic impact on the behavior of the bees, namely by inducing the worker

piping signal. In natural conditions, worker piping either announces the swarming process of the bee colony or is a signal of a disturbed bee colony (Favre, 2011).

A study by the University of Athens on fruit flies exposed to 6 minutes of 900 MHz pulsed radiation for 5 days showed reduction in reproductive capacity (Panagopoulos *et al.*, 2004). Likewise in 2007, in both 900 and 1800 MHz, similar changes in reproductive capacity with no significant difference between the two frequencies were observed (Panagopoulos *et al.*, 2007). In a third study, it was found it was due degeneration of large numbers of egg chambers after DNA fragmentation (Panagopoulos *et al.*, 2010). When *Drosophila melanogaster* adult insects were exposed to the radiation of a GSM 900/1800 mobile phone antenna at different distances ranging from 0 to 100 cm, these radiations decreased the reproductive capacity by cell death induction at all distances tested (Levengood, 1969).

Studies on Amphibians and Reptiles

Salamanders and turtles have navigational abilities based on magnetic sensing as well as smell. Many species of frogs have disappeared all over the world in the last 3–5 years. Amphibians can be especially sensitive because their skin is always moist, and they live close to, or in water, which conducts electricity easily (Hotary and Robinson, 1994). Toads when exposed to 1425 MHz at a power density of 0.6 mW/cm^2 developed arrhythmia (Levitina, 1966). Increased mortality and induced deformities were noted in frog tadpoles (*Rana temporaria*) (Levengood, 1969). It was observed that experimental tadpoles developed more slowly, less synchronously than control tadpoles, remain at the early stages for a longer time, developed allergies and that EMF causes changes in the blood counts (Grefner *et al.*, 1998). In a two-month study in Spain in common frog tadpoles on the effects of mobile phone mast located at a distance of 140 m noted low coordination of movements, an asynchronous growth, resulting in both big and small tadpoles, and a high mortality (90%) in exposed group. For the unexposed group in Faraday cage, the coordination of movements was normal, the development was synchronous, and a mortality of 4.2% was obtained (Balmori, 2009). In the eggs and embryos of *Rana sylvatica* and *Ambystoma maculatum* abnormalities at several developmental stages were noted such as microcephalia, scoliosis, edema, and retarded growth. Tadpoles developed severe leg malformations and extra legs, as well as a pronounced alteration of histogenesis which took the form of subepidermal blistering and edema. Effects were noted in reproduction, circulatory, and central nervous system, general health and well being (Balmori, 2010; Balmori, 2005).

Studies on Birds

A study by the Centre for Environment and Vocational Studies of Punjab University noted that embryos of 50 eggs of house sparrows were damaged after being exposed to mobile tower radiation for 5–30 minutes (MOEF, 2010). Observed changes included reproductive and coordination problems and aggressiveness. Tower-emitted microwave radiation affected bird breeding, nesting, and roosting in Valladolid, Spain (US Fish & Wildlife Service, 2009). House sparrows, white storks, rock doves, magpies, collared doves exhibited nest and site abandonment, plumage deterioration (lack of shine, beardless rachis, etc.), locomotion problems, and even death among some birds. No symptoms were observed prior to construction of the cell phone towers. According to Balmori, plumage deterioration and damaged feather are the first signs of weakening, illnesses, or stress in birds. The disappearance of insects, leading to lack of food, could have an influence on bird's weakening, especially at the first stages in young bird's life. In chick embryos exposed to ELF pulsed EMR, a potent teratogenic effect was observed, leading to microphthalmia, abnormal trunkal torsion, and malformations on the neural tube (Lahijani and Ghafoori, 2000).

White storks were heavily impacted by the tower radiation during the 2002–2004 nesting season in Spain. Evidence of a connection between sparrow decline in UK and the introduction of phone mast GSM was established (Balmori, 2009). In a study in Spain, the effects of mobile phone mast has been noted in house sparrow (*Passer domesticus*), white stork (*Ciconia ciconia*), reporting problems with reproduction, circulatory, and central nervous system, general health and well-being (microwave syndrome) (Balmori, 2009). Deformities and deaths were noted in the domestic chicken embryos subjected to low-level, non-thermal radiation from the standard 915 MHz cell phone

frequency under laboratory conditions (US Fish & Wildlife Service, 2009). Neural responses of Zebra Finches to 900 MHz radiation under laboratory conditions showed that 76% of the neurons responded by 3.5 times more firings (Beason and Semm, 2002). Eye, beak, and brain tissues of birds are loaded with magnetite, sensitive to magnetic fields, interferes with navigation (Mouritsen and Ritz, 2005).

Studies on Mammals

In a survey of two berry farms in similar habitats in Western Massachusetts (Doyon, 2008), one with no cell phone towers, there were abundant signs of wildlife, migrating and resident birds, bats, small and large mammals, and insects including bees and the other farm with a cell-phone tower located adjacent to the berry patch, virtually no signs of wildlife, tracks, scat, or feathers were noted. The berries on bushes were uneaten by birds and insects and the berries that fell to the ground were uneaten by animals. Whole body irradiation of 20 rats and 15 rabbits at 9.3 GHz for 20 minutes revealed statistically significant changes in cardiac activity (Repacholi *et al.*, 1998). Bradycardia developed in 30% of the cases. Separate ventricular extra systoles also developed. In a study on cows and calves on the effects of exposure from mobile phone base stations, it was noted that 32% of calves developed nuclear cataracts, 3.6% severely. Oxidative stress was increased in the eyes with cataracts, and there was an association between oxidative stress and the distance to the nearest mast (Hässig *et al.*, 2009). It was found that at a GSM signal of 915 MHz, all standard modulations included, output power level in pulses 2 W, specific absorption rate (SAR) 0.4 mW/g exposure for 2 hours, 11 genes were up-regulated and one down-regulated, hence affected expression of genes in rat brain cells (Belyaev *et al.*, 2006). The induced genes encode proteins with diverse functions including neurotransmitter regulation, blood-brain barrier (BBB), and melatonin production.

When rats were exposed for 2 hours a day for 45 days at 0.21 mW/cm^2 power density SAR (0.038 W/kg), a significant decrease in melatonin and increase in both creatine kinase and caspase 3 was found (Kesari *et al.*, 2011). This shows that chronic exposure to these radiations may be an indication of possible tumor promotion. A study on pregnant rats and brains of fetal rats was carried out after irradiating them with different intensities of microwave radiation from cellular phones for 20 days three times a day. Superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), malondialdehyde (MDA), noradrenaline (NE), dopamine (DA), and 5-hydroxyindoleacetic acid (5-HIAA) in the brain were assayed. The significant content differences of noradrenaline and dopamine were found in fetal rat brains (Jing *et al.*, 2012). A study in rabbits exposed to continuous wave and pulsed power at 5.5 GHz found acute effects in the eyes, where lens opacities developed within 4 days (Birenbaum *et al.*, 1969).

Behavioral tasks, including the morris water maze (MWM), radial arm maze, and object recognition task have been extensively used to test cognitive impairment following exposure of rodents to mobile phone radiation (GSM 900 MHz) on various frequencies and SAR values (Fragopoulou *et al.*, 2010). Exposed animals in most of the cases revealed defects in their working memory possibly due to cholinergic pathway distraction. Mobile phone RF-EMF exposure significantly altered the passive avoidance behavior and hippocampal morphology in rats (Narayanan *et al.*, 2010).

With regards to DNA damage or cell death induction due to microwave exposure, in a series of early experiments, rats were exposed to pulsed and continuous-wave 2450 MHz radiation for 2 hours at an average power density of 2 mW/cm^2 and their brain cells were subsequently examined for DNA breaks by comet assay. The authors found a dose-dependent (0.6 and 1.2 W/kg whole body SAR) increase in DNA single-strand and double-strand breaks, 4 hours after the exposure to either the pulsed or the continuous-wave radiation. The same authors found that melatonin and PBN (N-tert-butyl-alpha-phenylnitrone) both known free radical scavengers, block the above effect of DNA damage by the microwave radiation (Lai and Singh, 1995, 1996, 1997). Death in domestic animals like hamsters and guinea pigs were noted (Balmori, 2003). Bats use electromagnetic sensors in different frequencies. Since 1998, a study on a free-tailed bat colony, having *Tadarida teniotis* and *Pipistrellus pipistrellus* has been carried out in Spain and a decrease in number of bats were noted with several phone masts 80 m from the colony. A dead specimen of *Myotis myotis* was found near a small antenna in the city centre (Balmori, 2009).

The most affected of the species are bees, birds, and bats and without these pollinators visiting flowers, 33% of fruits and vegetables would not exist, and as the number of pollinators decline, the agricultural crops will fall short and the price of groceries will go up (Kevan and Phillips, 2001).

Studies on Humans

The exposure to continuous RF-EMF radiation poses a greater risk to children, particularly due to their thinner skulls and rapid rate of growth. Also at risk are the elderly, the frail, and pregnant women (Cherry, 2001). DNA damage via free radical formation inside cells has also been recorded (Lai and Singh, 1996). Free radicals kill cells by damaging macromolecules such as DNA, protein, and membrane are carcinogenic. In fact, EMR enhances free radical activity. Single- and double-strand DNA breaks are seen in rat brain cells after acute exposure to radio-frequency electromagnetic radiation. Kane (2001) denotes that RF-EMF radiations lead to tissue damage, DNA damage, or chromosome mutations. In 2008, the Austrian Department of Health found a higher risk of cancer among people living within 200 m of a mobile phone base station and that cancer risk rose with increasing exposure, reaching 8.5 times the norm for people most exposed. From a study on in vitro cell response to mobile phone radiation (900 MHz GSM signal) using two variants of human endothelial cell line, it was suggested that the cell response to mobile phone radiation might be genome- and proteome-dependent. Therefore, it is likely that different types of cells and from different species might respond differently to mobile phone radiation or might have different sensitivity to this weak stimulus (Nylund and Leszczynski, 2006).

The results of the Interphone, an international case–control study to assess the brain tumor risk in relation to mobile telephone use, reveals no overall increase in risk of glioma or meningioma but there were suggestions of an increased risk of glioma at the highest exposure levels (30 minutes per day of cell phone use for 8–10 years) and ipsilateral exposures (ICNIRP, 2011). Children and young adults were excluded from the study and a separate study called Mobi-Kids is underway. According to Santini *et al.* (2002), comparisons of complaints in relation with distance from base station show significant increase as compared to people living greater than 300 m or not exposed to base station, till 300 m for tiredness, 200 m for headache, sleep disturbance, and discomfort, and 100 m for irritability, depression, loss of memory, dizziness, and libido decrease. Women significantly more often than men complained of headache, nausea, loss of appetite, sleep disturbance, depression, discomfort, and visual perturbations (Santini *et al.*, 2002). According to Oberfeld *et al.* (2004) in Spain, a follow-up study found that the most exposed people had a higher incidence of fatigue, irritability, headaches, nausea, loss of appetite, sleeping disorders, depression, discomfort, difficulties concentrating, memory loss, visual disorders, dizziness, and cardiovascular problems. Women are more at risk as they tend to spend more time at home and are exposed to radiation continuously. The authors recommended a maximum exposure of 0.0001 $\mu W/cm^2$ or 0.000001 W/m^2. There was prevalence of neuropsychiatric complaints among people living near base stations (Abdel-Rassoul *et al.*, 2007). Urban electromagnetic contamination (electrosmog) 900 and 1800 MHz pulsated waves interfere in the nervous system of living beings (Hyland, 2000). Growing amounts of published research show adverse effects on both humans and wildlife far below a thermal threshold, usually referred to as "non-thermal effects", especially under conditions of long-term, low-level exposure (Levitt and Lai, 2010).

Australian research conducted by De Iuliis *et al.* (2009) by subjecting in vitro samples of human spermatozoa to radio-frequency radiation at 1.8 GHz and SAR of 0.4–27.5 W/kg showed a correlation between increasing SAR and decreased motility and vitality in sperm, increased oxidative stress and 8-Oxo-2′-deoxyguanosine markers, stimulating DNA base adduct formation and increased DNA fragmentation. GSM mobile phone exposure can activate cellular stress response in both humans and animal cells and cause the cells to produce heat shock proteins (HSP27 and HSP70) (Leszczynski, 2002). HSPs inhibit natural programmed cell death (apoptosis), whereby cells that should have committed suicide continue to live. Recent studies have shown that these HSPs inhibit apoptosis in cancer cells. In several cases, melatonin hormone which controls the daily biological cycle and has an oncostatic action, produced by the epiphysis (pineal gland) in mammals, mainly during the night, is found to reduce the action of EMR exposure, but the synthesis of melatonin itself seems to be reduced

by EMR (Panagopoulos *et al.*, 2008). In a study to observe the effects of melatonin in hormone balance in a diabetic, it was found that melatonin caused reduction in serum insulin, serum cortisol, serum ACTH, and serum TSH levels while increase in serum gastrin level. Of the biochemical parameters, melatonin caused reductions in TLC, LDLC, and FBS while increase in HDLC. It also caused reduction in neutrophil and increase in lymphocyte count in a diabetic with increase in faecal fat excretion (Mitra and Bhattacharya, 2008).

