Monitoring Programme for Public Exposure to Electromagnetic Fields (0 Hz – 300 GHz)

Office of Radiation Protection & Environmental Monitoring

Environment and Health Programme

2021-2023 Programme

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1. Introduction

The Radiological Protection Act 1991 (Non-Ionising Radiation) Order 2019, S.I. 190 of 2019 (Government of Ireland, 2019), extended the functions of the Environmental Protection Agency (EPA) to cover public exposure to Non-Ionising Radiation (NIR) in the range 0 Hz to 300 GHz. This part of the NIR spectrum includes electric, magnetic and electromagnetic fields (EMF) or radiation, widely referred to as EMF. The acronym EMF is therefore used hereafter to refer to all these physical terms. Thus, EMF may refer to static and extremely-low frequency electric and magnetic fields (ELF-EMF) or to radiofrequency electromagnetic fields (RF-EMF), depending on the frequency.

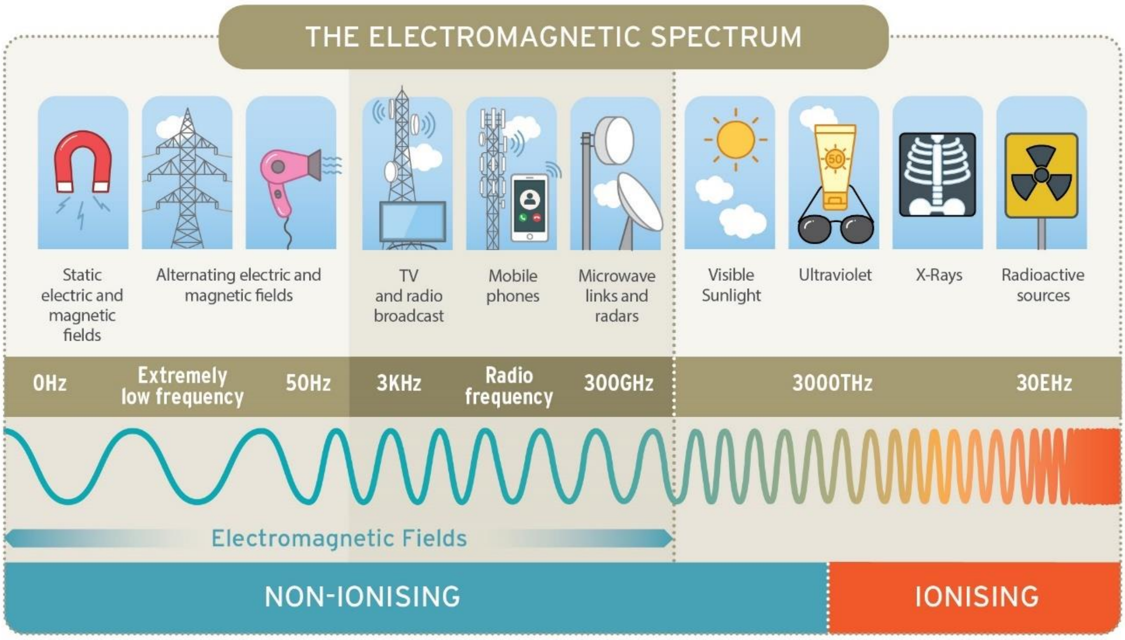

Figure 1. The electromagnetic spectrum.

The functions of the EPA, as set out in SI 190 of 2019, include:

- the provision of advice and information to the Government and the public on exposure to EMF and;
- to carry out independent monitoring of public exposure to EMF to inform our advice function.

Electromagnetic fields are generated whenever electricity is produced, distributed or used. EMF are also used to transmit information over great distances and to heat things such as food or other low-conductivity products. EMF are, therefore, produced or used by practically all the services that are expected by a modern society and required by a modern economy, including:

1. to transmit information over great distances, and so are used extensively to broadcast media (e.g. radio, television, internet) and for mobile connectivity (e.g. mobile phones, Wi-Fi, Bluetooth). This part of the EMF spectrum (3 kHz to 300 GHz) is commonly referred to as radiofrequency electromagnetic fields or RF-EMF.

2. as a by-product when electricity is generated, distributed or used. This part of the EMF spectrum, from 0 Hz to 3 kHz, includes static and extremely-low frequency (ELF) electric and magnetic fields. Static fields (0 Hz) do not change over time and are generated from the use of direct current (DC) electricity (e.g. trains, trams) or electromagnets (e.g. MRIs) and can also arise naturally. ELF electric and magnetic fields (1 Hz – 3 kHz) are emitted by equipment used with alternating current (AC) electricity (e.g. power lines, substations, transformers, electrical appliances).

2. Other agencies / institutions with roles on EMF in Ireland

As part of the EPA's role on EMF, we work with several stakeholders with responsibilities on public exposure to EMF in Ireland. Our main role is to provide information and advice to the public and the government and this function is therefore informed by these relationships and in so doing we add value and avoid duplication of effort.

Other governmental organizations with responsibilities on EMF in Ireland include:

- Department of Communications, Climate Action and Environment (DCCAE), responsible for policy relating to the health effects of electromagnetic fields. DCCAE also has responsibilities to facilitate the deployment of improved connectivity capabilities across the country;
- Commission for Communications Regulation (ComReg), responsible for allocating and licensing the use of the radiofrequency spectrum for telecommunication purposes;
- EirGrid and ESB Networks, responsible for ensuring that public exposure to EMF from electricity installations (e.g. power lines, substations) and other infrastructure (e.g. smart meters) is below international guidelines;
- Commission for Regulation of Utilities (CRU) has a range of economic, customer protection and safety responsibilities in energy and water;
- Health and Safety Authority (HSA), with responsibility for occupational exposure to EMF under SI No 337 of 2016;
- Health Service Executive (HSE), with responsibility for advice on public health;
- National Standards Association of Ireland (NSAI), responsible for the development and application of Irish Standards including those related to human exposure to EMF and electromagnetic compatibility (EMC) of devices;
- Local Authorities (Broadband Officers, BBOs), responsible for authorising smaller infrastructure projects (e.g. placement of telecommunication equipment) in compliance with existing guidelines (e.g. "Guidelines for Planning Authorities - Telecommunications Antennae and Support Structures"), BBOs also work to facilitate the deployment of improved connectivity at a local level;
- Department of Rural and Community Development (DRCD), facilitate the work of LAs and Broadband Officers to address connectivity deficits, especially in rural areas;
- Department of Housing, Planning and Local Government has responsibilities for the development and update of planning guidelines such as "Guidelines for Planning Authorities - Telecommunications Antennae and Support Structures";
- An Bord Pleanála, responsible for the authorisation of major infrastructure projects some of which may involve EMF exposure (e.g. North-South high-voltage interconnection).

2.1 ComReg and their role in RF-EMF

The RF-EMF spectrum is a national resource managed in Ireland by the Commission for Communications Regulation (ComReg), which allocates specific frequencies for specific purposes or services (e.g. mobile telephony, satellite, TETRA) through the provision of licenses or general authorizations. Until 2020, compliance with the reference levels recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for public exposure to RF-EMF (ICNIRP, 1998) was a mandatory requirement of ComReg's licenses and authorizations. In 2020, ComReg adopted the updated ICNIRP guidelines (ICNIRP, 2020) which are now a requirement of ComReg's licenses and authorizations. ComReg carry out compliance monitoring of RF emissions around licensed telecommunication infrastructure to ensure that RF-EMF levels are within the ICNIRP recommendations. The results of this monitoring are published on ComReg's websites Siteviewer and www.comreg.ie/nir-reports-2/ and are an important resource of information. However, these measurements are performed in the proximity of specific transmitter sites to identify the maximum exposure that a member of the public may be exposed to from a specific site and compare it with ICNIRP recommended limits. To date, all measurements performed by ComReg have been below the ICNIRP recommendations for members of the public, in most cases several orders of magnitude below the ICNIRP frequency-specific reference levels.

