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1 Objective

The current deliverable is the result of the work performed in the first work-package (WP1) of the project. The objective of WP1 was to conduct a comprehensive review of the literature on exposure assessment, as well as experimental dosimetric evaluations of present and emerging wireless network devices. Eventually, the deliverable should identify knowledge gaps in the available data about human exposure and in the methods/techniques used to assess it.

2 Exposure situations

2.1 General definitions

Wireless networks are structured as combinations of fixed and mobile (portable) components (devices), which exchange information with the emission of electromagnetic (EM) radiation. Broadcasting systems can also be considered as wireless networks with fixed transmitters and mobile or stationary receivers. In order to assess human exposure to non-ionizing EM radiation at a specific location and for a specified period of time, it is necessary to use experimental and/or computational methods. Depending on the proximity of network devices to the exposed subject in conjunction with the subject's control over the use of these devices, it is possible to distinguish between two major exposure situations:

1. **Background Radiation**. This situation defines the exposure to EM radiation emanating from various sources that exist in the surroundings of the subject, the operation of which the subject does not need or cannot actively control in order for the wireless network to operate. Such sources include, for example, cellular base stations, broadcasting stations, wireless routers, DECT base units, RFID scanners or even portable network devices used by people around the exposed subject. As for the environment where this background radiation should be assessed, this could include the outdoors, the home, work, office, hospitals, schools, industrial premises and so on. Another approach to background radiation would be to consider it as uncontrolled/ubiquitous exposure.
2. **User Exposure**. This situation identifies the exposure of subjects due to their use of portable wireless network devices, such as mobile phones, DECT handsets, WiFi services on portable computers and PDAs, walkie-talkies, wireless physiological/medical sensors/data-loggers and active RFID tags, to mention but a few of the existing and emerging wireless applications. The (informed) subject is aware of this kind of exposure which occurs voluntarily/intentionally.

The regulations (guidelines/standards), which aim at protecting workers, citizens and consumers from established adverse health effects of non-ionizing EM radiation, should take the combination of both the above situations into account when restricting exposure (see §2.2 below).

The following paragraphs explain how the methods to demonstrate compliance with the regulations or simply estimate exposure for informative/epidemiological reasons differ for the above two situations: A short introduction is given to each method found in the literature, including how it was implemented, its results and its limitations.

2.2 Guidelines for limiting exposure

The World Health Organization (WHO) established the International EMF Project in 1996 to assess the scientific evidence of possible health effects of EMF in the frequency range from 0 to 300 GHz. Its standards data base was established in 2001 [1] and shows that harmonization of regulation related to human exposure to electromagnetic fields has not yet been achieved. However, the most cited documents for limiting exposure are the ICNIRP guidelines [2] and the IEEE standard [3]. Since typical exposure is only rarely due to a single source, these documents have adopted an approach for assessing compliance in the case of multiple sources. In the frequency range pertinent to the current document, this approach includes the summation of the time-averaged squared electric (magnetic) fields from each source over the squared value of the reference level (maximum permissible exposure limit, MPE) at the frequency the source is operating, i.e.:

$$\sum_{f_i} \frac{E_{f_i}^2}{L_{f_i}^2} < 1 \tag{1}$$

and

$$\sum_{f_i} \frac{H_{f_i}^2}{L_{f_i}^2} < 1 \tag{2}$$

There are many studies where the researchers report their results (measurements or calculations) in terms of a fraction of the ICNIRP level, which is usually the percentage value derived from (1). Unfortunately, it is not possible to deduce an effective electric field strength from this value that would be measured with a broadband or narrowband probe.

3 Background Radiation

3.1 Calculations

3.1.1 Introduction

The advantages of calculations over measurements for the estimation of the electromagnetic radiation in the environment include:

- less time and person effort,
- lower cost,
- better information on average exposure compared to measurements,
- identification of 'hot spots', and
- information on exposure classification for epidemiological studies.

The limitations of computer modeling include:

- Accurate and complete transmitter data is not always available to be used as an input to the model.
- The geometrical description of buildings is crucial as it can affect the results by several orders of magnitude even for outdoor points (e.g. line-of-sight and non-line-of-sight at the calculated point).
- Propagation models concern outdoor spaces and the exposure inside buildings from outdoor sources is very difficult.

3.1.2 Numerical techniques

Several numerical techniques have been used to calculate the electromagnetic field generated in the environment by fixed wireless network devices (base stations, access points). The purpose of most studies was the distribution of received power indoors and outdoors, since they were interested in the propagation of the signal and the quality of telecommunication services rather than in population exposure. Among the numerical methods that have prevailed for electric field calculations from fixed emitters are ray-tracing (geometrical optics) [4],[5], radiosity (physical optics) [6],[7], Finite-Difference Time-Domain (FDTD) (full wave analysis) [8],[9] and hybrid versions of the above [10]-[13]. The results of the above studies show that the best approach for the calculation of human exposure to background radiation numerically is to use a hybrid technique. In particular, the Method of Moments (MoM) combined with FDTD or the multiple region FDTD should be used when there is strong coupling between the radiation source and the human body (scatterer). On the other hand, geometrical optics techniques together with FDTD must be employed in the case of complex multi-scattering environments. It was shown in [8] that compliance with exposure guidelines for a typical antenna used in the urban environment was guaranteed even at a distance of 8 m in front of the antenna mast; differences in whole body averaged SAR of two order of magnitudes were observed in the investigated exposure situations.