RF-EMR produces DNA damage via free radical formation inside cells. Free radicals kill cells by damaging macromolecules such as DNA, protein, and membrane, also shown to be carcinogenic. EMR enhances free radical activity. EMR interferes with navigational equipments, lifeline electronic gadgets in hospitals, and affects patients with pacemakers. A short-term exposure (15 and 30 minutes) to RFR (900 MHz) from a mobile phone caused a significant increase in DNA single strand breaks in human hair root cells located around the ear which is used for the phone calls (Çam and Seyhan, 2012). Various in vitro studies have shown that 1800 MHz RF-EMF radiation could cause oxidative damage to mtDNA in primary cultured neurons. Oxidative damage to mtDNA may account for the neurotoxicity of RF radiation in the brain (Xu *et al.*, 2010).

Studies carried out on the RF levels in North India, particularly at the mobile tower sites at Delhi have shown that people in Indian cities are exposed to dangerously high levels of EMF pollution (Tanwar, 2006). An independent study was commissioned by the Cellular Operators Association of India (COAI) and Association of Unified Telecom Service Providers of India (AUSPI) as a proactive measure stemming from the concern for the public health and safety issues on electromagnetic radiation measurement at New Delhi showed compliance with ICNIRP standards. 180 areas were studied across the capital to understand the extent of RF-EMF radiations emitting from the mobile towers, revealed that the readings were 100 times below international safety guidelines. The study measured cumulative emissions within the 800–2000 MHz band of frequency (which includes both GSM and CDMA technologies) across in the nation's capital using carefully calibrated equipment, as per the DoT prescribed procedure in line with the ICNIRP specifications. In a similar, but independent case study in Mumbai, it was found that people living within 50–300 m radius are in the high radiation zone and are more prone to ill-effects of electromagnetic radiation. Four cases of cancer were found in three consecutive floors (6th, 7th, 8th) directly facing and at similar height as four mobile phone towers placed at the roof of the opposite building (Kumar, 2010). According to the Seletun Scientific Statement (2011), low-intensity (non-thermal) bioeffects and adverse health effects are demonstrated at levels significantly below existing exposure standards. ICNIRP/WHO and IEEE/FCC public safety limits are inadequate and obsolete with respect to prolonged, low-intensity exposures (New International EMF Alliance, 2011). New, biologically-based public exposure standards are urgently needed to protect public health world-wide. EMR exposures should be reduced now rather than waiting for proof of harm before acting (Fragopoulou *et al.*, 2010).

Electrohypersensitivity (EHS) and Electromagnetic Field Intolerance (EFI) Syndrome

Electrosensitivity of people is now recognized as a physical impairment by government health authorities in the United Kingdom and Sweden. The UK Health Protection Agency (HPA) recognized that people can suffer nausea, headaches, and muscle pains when exposed to electromagnetic fields from mobile phones, electricity pylons, and computer screens. A case study in Sweden, one of the first countries where mobile technology was introduced approximately 15 years ago, shows that 250,000 Swedes are allergic to mobile phone radiation. Sweden has now recognized EHS as a physical degradation and EHS sufferers are entitled to have metal shielding installed in their homes free of charge from the local government (Kumar, 2010; Johansson, 2010).

Belpomme (2011) in his presentation at the 8th National Congress on Electrosmog in Berne in 2011 elaborates on the dangers of wireless technology and the diagnostics and treatment of the electromagnetic field intolerance (EFI) Syndrome. In his study from 2008 to 2011, the patients with EHS were investigated with a pulse equilibrium brain scan, dosage of histamine in the blood, dosage of the heat shock proteins HSP70 and HSP27, and appearance and disappearance of symptoms on exposure to an electromagnetic field source. Diagnosis of fatigue and depression were noted. The physiological changes such as vitamin D deficiency, decrease in heat

shock proteins, increase in histamines, increase in biomarker of the opening of blood-brain barrier, protein S100P, decrease in urinary melatonin, and increase in blood anti-myelin proteins were noted in the electrosensitives. Around 50% of the patients in the study had used a mobile phone for more than one hour per day during several years and his findings were similar to the figures published by Hardell's study (2007) dealing with the cancer occurrences and electromagnetic fields.

Future Challenges and Solutions

Research into the advantages of radio-frequency energies seen in tissue heating in benign prostatic hyperplasia (BPH), electrical therapy for cardiac arrhythmia, radio-frequency ablation, use of 41.5–44.5°C temperature to kill tumors, shortwave and microwave diathermy for musculoskeletal injuries, and microwave oven used in food preparation are all carried out under controlled conditions. But effects, if any, from RF-EMF radiations released into the environment over a long period of time in densely populated areas where people are continuously exposed to them will show in years to come. According to Osepchuk (1983), frequencies used in industrial, scientific, and medical heating processes are 27.12, 40.68, 433, 915, 2450, and 5800 MHz. Out of which, for diathermy, frequencies used are 27.12, 915, and 2450 MHz in US and 433 MHz is authorized in Europe. According to Kasevich (2000), "the physics of electromagnetic waves and their interactions with material and biological systems is based on the concept that the electromagnetic wave is a force field which exerts a mechanical torque, pressure or force on electrically charged molecules. All living things contain these dielectric properties. The thermal effects produced by absorption of electromagnetic energy are the direct result of water molecules acted upon by the oscillating electric field, rubbing against each other to produce electric heat (thermal effects)". Research work on electromagnetic bioeffects in humans and animals in the non-thermal range is continuing where effects are noted even at intensities lower than 1 mW/m^2 (0.001 W/m^2 or 1000 ∝W/m^2, 0.0001 mW/cm^2 or 0.1 ∝W/cm^2).

According to Levitt (2007), adverse outcomes of pregnancy can be mutagenic, teratogenic, oncogenic or carcinogenic, and ionizing radiations can cause all three. In animal studies, non-ionizing radiation was also found to be teratogenic and oncogenic, and likely mutagenic, but it is unclear if these observations were due to heating affect, non-thermal affects or both. Trees, plants, soil, grass, and shrubs have the ability to absorb electromagnetic wave energy over a very broad range of wavelengths. According to the resonance concept, human beings can act as receiving antennas for some frequencies, where the absorbed energy is maximized in some areas of the body, like the brain (Levitt, 2007).

In the Bioinitiative Report, a document prepared by 14 international experts in a nine-month project, in which over 2000 scientific studies were reviewed, Sage (2007) came to a conclusion that there may be no lower limit that may be safe, and there was a need for biologically-based limits (1 mW/m^2 or 0.001 W/m^2) and children are at most risk. Safety limits suggested are 0.001 W/m^2 for outdoor cumulative radio-frequency exposure and 0.0001 W/m^2 for indoor, cumulative radio-frequency exposure. According to Blank (2012), there is a need for a realistic biological standard to replace the thermal (SAR) standard. The precautionary approaches includes prudence avoidance for public and ALARA, which stands for "as low as reasonably attainable" for regulatory agencies.

According to Havas (2006), several disorders, including asthma, ADD/ADHD, diabetes, multiple sclerosis, chronic fatigue, fibromyalgia, are increasing at an alarming rate, as is electromagnetic pollution in the form of dirty electricity, ground current, and radio-frequency radiation from wireless devices and the connection between electromagnetic pollution and these disorders needs to be investigated and the percentage of people sensitive to this form of energy needs to be determined. According to Milham (2010), 20th century epidemic of the so-called diseases of civilization, including cardiovascular disease, cancer, diabetes, and also suicides, was caused by electrification and the unique biological responses we have to it and that our evolutionary balance, developed over the millennia has been severely disturbed and disrupted by man-made EMFs.

Conclusion

The Department of Telecommunication (DoT) in India has set new norms for cell phone towers with effect from September 1, 2012 (The Hindu, 2012). Exposure standards for RF-EMF radiation has been reduced to one-tenth of the existing level and SAR from 2 to 1.6 W/kg. This came after the Ministry of Environment and Forests

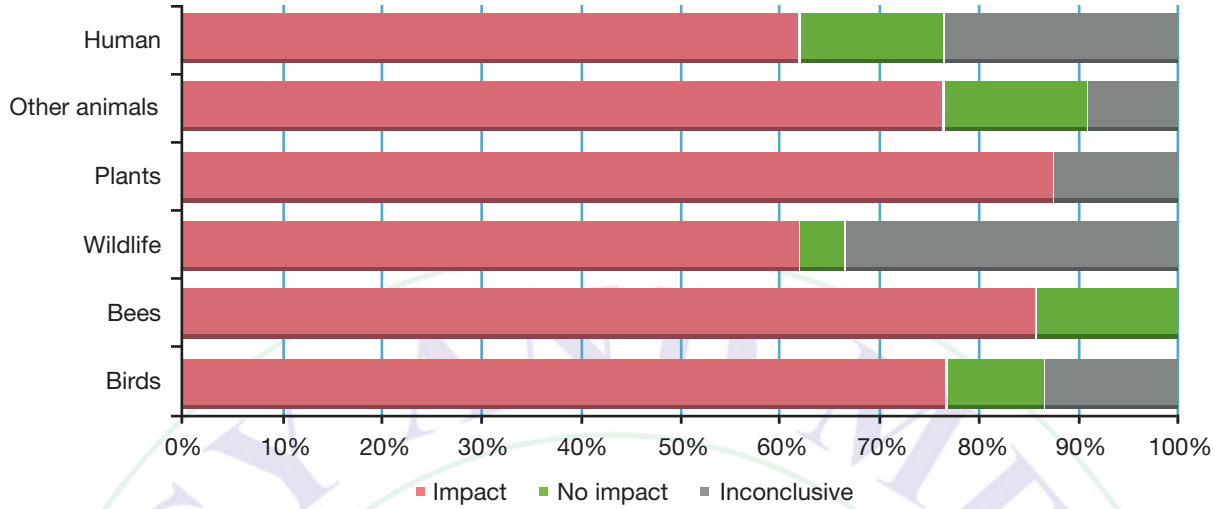

Figure 2: Percentage of studies that reported harmful effect of EMR in various groups of organisms (n = 919), MOEF Report (2010).

(MOEF) set up an Inter-Ministerial Committee (IMC) to study the effects of RF-EMF radiations on wildlife (Figure 2) and concluded that out of the 919 research papers collected on birds, bees, plants, other animals, and humans, 593 showed impacts, 180 showed no impacts, and 196 were inconclusive studies. They conclude that there are no long-term data available on the environmental impacts of RF-EMF radiations in India. The population of India is increasing as well as the cell phone subscribers and the cell towers as supporting infrastructure. Hence, there is an urgent need to fill the gaps and do further research in this field with emphasis on the effects of early life and prenatal RF-EMF radiation exposure in animals, dosimetry studies, cellular studies using more sensitive methods, and human epidemiological studies, especially on children and young adults on behavioral and neurological disorders and cancer. Meanwhile, one can take the precautionary principle approach and reduce RF-EMF radiation effects of cell phone towers by relocating towers away from densely populated areas, increasing height of towers or changing the direction of the antenna.

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Radiofrequency radiation injures trees around mobile phone base stations

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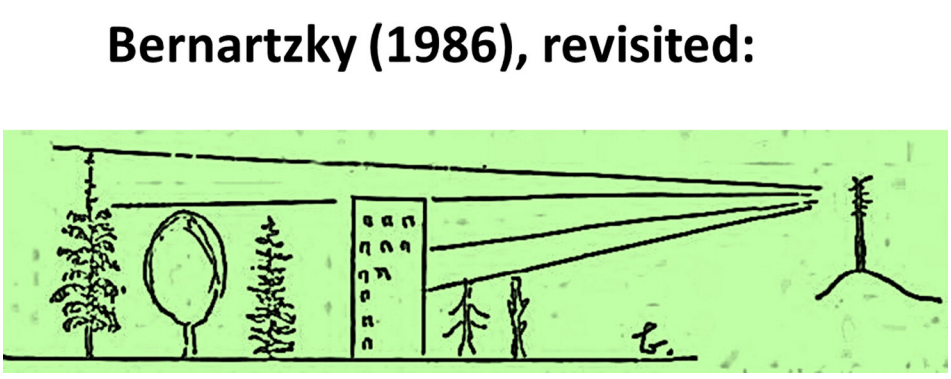
HIGHLIGHTS

- High frequency nonionizing radiation is becoming increasingly common.
- This study found a high level of damage to trees in the vicinity of phone masts.
- Deployment has been continued without consideration of environmental impact.

