DERBYSHIRE County Council

The Health Impacts of 5G Technology

KIT Evidence Summary

Population Knowledge & Intelligence Team

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The information in this evidence summary is designed to give readers an overview of the currently available research evidence on the topic in question. It is drawn from material accessible to KIT free of charge online; this means that it may not be representative of the whole body of evidence on the topic. No critical appraisal or quality assessment of articles has been performed on the evidence included in this report

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KIT Evidence Summary

The health impacts of 5G Technology

5G technology is the next generation of mobile technology, providing advances in mobile broadband access that is expected to provide a range of benefits to individuals, businesses and communities.

This 'fifth generation' technology will transmit data across a dense network of antennae, or aerials, and in doing so will expose the population to higher levels of radio frequency electromagnetic fields (RF-EMF) than experienced using existing technology. There are some concerns that this exposure will be potentially harmful to health.

This evidence summary has been produced to provide an overview of recent guidelines and evidence related to the health

KEY FINDINGS:

- 5G technology will increase the speed of communication networks; this means that data can be transmitted more speedily, improving performance, responsiveness and connectivity. Potential uses of 5G are far reaching in terms of 'the development of smarter homes, wearable health devices, smart transport, smart public infrastructure, plus improved monitoring and control of manufacturing processes.

- 5G technology will require a network of antennae to transmit data; this will increase the population's exposure to RF-EMF. There are concerns that this will have health implications. There is limited evidence available on this controversial topic.

- 5G technology uses higher frequencies than existing technologies. Evidence shows that the energy of these high frequencies may be transferred into superficial tissues such as the skin. This transfer of energy could lead to a small increase in body temperature.

- The International Commission on Non-Ionizing Radiation Protection (INCIRP) has produced guidelines on exposure levels for all RF-EMF which set out safe levels for the general population.

  Reviews of published research, suggest that there are no health effects below the accepted INCIRP guidelines. There are, however, academics that suggest guidelines do not incorporate all of the evidence and may be misleading.

INTRODUCTION

Who is this evidence summary for?

This work was undertaken for Derbyshire County Council's Public Health and Economy Transport and Environment (ETE) departments.

Information about the evidence summary

The materials used to produce this summary have been drawn from information sources free of charge to KIT. No assessment of quality has been incorporated into the process of synthesis.

☑ This summary includes:

- **Key findings** from evidence identified in a non-systematic search of journals available to Public Health via HDAS and the internet.

☒ This summary does not include:

- Critically appraised evidence
- Recommendations

Further information about the methodology and content for this evidence summary can be obtained on request by emailing:

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INTRODUCTION

Derbyshire County Council is anticipating the introduction of 5G technology infrastructure. This evidence summary provides an overview of the current evidence on the potential health impacts of 5G technology.

1.1 What is 5G Technology?

5G technology is the next generation of mobile and wireless network communication. Currently mobile networks work using 3G and 4G technology. 5G will use a range of new technologies to provide significant increases in speed and volume of data[1] *(A full list can be found in the appendix).*

1.2 The potential of 5G

The Government has set out a framework to develop 5G mobile networks and services as part of an ambition for the country to become a global leader in mobile technology, a commitment outlined in the UK's Digital Strategy[1].

In the short term, 5G is expected to improve the speed and capacity of mobile broadband offered by mobile networks, impacting on levels of connectivity for people and businesses[3]. In the long term, it is anticipated that 5G will be used by sectors including transport, health care and manufacturing to help boost productivity and drive innovation that may change the way people live and work [1,3].

The Department for Digital, Culture Media and Sport commissioned an independent review of the literature on the economic and social impacts of 5G technology; this reports that the implementation of current mobile technologies (3G & 4G) had a positive impact on the economy, in terms of gross domestic product levels and employment; it expects 5G to have a similar effect.