2.2 EirGrid, ESBN and CRU and their role on EMF

The responsibility for decisions regarding the development and operation of the public electricity networks in Ireland is conferred by two system operator licenses: one held by ESB Networks (ESBN) DAC (Distribution System Operator) and another held by EirGrid (Transmission System Operator). EirGrid, as the licensed Transmission System Operator, is responsible for operating, ensuring the maintenance of, and developing a safe, secure, reliable, economical and efficient electricity transmission system. ESB Networks is responsible for operating, ensuring the maintenance of, and developing a safe, secure, reliable, economical and efficient electricity distribution system. ESB owns the distribution system and through its networks business unit, carries out the instructions of the Distribution System Operator in relation to its operation, maintenance and development. The System Operators are required to operate, ensure the maintenance of, and develop a safe, secure, reliable and economical and efficient electricity system while having due regard for health and the environment.

Ireland's electricity networks operate at 50 Hz and the associated EMF emissions are in the extremely low frequency (ELF) range. EirGrid and ESBN are responsible to ensure that ELF-EMF emissions from all electricity networks remain below recommended exposure guidelines. This includes EMF from power lines, substations, transformers and related equipment. Both EirGrid and ESB Networks have produced public information material which, among other things, refer to the ELF measurements collected and give comparison with other sources[1]. EirGrid have carried out measurements close to transmission system infrastructure which are publicly available (EirGrid ELF measurements). These results are compared with relevant international recommendations (i.e. ICNIRP).

The Commission for Regulation of Utilities (CRU) is responsible for regulation of electricity networks and licencing of the transmission and the distribution electricity network operators. CRU's responsibilities include regulation of the roll out of Smart Meters, which, when fully deployed, will send electricity metering information (e.g. electricity consumption) to the Distribution System Operator using text messaging via RF-EMF similar to 2G mobile technology.

3. Objectives of the EMF Monitoring Programme

The objective of the EPA's EMF monitoring programme is to support our advisory role to Government and to assess the typical exposure of the public to EMF in a range of everyday environments. The programme aims to assess the population exposure to EMF by determining the typical levels of EMF exposure found in everyday environments in Ireland, particularly in those areas with a high population and/or footfall.

Exposure to man-made sources of EMF is practically ubiquitous. However, exposure to static and ELF fields is only relevant close to electricity infrastructure (e.g. less than about 100 m from high-voltage

[1] EMF and You - ESB

power lines) or electrical equipment and appliances (e.g. less than about 0.5 m from small appliances), whereas broadcasting and mobile telecommunication lead to continuous exposure of the public to RF-EMF. Likewise, although exposure to power lines may also give rise to some public concern, it is concerns about exposure to RF-EMF, and 5G in particular, that to date have given rise to the majority of our queries and on which we are mainly called upon to provide information and advice. For this reason, our EMF monitoring program will initially focus on RF-EMF but will be extended to include static and ELF fields in the future.

> The monitoring program will start with RF-EMF but will be extended to include static and ELF fields.

The aim of our RF-EMF surveys is to complement the compliance monitoring work carried out by ComReg which aims to measure RF-EMF levels nearby specific licensed transmitter sites (commonly known as "masts") to ensure compliance with the conditions attached to the licence or general authorisation. This may include mobile phone base stations (e.g. 2G, 3G, 4G and/or 5G), radio, TETRA or other telecommunication antennas. ComReg's monitoring provides information about compliance under worst-case exposure scenarios at the source level, i.e. nearby the masts. The results obtained from ComReg's measurements represent the maximum exposure level that a member of the public may experience near a particular transmitter site. However, our focus will be on assessing exposure to RF-EMF at the population (receptor) level in everyday environments, which may include exposure to multiple transmitter sites as well as other RF sources. (e.g. radio, TV, mobile phone handsets and base stations, Wi-Fi routers, microwave links, radars). The EPA's RF-EMF monitoring work should also enable us to assess the impact that the deployment of new RF technologies (e.g. 5G and subsequent technologies) may have on the public exposure to EMF and to provide advice accordingly.

The EPA monitoring programme will therefore seek to measure:

- in areas where people may gather such as city centre locations, shopping centres etc,;
- in outdoor areas such as parks, playing fields or playgrounds.

The first group of measurements aims to develop a picture of typical everyday RF-EMF levels in populated/busy areas. The second category will allow comparison between urban and rural areas and help develop the concept of a background RF-EMF level in Ireland. Similar RF-EMF monitoring efforts carried out in Europe and elsewhere may be used as a reference. For example, the Norwegian radiation protection authority carried out an RF-EMF survey including measurements in 91 locations in 6 cities (Sjømoen et al., 2011). A follow-up survey carried out five years later (NRPA, 2016) allowed assessing the impact that a new RF technology (4G) had on EMF exposure levels in Norway. Several published studies carried out in other European countries (Gajšek et al., 2015; Sagar et al., 2018) provide further information about typical RF-EMF levels in everyday environments in Europe.

ComReg monitors RF-EMF at the source level, i.e. nearby telecommunication sites (or masts).

EPA will monitor RF-EMF at the receptor level, i.e. where people gather and may be exposed to multiple RF sources at a time, including telecommunication sites (or masts).

4. EMF Standards and Exposure Limits

International guidelines for public exposure to electromagnetic fields are developed and regularly updated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE). Both guidelines are endorsed by the World Health Organization (WHO). The latest updates of the IEEE and the ICNIRP guidelines were published in 2019 (IEEE, 2019) and 2020 (ICNIRP, 2020), respectively. The European Commission (EC) issued the EC Recommendation in 1999 (EC, 1999), based on the ICNIRP 1998 guidelines for public exposure (ICNIRP, 1998). ICNIRP reviewed and re-confirmed the 1998 guidelines in 2009 (ICNIRP, 2009). A review of the ICNIRP guidelines covering low frequency fields (< 100 kHz) was issued in 2010 (ICNIRP, 2010). A review of the ICNIRP guidelines for frequencies above 100 kHz was published in 2020 (ICNIRP, 2020). Given the improvements introduced in the new RF guidelines for frequencies > 6 GHz (particularly relevant for 5G emissions) it is anticipated that most European and other countries worldwide will adopt the new RF guidelines (ICNIRP, 2020). The most restrictive exposure limit (known as reference level) for public exposure to RF-EMF recommended by both the European Commission (EC, 1999) and ICNIRP (ICNIRP, 2020, 1998) is 28 V/m for electric fields or 2 W/m^2 for power density, which corresponds with the 10-400 MHz frequency range used, for example, for FM radio and VHF TV broadcasting. The reference levels for higher frequencies (> 400 MHz), associated for example with UHF TV, mobile telephony and heating devices (e.g. microwave ovens), are higher (e.g. 61 V/m or 10 W/m^2 for frequencies between 2-300 GHz). Therefore, compliance with the most stringent level (i.e. 28 V/m or 2 W/m^2) ensures compliance throughout the RF range.

A measured EMF level of 28 V/m (2 W/m^2) or lower ensures compliance with ICNIRP/EC recommendations across the RF-EMF range.

ComReg's measurement methodology to assess compliance with ICNIRP reference levels requires measurements to be made at the maximum public exposure point. Therefore, compliance measurements are generally carried out relatively near the transmitter sites, typically in their line of sight, to ensure that measurements are representative of the maximum exposure of the public near an active transmitter. RF levels measured throughout the country between 2008 and 2020 available from public reports (www.comreg.ie/nir-reports-2/ and https://siteviewer.comreg.ie/) show typical (rms) RF levels around 1-2 V/m and maximum (rms) values up to around 9 V/m in the vicinity of the measured transmitters.

Typical levels measured by ComReg close to base stations throughout the country are between 1-2 V/m, with maximum values up to around 9 V/m.