GRAPHICAL ABSTRACT



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ABSTRACT

In the last two decades, the deployment of phone masts around the world has taken place and, for many years, there has been a discussion in the scientific community about the possible environmental impact from mobile phone base stations. Trees have several advantages over animals as experimental subjects and the aim of this study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure. To achieve this, a detailed long-term (2006–2015) field monitoring study was performed in the cities of Bamberg and Hallstadt (Germany). During monitoring, observations and photographic recordings of unusual or unexplainable tree damage were taken, alongside the measurement of electromagnetic radiation. In 2015 measurements of RF-EMF (Radiofrequency Electromagnetic Fields) were carried out. A polygon spanning both cities was chosen as the study site, where 144 measurements of the radiofrequency of electromagnetic fields were taken at a height of 1.5 m in streets and parks at different locations. By interpolation of the 144 measurement points, we were able to compile an electromagnetic map of the power flux density in Bamberg and Hallstadt. We selected 60 damaged trees, in addition to 30 randomly selected trees and 30 trees in low radiation areas (n = 120) in this polygon. The measurements of all trees revealed significant differences between the damaged side facing a phone mast and the opposite side, as well as differences between the exposed side of damaged trees and all other groups of trees in both sides. Thus, we found that side differences in measured values of power flux density corresponded to side differences in damage. The 30 selected trees in low radiation areas (no visual

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contact to any phone mast and power flux density under 50 μW/m^2) showed no damage. Statistical analysis demonstrated that electromagnetic radiation from mobile phone masts is harmful for trees. These results are consistent with the fact that damage afflicted on trees by mobile phone towers usually start on one side, extending to the whole tree over time.

1. Introduction

For many years, there has been a discussion in the scientific community about whether artificial radiofrequency radiation has harmful effects on living organisms and, more specifically, on the environmental impact from mobile phone base stations (Panagopoulos et al., 2016). Trees have several advantages over animals as experimental subjects: they are continuously exposed to radiation in a constant orientation in the electromagnetic field due to their inability to move (Vian et al., 2016). Additionally, it is possible to easily document changes over time, such as disturbed growth, dying branches, and premature colour change of leaves. Moreover, the damage to trees is objective and cannot be attributed to psychological or psychosomatic factors.

Plants are specialized in the interception of electromagnetic radiation (light) but radiofrequency radiation impact on plants, which is becoming common in the environment because of the exponential use of mobile phone technology, has received little attention and his physiological effect has long been considered negligible.

Since the mid-twentieth century, several researchers have investigated the effects of electromagnetic radiation on plants, both in the laboratory (Kiepenheuer et al., 1949; Brauer, 1950; Harte, 1950, 1972; Jerman et al., 1998; Lerchl et al., 2000; Sandu et al., 2005; Roux et al., 2006, 2008; Sharma et al., 2009; Tkalec et al., 2005, 2009; Beaubois et al., 2007; Kundu and IEEE, 2013; Pesnya and Romanovsky, 2013; Cammaerts and Johansson, 2015; Grémiaux et al., 2016; Vian et al., 2016), and in nature (field observations) (Bernatzky, 1986; Volkrodt, 1987, 1991; Selga and Selga, 1996; Balodis et al., 1996; Haggerty, 2010). Both kinds of study have frequently found pernicious effects.

Around the world, phone masts have been deployed in the last two decades everywhere. Preliminary published studies have indicated deleterious effects of radiofrequency radiation on trees (Balmori, 2004; Van't Wout, 2006; Schorpp, 2011; Waldmann-Selsam, 2007; Waldmann-Selsam and Eger, 2013), cautioning that research on this topic is extremely urgent (Balmori, 2015). However, these early warnings have had no success and deployment has been continued without consideration of environmental impact.

In a review of the effects of environmental microwaves on plants (Jayasanka and Asaeda, 2013), it was indicated that effects depend on the plant family and the growth stage, as well as the exposure duration, frequency, and power density. This review concluded that most studies that address the effects of microwaves on animals and plants have documented effects and responses at exposures below limits specified in the electromagnetic radiation exposure guidelines and it is therefore necessary to rethink these guidelines (Jayasanka and Asaeda, 2013).

Since 2005, on the occasion of medical examinations of sick residents living near mobile phone base stations, changes in nearby trees (crown, leaves, trunk, branches, growth…) were observed at the same time as clinical symptoms in humans occurred. Since 2006 tree damages in the radiation field of mobile phone base stations were documented (http://kompetenzinitiative.net/KIT/KIT/baeume-in-bamberg/). In the radio shadow of buildings or that one of other trees, the trees stayed healthy.

Additionally, unilateral crown damage, beginning on the side facing an antenna, pointed to a possible link between RF-EMF (Radiofrequency Electromagnetic Fields) and tree damage. We carried out measurements on both sides of unilaterally damaged trees. Most of the trees had been exposed to RF-EMF for at least five years. Each time we found considerable differences between the measured values on the damaged and on the healthy side.

The aim of the present study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure.

2. Materials and methods

The official information of 65 mobile phone sites in the neighbouring cities Bamberg and Hallstadt was extracted from the EMF database (EMF-Datenbank) of the German Federal Network Agency (Bundesnetzagentur, in March 2011 and October 2015). Each site certificate ("Standortbescheinigung") provides information on the mounting height of antennas, the number and main beam direction of the sector antennas, the number of omnidirectional antennas (ND), the number of other transmitters, as well as the horizontal and vertical safety distances. The current specifications of the transmission facilities are available at: http://emf3.bundesnetzagentur.de/karte/Default.aspx

On most of the 65 mobile phone sites several sector antennas emitting RF-EMF with differences in frequency, modulation and other physical characteristics are installed (GSM 900, GSM 1800, UMTS, LTE (4th generation), TETRA). In 2011 there was a total of 483 sector antennas, in 2015 a total of 779 sector antennas.

Numerical code, address and UTM 32N coordinates for the 65 Mobile phone (base stations) sites in Bamberg and Hallstadt are shown in Table 1.

Between 2006 and 2015 there was observation and documentation of tree damages. There were some preliminary measurements on both sides of unilaterally damaged trees and approximately 700 trees in Bamberg and Hallstadt were visited. The condition of numerous trees has been documented in photographs. The photographs record the state of trees showing damage patterns not attributable to diseases, pests, drought or other environmental factors in order to monitor damage and growth over several years (in 2006, Olympus FE-100 was used; since 2007, Panasonic DMC-FZ50 was used).

In 2015 we selected a polygonal study site, with an approximate area of 30 km^2, which includes partial municipalities of Bamberg and Hallstadt (70 km^2). The study area with the location of the phone masts in the layer of natural areas and municipalities is shown in Fig. 1. In this area, different measurements (see below) were done both for having a radiation map and for knowing which are the incident power densities beside different trees. In spite of the fact that measurements are changing continuously, they do not show significant differences between times (own data, see below).

In this polygon, we performed 144 measurements of the radiofrequency electromagnetic fields at a height of 1.5 m at different points in the city. These measurements were taken in streets and parks and allowed the preparation of an electromagnetic map of Bamberg and Hallstadt with their interpolation. The measurements were carried out with an EMF-broadband analyzer HF 59B (27–3300 MHz) and the horizontal-isotrope broadband antenna UBB27_G3, (Gigahertz Solutions). Measurements of the sum peak values of power flux density were in μW/m^2, which can be converted in V/m.

In general, a sector antenna covers an angle of 120° and the radiation of the sector antennas is distributed in main and secondary beams, bundled vertically and horizontally. The high-frequency emissions are reflected/diffracted and/or absorbed by buildings and trees. Therefore,

Table 1
Official information of the 65 mobile phone base stations in Bamberg and Hallstadt.

Code number	Adress in Bamberg and Hallstadt	X	Y	Code number	Adress in Bamberg and Hallstadt	X	Y
1	Altenburg	634268	5527019	34	Ludwigstr. 25 (Post)	636318	5529177
2	Am Borstig 2	636070	5531636	35	Luitpoldstr. 51	636241	5529232
3	Am Hirschknock	637511	5532267	36	Mainstraße, Ladekai 2	633924	5530319
4	An der Breitenau 2	637253	5530650	37	Mainstraße, Ladekai 3	633816	5530130
5	(An der Breitenau, P&R) ca.	637259	5526912	38	Margaretendamm 28	635341	5529331
6	(Artur-Landgraf-Straße)	635183	5526912	39	Memmelsdorfer Straße (Post) ca.	637769	5531392
7	Breitäckerstr. 9	632965	5529621	40	Memmelsdorfer Str. 208a	637568	5531191
8	Coburger Str. 6a	635877	5529951	41	Memmelsdorfer Str. 208a	634861	5528541
9	Coburger Str. 35	635252	5530468	42	Mußstr. 1	634949	5528827
10	Erlichstr. 47/51	637291	5527903	43	Pödeldorfer Str. 144	637828	5529305
11	Franz-Ludwig-Str. 7	635843	5528490	44	Rheinstr. 16 ca.	632910	5530367
12	Geisfelder Str. 30	637689	5528020	45	Robert-Bosch-Str. 40	637767	5528292
13	Grüner Markt 1	635624	5528370	46	Schildstr. 81	637049	5529049
14	Grüner Markt 23	635640	5528565	47	Schranne 3	635511	5528166
15	Gutenbergstr. 20	638448	5527180	48	Schützenstr. 23	636197	5527961
16	Hainstr. 4	635945	5528229	49	Schwarzenbergstr. 50	636762	5528732
17	Hainstr. 39	636341	5527550	50	Siemensstr. 37-43	638091	5528505
18	Hauptsmoorstr. 26a	638223	5530558	51	Theresienstr. 32	637487	5527866
19	Hauptsmoorwald, Pödeldorfer Straße	639683	5529635	52	Unterer Kaulberg 4	635350	5528084
20	Hauptsmoorwald, Geisfelder Straße	639890	5528022	53	Von-Ketteler-Str. 2	637905	5527553
21	Heiliggrabstr. 15	636054	5529240	54	Wilhelmsplatz 3	636316	5528259
22	Heinrichsdamm 1	635849	5528723	55	Zollnerstr. 181	637772	5530133
23	Heinrichsdamm 33a, P&R	636748	5527529	56	Heganger 18	634327	5530982
24	Hohenlohestr. 7	634794	5526480	57	Biegenhofstr. 13	633963	5531045
25	Kantstr. 33	637161	5530333	58	Seebachstr. 1	634399	5531764
26	Katzenberg	635374	5528266	59	Landsknechtstr.	634800	5531918
27	Kirschäckerstr. 37	636649	5530756	60	Lichtenfelser Str.	634864	5532621
28	(Kloster-Langheim-Str. 8)	637190	5529182	61	Michelinstr. 130 ca.	635629	5532106
29	Kronacher Str. 50	636722	5531496	62	Margaretendamm	634991	5529497
30	Lagerhausstr. 4-6	634850	5529871	63	Mainstr. 36a/Kiliansplatz	634326	5532386
31	Lagerhausstr. 19	634304	5530136	64	Bamberger Straße	635964	5526050
32	(Laurenziplatz 20)	635207	5527404	65	Würzburger Str. 76	635359	5526709
33	Ludwigstr. 2	635207	5529103				

due to existing obstacles there is an inhomogeneous radiofrequency field distribution. Buildings and vegetation (trees and foliage) can shield and reduce radiation and thus affect the quality of signal propagation (e.g. Meng and Lee, 2010). Living material is not a perfect dielectric object and interferes with high frequency electromagnetic fields in a way that depends upon several parameters, including the general shape, conductivity, and density of the tissue, and the frequency and amplitude of the electromagnetic radiation (Vian et al., 2016).

In the polygon mentioned before we selected 60 trees showing unilateral damage. The selection was limited by the fact that we were able to measure with the telescopic rod only up to a height of 6 m. Many trees (*Tilia, Betula, Quercus, Populus, Picea*) showing damage above the

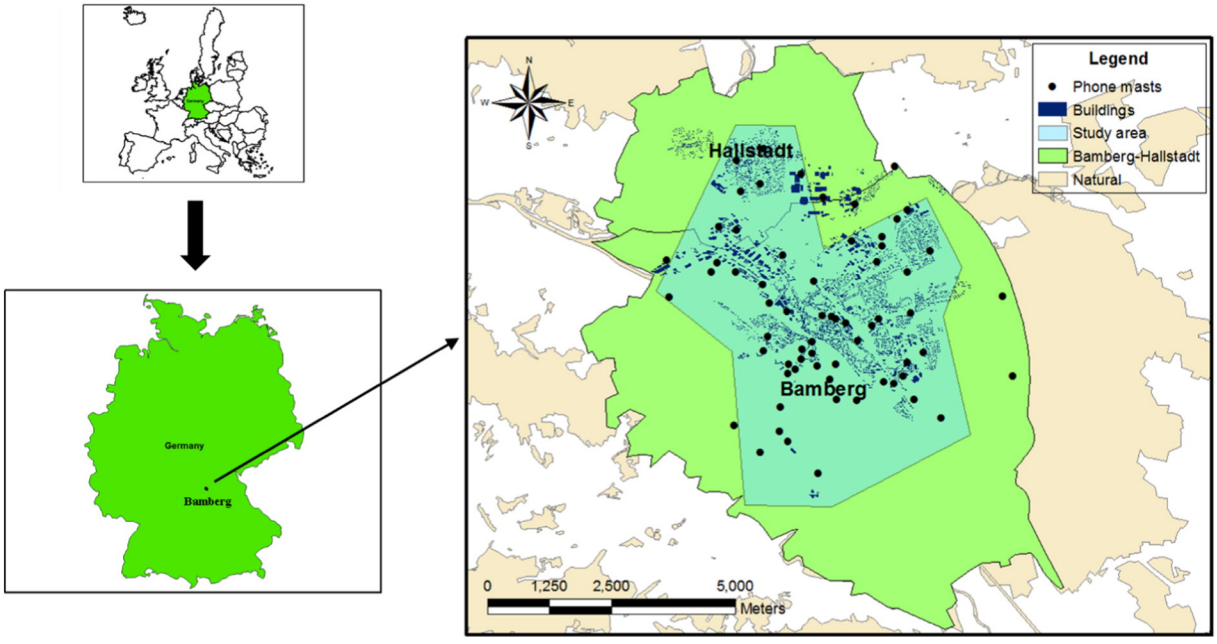

Fig. 1. The study area with the location of the phone masts in the layer of natural areas, buildings, and municipalities.

height of 6 m could not be included. The measurements at the trees were done between April and October 2015. *Acer platanoides*, *Carpinus betulus*, *Tilia* sp., *Taxus baccata* and *Thuja occidentalis* are widely spread in Bamberg and Hallstadt and can be reached for measurements. Therefore they are the most represented species.