The possible uses for 5G vary significantly. A review[3] summarises six key sectors where 5G could be used: transport, healthcare, media and entertainment, public services, agriculture, and manufacturing.
It suggests that the benefits resulting from 5G will be improved connectivity, new consumer devices and services, Internet of Things solutions (connecting everyday items to the internet), smarter infrastructure and public services[4]. Below is an overview of some of the advancements relating to key sectors identified in the review:

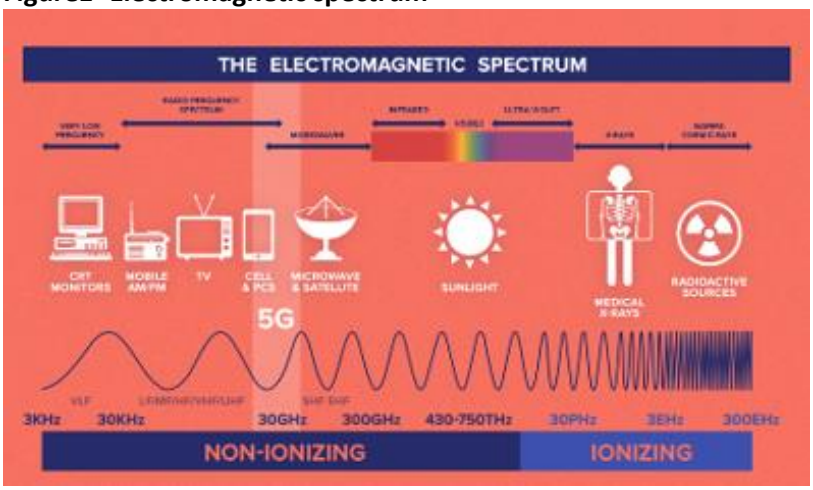
- **Transport:** Development of connected and autonomous vehicles, whereby a car, for example, connects to the surrounding environment and other vehicles. This could lead to new safety features with cars will be able to 'see' beyond the traditional line of sight. This may have a positive effect on congestion and could also introduce driving for those otherwise unable to operate a vehicle.
  Healthcare: Wearable and implanted health monitoring devices would allow remote monitoring of patients and out-of-hospital care models.
- **Public services:** Development of smart public infrastructure will help to provide increased safety, cost savings and environmental benefits. For example, sensors in signage, remotely controlled street lighting, flood detection, HD CCTV.
- **Agriculture**: 5G could be used to monitor livestock, crops and the development of automated farming systems.
- **Manufacturing**: Remotely controlled and monitored systems that could improve processes and increase profitability.
- **Media and entertainment**: Advances in Augmented and Virtual Reality (AR/VR), would allow streaming of higher resolution videos.

The creation of a new 5G network could represent a potential revenue stream for Local Authorities. Local Authorities may be able to rent the space (such as lamp posts) required for installation of the 5G antennae to mobile network companies.

1.3 How 5G works

All modern radio, mobile and wireless communications use radio frequency electromagnetic fields (RF-EMF) to transmit data. RF-EMF are fields of energy produced by all sources including electrical wiring, powerlines, radios, televisions, microwaves, Wi-Fi, mobile phones and even the human body. There are different frequencies of RF-EMF that make up the electromagnetic spectrum[2] (Fig1).

Figure1- Electromagnetic spectrum



Source: Cnet

The electromagnetic spectrum can be described in two parts:

Ionising: This part of the spectrum has enough energy to interact with atoms and break molecular bonds; these include radioactive sources and X-rays.

Non-ionising: This part of the spectrum has insufficient energy to cause ionisation; these include radio frequency waves.

The spectrum begins with extremely low frequencies (3-30Hz), the most common source of low frequencies is from power lines and electrical wiring.

Communication technologies transmit data at frequencies between 3KHz and 300GHz. Radio waves fall within the lower frequencies of this range. Current mobile technologies 2G, 3G and 4G use frequencies between 800MHz and 2.6GHz. 5G technology is expected to use the higher frequencies of this range, between 30GHz to 300GHz, this range of frequencies is known as millimetre waves[2].

