CLUE – H

The European research cluster on
Electromagnetic Fields and Health

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Policy Brief

THE USE OF DIFFERENT EXPOSURE METRICS IN THE RESEARCH ABOUT THE HEALTH IMPACTS OF ELECTROMAGNETIC FIELDS

The European research Cluster on EMF and Health

CLUE-H is the European research Cluster on EMF and Health (www.emf-health-cluster.eu). It comprises four projects:

- ETAIN – Electromagnetic fields and planetary health,
- GOLiAT - 5G exposure, casual effects and risk perception through citizen engagement,
- NextGEM - Next Generation Integrated Sensing and Analytical System for Monitoring and Assessing Radiofrequency Electromagnetic Field Exposure and Health,
- SEAWave - Scientific-Based Exposure and Risk Assessment of Radiofrequency and mm-Wave Systems from children to elderly (5G and beyond).

The CLUE-H network involves more than 70 European research organisations, with additional contributions from research groups in the USA, Korea and Japan. This extensive network of scientists aims to answer questions like: How much are we exposed to radiofrequency electromagnetic fields? How is our electromagnetic environment changing with the introduction of new wireless technologies, in particular 5G? Is there any impact on human health and the environment?

To answer the above questions, several studies on hazard identification and risk assessment will be performed within the framework of each project of the CLUE-H. In all cases, investigated biological or health endpoints need to be associated with well-characterized exposure. Within the four different projects, exposure characterization uses various physical quantities and metrics, which may lead to confusion.

The aim of the current policy brief is to explain why different exposure metrics are being used, what these quantities mean and why the different metrics help to achieve the respective policy and research objectives.

ETAIN NextGEM GOLiAT SEAWave

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Relevant metrics of radiofrequency electromagnetic fields

Wireless devices are ubiquitous today. This leads to a variety of different situations in which people are exposed to radiofrequency electromagnetic fields (RF-EMF). Either the whole body or only parts of it can be exposed to RF-EMF. Sources that are located far from the body (such as cellular network base stations), typically result in whole-body exposure. In contrast, RF-EMF sources located close to the body (such as a mobile phone operated close to the head) expose the body locally (Figure 1), and usually for a shorter period of time.

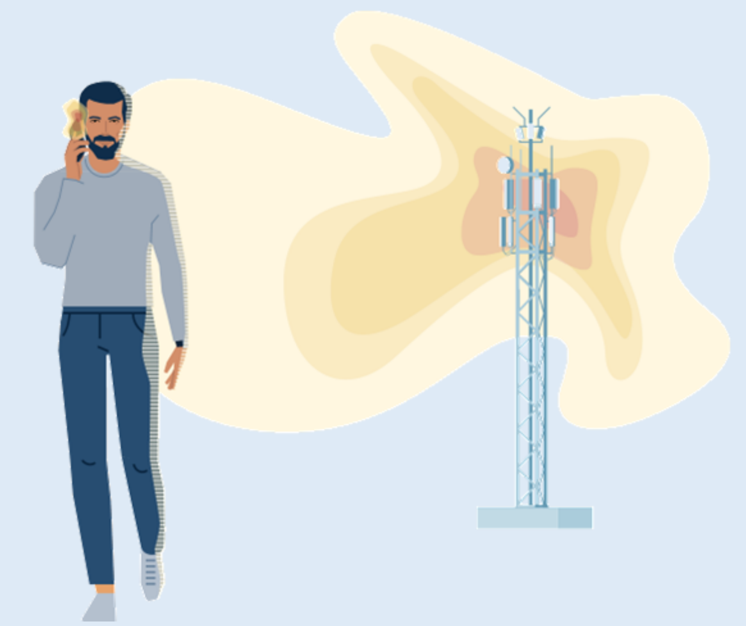


Figure 1. Near field sources (mobile phone) and far field sources (cellular network base stations) expose different parts of the body for different durations.

The magnitude of the RF-EMF acting externally on the body can be characterized by its electric field strength expressed in **Volt per metre (V/m)** and magnetic field strength expressed in **Ampere per metre (A/m)** or, in free space, **magnetic flux density expressed in Tesla (T).** At a certain distance from the source, which depends on the frequency of the RF-EMF and the dimensions of the source, the external RF-EMF acting on the body can also be characterized by its incident power density, which indicates the intensity, expressed in **Watt per metre squared (W/m^2).** These are so-called body-external exposure metrics because they are measured outside the body (Figure 2).