The selected 60 trees from the study polygon show damage patterns that are not usually attributable to harmful organisms, such as diseases (fungi, bacteria, viruses) and pests (insects, nematodes) or other environmental factors (water stress, heat, drought, frost, sun, compaction of the soil, air and soil pollutants).

The main features of damage from this source are:

- Trees are mainly affected on one side (showing side differences and unilateral damage) and can appear in any orientation. The damage only originates on one side.
- Damage appears without external indications that the tree is infested with insects, nematodes, fungi, bacteria or viruses.
- Damage appears on trees, which have previously grown well. Damage appears on once healthy trees within one or two years after Antennas were put into operation.
- Damage increases from the outside to the inner part of the crown over time.
- Trees of different species in the same location also show damage.
- Damage appears in favourable (gardens, parks) as well as in unfavourable locations.
- Trees in the same location, but that are shielded by buildings or other trees, are healthy.

For these damaged trees, we used 13 damage codes that may be recognised with the naked eye (for explanations, see Table 2). In order to explain each type of damage visually, a photograph was added for each damage code.

Table 2
Tree damage codes.

01 Damage only on one side: The tree shows damage only on one side. The damage can be recognized with the naked eye.	
02 Crown transparency (sparse leaves or needles): The number of leaves or needles is reduced. The crown transparency increases from year to year.	
03 Brown leaves (start at leaf margins): The leaves begin to turn brown in june. The browning starts at the leaf margins. It looks similar to effects by salt.	
04 Colour change of leaves prematurely: Leaves become yellow, red or brown (in the whole) early in the year.	
05 Tree leaves fall prematurely: The leaves begin to fall already from june on.	
06 Dead branches: Over a period of some years it can be observed how little and big branches die.	
07 Tip of the main guide dried.	
08 Irregular growth. The growth of deciduous and coniferous trees can be disturbed in different manners. One observation is that trees bend to a side.	
09 Not grow in height: Trees often stop to grow in height. The height was not measured. Only the visual impression was valuated.	
10 Colour change of needles. Needles can change their colour to yellow, red or brown.	
11 Dead parts were trimmed down: When bigger branches die, it becomes necessary to remove these parts for the sake of security of people passing.	
12 Damage on different sides: The trees show damages on different sides.	
13 No damage: The tree shows the typical habitus of its species. With the naked eye no damage can be seen.	

Table 3
144 selected points in Bamberg and Hallstadt with their measurements and UTM coordinates.

Number	Streets and parks in Bamberg and Hallstadt	Measurement μW/m²	X	Y	Number	Streets and parks in Bamberg and Hallstadt	Measurement μW/m²	X	Y
1	Wassermannpark	2300	637395	5530345	73	Ludwigstraße/Zollnerstraße	50	636228	5529444
2	Memmelsdorfer Str. 209	1830	637581	5531113	74	Landratsamt, Ludwigstraße, Einfahrt	670	636422	5529044
3	Holunderweg	10	638125	5530967	75	Wilhelmsplatz, Mitte	460	636250	5528263
4	Hauptsmoorstraße/Seehofstraße	3600	638039	5530857	76	Amalienstr. 16	16570	636303	5528086
5	Greifffenbergstr. 79	4210	638349	5530855	77	Otttostr. 7a	120	636133	5527878
6	Heimfriedweg 16	870	638393	5530621	78	Schönbornstr. 3	3640	636251	5527696
7	AWO, Innenhof, Parkplatz	3920	638223	5530584	79	Hainspielplatz	1530	636229	5527403
8	Ferdinand-Tietz-Str. 40	2600	637883	5530616	80	P&R Heinrichsdamm, Parkplatz bei Kirschen	3400	636706	5527667
9	Ferdinand-Tietz-Str. 38	80	637889	5530601	81	P&R Heinrichsdamm, südöstlich des Senders, Eichen	1690	636755	5527504
10	Petrinistr. 20	1340	637797	5530514	82	Luisenhain, Höhe Wasserwerk	260	636895	5526482
11	Petrinistr. 32	4700	637891	5530449	83	Kapellenstraße	2120	637050	5528148
12	Zollnerstraße 181	9300	637773	5530102	84	Geisfelder Str. 9, Gärtnerei	740	637410	5528164
13	Wassermannstr. 14	540	637424	5530125	85	Gereuthstr. 8	30	637621	5527424
14	Feldkirchenstraße/Kantstraße	2620	636803	5530069	86	Distelweg, Innenhof	15	637881	5527160
15	Breslaustr. 20	3890	637392	5530431	87	Am Sendelbach BSC 1920	30	637331	5526877
16	Berliner Ring	16920	637188	5530786	88	Am Sendelbach, Kleingartenanlage	10	637542	5526222
17	Rodezstr. 3	3780	637044	5530765	89	Robert-Bosch-Straße	2060	637504	5528200
18	Am Spinnseyer 3	880	637545	5530764	90	Ludwigstraße/Memmelsdorfer Straße	1000	635974	5529708
19	Kirschäckerstr. 24	4290	636655	5530857	91	Coburger Straße, Neubau Studentenwohnheim	3460	635867	5529878
20	Kammermeisterweg	810	636283	5530282	92	Coburger Straße, junge Platane	3400	635835	5529941
21	Eichendorff-Gymnasium, Hof	6340	637194	5529084	93	Gundelsheimer Str. 2	9000	635783	5529680
22	Starkenfeldstraße/Pfarrfeldstraße	3660	637092	5529138	94	Hallstadter Straße	12	635232	5530212
23	Parkplatz auf der Westseite der Polizei	9020	636921	5528970	95	Gerberstraße/Benzstraße	1280	635108	5530546
24	Starkenfeldstraße, Höhe Polizei	1120	636975	5529061	96	Coburger Straße, Einfahrt Fitnesszentrum	2000	635326	5530508
25	Starkenfeldstr. 2	860	637527	5529216	97	Kleintierzuchtanlage	890	635380	5530622
26	Pödeldorfer Str., Haltestelle	2180	636965	5529217	98	Margaretendamm, Eingang ehemaliges Hallenbad	1300	635455	5529178
27	Kindergarten St. Heinrich, Eingang	6450	637712	5529364	99	Margaretendamm/Europabrücke	1890	635200	5529365
28	Pödeldorfer Straße, Haltestelle Wörthstraße	1620	637654	5529433	100	Margartendamm 38, nahe Sendeanlage	5560	635003	5529497
29	Pödeldorfer Str. 142, Nordseite	30	637840	5529437	101	Hafenstraße/Regnitzstraße	7610	634719	5529740
30	Pödeldorfer Str. 142, Südseite	17060	637824	5529410	102	Lagerhausstraße	210	634556	5530102
31	Berliner Ring, Höhe Pödeldorfer Str. 144	4480	637900	5529380	103	Hafenstr. 28, Bayerischer Hafen	3200	634192	5530370
32	Schwimmbad Bambados, Vorgarten mit Bambus	1620	638074	5529315	104	Laubanger 29	160	634202	5530561
33	Schwimmbad Bambados, Parkplatz, Feldahorn	2540	638202	5529346	105	Heganger	1400	634341	5530812
34	Carl-Meinelt-Str.	5360	638043	5529094	106	Emil-Kemmer-Str. 2	5000	633822	5530863
35	Volkspark, FC Eintracht, Ostseite	120	638343	5529065	107	Emil-Kemmer-Str. 14	2500	634342	5531099
36	Michelsberger Garten, Teil Streuobst	5450	634831	5528673	108	Dr. Robert-Pfleger-Straße 60	90	634448	5530978
37	Michelsberger Garten, Terrassengarten, bei Eibe	2500	634988	5528508	109	Friedhof Gaustadt, Haupteingang	13100	632981	5529677
38	Michelsberger Garten, Südostecke, bei Holunder	910	635036	5528455	110	Friedhof Gaustadt, Ahornpaar	1400	632929	5529728
39	Michelsberg, Aussichtsterrasse, oberhalb Weinberg	1260	634924	5528463	111	Herzog-Max-Str. 21	1600	636245	5528071
40	Michelsberg, Aussichtsterrasse, Aussichtspunkt	780	634911	5528537	112	Gaustadter Hauptstr. 116	10	634042	5529457
41	Michelsberg, Nordostecke, bei jungen Linden	390	634874	5528565	113	Landesgartenschaugelände, Hafenerlebnispfad	2000	633789	5529894
42	Storchsgasse/Michelsberg	200	634725	5528415	114	Landesgartenschau, junge Baumgruppe	1270	633949	5529718
43	St. Getreu-Kirche, Südseite	55	634518	5528405	115	Würzburger Str.	340	635283	5527151
44	Villa Remeis, Garten	390	634295	5528203	116	Würzburger Straße/Arthur-Landgraf-Straße	1380	635355	5526862
45	Villa Remeis, Treppe	300	634400	5528237	117	Hohe-Kreuz-Straße/Würzburger Straße, Haltestelle	590	635383	5526733
46	Maienbrunnen 2	3920	634744	5528838	118	Hohe-Kreuz-Straße	10950	635469	5526729
47	Am Leinritt	2140	635071	5528617	119	Am Hahnenweg 6	3420	635332	5526729
48	Abtsberg 27	130	634526	5528935	120	Am Hahnenweg/Viktor-von-Scheffel-Straße	640	635307	5526710
49	Welcome Hotel, Garten	3200	634788	5529012	121	Am Hahnenweg 28 a	145	635028	5526654
50	Mußstraße, eingang Kindergarten	1670	634864	5529011	122	Schlüsselberger Straße	200	634712	5526534
51	Mußstraße/Schlüsselstraße	710	634846	5529034	123	Schlüsselberger Str./Haltestelle Hezilostr., Parkdeck	460	634749	5526549
52	Nebingerhof	2040	635069	5528901	124	Hezilostr. 13	70	634604	5526563
53	Graf-Stauffenberg-Platz	100	635120	5529009	125	Sückleinsweg, junge Hainbuchenhecke	75	634512	5526654
54	Don-Bosdo-Straße, Innenhof	10	635176	5529056	126	Rößleinsweg, oberes Ende	300	634708	5526789
55	Pfeuferstraße/Weide	1100	635222	5528820	127	Große Wiese	1500	634874	5526810

Table 3 (*continued*)

Number	Streets and parks in Bamberg and Hallstadt	Measurement µW/m²	X	Y	Number	Streets and parks in Bamberg and Hallstadt	Measurement µW/m²	X	Y
56	Weidendamm/Don-Bosco-Straße	1860	635166	5529195	128	Suidgerstraße	195	634508	5526409
57	Katzenberg/Karolinenstraße	1720	635316	5528239	129	Waizendorfer Straße	280	635317	5525864
58	Vorderer Bach	450	635305	5528141	130	Waizendorfer Straße, Einfahrt Gärtnerei	210	635326	5525582
59	Obere Brücke	8000	635565	5528289	131	Klinikum, Nähe Spielplatz	175	635732	5525672
60	Judenstraße	6	635479	5528040	132	Klinikum Weiher	100	635759	5525520
61	Tourist Information	4920	635674	5528172	133	Buger Straße/Bamberger Straße	2730	635829	5526082
62	Universität, Am Kranen 14, Innenhof	10	635501	5528535	134	Dunantstraße	470	635848	5526176
63	Fleischstraße	10	635703	5528683	135	Buger Straße/Paradiesweg	90	635743	5526286
64	ZOB	600	635882	5528541	136	Buger Straße/Abzweigung Münchner Ring	470	635528	5526499
65	Schönleinsplatz, Ostseite	900	636004	5528300	137	Hallstadt, Markplatz, bei Linde	2000	634582	5532426
66	Friedrichstraße, Parkplatz	165	635984	5528360	138	Hallstadt, Markplatz 21, Innenhof	8	634632	5532488
67	Franz-Ludwig-Straße/Luisenstraße	1720	636158	5528410	139	Hallstadt, Lichtenfelser Str. 12	4000	634659	5532474
68	Franz-Ludwig-Str, Strassenbauamt	90	636246	5528408	140	Hallstadt, Lichtenfelser Str. 8	9000	634720	5532516
69	Heiliggrabstraße, Nähe Sender	4740	636072	5529245	141	Hallstadt, Am Gründleinsbach/Kemmerner Weg	200	634743	5532784
70	Heiliggrabstr. 29, Landesjustizkasse	20	636063	5529399	142	Hallstadt, Valentinstraße/Seebachstraße	2200	634232	5532237
71	Heiliggrabstr. 57, Aussichtspunkt Schiefer Turm	4500	635797	5529410	143	Hallstadt, Johannisstr. 6	5000	634805	5532078
72	Bahnhof, ParkplatzWestseite	1600	636300	5529374	144	Hallstadt, Bamberger Straße/Michael-Bienlein-Straße	1860	634805	5531969

For each selected tree, the types of damage and the Universal Transversal Mercator (UTM) coordinates were recorded. In addition, two measurements were recorded: on the side showing damage and on the side without damage, generally corresponding to opposite sides of each tree. On both sides, the measurements were carried out at a variable height of 1–6 m (depending on the height of the tree), using a telescopic rod, a ladder, and the broadband radiofrequency meter.