The public are usually relatively far from transmitter sites but can be exposed to several transmitters and other RF-EMF sources at the same time. Therefore, the aim of the EPA's RF EMF monitoring programme is to obtain information about typical (e.g. average and range/maximum) levels of exposure experienced by members of the public in everyday environments from all potential RF sources, including transmitter sites (or masts). Available information from RF surveys in other European countries show that typical levels in everyday environments are between 0.04 and 0.76 V/m indoors and from 0.07 to 1.27 V/m outdoors (Jalilian et al., 2019). Although it is expected that similar results would be found in Ireland, this information has never been collected.

Typical everyday RF-EMF levels reported in other European countries are 0.04 – 0.76 V/m indoors and 0.07 – 1.27 V/m outdoors.

The EPA monitoring programme aims to obtain these data for Ireland.

5. RF-EMF measurement methodology

Initially, the monitoring programme will involve RF-EMF spot measurements using portable equipment (see chapter 9 for more details) to assess public exposure in everyday environments covering all potential sources of EMF in the RF frequency range 100 kHz to 90 GHz. This is the frequency range of available RF-EMF equipment. Spot measurements of RF-EMF emissions provide information of typical whole-body (far-field)[2] exposure levels experienced by members of the public from fixed RF-EMF sources (e.g. mobile phone base stations, radio and TV transmitters, radars) as well as from portable sources being used by other people (e.g. mobile phone handsets used by other people nearby). The main fixed sources within this frequency range that lead to continuous RF exposure are listed on Table 1 below. Spot measurements are not capable of assessing localized (near-field) RF-EMF exposure under specific situations such as when making a call with a mobile phone in contact with the body (e.g. at the ear). Therefore, RF-EMF sources which typically lead to near-field, localized exposure (e.g. mobile phone handsets, tablets or virtual reality glasses) are not included here. The programme will be reviewed every two years. Future developments may include the use of long-term fixed area monitors and the development of a fixed monitoring network.

Table 1. Main sources responsible for RF EMF public exposure in everyday environments.

Source	Technology	Frequency Range
Radio broadcasting antenna	Longwave	252 kHz
Antitheft gates and tag systems	EAS, RFID	5 kHz – 915 MHz
Radio broadcasting antenna	FM	87.5–108 MHz
Digital radio broadcasting antenna	T-DAB	174–230 MHz
Digital television broadcasting antenna	DTT	470 - 694 MHz
Mobile phone base station (4G)	LTE-800	791–821 MHz
Railway communication antenna	GSM-R	876.2–879.6 MHz
Railway communication antenna	GSM-R	921.2–924.6 MHz
Mobile phone base station (2G)	GSM-900	925–960 MHz
Mobile phone base station (2G)	GSM-1800	1805–1880 MHz

[2] Far-field & near-field: See chapter 8.3 in the Appendix for a detailed explanation of these terms.

Mobile phone base station (3G)	UMTS-1900	1900–1920 MHz
Mobile phone base station (3G)	UMTS-2100	2110–2170 MHz
Wi-Fi - 2.4 GHz	2.4 GHz band	2400–2484 MHz
Wi-Fi - 5GHz	5 GHz band	5150–5350 MHz
Mobile phone base station (4G)	LTE-2600	2620–2690 MHz
Mobile phone base station (5G)	New Radio (NR 3.6 GHz Band)	3410–3800 MHz
Emergency and professional systems	Terrestrial Trunked Radio (TETRA)	380–400 MHz
Emergency and professional systems	Professional Mobile Radio (PMR)	75.2–470 MHz
Radar	Acquisition and Tracking	1–35 GHz
Microwave point-to-point link	Relay	43–94 GHz

5.1 Spot measurement methodology

To obtain reliable and representative measurements of RF-EMF public exposure in everyday Irish environments it is important to set out the criteria for the selection of the measurement locations, define the measurement protocols to be followed as well as the equipment to be used.

5.1.1 Selection of measurement locations. General criteria.

The deployment of 5G in Ireland has given rise to concern among some members of the public. It is the topic on which we are most often called upon to provide advice and information. Therefore, when deciding where to measure during initial stages of our EMF monitoring programme we will take account of areas where 5G equipment has been deployed.

> The RF EMF monitoring programme will initially include locations where 5G has been deployed. As it progresses, it will take account of all frequencies and exposure scenarios.

The selection of the locations or points where measurements will be made is an important decision to ensure that our measurement data are representative of typical RF-EMF exposure levels experienced by members of the public in Ireland. In general, the locations of interest are those where public tend to gather and spend more time on a regular basis. The number and type of RF sources (e.g. mobile base stations, radio and TV transmitters, radars etc) in such areas also needs to be considered. Therefore, the selection of measurement points will be based on the number of people likely to be exposed (based, for example, on absolute population or population density) as well as on available data on footfall in the selected locations. The density of RF sources, particularly mobile phone base stations, is an important contributing factor to the overall RF-EMF exposure. Since areas with high population tend to also have high density of mobile phone base stations/antennas, the selection of measurement locations based on population ensures that situations of potential high exposures due to high density of these sources are also captured. However, this may not be the case for other RF sources, such as radio and TV broadcasting antennas, microwave links or radars. Available data on local population/footfall and RF sources distribution throughout the country will be used to select the locations where measurement data best represent typical exposure levels of the public. Thus, measuring where there is a higher density of population will allow us to obtain information on the typical exposure levels experienced by a large proportion of people in Ireland. Our initial surveys will focus on measuring micro-environments such as streets, shopping centres, parks, train/bus stations and other locations which are likely to have a high footfall due to work, study, commercial or touristic interest. Future surveys may include measurements in other micro-environments of special interest due to the presence of RF sources such as TV/radio transmitters, radars, etc, regardless of whether they have or not a high footfall/population.

5.1.2 Selection of measurement locations. Specific criteria.

Measurement locations will be selected based upon the population of the wider area by first selecting the most populated "settlement". For each settlement, one or more "small areas" (SA) with the highest (absolute) population or population density will be selected. To select the specific measurement location(s) within each SA, information obtained locally as well as data on available "daytime population" or footfall will be used as identified by the most recent census data (CSO, 2016)[3] or other sources of information (e.g. county councils registries)

Priority will be given to areas where large numbers of people live. First, settlements with more 10,000 inhabitants will be selected. If a county does have a settlement of > 10,000 people, then it is proposed to measure in the most populated settlement in that county. (See Figure 1 and Table A1). Within the selected settlement, small areas with the highest absolute population or population density will be chosen. Within the selected small area, measurement locations with high footfall will be prioritised. These could be a location of particular interest, e.g. a university or large school, an industrial estate/ business park, a tourist attraction or a busy street within a residential area.

Small areas are based upon the number of dwellings in the area. To capture the daily movement in population it may be necessary to supplement the Small Area measurement with another done in an area of highest daytime population. This is likely to be necessary in the larger urban areas. Where possible, indoor and outdoor locations will be measured within the selected areas. Priority will also be given to locations where 5G networks are in place given that they represent the newest RF technology and there is a significant public concern about them.

[3] A settlement or census town is defined as "there being a minimum of 50 occupied dwellings, with a maximum distance between any dwelling and the building closest to it, of 100 metres, and where there was evidence of an urban centre (shop, school etc)." Small areas are the lowest level of geography for the compilation of statistics in line with data protection guidelines and typically contain between 50 and 200 dwellings nested within Electoral Division boundaries. Census 2016 included data on the 'daytime population' of areas. The daytime population includes everybody who indicated they worked or studied in a particular area, along with persons in that area not in that category but who are there during the day.