For possible biological effects, however, body-internal exposure metrics are relevant. Due to the dielectric properties of body tissues and the interaction of RF-EMF with the body, the magnitude of body-internal electric and magnetic field strengths differs from the one of the body-external fields. Upon exposure, body tissue absorbs electromagnetic energy, and the higher the frequency of the RF-EMF, the more efficient the absorption process is. For this reason, RF-EMF penetrates less deeply into the body as the frequency increases.

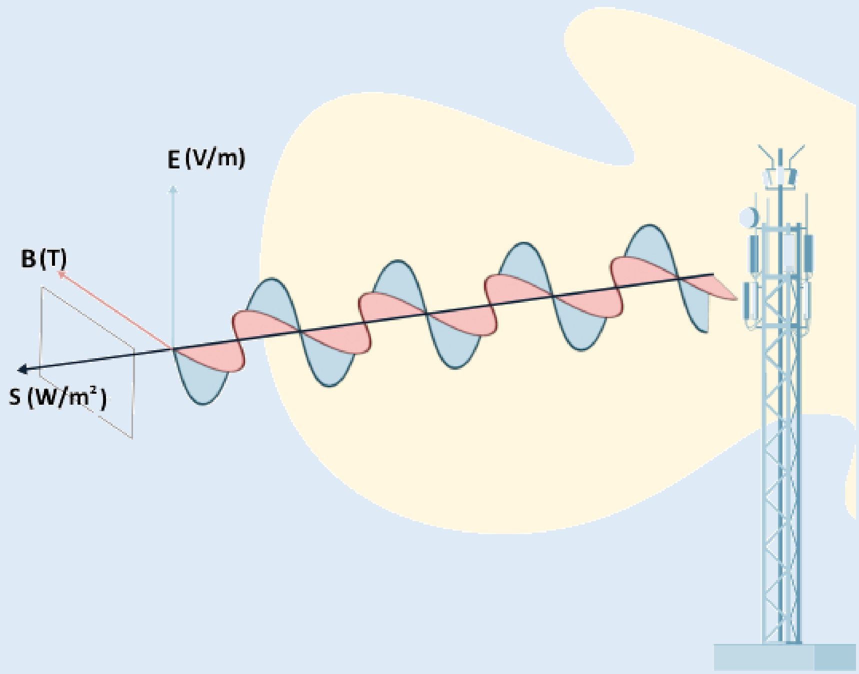


Figure 2. Characterization of exposure external to the body and far from the source

Figure 3. Characterization of internal exposure and proximity of the exposure source

According to current knowledge, the absorbed RF-EMF power normalized to the mass of the respective body tissue is relevant for possible biological reactions. This important body-internal exposure metric (Figure 3) is termed specific energy absorption rate (**SAR**) and is expressed in **Watt per kilogram (W/kg)**. Depending on the position of the source with respect to the body, it is useful to average the SAR over very localized parts of the body (at the local exposure maximum) or over the whole body.

For very high RF-EMF frequencies with extremely shallow penetration depths, the absorbed power density (**APD**) expressed in **Watt per metre squared (W/m²)** is used as a relevant body-internal exposure metric because the volumetric nature of absorption becomes more and more two-dimensional (Figure 4).