Most measurements were done in the afternoon or in the evening on different days between April and October 2015. But the measurements on the two sides of each single tree were done one after another immediately on the same day and at the same time. The measurements took about 5 min on each side. When we stood on the ground or on a ladder we measured the peak values. When we used the telescopic rod we measured the peak hold values. Using the telescopic rod and measuring peak hold values it took longer, because the measurements had to be repeated often in cases where RF-EMF emitting cars or passengers disturbed the results. At each single tree the two measurements were done in the height where the damage had appeared. Because the height of the 120 trees differed, it was necessary to do the measurements at different heights.

In theory, although measurements are changing continuously there is no evidence about significant changes in power densities of electromagnetic radiation produced by phone masts over time. One study carried over one year in the city of Madrid showed no changes in terms of radiation intensity between the three rounds of measurements

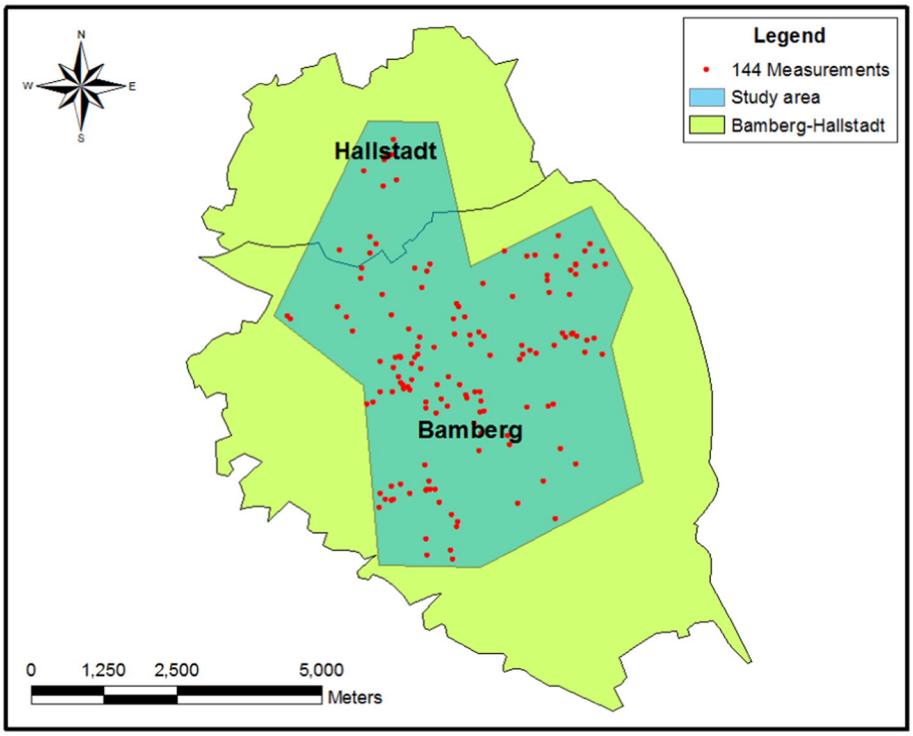

Fig. 2. Location of the 144 measurements points in Bamberg and Hallstadt in the study area.

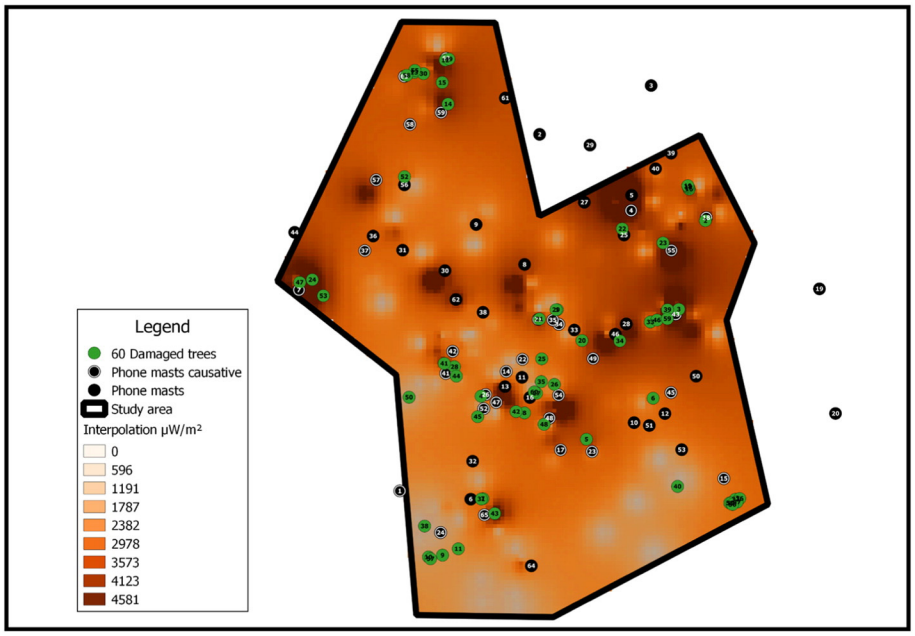

Fig. 3. Map showing the 60 damaged trees and phone masts (both with code numbers) over the interpolation electromagnetic map of the 144 measurement points.

performed in about 200 sampling points (own data). Repeatability analysis checked this. Despite the fact that the increase in sector antennas (observed between 2011 and 2015) would have probably increased the radiation in the environment of the study area, measurements used in this study were mostly done in 2015.

In an attempt to link the electromagnetic radiation measured at every tree to specific phone masts, the distances to the three nearest antennas that could be mainly responsible for the radiation measurements at each tree were calculated in meters with Geographical Information System (GIS) programs, following the general approach criteria of proximity. However, it must be taken into account that buildings and vegetation diminish radiation intensity and, in many cases, the nearest phone mast or masts may be obscured by obstacles. In other cases, the phone mast is in direct line of sight from the tree and the radiation can reach the tree directly.

Additionally, 30 random points were generated inside the polygonal study area and outside a layer of buildings, downloaded from: http://www.mapcruzin.com/free-germany-arcgis-maps-shapefiles.htm using a Random Points tool of QGIS 2.6.0-Brighton (QGIS Development Team, 2014) allowing create random points inside a specific layer. Therefore the points were randomly situated in specific places in the study area outside buildings but not frequently concur with the location of trees. That is why measurements were taken from the nearest tree for each random point, generating a random tree group. Measurements and damage characteristics were scored in the same way as with 60 damaged trees explained above, measuring the maximum value of radiation corresponding to opposite sides of each tree.

In areas of the city with low measurements of electromagnetic radiation (no visual contact to any phone mast and power flux density <50 µW/m^2), we scored another 30 trees in the same way as with 60 damaged trees and 30 random points. The UTM coordinates and the three nearest phone masts of each tree in these last two groups (random and low radiation trees) were also recorded.

To generate electromagnetic maps, we used ArcGis 9.3 (ESRI, 2008) and QGIS 2.6.0-Brighton (QGIS Development Team, 2014). To check possible differences between groups of data and taking into account that there were two measures made in each tree, repeated measures analysis of variance were applied, considering a repeated measures factor (within-subjects) and another between-subjects. The post hoc Bonferroni test was used in all cases to elucidate significant differences. Statistics were performed using STATISTICA 7 program (StatSoft, Inc, 2004).

3. Results

The results of radiation measurements obtained at 144 points in Bamberg and Hallstadt at a height of 1.5 m were between 6 µW/m^2 (0.047 V/m) and 17,060 µW/m^2 (2.53 V/m) (for measurements and UTM coordinates, see Table 3). The measured values are far below the current limit values (41 V/m for GSM system and 61 V/m for UMTS; ICNIRP, 1998).

The locations of these points in the study area are shown in Fig. 2. By interpolation of the 144 measurements points (Table 3), we prepared a map of the power flux density in Bamberg and Hallstadt (Fig. 3). This map is theoretical and approximate, since many factors affect the true electromagnetic values. However, the map is useful to provide approximate differences in exposure (electromagnetic pollution) throughout the city.

The 60 selected trees showing damage patterns not attributable to diseases, pests or other environmental factors are presented in Table 4. In this Table, we added the tree code number, the scientific name, the UTM coordinates, the measurements (power flux density) on both sides of each tree, and the distances (meters) and code numbers to the three nearest antennas for each tree, which may be mainly responsible for the electromagnetic radiation measured. We also included the orientation of the tree damage and the number of main (nearest) phone mast(s) in direct line of sight, whose lobe of radiation most directly affected each tree. Finally, we included the codes of damage observed in the 60 trees.

From all 60 selected trees, one or more phone mast(s) could be seen, with no obstacles between the phone mast and damaged tree. In many cases, one of the three closest antennas caused the main radiation on the tree surface. In ten trees (codes: 4, 7, 9, 10, 15, 26, 27, 31, 35, and 50), another antenna in direct line of sight caused the measured radiofrequency exposure. This was determined using topography and existing buildings (Table 4 and Fig. 3).

The 60 damaged trees (with their code number) and the phone masts are overlaid on the electromagnetic map prepared by interpolation of the 144 measurements points (Fig. 3). The likely antenna or

antennas causing radiation damage to each tree are also shown (Fig. 3). The measurements at all selected trees revealed significant differences between the damaged side facing a phone mast and the intact (or less damaged) opposite side. On the side facing a phone mast, the measured values were 80–13,000 μW/m^2 (0.173–2.213 V/m). On the opposite side the values were 8–720 μW/m^2 (0.054–0.52 V/m).

Table 4
60 selected trees showing damage patterns not attributable to diseases, drought or other environmental factors.

														Effect codes												
														1	2	3	4	5	6	7	8	9	10	11	12	13
N°	Scientific name	X	Y	Side antenna measurement μW/m²	Opposite side measurement μW/m²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Direction of damage	Number of main phone mast(s) causing the radiation	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	*Acer platanoides*	636298	5529366	970	130	35	145,6	34	190,1	21	274,6	S, SW	35,34,21	+	+	+		+	+	+		+				
2	*Acer platanoides*	638211	5530518	680	80	18	41,76	55	583,9	40	930,8	N	18	+	+	+		+	+			+		+		
3	*Acer platanoides*	637868	5529371	2100	290	43	77,18	28	703,9	55	768	S	43	+	+	+		+	+	+		+				
4	*Acer platanoides*	635316	5528245	2300	130	26	61,68	52	164,6	47	210,4	E, S	26,52,47, 14	+	+	+		+	+	+		+		+		
5	*Acer platanoides*	636677	5527688	3600	290	23	174,1	17	363,2	48	552,2	S	23	+	+	+		+	+	+		+		+		
6	*Acer platanoides*	637536	5528219	700	140	45	242,3	12	251	51	356,4	E	45	+	+	+		+	+	+						
7	*Acer platanoides*	635339	5526919	270	30	6	156,2	65	211	32	502,6	W	1	+		+		+	+	+		+		+		
8	*Acer platanoides*	635876	5528029	80	10	16	211,6	48	328,1	47	389,9	W	47	+	+	+		+								
9	*Acer platanoides*	634819	5526187	160	20	24	294,1	65	751,1	6	811,2	N	24, 1		+	+		+	+					+		
10	*Acer platanoides*	634638	5526163	180	55	24	353,3	65	904,4	6	926,3	N	24, 1		+	+		+	+							
11	*Acer platanoides*	635022	5526270	95	20	24	310	65	553,4	6	661,9	NW	24	+	+			+								
12	*Acer platanoides*	634854	5532596	11800	400	60	26,93	63	568,2	59	680,1	N	60	+	+	+		+	+	+		+				
13	*Acer platanoides*	634455	5532438	9900	620	63	139,1	60	448,1	59	624	W	63	+			+							+		
14	*Acer platanoides*	634890	5532028	3380	500	59	142,1	58	557,5	60	593,6	SW	59	+	+	+		+	+	+		+		+		
15	*Acer platanoides*	634815	5532307	1050	50	60	317,8	59	389,3	63	495,3	SW	58	+	+	+		+	+	+		+		+		
16	*Carpinus betulus*	638001	5530928	1210	120	18	431,5	40	506,6	39	518,8	S	18	+	+	+		+	+							
17	*Carpinus betulus*	637996	5530945	2520	150	18	448,7	40	493,7	39	501,3	S	18	+	+	+		+	+							
18	*Carpinus betulus*	637987	5530959	890	90	18	465,3	40	478,9	39	484,8	S	18	+	+	+		+								
19	*Carpinus betulus*	637984	5530970	670	10	40	471,1	39	473,6	18	476,3	S	18	+	+	+		+								
20	*Carpinus betulus*	636619	5528966	1000	200	33	169,6	49	274,2	34	367,6	SE	49		+	+		+	+			+		+		
21	*Carpinus betulus*	636068	5529245	430	20	21	14,87	35	173,5	34	259,1	W	21	+	+	+		+				+		+		
22	*Carpinus betulus*	637138	5530413	4340	110	25	83,24	4	263,4	5	450,6	NE	4	+	+	+		+	+	+		+				
23	*Carpinus betulus*	637664	5530231	990	60	55	145,8	25	513,2	4	586,9	E	55	+	+	+		+	+							
24	*Carpinus betulus*	633137	5529754	2700	50	7	217,4	44	653,7	37	776,2	E	37	+	+	+		+	+							
25	*Tilia sp.*	636098	5528729	870	150	22	249,1	11	349,5	14	486,5	W	22	+	+	+		+	+							
26	*Tilia sp.*	636261	5528398	410	20	54	149,5	16	358,4	11	428	W	14	+		+		+								
27	*Tilia sp.*	636030	5528283	680	160	16	100,7	11	279	54	287	S	48	+	+		+	+	+					+		
28	*Tilia sp.*	634972	5528626	660	170	41	139,8	42	202,3	26	539,6	SW	41	+	+	+		+	+	+		+		+		
29	*Tilia sp.*	636283	5529365	2450	160	35	139,5	34	191,2	21	260,9	SW	35, 34, 21	+		+		+				+		+		
30	*Tilia sp.*	634573	5532422	3800	420	63	249,6	60	352,5	59	552,8	NE	60	+	+	+		+	+					+		
31	*Tilia sp.*	635319	5526914	380	120	6	136	65	208,9	32	502,6	W	1	+	+		+	+	+	+						
32	*Quercus robur*	638598	5526911	860	130	15	308	53	944,7	12	1434	NW	15		+			+	+							
33	*Quercus rubra*	637501	5529207	1340	120	28	312	43	341,4	46	478,8	E	43	+	+			+	+							
34	*Quercus rubra*	637107	5528961	1650	250	46	105,4	28	236,1	49	414,1	SW	49	+	+				+							
35	*Aesculus hippocastanum*	636092	5528434	400	20	16	252,3	11	255,2	54	284,3	W	14	+	+	+		+	+	+		+				
36	*Robinia pseudoacacia*	638653	5526920	1300	40	15	331,1	53	979,9	12	1463	NW	15	+			+		+	+		+				