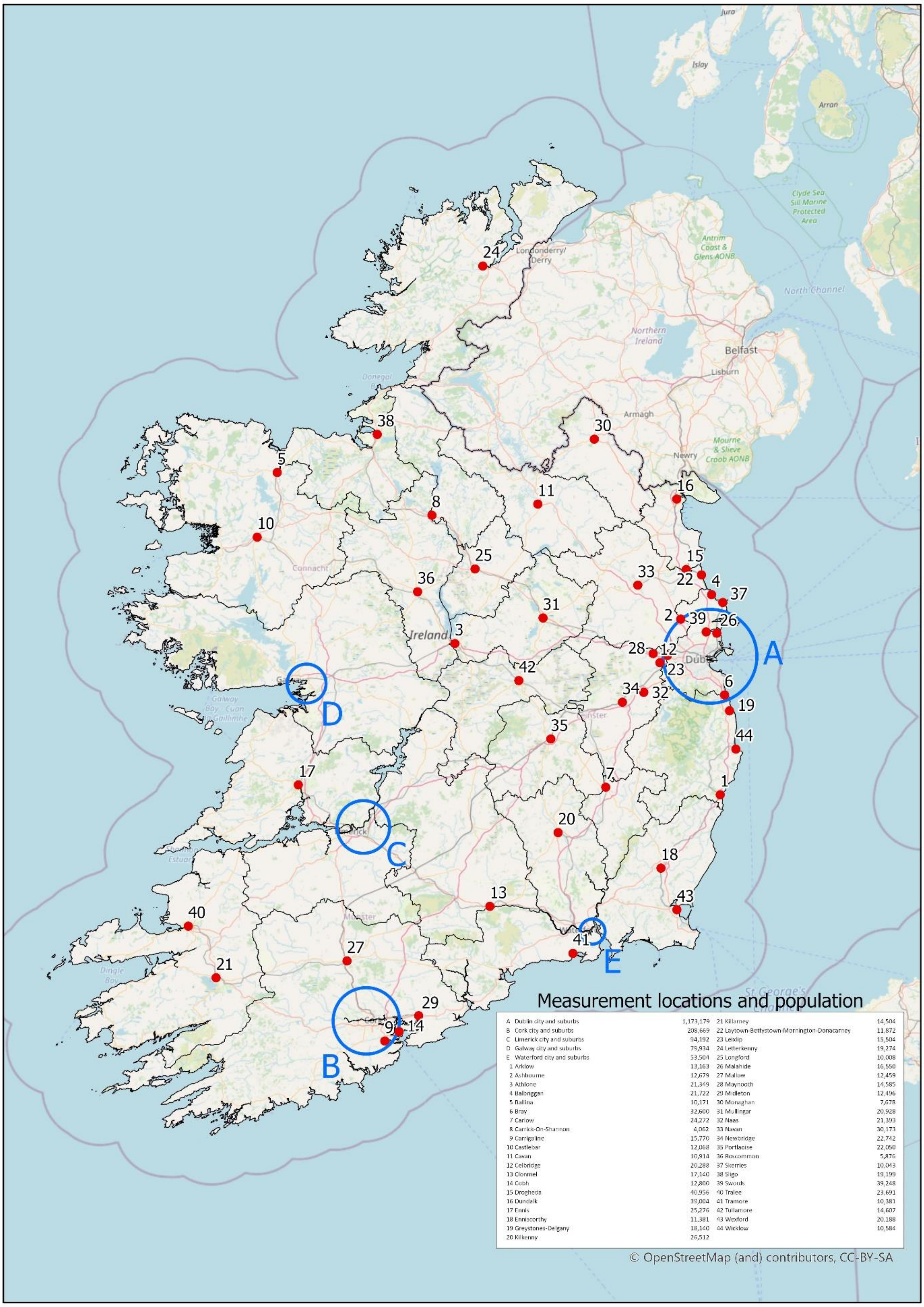

Figure 1. Map of measurement locations (settlements) for the EMF Monitoring Programme 2020-2022 (see also Table A1 in section 9.6 of the Appendix).

Initial measurements will focus on the main Irish cities and towns (e.g. Dublin, Cork, Waterford, Galway, Wexford). For example, the Dublin area contains the highest population and footfall in the country (Co Dublin has a population of about 1.4 million while around 250,000 people work in Dublin city centre). Dublin also has the highest number of mobile phone base stations nationwide (around 2,700 as of March 2020), including 5G infrastructure. The most current census data on population and population density as well as available information (e.g. local knowledge) on footfall for the main cities and towns will be used to select the locations to be measured..

The flowchart below summarizes the methodology and criteria to select measurement locations.

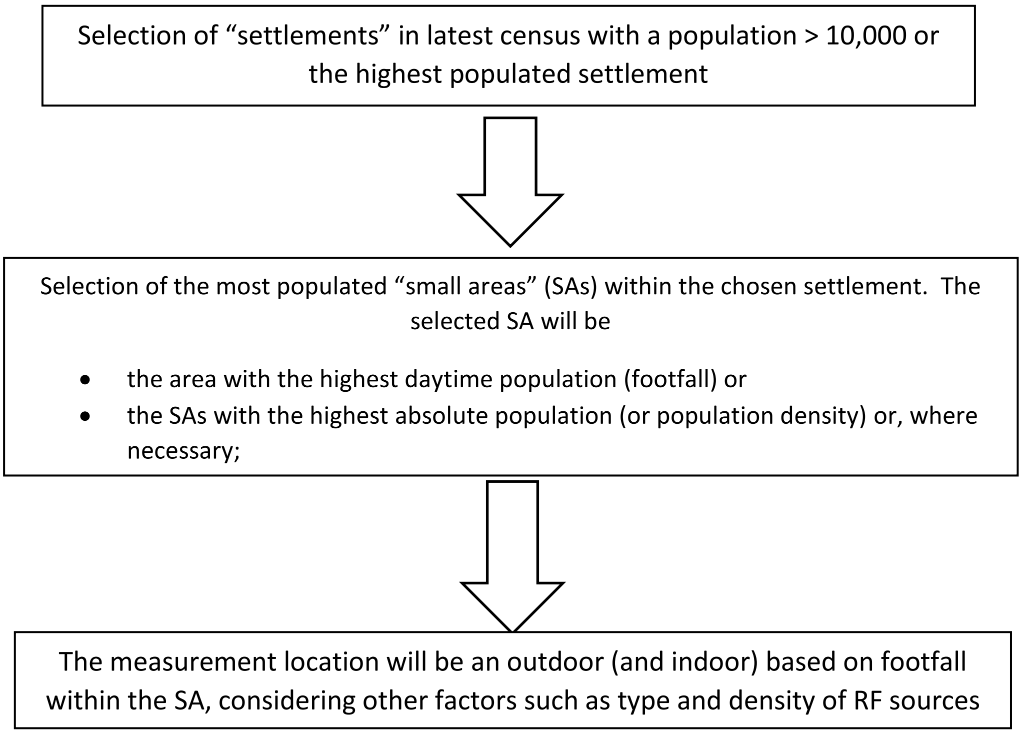

Figure 2. Criteria for selecting EMF measurement locations. (See also main map or Table A1 & A2).

The aim of our monitoring programme is to cover all sources of RF-EMF that contribute to population exposure and not only mobile phone base stations (Figure A2). Therefore, as the programme develops information about other RF sources (e.g. radio and TV transmitters, microwave links, radars) will be collected and used to select measurement locations of special interest given the existence of these sources. For example, radio and TV transmitters (Figure A3) or airport radars (Figure A4) are likely to be important contributors to the overall RF-EMF exposure of people living or working near these sources.

Several studies have found that RF-EMF exposure levels may differ indoors and outdoors, given the different relevant sources present in these environments (Gajšek et al., 2015; Jalilian et al., 2019; Joseph et al., 2010; Sagar et al., 2018; Viel et al., 2009). Thus, while fixed telecommunication antennas tend to be more relevant outdoors, the main RF EMF sources indoors are usually Wi-Fi routers and mobile phones handsets. RF-EMF measurements will mainly be made in outdoor public spaces, because access to such areas is not likely to be a problem. Where feasible, indoor public spaces such as shopping centres, bus/train stations that allow public access will also be measured. Measurements in indoor environments where public access is not generally permitted, such as offices, schools or dwellings, is not envisaged in this programme.