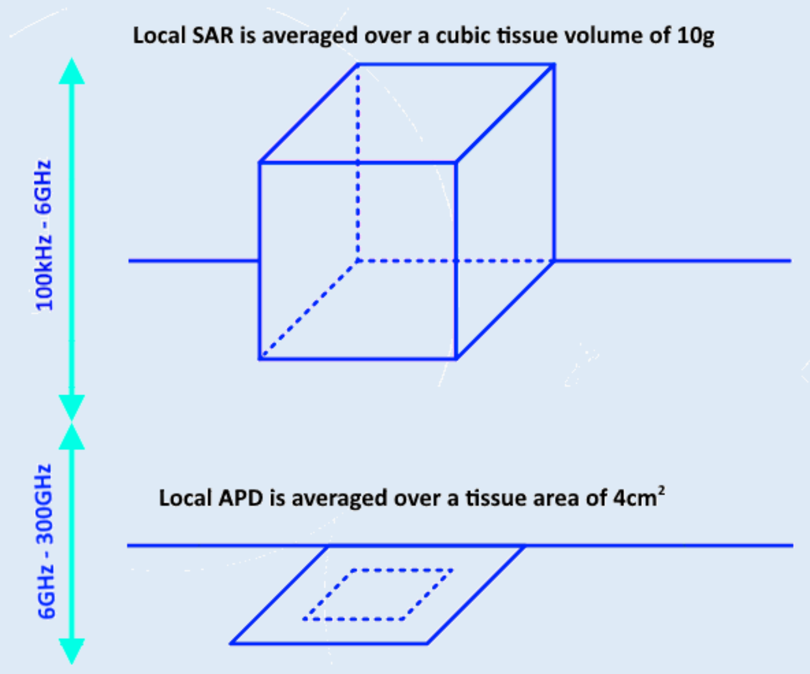


Figure 4. Above the frequency of 6 GHz, local exposure metrics are not volume- but surface-averaged due to the superficial absorption of RF energy

In order to prevent exposure related adverse health risks, exposure restrictions that concern both, body-internal and body-external exposure metrics, are recommended or specified in guidelines, safety standards and to some extent also in national regulations.

Exposure assessment in health and biological research

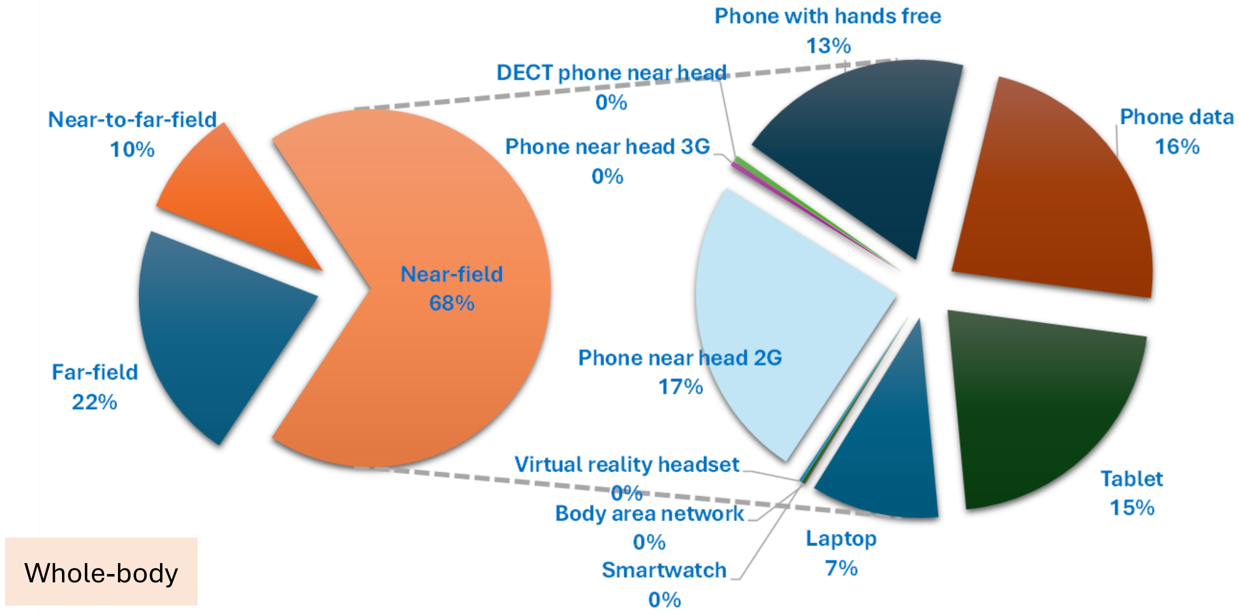
When RF-EMF-related health risk assessment studies are conducted, it is mandatory to generate and assess the exposure as accurately as possible. The choice of a suitable exposure metric for the study depends on the type of study. While for experimental studies on humans, animals, or cells it is recommended to assess internal body metrics to obtain a direct link to possible biological effects, this is often not possible for observational studies in humans. This is because in such studies the multitude of parameters that influence the internal metric are not easy to control or assess. Here, often metrics are selected for their ease of use and because they are seen as a reasonable proxy for longer-term exposure, such as total cumulative duration of wireless phone calls of a person. Despite the complexity, in the last years researchers have translated such information into estimates of body-internal exposure metrics for human observational studies. This was done by combining detailed exposure data with numerical simulations.