Higher frequency RF-EMF travel shorter distances through the air. 5G frequencies can travel hundreds of metres compared to the kilometres travelled of the lower frequencies used by 3G and 4G[1]. This reduced transmission distance requires the need for a dense network of transmitters/antennas throughout communities.

The introduction of a dense network of transmitters would increase the risk of exposure to RF-EMF to local populations. This, and use of higher frequencies, has raised concerns over the potential impact this might have on people's health.

2 SYNTHESIS OF THE EVIDENCE

2.1 Potential health impacts of 5G technology

A search of the databases available to the Public Health was conducted. Further searches of Google Scholar were undertaken to identify relevant articles for inclusion in the evidence summary.

Each of the included articles was mapped in Section 3; a short summary of the key content has been included in the table. Below is a summary of these articles:

- There is limited evidence of the health impacts of RF-EMF. There are few epidemiological studies available. The majority of the evidence that is available consists of experimental studies in animals and cells. Studies focus on a few health areas of interest, including cancer, fertility and brain function. Published reviews of the evidence and guidance, group RF-EMF frequencies between 100KHz and 300GHz; evidence specific to 5G frequencies (30GHz-300GHz) is therefore limited.

- The rollout of 5G is a controversial topic. International organisations such as the WHO, EU, International Agency for Research on Cancer (IARC) and Public Health England (PHE) state that RF-EMF under the recommended limits set out by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) does not have an impact on health. There is, however, a number of academics that argue consideration has not been given to key studies and the produced guidance and advice is misleading[13]. These academics argue that most of the evidence is experimental and more epidemiological studies are needed before exposing populations to 5G technologies.

- To date improved communication technology via wireless devices (mobile phones, Wi-Fi and Bluetooth) has led to an increase in the population's exposure to RF-EMF at a range of different frequencies. The introduction of 5G technology will increase this exposure further and will also introduce exposure to higher frequencies.

- The ICNIRP have published guidelines that are recognised by the WHO and PHE. The guidelines set out safe level of exposure to RF-EMF based on the best evidence currently available[8].

- Research has shown that RF-EMF can affect the body in different ways. The three main mechanisms reported within ICNIRP guidelines are nerve stimulations, cell membrane permeabilization and temperature elevation:

  Nerve stimulations occurs when electrical fields stimulate the nerves, possibly causing a tingling effect. This effect occurs at frequencies lower than the 5G range.

  Cell membrane permeabilization is an increase in the rate at which molecules diffuse through the cell membrane. Cell membrane permeabilization has been shown to occur at frequencies within the 5G range; however, the levels of exposure were significantly higher than those recommended by ICNIRP.

  Temperature elevation occurs when energy from RF-EMF is transferred to the body; this is thought to be the primary interaction between 5G frequencies and the body. When the body is exposed to RF-EMF fields some of the energy can be transferred into the body, which may lead to heating of body tissues. Frequencies between 30-300GHz (5G range) are less penetrating and absorbed by superficial tissues such as the skin. This absorption can cause localised temperature rises, which could lead to an increase in core temperatures. Below the ICNIRP recommended exposure levels, temperature increase are very small and the human body's thermoregulation process is thought to control increases.

  Other possible mechanisms suggested in the literature are:

  Gene expressions: This is a process required to produce proteins within cells. Reviews of the evidence present mix findings, with some experimental studies in cells indicating that exposure to frequencies over 30GHz could produce changes in gene expression.

  Oxidative stress: This is a result of excess 'oxygen radicals' being produced within cells,

exposure to ionising radiation is known to cause this. Experimental studies in cells using frequencies below 5G have caused this effect.