Outdoor measurement points are particularly important since previous studies in other European countries, as well as the results from ComReg in Ireland, show that most members of the public experience the highest (whole body or far-field[4]) exposure levels outdoors (Gajšek et al., 2015; Jalilian et al., 2019; Sagar et al., 2018). This is mainly due to the lower number of physical obstacles between fixed transmitters, such as mobile phone masts, and the public. Indoors, walls and other physical obstacles reduce RF-EMF levels from outdoor sources. Here, indoor sources such as Wi-Fi, DECT phone base stations and mobile phone handsets become more relevant. These studies also show that (whole body or far-field) RF-EMF exposure levels indoors tend to be lower than outdoors as the total contribution of all indoor sources tend to be lower than that of all outdoor sources. However, indoor measurements are also important as both a reference and to provide information about exposure from indoor RF-EMF sources.

The most relevant sources of exposure indoors are typically mobile phone handsets, Wi-Fi routers, Bluetooth and smart meters. Indoor exposure levels from outside transmitters can be around 40% lower than the levels outdoors (Jalilian et al., 2019). Exposure from mobile phone handsets and the exposure from other people using a mobile phone indoors may be important to the total indoor RF exposure level. Some studies have shown that exposure from mobile phone handsets increase when the RF signal is low (i.e. poor coverage), given the attenuation that RF signals experience indoors due to walls and other physical obstacles (ITU-R, 2015). For comparison, exposure outdoors from your own mobile phone handset may be up to 10 times higher than that from surrounding base stations. Indoors, exposure from your own mobile phone in contact with your body (e.g. making a call with the phone at the ear) with low to moderate coverage may be 100-400 times the levels from surrounding base stations (Stewart, 2000).

Indoor areas where substantial numbers of people tend to gather (e.g. shopping centres, trains, buses and trams etc) may provide a good opportunity to measure typical exposure of large number of people. Given the number of people using mobile phone handsets at the same time, overall (uplink and downlink) exposure may be significant. Although this is already the case for 4G networks, it may be important when 5G networks are in place given the use of beamforming[5] technology. Some studies have found that the highest RF-EMF exposure levels in everyday environments occur in public transportation systems (inside trains and trams), mainly due to uplink signals emitted from mobile phone handsets (Sagar et al., 2018) as well as at train and tram stations, in this case mainly due to downlink signals (Jalilian et al., 2019).

Radio frequency (RF) signals from telecommunication systems are stochastic and exhibit temporal variations. Therefore, sampling and averaging times used to perform EMF surveys are important to reliably describe EMF levels in specific environments. Following recommendations issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998), the protocol to obtain reliable EMF values for frequencies between 100 kHz and 10 GHz involves averaging all EMF values obtained over any 6-min period. Several extrapolation methods have been approved to estimate maximum RF exposure levels associated with maximum volume of calls and/or data traffic depending on the technology (e.g. GSM, UMTS, LTE). These methods are described in detail in official RF measurement Standards such as EN 62232-2019, which includes recommendations to estimate

[4] Far-field & near-field: See chapter 9.3 in the Appendix for a detailed explanation of these terms.

[5] Beamforming allows sending 5G signals only where and when they are needed, in contrast with previous technologies which usually emit continuously in all directions.

maximum 5G signals. These methods and other recommendations within the most recent RF guidelines (ICNIRP, 2020; IEEE 2019) will be considered to obtain reliable estimates of the RF exposure experienced by members of the public.

6. Access to monitoring EMF measurement data

EMF data obtained from our monitoring programme will be made available on the EPA website. Measurement data will be uploaded on a regular basis. Initially, reports of summarized data will be available for download. In the future, interactive maps with historical data will be included. On this website, we will also provide links to EMF measurement data obtained by other governmental agencies within Ireland or abroad.

7. Timeline

The EMF measurement programme will be reviewed every two years. The following activities are envisaged during the first period of the programme:

Year 1 (First 12 months)

- Consultation with the Stakeholders.
- Public Consultation.
- Begin RF measurements, initially focussing on 5G (3.6 GHz) in the main cities and towns.

Year 2

- Continue RF measurements, including 5G (3.6 GHz as well as 700 MHz & 26 GHz if they are in place), in public areas throughout the country.
- Investigate the need or added value of using fixed RF monitoring sites.
- Develop the ELF and static fields monitoring programme, including a public consultation
- Review and development of EMF programme for next 2 years.

8. References

CSO, 2016. Census 2016 Small Area Population Statistics [WWW Document]. URL https://www.cso.ie/en/census/census2016reports/census2016smallareapopulationstatistics/ (accessed 20.04.20).

CSO, 2016. Census 2016 Daytime population and workplace zones. URL https://www.cso.ie/en/census/census2016reports/workplacezonesand1kmpopulationgrids/EC, 1999. Council Recommendation (1999/519/EC) of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) - Publications Office of the EU [WWW Document]. URL https://op.europa.eu/en/publication-detail/-/publication/9509b04f-1df0-4221-bfa2-c7af77975556/language-en (accessed 11.15.19).

Gajšek, P., Ravazzani, P., Wiart, J., Grellier, J., Samaras, T., Thuróczy, G., 2015. Electromagnetic field exposure assessment in Europe radiofrequency fields (10 MHz–6 GHz). J. Expo. Sci. Environ. Epidemiol. 25, 37–44. https://doi.org/10.1038/jes.2013.40

Government of Ireland, 2019. S.I. No. 190/2019 - Radiological Protection Act 1991 (Non-Ionising Radiation) Order 2019.

ICNIRP, 2020. Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz). Health Phys. 118, 483–524. https://doi.org/10.1097/HP.0000000000001210

ICNIRP, 2010. ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz-100 kHz). Health Phys. 99, 818–836. https://doi.org/10.1097/HP.0b013e3181f06c86

ICNIRP, 2009. Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz - 300 GHz). ICNIRP.

ICNIRP, 1998. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys., International Commission on Non-Ionizing Radiation Protection 75, 535. https://doi.org/10.1097/HP.0b013e3181aff9db

IEEE, 2019. C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz. Institute of Electrical and Electronics Engineers (IEEE), New York (USA). https://doi.org/10.1109/IEEESTD.2019.8859679

ITU-R, 2015. P.2040 : Effects of building materials and structures on radiowave propagation above about 100 MHz [WWW Document]. URL https://www.itu.int/rec/R-REC-P.2040-1-201507-I/en (accessed 4.29.20).

Jalilian, H., Eeftens, M., Ziaei, M., Röösli, M., 2019. Public exposure to radiofrequency electromagnetic fields in everyday microenvironments: An updated systematic review for Europe. Environ. Res. 176, 108517. https://doi.org/10.1016/j.envres.2019.05.048

Joseph, W., Frei, P., Ro??sli, M., Thur??czy, G., Gajsek, P., Trcek, T., Bolte, J., Vermeeren, G., Mohler, E., Juh??sz, P., Finta, V., Martens, L., 2010. Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. Environ. Res. 110, 658–663. https://doi.org/10.1016/j.envres.2010.06.009

Sagar, S., Dongus, S., Schoeni, A., Roser, K., Eeftens, M., Struchen, B., Foerster, M., Meier, N., Adem, S., Röösli, M., 2018. Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: A systematic literature review. J. Expo. Sci. Environ. Epidemiol. 28, 147–160. https://doi.org/10.1038/jes.2017.13

Sjømoen, T., Lervik, H., Heimdal, P., Klæboe, L., Hannevik, M., 2011. Radio frequency field in our surroundings. Measurements in the frequency range 80 MHz – 3 GHz. RadiationprotectionReport2011:6. Østerås: Statens strålevern. Norwegian Radiation Protection Authority, Post and Telecommunications Authority.