The body-internal exposure metric generated in this way is also a cumulative measure and describes the total energy absorbed in the body over a given period of time. The metric combines all types of RF-EMF sources and is normalized to the relevant mass of the body tissue. The corresponding metric is expressed for example as Joule per kilogram organ/body weight per day (**mJ/kg/day**). It is therefore a dose metric for which there is no known biological effect. However, the observational studies are designed to identify if there are possible relevant effects of RF-EMF exposure on health which cannot be investigated in experimental settings. The underlying reason is that there may be as yet undetected effects on health from longer-term, usually low-level, exposures. The cumulative metric aims to capture this type of exposure.

In a recent publication, van Wel *et al* [1] calculated the contribution of various sources to the cumulative dose of the whole-body and of the brain for the general population. Their results indicate that near-field sources contribute the most to the energy absorbed by biological tissues, although this contribution is different for the whole body and the brain (Figure 5). This specific study did not consider 4G and 5G devices, due to the time it was conducted. However, such calculations to assess cumulative dose of latest cellular network technologies are planned within the projects of the CLUE-H.

Differentiation of dosimetry based on type of research study

In an ideal situation, when dealing with risk assessment of an environmental exposure, the biological mechanism for a specific disease is known. For instance, for ionizing radiation, high photon energy can produce DNA damage at any exposure level and progression to cancer is thus a matter of likelihood, i.e., the more exposure, the more likely a disease will occur. The corresponding exposure-response model is the linear-no-threshold model (LNT). In principle, the temporal pattern of exposure does not matter, and thus cumulative (organ-specific) dose is the relevant metric for research and regulation.



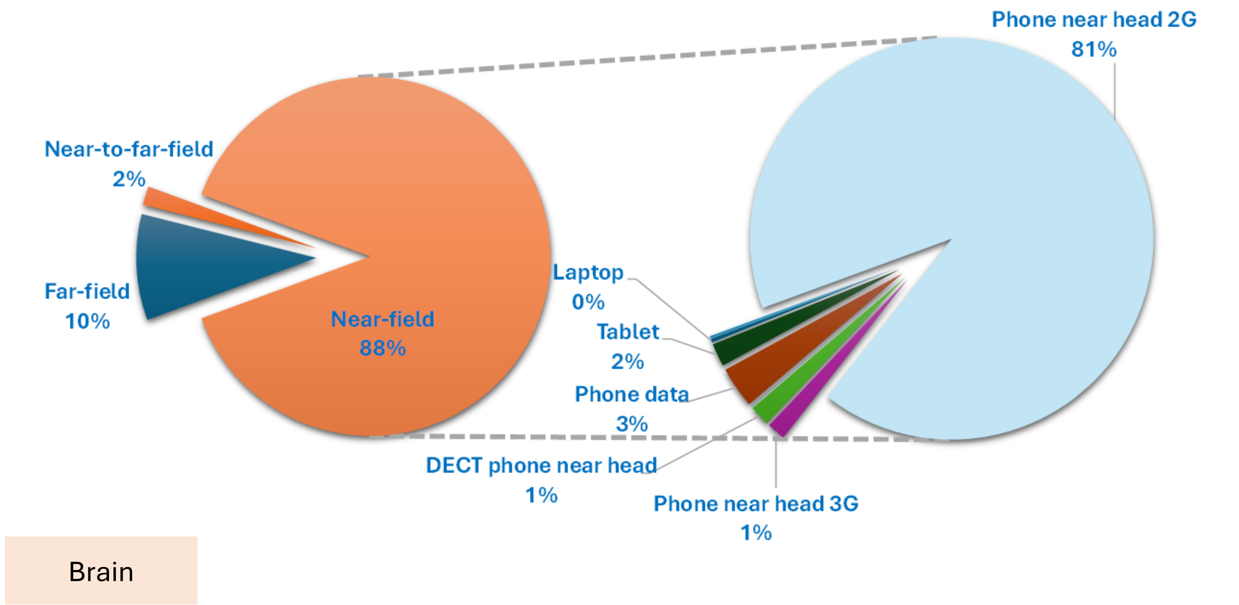


Figure 5. Near-field sources contribute most to the RF-EMF energy absorbed by the human body. However, the contribution of individual near-field sources depends on their positioning with respect to the investigated organ or part of the body. The mean overall cumulative dose for whole-body was calculated at 0.29 J/kg/day and for brain it was 0.81 J/kg/day [1].