The five mechanisms described above are thought to affect biological processes that may lead to disease states. Reviews on the effects of RF-EMF (these are not specific to 5G frequencies) have reported the following:

- **Cancer**: The International Agency for Research on Cancer (IARC) classified all RF-EMF as potentially carcinogenic grouped into the same category as talcum powder, petrol engine exhaust and Aloe Vera Extracts. Some researchers believe this should be changed to carcinogenic [12]
- **Fertility**: Epidemiological studies and experimental studies have found some negative associations between RF-EMF and sperm quality, but there are no strong association below recommended levels and at the frequencies of 5G.
- **Electrosensitivity:** This is classified as a variety of non-specific symptoms which individuals attribute exposure to RF-EMF. Symptoms vary widely and include nausea, dizziness, burning sensations, and tingling effects. The included articles suggest this is a controversial topic; the AGNIR reports that there is increasing evidence that RF-EMF below the INCIRP guidelines does not cause symptoms and cannot be detected by individuals.
- **Ocular damage/effects**: It has been suggested that the eyes may at risk of harm from the possible heating effects of 5G technology due to the inability to dissipate heat as well as the skin. International guidelines state that there are no effects under ICNIRP recommended levels. Studies in animals have demonstrated mixed results and has been suggested more evidence is needed.
- **Non cancer morbidity**: No effects have been reported.

3 TABLES

3.1 Guidelines

<table>
<tr><th>Citation (year)</th><th>Article type</th><th>RF-EMF Frequency</th><th>Summary of findings</th></tr>
<tr><td>ICNIRP (2018)[6] (raft update on the 1998 guidelines)</td><td>Guidelines</td><td>General RF-EMF (all frequencies between 100kHz to 300GHz)</td><td>The ICNIRP's guidelines for protecting humans includes evidence on RF-EMFs between 100kHz and 300GHz and distinguishes between those working with NIR and members of the public. It aims to establish guidelines for limiting exposure to RF-EMF.

The guidelines reports consideration of three primary biological effects from RF-EMF:
Nerve Stimulation: frequencies up to 10MHz can stimulate nerves, this is below the frequency ranges for 5G.
Membrane permeabilization: Pulsed EMF at low frequencies can cause cells to become permeable leading to cellular level changes. Cell permeabilization has been reported at frequencies of 18GHz in Vitro, but these were seen at high level, that exceed the guidelines.
Temperature elevations: RF can generate heat in the body, however research has shown that for low levels of exposure the amount of heat generated is not sufficient to cause harm.

The guidelines report that of frequencies at 6-300 GHz (5G range) are absorbed superficially into the surface of skin; any small temperature rises are easily dissipated via thermoregulation. There is no evidence of the 5G frequencies affecting core body temperature, or causing harm.

The guideline report to be conservative when setting the references levels:
<table><tr><th></th><th></th><th colspan="6">Radiofrequency</th></tr><tr><th></th><th></th><th colspan="2">Electric field (V/m)[i]</th><th colspan="2">Power density (W/m^2)[i]</th><th colspan="3">Specific absorption rate (SAR) (W/kg)[i]</th></tr><tr><th>Country</th><th>Year</th><th>900 MHz</th><th>1800 MHz</th><th>900 MHz</th><th>1800 MHz</th><th>Whole body</th><th>Head and trunk</th><th>Limbs</th></tr><tr><td>United Kingdom of Great Britain and Northern Ireland</td><td>2017</td><td>[41.25]</td><td>[58.34]</td><td>[4.5]</td><td>[9.0]</td><td>[0.08]</td><td>[2]</td><td>[4]</td></tr></table>
The paper does acknowledge that there are gaps in the evidence and states guidelines will be revised as scientific knowledge develops.</td></tr>
<tr><td>ICNIRP- Health Risk Assessment Literature (2018)[7] (draft update on the 1998 guidelines)</td><td>Supporting literature review for the ICNIRP guidelines</td><td>General RF-EMF (all frequencies between 100kHz to 300GHz)</td><td>An appendix item to the above ICNIRP guidelines that summarises research on biological and health effects of RF-EMF; it includes experimental research on cells and animals, and epidemiological studies.
The paper reviews evidence on the following areas:
Brain function: No substantiated experimental or epidemiological evidence that RF-RMF affects cognitive function.
Auditory, vestibular and ocular function: No effect on these systems has been substantiated.
Neuroendocrine system: In vitro studies have shown RF-EMF can have an effect on the neuroendocrine system at 4W kg^{-1}, but there is no evidence this translates to humans.
Neurodegenerative diseases: At the time of the review, no human experimental studies have been reported. No adverse health effects have therefore be reported.</td></tr>
</table>