Stewart, W., 2000. EMF-Portal | Mobile Phones and Health (The Stewart Report). [WWW Document]. URL https://www.emf-portal.org/en/article/11173 (accessed 4.29.20).

Viel, J.F., Cardis, E., Moissonnier, M., de Seze, R., Hours, M., 2009. Radiofrequency exposure in the French general population: Band, time, location and activity variability. Environ. Int. 35, 1150–1154. https://doi.org/10.1016/j.envint.2009.07.007

9. Appendix

9.1 Equipment used for RF EMF spot measurements

Considering the aim of our monitoring programme, two main types of equipment will be used to obtain RF measurements: frequency selective RF meters with spectrum analysis capabilities and broadband RF meters with isotropic probes.

9.1.1 Broadband RF meter with isotropic (non-directional) probes

- Description: It allows the assessment of the total RF level in a specific location, including most RF frequency bands (e.g. radio, TV, mobile telephony etc). The result(s) obtained can be directly compared with the strictest reference level(s) for the public.
- Details: The Narda NBM 550 allows to measure both E and H fields between 1 Hz – 90 GHz (including all potential 5G signals), depending on the probe used. It can store up to 5,000 measurement results (using four rechargeable AA batteries). It allows storage of measurement and geolocation data when connected to an external GPS device.

Narda NBM 550

9.1.2 Frequency selective (narrowband) RF meter & spectrum analyser

- Description: This meter/spectrum analyser allows to quantify the contribution to the total RF level from each of the RF source(s) present or detected depending on the probe(s) used.
- Example(s): The Narda SRM 3006 allows to obtain RF measurements of E- or H-fields between 9 kHz and 6 GHz (only applicable for 5G frequencies 700 MHz and 3.6 GHz), depending on the probe used. It also allows data storage including geolocation information and many other features being not only an RF meter but also a spectrum analyser.

Narda SRM 3006

9.2 Measurement methodology using portable equipment

In summary, an initial measurement of the total RF level is performed in the selected location using a broadband RF meter and appropriate probes. If any of the measurements obtained with the broadband meter are higher (e.g. above 10%) of the ICNIRP reference level for public exposure, a frequency selective (narrowband) meter should be used to identify the source(s) of incompliance and their contribution to the total RF level. Since non-compliance with the most restrictive reference level for public exposure (i.e. 28 V/m or 2 W/m^2) is unprecedented in Ireland in public spaces it is common practice for RF surveys of public exposure to also perform a measurement using frequency selective equipment and various probes to cover the maximum RF frequency range possible and provide information about the RF sources present in each specific location.

9.3 Common units and magnitudes used to characterize EMF

Several physical magnitudes and units are used to characterize electromagnetic fields (EMF), depending on their frequency. Electric (E) fields are usually measured in volts per meter (V/m). Static and ELF magnetic fields (B) are commonly measured in micro Tesla (µT) while RF magnetic fields (H) are measured in amperes per metre (A/m). Static (0 Hz) as well as extremely-low frequency (ELF) electric and magnetic fields (1 Hz – 3 kHz) are independent and need to be measured separately. However, since electric fields are easily shielded by solid materials (e.g. walls, trees etc), both static and ELF EMF are commonly characterized using the magnetic fields only. RF electric and magnetic fields are proportional to each other in the far-field (where public exposure to fixed transmitters occur), RF fields are commonly characterized using just the electric fields.

Radiofrequency EMF (3 kHz – 300 GHz) travel through space as waves where electric and magnetic fields tend to be proportional to each other, particularly at a distance from the RF source known as "far-field". The "far-field" distance depends on several factors including frequency and size of the source/antenna. For mobile phone base stations, the "far-field" area (where electric and magnetic fields are exactly proportional) starts a few tens of meters from the antenna. The "far-field" area for mobile phone handsets start only a few centimetres from the device. Members of the public are exposed in the "far-field" area of fixed antennas such as base stations, TV/radio transmitters or radars, since only workers and other authorized personnel are allowed to enter the areas closer to the antennas, known as "near-field"[6]. Under far-field conditions, only the electric (E) or the magnetic (H, in A/m) field needs to be measured as the non-measured magnitude can be easily calculated based on the measured one. Power density (S) can also be calculated from E and/or H:

$$\text{Far-field } (r > 2D^2/\lambda) \Rightarrow E = H * Z_0;\ S = E * H = E^2 / Z_0,$$

where r is the distance where far-field conditions start, D is the size of the antenna, λ is the wavelength and Z_0 is the impedance of free space (377 Ohms).

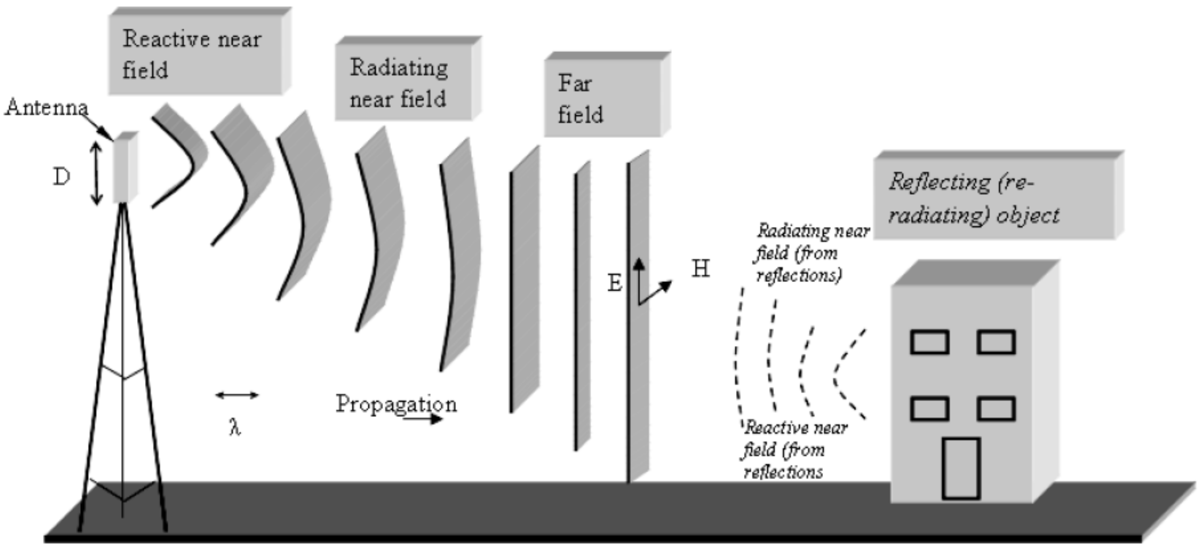

Figure 3. Near- and far-field areas around an RF-EMF antenna (e.g. mobile phone base station). Source: (ICNIRP, 2009).

[6] Exposure limitations within the "near-field" of fixed antennas are a responsibility of the Health & Safety Authority (HSA) under S.I. No. 337/2016.

9.4 Characteristics of the RF EMF sources of interest

9.4.1 Telecommunication equipment

RF-EMF sources are commonly used to transmit information (e.g. data, voice, images) over great distances (i.e. telecommunication). The type of RF emission/signal depends on the frequency as well as on other factors (e.g. antenna size, modulation, pulses).

9.4.2 Mobile phone base stations and handsets

Mobile telecommunication networks are comprised of fixed antennas (aka base stations), typically mounted on masts, either self-standing or built on top of buildings, and mobile phone handsets or other portable devices (e.g. tablets, laptops). RF signals are emitted from the base stations down to the portable devices (this signal is known as "downlink"). Portable devices communicate with fixed antennas emitting a signal ("known as "uplink") using a slightly different frequency within the same frequency range depending on the mobile technology used. Current mobile telecommunication technologies or generations (G) include 2G (including various modulations, e.g. GSM, CDMA), 3G (UMTS), 4G (LTE) and 5G. Currently, only one frequency band for 5G is available in Ireland (i.e. 3.5 GHz). It is expected that other frequency bands will be add to the 5G networks in the near future (e.g. 700 MHz & 26 GHz).