Table 4 *(continued)*

37	*Robinia pseudoacacia*	638619	5526874	660	240	15	350,5	53	985,3	12	1476	NW	15	+			+		+					+		
38	*Sorbus occuparia*	634587	5526564	84	8	24	223,4	1	555,7	6	690,2	N	1	+	+	+		+	+	+		+				
39	*Acer negundo*	637722	5529366	3060	310	43	122,3	28	562,9	46	743,9	SE	43	+	+			+	+			+		+		
40	*Acer saccharinum*	637852	5527078	840	180	53	477,9	15	604,7	51	868,4	E	15	+	+			+								
41	*Juglans regia*	634841	5528669	4500	590	41	129,6	42	191,4	26	668,2	N, E	42	+	+			+	+	+	+	+				
42	*Taxus baccata*	635767	5528046	300	70	16	255,3	47	282,7	13	354,2	NW	47	+	+				+					+	+	
43	*Taxus baccata*	635491	5526727	8970	190	65	133,2	6	359,3	32	734,2	W	65	+	+				+					+	+	
44	*Taxus baccata*	634997	5528506	2500	240	41	140,4	42	324,6	26	446,9	N,E,W	41,42		+				+					+	+	
45	*Taxus baccata*	635272	5527980	2700	70	52	130	47	302,8	26	303,6	NE	52	+	+				+					+	+	
46	*Taxus baccata*	637586	5529231	1520	190	43	253,1	28	399	46	567	E	43	+	+									+	+	
47	*Thuja occidentalis*	632975	5529719	910	30	7	98,51	44	651,3	37	936,1	S	7	+	+				+					+		
48	*Thuja occidentalis*	636128	5527881	120	10	48	105,6	16	393,2	17	393,6	S	17	+	+				+					+		
49	*Thuja occidentalis*	634900	5532611	13000	520	60	37,36	63	616,5	59	700,2	NW	60	+	+				+					+		
50	*Thuja occidentalis*	634387	5528232	290	50	41	565,8	42	818,5	52	974,3	S	1	+	+				+	+				+		
51	*Picea pungens*	638525	5526863	770	90	15	326,2	53	927,6	12	1427	NE	15	+	+				+					+		
52	*Picea pungens*	634328	5531086	3080	310	56	104	57	367,3	58	681,7	W	57		+				+				+	+		
53	*Picea pungens*	633280	5529546	1350	200	7	323,8	37	792,7	44	900,5	W	7	+	+				+		+			+		
54	*Pinus sylvestris*	638542	5526861	790	50	15	332,6	53	940,5	12	1439	NE	15		+				+		+	+		+		
55	*Pinus sylvestris*	634461	5532462	5300	130	63	154,9	60	433,2	59	641	SW	63	+	+									+		
56	*Pseudotsuga menziesii*	638560	5526844	1720	60	15	354,2	53	965,2	12	1463	NE	15	+	+				+	+		+		+		
57	*Juniperus communis*	634664	5526141	160	20	24	363,1	65	897,6	6	929,4	N	24	+	+				+					+		
58	*Corylus avellana 'Contorta'*	634355	5532399	420	80	63	31,78	60	555,3	58	636,5	W	63	+	+	+		+	+							
59	*Corylus avellana*	637720	5529249	3880	720	43	121,7	28	534,2	46	700,2	N	43	+	+	+		+							+	
60	*Symphoricarpos albus*	636002	5528299	1200	320	16	90,27	11	248,5	54	316,5	E	54	+	+			+	+						+	

In the five most represented species ($n \geq 4$) among the 60 affected trees, most trees showed damage only on one side: unilateral damage (Damage code 1, Tables 2 and 4). By species and percentages: *Acer platanoides* (86%), *Carpinus betulus* (88%), *Tilia* sp. (100%), *Taxus baccata* (80%) and *Thuja occidentalis* (100%). On the seven trees not given code 1, the damage spread over the whole tree, but trees still showed side differences. Most of these trees were characterized with sparse leaves or needles (crown transparency) (Damage code 2, Tables 2 and 4). By species and percentages: *Acer platanoides* (86%), *Carpinus betulus* (100%), *Taxus baccata* (100%) and *Thuja occidentalis* (100%). In many of the trees with the one-sided damage, the leaves turned prematurely yellow or brown in June – this always began at the leaf margins (Damage code 3, Tables 2 and 4). The species with higher percentages were: *Acer platanoides* (86%) and *Carpinus betulus* (100%). In many trees leaves fall prematurely: *Acer platanoides* (93%), *Carpinus betulus* (100%) and *Tilia sp.* (100%) (Damage code 5, Tables 2 and 4). Many trees of the species *Acer platanoides* (80%), *Taxus baccata* (80%) and *Thuja occidentalis* (100%) had dead branches (Peak branches dried) (Damage code 6, Tables 2 and 4). All the trees of the species *Taxus baccata* (100%) and *Thuja occidentalis (100%)* exhibited color change of the needles (Damage code 10, Tables 2 and 4). Finally, in all trees of the species *Taxus baccata*, dead parts were trimmed (Damage code 11, Tables 2 and 4). Some trees stopped growing in height while, in others, the main guide died (see Tables 2 and 4).

The 30 randomly selected trees are presented in Table 5 with the tree code number, the scientific name, the UTM coordinates, the measurements (power flux density) on both sides of each tree, the distance (meters) to the three nearest antennas, their code number and the damage codes. Trees in these locations may be in areas with either high or low radiation. Seventeen trees in this group were situated in places with low radiation and showed no signs of damage. The measurements were 8–50 μW/m^2 (0.054–0.137 V/m) and showed no difference between the two opposite sides. Thirteen trees stood in the radiation field of one or more phone mast. Six of these had damage only on the side facing a phone mast, and five had damages on other sides. The measurements on the exposed sides were 40–4600 μW/m^2 (0.122–1.316 V/m).

The 30 trees selected in areas with low radiation (radio shadow of hills, buildings or trees) are presented in Table 6 with the tree code number, scientific name, UTM coordinates, measurements (power flux density) on both sides of each tree, distance (meters) to the three nearest antennas, their code number and the damage codes. All trees selected in low radiation areas showed no damage (code 13). The power flux density values measured were 3–40 μW/m^2 (0.033–0.122 V/m) and no significant differences were found between the two opposite sides.

The trees in random points and the trees in areas of low radiation are represented In Fig. 4 over the electromagnetic map prepared by interpolation of the 144 measurements points.

We performed a Repeated Measures ANOVA analysis in order to include the measurements of the exposed and shielded side of each tree (R1 = within subjects factor) in the three groups of trees (damaged, random, and low radiation), and to avoid pseudoreplication. The comparisons of all factor levels revealed significant differences, including the interaction between factors. A post hoc Bonferroni comparisons test, recommended for different sized groups of samples, revealed significant differences between measurements from the exposed side of damaged trees and all other groups (Table 7). Fig. 5 shows the measurements (mean and standard error) in all groups.

In the "Random points" group of trees, we performed another Repeated Measures ANOVA (R1 = within subjects factor) for trees damaged and undamaged within this group (Table 8). The results showed significant differences in both factors, including the interaction, which means that depending on the group of tree (damaged or undamaged),

Table 5
Results of the tree measurements at the 30 random points.

												Effect codes												
												1	2	3	4	5	6	7	8	9	10	11	12	13
N°	Scientific name	X	Y	Side antenna measurement µW/m²	Opposite side measurement µW/m²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	*Salix viminalis*	634095	5532455	10	10	63	241,1	58	754,9	60	786,7													+
2	*Thuja occidentalis*	634760	5532680	500	120	60	119,6	63	524,2	59	763		+				+	+			+		+	
3	*Abies alba*	634030	5530490	2200	900	36	201,2	37	418,8	31	447,7		+				+			+	+		+	
4	*Acer campestre*	634545	5530739	890	320	56	326,5	31	649,4	57	657,5	+	+				+							
5	*Acer platanoides*	634557	5530005	4600	1100	31	284,9	30	322,2	62	668,1	+	+	+		+						+		
6	*Picea abies*	635311	5530644	1900	210	9	185,6	8	894,8	30	900									+	+			
7	*Thuja occidentalis*	635635	5529879	10	10	8	252,5	38	621,9	9	702,6													+
8	*Acer platanoides*	635693	5529848	2600	310	8	210,9	38	625,5	21	707,1	+	+			+	+					+		
9	*Cornus sanguinea*	636415	5530248	40	30	27	559,3	8	614,5	25	750,8													+
10	*Acer pseudoplatanus*	637525	5530896	50	50	5	270,5	40	298,1	4	366,7													+
11	*Syringa*	638111	5531436	10	10	39	344,8	40	595,7	18	885,1													+
12	*Acer platanoides 'Globorum'*	637928	5530541	30	30	18	295,5	55	436,8	4	683,7													+
13	*Acer platanoides*	637159	5529361	20	15	28	181,7	46	330,8	43	671,3													+
14	*Quercus rubra*	638342	5528994	1480	570	50	549,7	43	600,8	45	907,4		+			+	+					+	+	
15	*Thuja occidentalis*	638359	5528569	25	20	50	275,5	45	653,6	12	866,2													+
16	*Tilia sp*	637412	5527922	460	320	51	93,6	10	122,5	12	293,8											+		
17	*Quercus robur*	637363	5527807	45	33	10	120	51	137,3	12	389,4													+
18	*Larix decidua*	637804	5527628	4400	3170	53	125,8	51	396,4	12	408,5		+				+		+				+	
19	*Acer pseudoplatanus*	637919	5527135	760	120	53	418,2	15	530,9	51	849,1	+	+			+	+	+				+		
20	*Acer negundo*	637329	5526888	190	30	23	865,1	53	879,8	51	990,7	+										+		
21	*Quercus robur*	637115	5527423	46	26	23	382	10	511,2	51	578,5													+
22	*Thuja occidentalis*	637315	5526260	40	13	64	1367	23	1390	53	1421	+									+			
23	*Salix matsudana 'Tortuosa'*	635403	5525413	15	12	64	848,8	24	1229	65	1297													+
24	*Populus tremula*	635410	5525828	15	9	64	596,8	65	882,5	24	897													+
25	*Salix matsudana 'Tortuosa'*	634981	5526161	41	23	24	369,8	65	665,7	6	777,7													+
26	*Prunus sp.*	634829	5526050	28	21	24	431,4	65	845,7	6	931,9													+
27	*Picea pungens*	634791	5526809	470	340	24	329	6	405,3	1	563,6		+				+		+				+	
28	*Cornus sanguinea*	635164	5527863	15	15	52	288,9	26	454,4	47	460,7													+
29	*Cornus sanguinea*	634905	5528779	20	20	42	65,12	41	242	26	695,1													+
30	*Acer negundo*	634202	5529092	8	8	42	792,6	41	859	62	886,9													+

significant or non-significant respectively differences between the measurements of the two sides are seen (Fig. 6). A post hoc Bonferroni comparisons test showed significant differences between the measurements from the exposed side of damaged trees and all other groups in the random points group (Table 8).