			Cardiovascular systems, Autonomic Nervous system and Thermoregulation: There are numerous human and animal studies on this topic. Epidemiological studies have demonstrated no links between RF-EMF and Cardiovascular health. Below recommended ICNIRP exposure levels RF-EMF no health effects on the Cardiovascular systems, Autonomic Nervous system and Thermoregulation have been substantiated. In hamsters there is some evidence that suggests exposure levels above recommendation are not sufficient to alter core body temperature. However in rats evidence that whole body exposures are sufficient to increase core temperature and have serious adverse health effects. **Immune system and haematology**: Currently there is no evidence to indicate RF-EMF affects health in humans via the immune system or haematology. **Fertility, reproduction, and childhood development**: Some epidemiological studies found association between RF-EMF and sperm quality/male infertility, but there is no strong evidence for an association. No adverse effects of RF-EMF exposure on fertility have been substantiated. **Cancer**: There is a large amount of evidence around cancer and RF-EMF; there is variation outcomes measured, but overall no effects of RF-EMF on cancer have been substantiated. Summary- There is little epidemiological research on the effects of RF-EMF on human health

3.2 Literature reviews

The Advisory Group on Non-Ionising Radiation AGNIR (2012)[2]	Literature review	General RF-EMF (100kHz to 300GHz)	The AGNIR have published a full review on the scientific research related to the potential health effects from exposure to RF fields. Concentrating on evidence since their original report in 2003. The 2012 report incorporates experimental and epidemiological studies. It highlights that there are a lot more experimental studies (in vitro and in vivo) than there are epidemiological studies. The review includes research on RF-EMF frequencies between 100kHz-300GHz The report conclude that research of cells in vitro found no convincing evidence that RF fields cause genetic damage or risk of malignant. Animal studies of the RF-EMF below internationally accepted guidelines had no effects. There report also concluded that short term exposure to levels above limits can cause thermal effects. (humans/IV) Cellular Studies: There are conflicting results and no study has provided robust evidence of effect. Animal Studies: No evidence of harmful effects with low-level exposures. Neurocognitive effects in Humans: Symptoms in Humans: Effects commonly attributed to RF are acute subjective symptoms such as headaches and nausea. Studies that have found associations have methodological false, making it difficult to draw robust conclusions from their findings. Other (non-cancer) effects in humans: No evidence to indicate adverse effects on the cardiovascular system or other non-cancer morbidity outcomes. Cancer in Humans: Available epidemiological studies have various weakness but show no casual association between phone use and fast growing brain tumors (glioma).
SCENIHR (2015)[8]	Literature review	General RF-EMF (100kHz to 300GHz)	This publication is an opinion update on the 2009 health effects EMF. That explores research on the mechanisms and health effects of EMF. Similar to other guidelines, this publication includes research on the entire frequency range. It foresees the future use of 5G frequencies and reports this will operate at lower exposure levels, it also reports there will be less penetration and 5G will only affect superficial tissues.
IARC (2012)[9]	Monograph	General RF-EMF (30kHz to 300GHz)	This is a monograph on the carcinogenic hazards to humans of RF-EMF. The paper states there is limited evidence in humans. Positive associations have been observed between exposure to radiofrequency radiation from wireless phones and glioma, and acoustic neuroma. The IARC have