Members of the public may be exposed to RF EMF emitted by fixed antennas (base stations) up to several kilometres away from them. However, since base stations are usually located several meters away from public areas, exposure levels are commonly very low (e.g. 1-2 V/m). The public may also be exposed to mobile phone handsets and other mobile devices, both when being used by themselves or by other people nearby. RF EMF exposure levels from mobile phones away from the body or being used by other people are typically very low and similar to the levels from fixed antennas. Only when mobile phones are used in contact with the body exposure levels can be relatively high (up to 100-400 times higher). Since localised exposure to mobile phone handsets and, potentially, other devices occur in the near-field (i.e. a few millimetres away from the RF source), it is recommended to comply with the ICNIRP exposure limit (reference level) for head/trunk exposure (2 W/kg). Manufacturers of mobile devices need to comply with this requirement. Therefore, only the far-field exposure component of mobile phone emissions is relevant for RF surveys and contribute to the total (whole body) RF exposure level of the public.

9.4.3 Radio and television broadcasting antennas

Radio and television transmitters are also comprised by fixed antennas and portable or fixed receptors (TV and radio sets). However, unlike mobile phones, the TV and radios set cannot send information back to the broadcasting antennas. Therefore, information is only one way. Broadcasting antennas send RF emissions/signals continuously which can typically reach several kilometres. Exposure of the populations to these emissions/signals occurs whenever there is radio/TV coverage. Exposure levels near radio and TV transmitters can be higher than from mobile phone base stations. However, since broadcasting antennas are typically located far away from residential areas exposure levels are usually low and comparable to mobile phone base stations (1-2 V/m).

9.4.4 Emergency and professional systems (TETRA & PMR)

Terrestrial Trunked Radio (TETRA; formerly known as Trans-European Trunked Radio) provides a secure national communications network to emergency services in Ireland, including An Garda

Síochána, the fire Brigade services, the Ambulance services, the Irish Coast Guard (including the rescue services provided by the Air Corps), and the mountain rescue services. TETRA antennas are therefore located near emergency buildings. Thus, members of the public may be exposed to the signal emitted in the surrounding of these antennas.

Personal mobile radio (PMR) and other “business radio” systems are used to allow communication from one fixed point (base station) and several mobile terminals (e.g. walkie talkies). Members of the public may be exposed to these signals when in proximity to both the fixed and mobile equipment. Exposure levels from both TETRA and PMR are in the range of mobile phone base stations or lower.

9.4.5 Wireless Local Area Networks (WLAN) & Wi-Fi

Wi-Fi is a trademarked name for wireless networking products that are certified to be compliant with a specific IEEE family of standards by the Wi-Fi Alliance. Wi-Fi networks have become omnipresent in modern society. Wi-Fi devices contain low-powered radiofrequency (RF) transceivers that support wireless local area networks (WLANs). Their most common use is probably to provide access to the Internet to laptop computers, mobile phones, tablets etc. Wi-Fi is now the basis of virtually all wireless connectivity in homes, offices, and other environments. At present, virtually every laptop computer and SmartPhone can use Wi-Fi. Under any plausible exposure scenario, the levels of RF exposure from a WLAN (either from the client card in a laptop or the access point located in a house) are far below international guidelines.

9.4.6 Radars, satellite communication and microwave links

Radiofrequency radiation emitting systems with highly directional (high-gain) aperture antennas used for satellite communication, radar, and microwave radio, ordinarily are installed and used in ways that preclude possibilities of members of the public being exposed to the main beams. Exposure of the public, however, can occur due to the antenna side-lobe radiation patterns rather than main-beam radiation. Individuals near airports and military bases may be exposed to side-lobe radiation from systems having stationary or slowly moving antennas. Some studies show that continuous or time-averaged exposure levels are in the range 0.1-1 W/m^2 may occur at distances up to about 1 km from these antennas. Microwave point-to-point links use frequencies in the GHz range and are used to connect two distant points. The beams used are usually very narrow and are tightly directed to the receiving antennae. Therefore, exposure of the public to this is rare. However, public exposure is possible under certain conditions such as when links are placed near the ground or if buildings are located between two links.

9.5 RF sources which may lead to intermittent exposure

Several types of equipment emit RF EMF and may lead to intermittent RF exposure. Microwave ovens use RF EMF in the microwave range (> 300 MHz) to heat food or other materials. Any RF fields external to microwave ovens likely to be intermittent only while using the device. Similarly, RFID (e.g. tag systems, object detection) and Electronic Article Surveillance (EAS) equipment (e.g. anti-theft gates), with frequencies between 5 kHz – 915 MHz, may lead to exposure only when near them. Some airport security scanners use EMF in the millimeter frequency range (i.e. > 30 GHz) to detect illegal or other contraband products. The travelling public are exposed to these millimeter waves when going through the scanner gates although exposure levels are usually relatively low. ESB Networks are deploying Smart Meters to all electricity customers. This programme is due for completion in 2024 uses RF EMF technology (2G) to gather information on electricity usage across the country.

9.6 Supplementary tables and figures

Table A1. Settlements selected for RF EMF measurement surveys.

Settlement/Census Town	Population	County/Area
Dublin city and suburbs	1,173,179	Dublin city
		Fingal
		DL-Rathdown
		Kildare
		Meath
		South Dublin
		Wicklow
Cork city and suburbs	208,669	Cork city
		Cork county
Limerick city and suburbs	94,192	Limerick City and County
Galway city and suburbs	79,934	Galway City
		Galway County
Waterford city and suburbs	53,504	Waterford City and County
Drogheda	40,956	Drogheda
Swords	39,248	Fingal
Dundalk	39,004	Louth
Bray	32,600	Wicklow
Navan	30,173	Meath
Kilkenny	26,512	Kilkenny
Ennis	25,276	Clare
Carlow	24,272	Carlow
Tralee	23,691	Kerry
Newbridge	22,742	Kildare
Portlaoise	22,050	Laois
Balbriggan	21,722	Fingal
Naas	21,393	Kildare
Athlone	21,349	Westmeath
Mullingar	20,928	Westmeath
Celbridge	20,288	Kildare
Wexford	20,188	Wexford

Letterkenny	19,274	Donegal
Sligo	19,199	Sligo
Greystones-Delgany	18,140	Wicklow
Clonmel	17,140	Tipperary
Malahide	16,550	Fingal
Carrigaline	15,770	Cork County
Leixlip	15,504	Kildare
Tullamore	14,607	Offaly
Maynooth	14,585	Kildare
Killarney	14,504	Kerry
Arklow	13,163	Wicklow
Cobh	12,800	Cork County
Ashbourne	12,679	Meath
Midleton	12,496	Cork County
Mallow	12,459	Cork County
Castlebar	12,068	Mayo
Laytown-Bettystown-Mornington-Donacarney	11,872	Meath
Enniscorthy	11,381	Wexford
Cavan	10,914	Cavan
Wicklow	10,584	Wicklow
Tramore	10,381	Waterford City and County
Ballina	10,171	Mayo
Skerries	10,043	Fingal
Longford	10,008	Longford
Monaghan	7,678	Monaghan
Roscommon	5,876	Roscommon
Carrick-On-Shannon	4,062	Leitrim

Note: Data for settlements from CSO, 2016.

Figure A1. Settlements according to CSO, 2016 (Source: http://census.cso.ie/sapmap/).