For RF-EMF, well-established effects include tissue heating, microwave hearing for highly pulsed radiation (e.g., from a radar), and tissue stimulation (e.g., from contact currents). Accordingly, different metrics are specified in the regulations to prevent these effects from happening. For instance, thermal effects are only a problem for health if a certain threshold is exceeded. Below this threshold, temperature rise is not expected to cause health effects.

In RF-EMF research, thermal effects are of limited interest because they are well understood. However, research has provided indications for biological effects below the thermal threshold such as effects on brain physiology or oxidative balance. Such biological effects, which per se are not health effects, could be the consequences of unknown biological mechanisms or could occur due to subtle warming of the tissue below the thermal damage threshold. Historically, epidemiology has been investigating health effects without prior knowledge of the underlying disease mechanism by comparing people who are exposed to a variable extent to the agent of interest. In this case a common approach for complex exposure situations is the time weighted average (TWA), i.e., exposure levels in different situations (e.g., at home, at work, during commuting) are averaged taking into account the time spent in these situations. This approach has also been applied in RF-EMF research dealing with far field exposures. However, it is not suitable for combining near and far field exposures since different metrics are used for these two types of exposure. Thus, a cumulative dose metric was introduced in RF-EMF research a few years ago. In an approach to the TWA concept, SAR for various exposure situations (e.g., mobile phone call, WiFi access point exposure, etc.) is multiplied with the corresponding exposure duration to obtain a cumulative RF-EMF dose, often expressed per day (J/kg/day).

Calculation of cumulative dose in RF-EMF epidemiology allows combining different exposure situations into one metric. It considers magnitude and duration of each exposure situation and is based on the same philosophy as a time weighted average. In principle, cumulative dose refers to a linear-no-threshold model but is actually correlated to most other plausible effect models such as time spent above a certain threshold. It is a conservative approach, since it considers the possibility that long-term exposure to low levels might affect health, which is a common concern of parts of the population in relation to environmental RF-EMF exposure. It may also be helpful for risk communication as it enables to compare the contribution of various RF-EMF exposure situations to a combined metric of the absorbed RF-EMF.

The use of a cumulative dose metric in research should not be mistaken as an indication or proof that cumulative exposure to very low levels can be harmful to health. It just serves as the currently best metric to analyse if there could be effects on health, outside of a known biological mechanism.

Conclusion

In conclusion, the existence of various exposure measures in the field of RF-EMF research on health reflects the involvement of different biophysical concepts and exposure situations. Further, different metrics are used for different purpose:

- **For biological research, physical quantities that best represent an underlying biophysical mechanism are usually the preference (e.g., SAR value, internal electrical field).**
- **For observational research aiming to explore a yet unknown effect on health, preference may be given to metrics that combine similar sources (e.g., time-weighted average, cumulatively absorbed dose) and are seen as superior in capturing exposures experienced over a long time period.).**
- **For regulation purposes, the suitable metric depends on the exposure situation (e.g., external electric field strength or power density for far field sources or spatially averaged SAR for localized near field exposures).**
- **For risk communication with the public, metrics which are intuitively understood, are considered most useful (e.g., fraction of regulatory limit).**

There is a Council Recommendation [2] that is currently being amended due to the fact that new measurement methods have emerged. The work of CLUE-H contributes to improving our knowledge base on measurement methods and limit values, which will be useful for future updates of the Recommendation.

References

[1] van Wel L, Liorni I, Huss A, et al. Radio-frequency electromagnetic field exposure and contribution of sources in the general population: an organ-specific integrative exposure assessment. J Expo Sci Environ Epidemiol. 2021;31(6):999-1007.

[2] 1999/519/EC: Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (OJ L 199 30.07.1999, p. 59