			categorised RF-EMF as possibly carcinogenic to humans (Group 2b), this is within the same category as caffeine, talc powder, pickled vegetables (traditional Asian) and petrol engine exhaust (a full list can be found at: https://monographs.iarc.fr/list-of-classifications-volumes/)
Bio initiative Report (2014)[10]	Literature review	General RF-EMF (100kHz to 300GHz)	A report produced by a group of international scientist and health experts. The report explores the possible risks of wireless technology and electromagnetic fields. It argues that the current guidelines are not adequate and insufficiently protective for public health due only considering the energy absorption and thermal effects of RF-EMF. And do not consider the non-thermal effects of RF-EMF exposure. The authors suggest that action should be precautionary and the use of 5G should be deferred till final proof/causal evidence is established.
Di Ciaula, A (2018)[11]	Literature Review	General RF-EMF (100kHz to 300GHz)	This summary explores peer reviewed studies on the biological and health effects of RF-EMF since the IARC statement 2011. A large part of the paper discusses the effects of RF-RMF generally, however does provide specific information about the possible health effects of 5G: -5G would increase the chance of exposure to RF-EMF due to the increase in the number of antennae. -Preliminary evidence suggest exposure over 30GHz could alter gene expression. - 5G could increase human skin temperature, stimulate cell proliferation, and alter the function of the cell membrane (effects limited to superficial tissues). -In vivo studies have seen mixed finding on ocular effects. The review concludes that evidence is accumulating of the biological impacts of RF-EMF, which have seen biological effects below the ICNIRP standards and suggests there is a need for further experimental and epidemiological studies to fully explore the health effects caused by generic and specific frequencies.
Russel, CL (2018)[12]	Literature Review	General RF-EMF (100kHz to 300GHz)	This paper reviews *literature* on the health effects of wireless technology including 5G. The paper highlights that is a controversial area and that some researchers feel that the IARC classifications are not appropriate and RF-EMF should be listed as probably or possible carcinogenic. It also highlights that there are a number of studies that have shown health effects well below the current safety standards, however most are experimental studies. The paper suggests there is a growing body of literature that non ionising radiation affects cause non-thermal cellular damage; including DNA integrity, cell membranes, protein synthesis, sperm damage, immune dysfunction and also impacts the oxidisation mechanism. It also reports there is an increasing number of people experiencing Electrosensitivity. The paper suggests that the thermal effects of 5G could be a concern for the eyes. It concludes that there may be significant consequences to human health and ecosystems.
Belpomme et al, (2018)[14]	Summary of evidence	General RF-EMF	A report providing an overview of the effects of EMF exposure summarising evidence for cancer, Alzheimer's, hypo fertility and electro-sensitivity. Case control studies found consistent findings of increased of glioma and acoustic neuroma associated with phone use. However these are assessing frequencies below those of 5G. Reports on Low intensity EMF. Author suggests there is sufficient evidence to categorise Electro hypersensitivity as a pathological disorder. Studies focus on RF-EMF generally, no mention of 5G frequencies.
Yakymenko, et al. (2018)[19]	Review of experimental data	10GHz, 2.4Ghz	A review of experimental data on the oxidative effects of low intensity radiofrequency in living cells. Of 100 reviews 93 reported radio frequency radiation caused an oxidative effect in biological systems. Only one study include in the review reported on frequencies in the 5G range, this study showed an increased level of malondialdehyde and decreased level of glutathione, these changes can cause oxidative stress.
Wu, T (2015)[17]	literature survey/review	30-300GHz	This is paper looks at the biological impact of millimetre wave radiation and on the human body. The paper highlights that the skin and the eyes would receive the most exposure to 5G frequencies, however it reports no ocular damage or unsafe temperature increase at the suggested exposure levels of 5G technology.