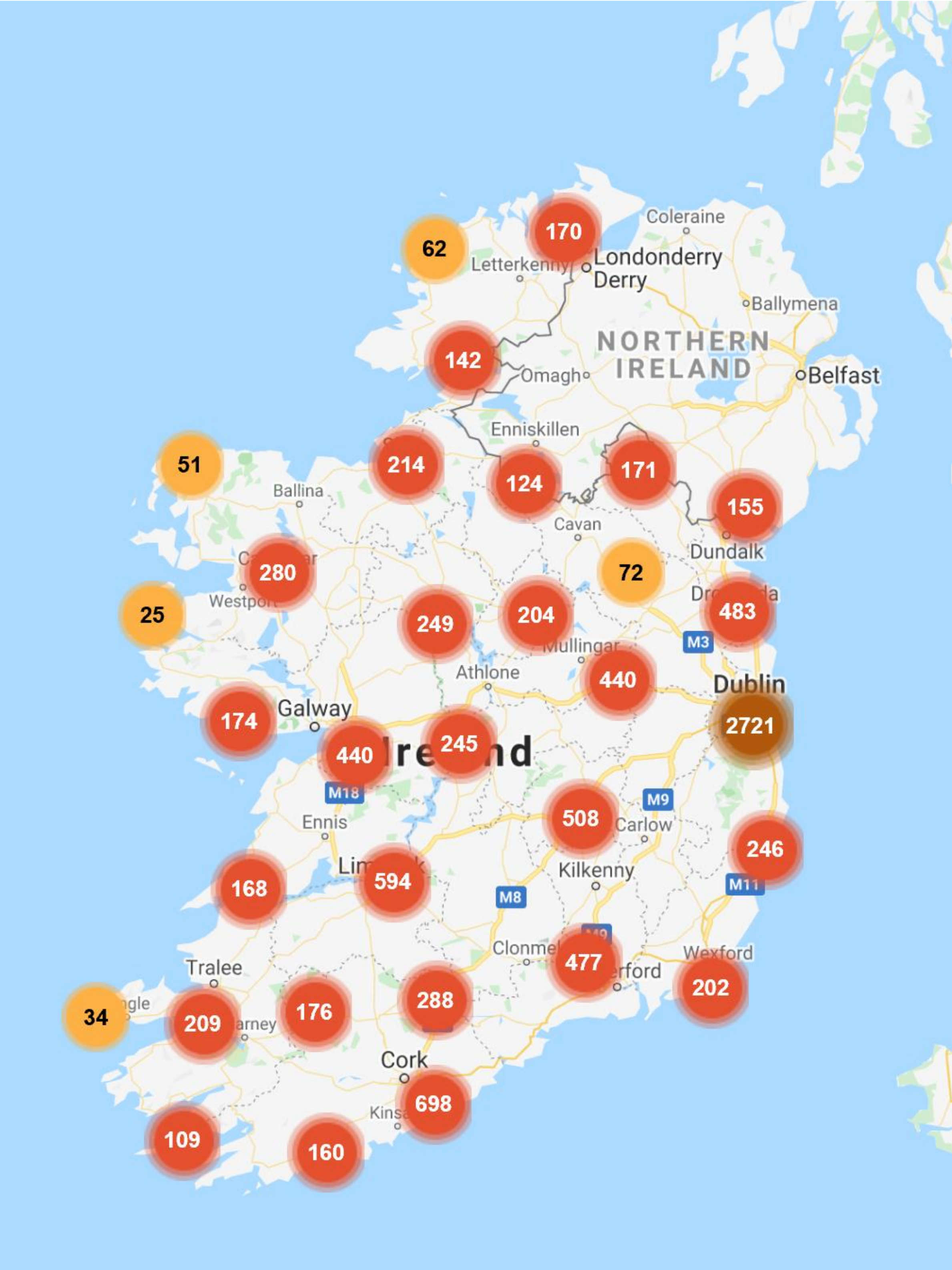

Figure A2. Mobile phone base stations licensed by ComReg (Data from https://siteviewer.comreg.ie/, March 2020).

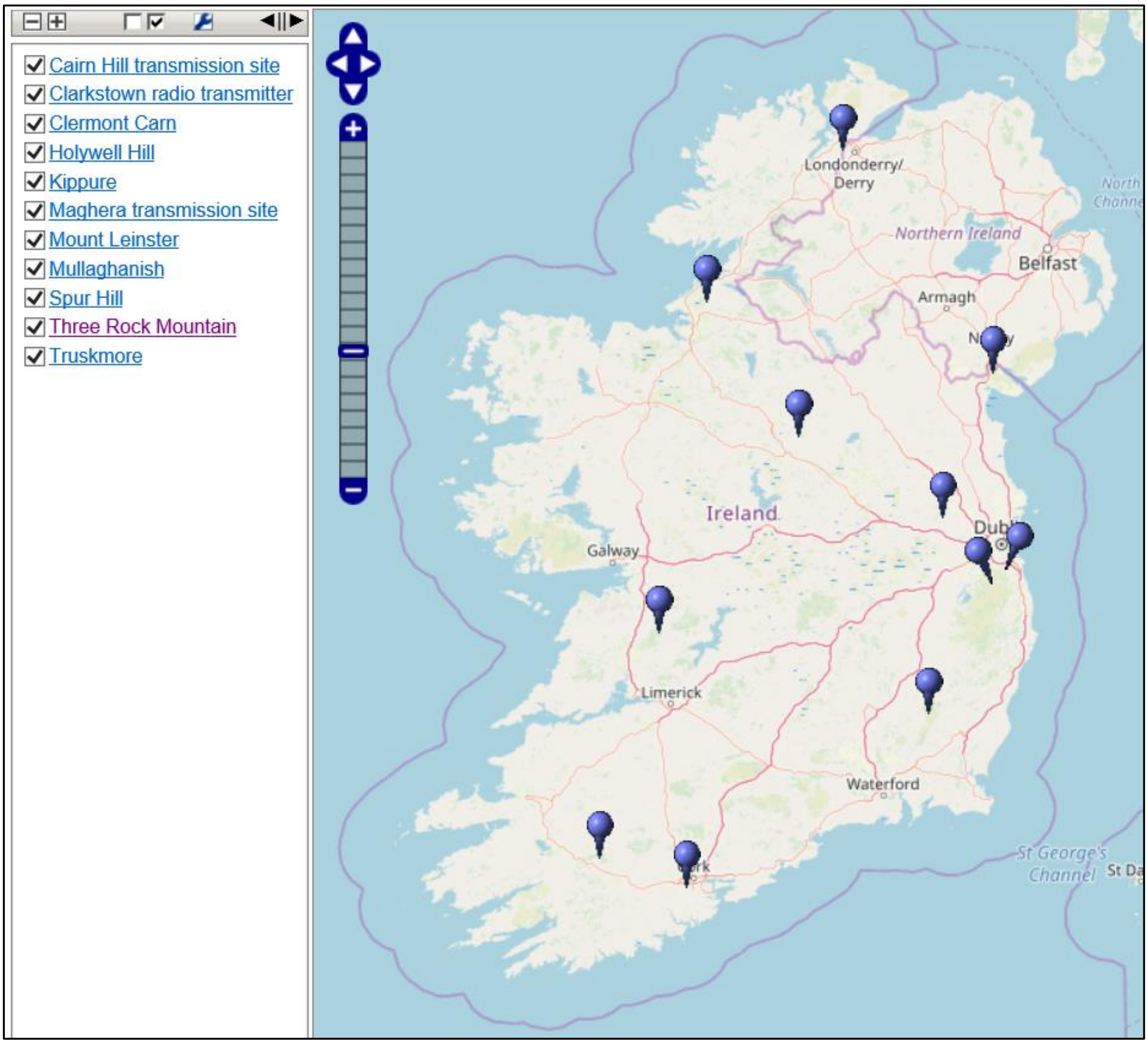

Figure A3. Radio and TV transmitter sites.

Figure A4. Air traffic (civilian) radar sites.