Of the 120 trees, those with lower mean distance to the three closest antennas have usually higher values of radiation (Fig. 7). However, screening is common in cities due to a large amount of buildings, thus some trees that are close to antennas show lower radiation values than expected. This means that radiation measurements at points close to antennas are variable (high and low) while trees farther from antennas always have low values.

A dossier with documentation gathered over the years and the examples of tree damages is presented in: http://kompetenzinitiative.net/KIT/KIT/baeume-in-bamberg/

4. Discussion

In the present study it was useful, that tree damages in the vicinity of phone masts in Bamberg and Hallstadt had been documented starting 2006. We found a high level of damage to trees in the vicinity of phone masts. The damage encountered in these trees is not attributable to harmful organisms, such as diseases, pests or other environmental factors. These would impact upon the entire tree, whereas damage to trees in the present study was only found on parts of the tree and only on one side (unilateral). Therefore, these factors cannot explain the damage documented here. Generally in all trees of this study, damage is higher in areas of high radiation and occurs on the side where the nearest phone mast is located (Table 4 and Fig. 3). Moreover, areas with more antennas have more levels of radiation and damaged trees are found most often in these high electromagnetic polluted areas. These results showed that side differences in damage corresponded to side differences in measured values of power flux density. This paper look at the effects on trees, but also provides information on how electromagnetic radiation is distributed in a city (interpolation map and Fig. 7).

In this study deciduous and coniferous trees were examined under the real radiofrequency field conditions around phone masts in Bamberg and Hallstadt. From most phone masts a broad band of frequencies with different modulations and pulse frequencies and fluctuating power densities is emitted (GSM 900, GSM 1800, UMTS, LTE, TETRA). Different signals may have different effects due to their physical parameters (Belyaev, 2010; IARC, 2013). We do not discriminate between these different signals and cannot answer the question which part of the

Table 6
Results of the tree measurements in the 30 points with low radiation.

												Effect codes												
												1	2	3	4	5	6	7	8	9	10	11	12	13
Nº	Scientific name	X	Y	Side antenna measurement µW/m²	Opposite side measurement µW/m²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	*Acer platanoides*	636741	5529855	26	20	25	636,3	33	784,1	35	798,8													+
2	*Carpinus betulus*	634853	5529041	10	8	42	234,5	62	476,4	41	500,1													+
3	*Carpinus betulus*	638311	5528439	12	10	50	229,7	45	563,5	12	750													+
4	*Carpinus betulus*	636753	5529880	8	8	25	609,6	33	811,5	28	823,5													+
5	*Carpinus betulus*	637817	5527130	15	12	53	432,1	15	633	51	806,6													+
6	*Carpinus betulus*	634931	5526731	15	15	24	286	6	310,3	65	428,6													+
7	*Tilia sp.*	636500	5529673	8	8	35	511,4	34	528,3	33	570,3													+
8	*Tilia sp.*	636824	5529794	17	9	25	635,7	28	713,1	33	755,3													+
9	*Quercus robur*	636455	5526130	9	8	64	497,5	65	1240	17	1425													+
10	*Quercus robur 'Fastigiata'*	636178	5528932	10	10	34	282,2	35	306,5	21	332													+
11	*Aesculus hippocastanum*	636828	5529780	10	10	25	645,5	28	699	33	744,2													+
12	*Aesculus carnea*	636463	5529709	12	12	35	526,1	34	551,4	33	608,6													+
13	*Robinia pseudoacacia*	635507	5528534	15	15	14	136,6	13	201,5	26	299,2													+
14	*Robinia pseudoacacia*	634720	5532783	8	8	60	216,7	63	559,3	59	868,7													+
15	*Acer campestre*	635697	5528689	40	30	14	136,5	22	155,8	11	246,8													+
16	*Acer campestre*	636486	5526116	6	6	64	526,2	65	1273	23	1437													+
17	*Juglans regia*	635744	5528667	20	15	22	119	14	145,7	11	202,8													+
18	*Platanus hispanica*	635496	5528529	17	15	14	148,4	13	204,1	26	289,9													+
19	*Prunus avium*	637958	5530874	10	8	18	412,4	40	502,6	39	551,4													+
20	*Prunus sp.*	636079	5528463	10	10	11	237,5	16	269,7	54	312,7													+
21	*Taxus baccata*	638407	5528502	5	5	50	316	45	673,6	12	864,8													+
22	*Taxus baccata*	638222	5531032	10	10	18	474	39	578,6	40	673,1													+
23	*Thuja occidentalis*	636518	5529853	9	9	8	648,4	35	680	34	705													+
24	*Thuja occidentalis*	635318	5528784	20	15	42	371,5	14	389,4	13	514,8													+
25	*Picea pungens*	636512	5529735	17	17	35	571,4	34	590,8	33	632													+
26	*Juniperus communis*	636549	5529756	8	8	35	607,8	34	623,4	33	653,7													+
27	*Cornus sanguinea*	638167	5529098	8	6	43	397,2	50	597,9	45	899,8													+
28	*Sambucus nigra*	635529	5525601	5	5	64	625,2	65	1121	24	1146													+
29	*Corylus avellana*	636422	5526181	5	3	64	476,4	65	1187	17	1371													+
30	*Corylus avellana*	636625	5529834	6	6	35	714	34	725,2	25	732,3													+

radiation has caused the damage. Nevertheless broad bands of frequencies, modulation, pulse frequencies, interferences and other physical characteristics may play an important role, since in some cases, damage already appears at low intensities. This can be a shortcoming of the study.

The aim of the present study was to find out whether there is a causal relationship between the unilateral tree damages, which had been observed since 2006, and the RF-EMF emitted from phone masts and a preliminary observation to find out whether various species react differently to RF exposure.

The selection of the 60 unilaterally damaged trees was limited by the fact that we could do measurements only up to a height of 6 m. Trees with damages above the height of 6 m could not be included.

Many factors can affect the health of trees: Air and soil pollutants, heat, frost, drought, as well as composition, compaction and sealing of the soil, road salts, root injury due to construction work, diseases and pests. Most of these factors do not affect a tree only on one side over a period of >5 years. Industrial air pollutants could eventually cause unilateral damage in direction to an industrial emitter. But the observed unilateral damages appeared in all directions and were not oriented to the incineration plant or other industrial plants. Root injury due to construction work can produce damage on one side of a tree, but 24 of the 60 selected trees were situated in gardens, parks or on the cemetery where they could not be affected by construction damages.

From the damaged side there was always visual contact to one or more phone mast (s). In each case measurements of the power flux density on the damaged side which was facing a phone mast and on the opposite side without (or with less) damage were carried out and the difference between the measured values on both sides was significant (Fig. 5), as well as between the exposed side of damaged trees and all other groups. In all 60 trees the gradient of damage corresponded to a gradient of measured values. The attenuation of the RF-EMF within the treetop offers an explanation: a part of the RF-EMF is absorbed by leaves or needles and another part is reflected, scattered and diffracted.

In the randomely selected group of 30 trees, 17 trees were situated on places with low radiation. These 17 trees showed no damages, the measured values were below 50 µW/m^2 (0.137 V/m) and there was no difference between opposite sides as in the low radiation group. On the other hand, 13 trees grew in the radiation field of one or more phone mast (s). These trees showed unilateral damage or damage on different sides. The measured values at damaged trees showed differences between both sides as in the previous group above.

In the group of 30 trees in areas with low radiation (radio shadow of hills, buildings or trees and without visual contact to phone masts)

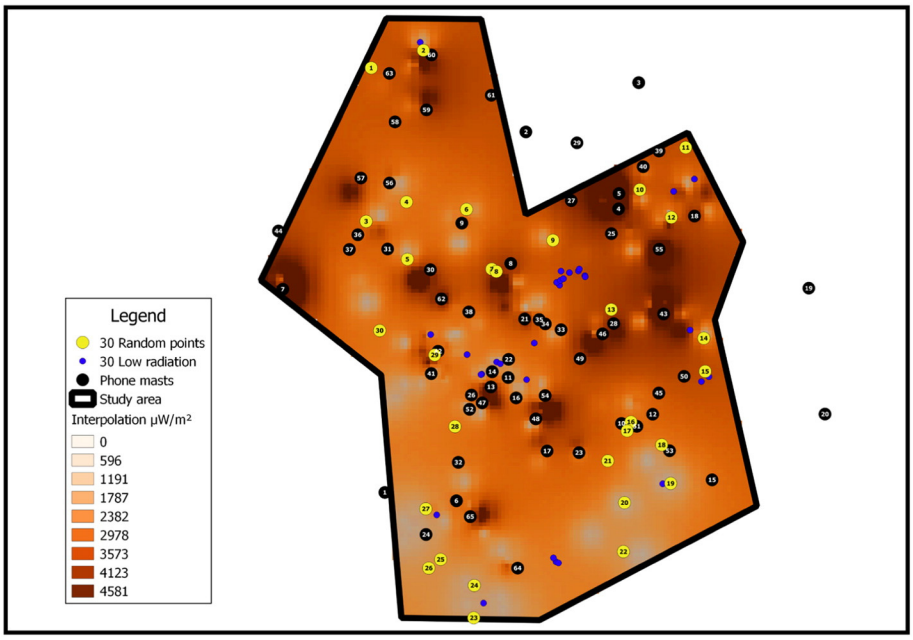

Fig. 4. Map showing the 30 trees at random points and the 30 trees in areas of low radiation (both with code numbers) over the interpolation electromagnetic map of the 144 measurement points. Phone masts (with code numbers) are also represented.

there were no unilateral damages. The measured values were below 50 μW/m^2 (0.137 V/m) and there was no difference between opposite sides. These results in the three groups point to a connection between unilateral tree damage and RF exposure.

In the electromagnetic field of all mobile phone base stations visited numerous tree damages were observed. The damage occurred in temporal relation with the putting into operation of new mobile phone base stations. Woody plants of all species are affected (deciduous and coniferous trees as well as shrubs).

In the five most represented species (n ≥ 4) among the 60 damaged trees (*Acer platanoides*, *Carpinus betulus*, *Tilia* sp., *Taxus baccata* and *Thuja occidentalis*), most trees showed damage only on one side (Damage code 1, Tables 2 and 4). Most of these trees were characterized with sparse leaves or needles (crown transparency) (Damage code 2, Tables 2 and 4). In many of the trees with the one-sided damage, the leaves turned prematurely yellow or brown in June – this always began at the leaf margins (Damage code 3, Tables 2 and 4). In many trees leaves fall prematurely (Damage code 5, Tables 2 and 4) or had dead branches (Peak branches dried) (Damage code 6, Tables 2 and 4). Some trees stopped growing in height while, in others, the main guide died (see Tables 2 and 4).

The differences in susceptibility of different species could be related to radiofrequency energy absorption properties of the trees (e.g., dielectric property). Perhaps this study cannot answer questions about these differences, however it is quite possible that differences are related to the electrical conductivity, related also with the density of the wood (species of fast or slow growth) and particularly with the percentage of water in the tissues. Poplars and aspen that grow near rivers and water bodies in Spain seem to be particularly sensitive to the effects of radiation. But the waves reflection in the water could also influence.

The results presented here lead us to conclude that damage found in the selected trees is caused by electromagnetic radiation from phone

Table 7
Repeated measures ANOVA analysis and Bonferroni post hoc comparisons ($p < 0.01$ values with *) in the three types of trees (damaged, random, and low radiation). Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree.

	SS	Degr. of	MS	F	p
Intercept	62663309	1	62663309	25.81460	0.000001*
Type of tree	52931692	2	26465846	10.90280	0.000046*
Error	284010086	117	2427437		
R1	33197069	1	33197069	18.28694	0.000039*
R1*Type of tree	44608664	2	22304332	12.28656	0.000014*
Error	212395158	117	1815343		

	Type of tree	R1	{1}	{2}	{3}	{4}	{5}	{6}
1	Damaged	Measurement Side1		0.000000*	0.001829*	0.000001*	0.000000*	0.000000*
2	Damaged	Measurement Side2	0.000000*		1.000000	1.000000	1.000000	1.000000
3	Random	Measurement Side1	0.001829*	1.000000		1.000000	1.000000	1.000000
4	Random	Measurement Side2	0.000001*	1.000000	1.000000		1.000000	1.000000
5	Low radiation	Measurement Side1	0.000000*	1.000000	1.000000	1.000000		1.000000
6	Low radiation	Measurement Side2	0.000000*	1.000000	1.000000	1.000000	1.000000	

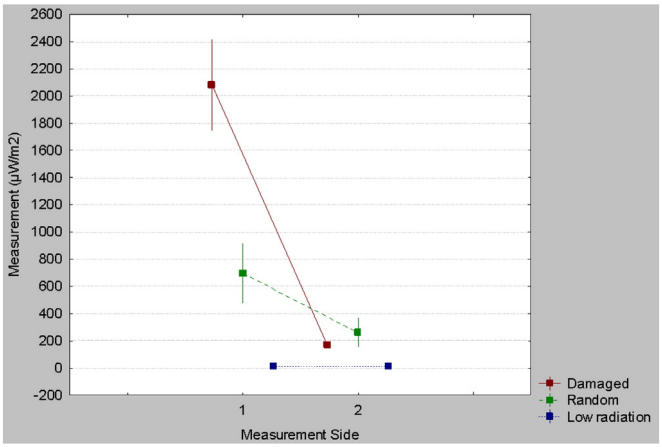

Fig. 5. Differences between measurements in both sides for the three different tree groups: damaged, random, and low radiation. Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree. The bars represent means ± standard errors. The central point represents the mean and the straight line ± 0.95*SE.