3.3 Studies/Articles

Falcioni L et al, (2018)[16]	Experimental study	1.8 GHz	This paper reports on a large experimental study on rats; 2448 were exposed to RFR at 1.8GHz at different levels of exposure. The results showed an increase in the incidence of tumours in the brain and heart in exposed rats. However, most of the increases are not statistically significant.
Berzalel et al.(2018)[15]	Summary of experimental study	Simulation at 75–110 GHz	This paper suggests that the coiled structure of sweat glands in the human skin could function as helical antennas at 5G frequencies. This could lead to health issues. The authors conclude that there is enough evidence available to suggest that 5G frequencies may lead to non-thermal biological effects that should be investigated further.
Starkey, SJ (2016)[13]	Review of AGNIR report	--	This is a paper that reviews the AGNIR's 2012 report [2] on the health effects from RF-EMF. The paper suggests that the AGNIR report is incorrect, misleading, and that the there is a conflicts of interest by the report's authors, as a number were also members of the INCIRP, and would be reporting on their own work.
Public Health England response to FOI request (2018)[5]	FOI response		This paper is a response from PHE to a Freedom of Information request made in Oct 2018 (response published Feb 2018). The response is a summary of published high level reviews and reports, and international guidelines on the health effects of exposure to RF-EMF including: • Health Effects from radiofrequency Electromagnetic fields – AGNIR (2012) • Guidelines from the ICNIRP (1998) • Recommendations from the EU Council (2011) • IARC monograph (2012) • A summary of the Exposure to EMF and Cancer and Electrical sensitivity. PHE advises that exposure to RF-EMF should comply with the ICNIRP guidelines, which is recognised by the WHO. The Advisory Group for Non Ion-ionising radiation (AGNIR) published a review of the biological effects of NIR. This report considers the health effects below ICNIRP guideline levels. International Agency for Research on Cancer (IARC) reviewed health effects to RF fields. Classified as possibly carcinogenic. The response states that PHE reviewed the documents produced by mandated organisations, giving greater weight to documents that use a rigorous review processes. These documents report that there is no clear evidence of harm to health from exposure to radio waves below internationally agreed ICNIRP guideline levels.

4 REFERENCES

1. Department for Digital, Culture, Media & Sport (2017). Next Generation Mobile Technologies: A 5G Strategy for the UK. https://www.gov.uk/government/publications/next-generation-mobile-technologies-an-update-to-the-5g-strategy-for-the-uk

2. AGNIR (2012). Health Effects from Radiofrequency Electromagnetic Fields. Documents of the Health Protection Agency, Series B: Radiation, Chemical and Environmental Hazards, RCE-20. https://www.gov.uk/government/publications/radiofrequency-electromagnetic-fields-health-effects

3. Ofcom (2018). Enabling 5G in the UK

4. Deloitte (2015). The impacts of mobile broadband and 5G - A literature review

5. Public Health England (2018) Freedom of Information request response. https://www.whatdotheyknow.com/request/health_implications_of_5g_techno [Accessed:May2019]

6. ICNIRP. (2018). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) (draft update). *Health Physics*, *74*(4), 494-522.

7. ICNIRP. (2018). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) - Health Risk Assessment Literature (draft update). *Health Physics*, *74*(4), 494-522.

8. Scientific Committee on Emerging Newly Identified Health Risks (2015). Opinion on potential health effects of exposure to electromagnetic fields. *Bioelectromagnetics*, *36*(6), 480-484. https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf

9. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (2013). Non-ionizing radiation, Part 2: Radiofrequency electromagnetic fields. IARC monographs on the evaluation of carcinogenic risks to humans, 102(PT 2), 1.

10. BioInitiative Working Group, Sage, C., & Carpenter, D. O. (2012). BioInitiative Report: A Rationale for Biologically-based Public Exposure Standards for Electromagnetic Radiation at www.bioinitiative. org. *December*, *31*(2012), 1557.

11. Di Ciaula, A. (2018). Towards 5G communication systems: Are there health implications?. *International Journal of Hygiene and Environmental Health*, *221*(3), 367-375.

12. Russell, C. L. (2018). 5 G wireless telecommunications expansion: Public health and environmental implications. *Environmental Research*, *165*, 484-495.

13. Starkey, S. J. (2016). Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionising Radiation. *Reviews on Environmental Health*, *31*(4), 493-503.

14. Belpomme, D., Hardell, L., Belyaev, I., Burgio, E., & Carpenter, D. O. (2018). Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective. *Environmental Pollution*.

15. Betzalel, N., Ishai, P. B., & Feldman, Y. (2018). The human skin as a sub-THz receiver–Does 5G pose a danger to it or not? *Environmental Research*, *163*, 208-216.

16. Falcioni, L., Bua, L., Tibaldi, E., Lauriola, M., De Angelis, L., Gnudi, F & Menghetti, I. (2018). Report of final results regarding brain and heart tumours in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station environmental emission. *Environmental Research*, *165*, 496-503.

17. Wu, T., Rappaport, T. S., & Collins, C. M. (2015). Safe for generations to come: Considerations of safety for millimeter waves in wireless communications. *IEEE microwave magazine*, *16*(2), 65-84.

18. https://www.who.int/peh-emf/publications/facts/fs296/en/

19. Yakymenko, I., Tsybulin, O., Sidorik, E., Henshel, D., Kyrylenko, O., & Kyrylenko, S. (2016). Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation. *Electromagnetic biology and medicine*, *35*(2), 186-202.

20. IEEE Spectrum (2019). Everything You Need to Know About 5G. https://spectrum.ieee.org/video/telecom/wireless/everything-you-need-to-know-about-5g [accessed 20/05/2019]

5 5G TECNOLOGIES

5G Technologies[19]

Beamforming: A way of transmitting the data to a user, base stations identify the best way to transmit data to a user.
Full Duplex: Current networks take turns to transmit and receive data on the same frequency, 5G will be able to receive and transmit data at the same time.
Massive MIMO: New mobile base stations that will have hundreds of transmitters rather than <10 of the current base stations.
Millimetre waves: The use of higher frequency waves to transmit data.
Small Cells: Small mobile base stations that transmit information. These will be used to make a network to transfer information.

6 GLOSSARY

Connectivity: the ability of a device to connect to other computers or to the internet
Hertz (symbol Hz)**:** A unit of measure used to describe frequencies of EMF. A hertz is defined as one cycle per second. A MHz (Megahertz) represents 1,000,000 (one million) Hz, A GHZ (Gigahertz) is equal 1,000,000,000 (one billion) Hz.
Internet of things: The connection of everyday items to the internet, enabling them to send and receive data.
Next generation: a 'next generation product' is one that has been developed using the latest technology (and is likely to replace an existing product).
Smart devices: electronic equipment that can be connected to other gadgets via wireless connections and also operate interactively and autonomously.
Thermoregulation: a process that allows your body to maintain its core internal temperature.

7 ABBREVIATIONS

AGNIR - Advisory Group for Non Ion-ionising radiation (The Advisory Group on Non-Ionising Radiation (AGNIR) is an independent advisory group that reported to PHE)
IARC - International Agency for Research on Cancer (The International Agency for Research on Cancer (IARC) is the specialized cancer agency of the World Health Organization.)
The objective of the IARC is to promote international collaboration in cancer research.
INCIRP - International Commission on Non-Ionizing Radiation Protection (ICNIRP), (The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an independent organisation that provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR). The organisation comprises experts from different countries and disciplines.)
PHE - Public Health England
RF-EMF- Radio Frequency Electromagnetic Field
SCENIHR - Scientific Committee on Emerging and Newly Identified Health Risks (The Committee provides opinions on emerging or newly-identified health and environmental risks and on broad, complex or multidisciplinary issues requiring a comprehensive assessment of risks to consumer safety or public health and related issues not covered by other Community risk) assessment bodies.
WHO – World Health Organisation