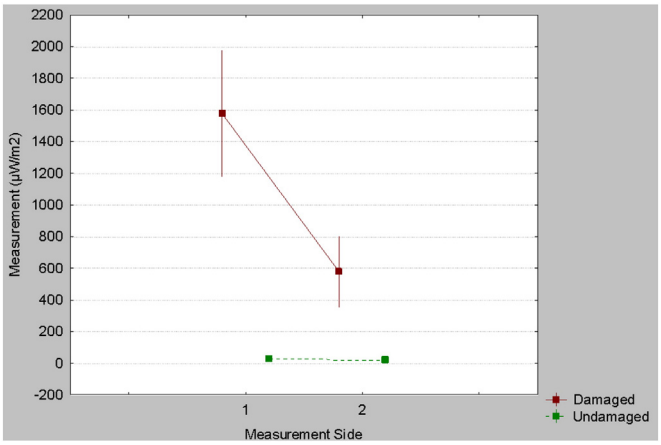

Fig. 6. Differences between measurements in both sides for the damaged and undamaged trees within the random trees group. Measurement side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree. The bars represent means ± standard errors. The central point represents the mean and the straight line ± 0.95*SE.

masts, as we proposed in previous studies (Balmori, 2004; Waldmann-Selsam, 2007; Waldmann-Selsam and Eger, 2013; Balmori, 2014). Interested parties are able to locate the damaged trees found in this work in Bamberg and Hallstadt with their UTM coordinates. However, trees with code numbers 20, 38 and 48 (Table 4) have been cut down and removed.

Research on the effects of radiation from phone masts is advancing rapidly. In February 2011 the first symposium on the effects of electromagnetic radiation on trees took place in Baarn, Netherlands (Schorpp, 2011 - http://www.boomaantastingen.nl/), where similar effects and results to those found in the current paper were presented.

Although there are some related experiments that show no effect of long-term exposure (3,5 years), 2450-MHz (continous wave) and power flux densities from 0.007 to 300 W/m^2 on crown transparency, height growth and photosynthesis of young spruce and beech trees (Schmutz et al., 1996), this result may not be transferred to modulated 2450-MHz or to other pulsed and modulated frequencies. In addiction, an increasing number of studies have highlighted biological responses and modifications at the molecular and whole plant level after exposure to high frequency electromagnetic fields (Vian et al., 2016). Plants can perceive and respond to various kinds of electromagnetic radiation over a wide range of frequencies. Moreover, a low electric field intensity (5 V/m) was sufficient to evoke morphological responses (Grémiaux et al., 2016). Electromagnetic radiation impacts at physiological and ecological levels (Cammaerts and Johansson, 2015), and evokes a multitude of responses in plants. The effects of high frequency electromagnetic fields can also take place at the subcellular level: it can alter the activity of several enzymes, including those of reactive oxygen species (ROS) metabolism, a well-known marker of plant responses to various kinds of environmental factors; it evokes the expression of specific genes previously implicated in plant responses to wounding (gene expression modifications), and modifies the growth of the whole plants (Vian et al., 2016). It could be hypothesized that membrane potential variations in response to electromagnetic radiation exposure may initiate electrical waves of depolarization (AP and/or VP) that could initiate immediate or delayed growth responses (Grémiaux et al., 2016). It has been proposed that electromagnetic fields act similarly in plants and in animals, with the probable activation of calcium channels via their voltage sensor (Pall, 2016).

Electromagnetic radiation (1800 MHz) interferes with carbohydrate metabolism and inhibits the growth of *Zea mays* (Kumar et al., 2015). Furthermore, cell phone electromagnetic radiation inhibits root growth of the mung bean (*Vigna radiata*) by inducing ROS-generated oxidative stress despite increased activities of antioxidant enzymes (Sharma et al., 2009). Germination rate and embryonic stem length of *Triticum aestivum* was also affected by cell phone radiation (Hussein and El-Maghraby, 2014). After soybeans were exposed to weak microwave radiation from the GSM 900 mobile phone and base station, growth of

Table 8
Repeated measures ANOVA analysis and Bonferroni post hoc comparisons ($p < 0.01$ values with *) in the random trees group. Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree.

	SS	Degr. of	MS	F	p
Intercept	17829607	1	17829607	16.60985	0.000343*
13 code	16391606	1	16391606	15.27023	0.000538*
Error	30056202	28	1073436		
R1	3701923	1	3701923	16.73250	0.000329*
R1*13 code	3627579	1	3627579	16.39647	0.000368*
Error	6194761	28	221241		

	13 code	R1	{1}	{2}	{3}	{4}
1	Undamaged	Measurement Side 1		1.000000	0.002129*	0.416303
2	Undamaged	Measurement Side 2	1.000000		0.000034*	0.927155
3	Damaged	Measurement Side 1	0.002129*	0.000034*		0.000055*
4	Damaged	Measurement Side 2	0.416303	0.927155	0.000055*	

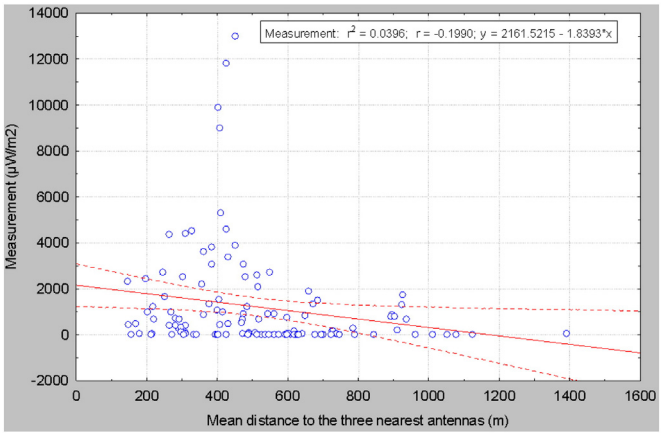

Fig. 7. Scatterplot showing the correlation between measurements from each of the 120 trees and the mean distance to the three nearest antennas. Dashed lines represent the 0.95 confidence interval.

epicotyl and hypocotyl was reduced, whereas the outgrowth of roots was stimulated. These findings indicate that the observed effects were significantly dependent on field strength as well as amplitude modulation of the applied field (Halgamuge et al., 2015). Phone mast radiation also affects common cress (*Lepidium sativum*) seed germination (Cammaerts and Johansson, 2015). In *Arabidopsis thaliana*, the long term exposure to non ionizing radiation causes a reduction in the number of chloroplasts as well as the decrease of stroma thylakoids and the photosynthetic pigments (Stefi et al., 2016). Finally, low-intensity exposure to radiofrequency fields can induce mitotic aberrations in root meristematic cells of *Allium cepa*; the observed effects were markedly dependent on the frequencies applied as well as on field strength and modulation (Tkalec et al., 2009).

In general, polarization from man-made electromagnetic radiation appears to have a greater bioactive effect than natural radiation, and significantly increases the probability for initiation of biological or health effects (Panagopoulos et al., 2015).

Tree damages as in Bamberg and Hallstadt were documented by the authors in several countries: Spain (Valladolid, Salamanca, Madrid, Palencia, León), Germany (Munich, Nürnberg, Erlangen, Bayreuth, Neuburg/Donau, Garmisch-Partenkirchen, Murnau, Stuttgart, Kassel, Fulda, Göttingen, biosphere reserve Rhön, Tegernsee Valley and in several small towns), Austria (Graz), Belgium (Brussels) and Luxemburg.

Each phone mast can harm many trees and each tree can be affected by several phone masts belonging to the same or different base stations. Damaged trees seem to exist around each antenna and the several million phone masts in the world could potentially be damaging the growth and health of millions of trees. This can occur not only in cities, but also in well-preserved forests, and in natural and national parks, where base stations are being installed without the necessary prior environmental impact studies, due to a lack of knowledge of the problem. For this reason, it is essential for an assessment on the environmental impact of any new base station prior to implementation.

Additionally, phone masts can cause a drop in timber productivity in plantations of pine, poplar, etc., as well as fruits, nuts, etc. Thus, the industry must be required to pay damages to plantation owners. Similarly, as trees are a common social good, the industry should compensate for damaged and dead trees around the world due to radiation. Further, the money spent by municipalities to repair or replace damaged trees should enter into the computation of costs/benefits of this technology. For installation of any new technology, the burden of proof should be to the industry that requires demonstration of safety prior to deployment.

Electromagnetic radiation from telecommunication antennas affected the abundance and composition of wild pollinators in natural habitats and these changes in the composition of pollinator communities associated with electromagnetic smog may have important ecological and economic impacts on the pollination service that could significantly affect the maintenance of wild plant diversity, crop production and human welfare (Lázaro et al., 2016).

Evidence for plant damage due to high frequency electromagnetic radiation was not taken into account in determining the current statutory regulations (the limit values). Once the problem becomes evident, the guidelines of radiation emitted by the antennas should be reviewed. Proper risk assessment of electromagnetic radiation should be undertaken to develop management strategies for reducing this pollution in the natural environment (Kumar et al., 2015).

Moreover, due to the lack of recognition, certain modern projects with interesting ideas for decreasing environmental pollution could have opposite effects than expected. For example, in the Netherlands, the TreeWiFi project (http://treewifi.org/), which aims to motivate people to use bikes and public transport in order to reduce the [NO2] pollution providing free WiFi when air quality improves, could be favoring electromagnetic pollution with even more harmful effects as it has been demonstrated in this manuscript (see also: http://www.greenpeace.org/canada/fr/Blog/le-wi-fi-tuerait-les-ar-bres/blog/33569/).

In addition, the number of sector antennas has increased in Bamberg and this increase appears to be accelerating: 483 sector antennas in 2011 and 779 sector antennas in 2015. Both radiation and damaged trees represent a loss of quality of life for citizens. This study began after finding that patients who claimed to be affected by phone masts, referred to as radiation, live in areas where affected trees and plants are located. Evidence of radiation damage was even found in potted plants inside patient homes (Waldmann-Selsam and Eger, 2013). Thus, this study is certainly complementary to the study by Eger and Jahn (2010) and other research that has shown effects on the health of people by phone masts located in their vicinity (Santini et al., 2002; Eger et al., 2004; Wolf and Wolf, 2004; Abdel-Rassoul et al., 2007; Khurana et al., 2010; Dode et al., 2011; Gómez-Perretta et al., 2013; Shahbazi-Gahrouei et al., 2014; Belyaev et al., 2015).

In the introduction to the International Seminar on "Effects of Electromagnetic Fields on the Living Environment" in 1999 in Ismaning, Germany, organized by WHO, ICNIRP and German Federal Office for Radiation Protection (BfS), M. Repacholi, head of the International EMF Project of the WHO, said: "By comparison, influences of these fields on plants, animals, birds and other living organisms have not been properly examined. Given that any adverse impacts on the environment will ultimately affect human life, it is difficult to understand why more work has not been done. There are many questions that need to be raised: …" and "…it seems that research should focus on the long-term, low-level EMF exposure for which almost no information is available. Specific topics that need to be addressed include: … EMF influences on agricultural plants and trees" (Matthes et al., 2000).

5. Conclusions

In this study we found a high-level damage in trees within the vicinity of phone masts. Preliminary laboratory studies have indicated some deleterious effects of radiofrequency radiation. However, these early warnings have had no success and deployment has been continued without consideration of environmental impact.

We observed trees with unilateral damage in the radiation field of phone masts. We excluded the possibility that root injury due to construction work or air pollutants could have caused the unilateral damage. We found out that from the damaged side there was always visual contact to one or more phone mast (s).

Statistical analyses demonstrated that the electromagnetic radiation from cellphone towers is harmful to trees. Results show that the measurements in the most affected sides of damaged trees (i.e. those that withstand higher radiation levels) are different to all other groups. These results are consistent with the fact that damage inflicted on

trees by cellphone towers usually start on one side, extending to the whole tree over time.

The occurrence of unilateral damage is the most important fact in our study and an important argument for a causal relationship with RF-EMF, as it supplies evidence for non-thermal RF-EMF effects. This constitutes a danger for trees worldwide. The further deployment of phone masts has to be stopped. Scientific research on trees under the real radiofrequency field conditions must continue.

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