3.1.3 Propagation models

The assessment of electromagnetic radiation generated by wireless networks in the environment can also be performed with the use of propagation models, several of which are already established in the area of telecommunications research. The simplest propagation model is that of free space [14] and its variants [15],[16]. However, these models lead to an overestimation of exposure [14],[17]. Therefore, more sophisticated models must be used, which also distinguish between line-of-sight (LOS) and non-line-of-sight (NLOS) conditions.

Buergi et al. [17] compared the exposure values they calculated with the use of two well-known models, i.e. COST Walfisch-Ikegami [18] for mobile phone base stations and ITU-R P.1546 [19] for broadcasting transmitters, with measurement data in a rural and in an urban area in Switzerland. The modeled total field strengths (i.e. integrated over all relevant frequency bands) were within a factor of 2 for 60% or 77% of the measurement values in the urban or the rural area, respectively. The calculated field values were within a factor of 4 for 95% or 100% of the measurements in the two areas, respectively. On the whole, correlation (Pearson's test) between measurements and modeling of the total electric field strength was 0.67 (95% confidence interval (CI): 0.33–0.86) in the urban area and 0.77 (95% CI: 0.46–0.91) in the rural area.

The correlation between calculations and measurements was in the same order of magnitude in the study of Schubert et al. [20], who investigated the exposure of the general public to digital broadcasting (DAB, DVB-T) compared to analogue (FM, TV). They found that, depending on the broadcast service, the calculations and measurements for 78–83% of all compared locations was within a factor of 2.

3.2 Measurements

3.2.1 Personal Exposure Meters (PEM)

3.2.1.1 Introduction

Currently, two commercially available PEM exist, the EME Spy 120/121 (Satimo, Brest, France [21]) and the ESM 140 (Maschek Elektronik, Bad Wörishofen, Germany [22]). The specifications of these two devices are shown in Table 1. Several studies have compared the two PEM. Their main difference is that EME Spy 121 (Satimo) is more isotropic in reception when worn at the subject's waist (belt) compared to ESM 140 (Maschek) when worn on the subject's arm. Moreover, the latter PEM does not include broadcasting and TETRA networks. However, due to its size, it is easier to handle in large-scale epidemiological studies.

Table 1. Specifications of Personal Exposure Meters

	Satimo EME Spy 121	Maschek ESM 140
Frequency bands		
FM	88–108 MHz	Not included
TV3	174–223 MHz	Not included
TETRA	380–400 MHz	Not included
TV 4&5	470–830 MHz	Not included
GSM900 Uplink	880–915 MHz	900 MHz[a]
GSM900 Downlink	925–960 MHz	935 MHz[a]
GSM1800 Uplink	1710–1785 MHz	1750 MHz[a]
GSM1800 Downlink	1805–1880 MHz	1850 MHz[a]
DECT	1880–1900 MHz	1895 MHz[a]
UMTS Uplink	1920–1980 MHz	1950 MHz[a]
UMTS Downlink	2110–2170 MHz	2140 MHz[a]
WLAN	2400–2500 MHz	2440 MHz[a]
Antennas	Isotropic three axis	Folded
Spectral analysis	Passive filters	Narrow band antennas
Measurement range	0.05–10 V/m	0.01–70 V/m
Logging interval	4-255 s	0.5–10 s
No of samples stored	12,540	260,000
Size	193 x 95.6 x 69.4 mm^3	100 x 45 x 20 mm^3
Weight	450 g	70 g

[a]Center frequency mentioned in the technical specifications

3.2.1.2 Results

Several studies assessing exposure to EM radiation with PEM, in particular for the purpose of conducting epidemiological studies, have appeared in the last three years.

The exposure assessment in the work of Thomas et al. [23] was performed with the ESM 140 (Maschek). In their report the authors focused mainly on the health endpoints of their study, therefore little information can be deduced about dosimetry. The study subjects (in total 329 adults aged between 18 and 65 years) originated from Munich (population of ~ 1,300,000) and another three smaller German towns (population ranging from 11,000 to 43,000). The results for exposure estimation were given in terms of percentage (%) of the ICNIRP reference levels, and it could be concluded that:

- Exposure levels were on average less than 1% of the ICNIRP reference level.
- Exposure varied by the size of the city (higher median exposure levels for the city of Munich and lower for the smaller towns).
- There was no difference in exposure between morning (6 am - 12 pm) and afternoon (12 pm - 6 pm).
- Exposure to WLAN frequencies was lower (mean 0.04%; maximum 0.10%) than exposure to GSM900 (mean 0.15%; maximum 0.47%) and GSM1800 (mean 0.11%; maximum 0.49%).

A second report of exposure assessment concerning children and adolescents was published from the same group in the framework of the German MobilEe-study [24]. The study was carried out in Munich and three more towns in the region of Bavaria (Augsburg, Rosenheim and Landsberg with a population ranging from

~260,000 to 28,000) and involved 1,484 children (aged between 8 and 12 years) and 1,508 adolescents (aged between 13 and 17 years).

- It was found that median exposure of adolescents (0.19% of ICNIRP reference level) was slightly higher than that for children (0.18%).
- It was confirmed that (as for the adults [23]) median exposure was highest in Munich (the largest urban area) and lowest in Landsberg (the smallest town of the study).
- However, this study showed an increase in exposure for both groups during afternoon hours (children median exposure morning: 0.17%, afternoon: 0.19%; adolescents median exposure morning: 0.18%, afternoon: 0.20%).
- Finally, median exposure in Munich for adults (Fig. 1 in [23]) was larger than that for children (Fig. 2 in [24]).

In a preliminary exposure analysis of 109 subjects (21-78 years of age; residents of Basel) from the QUALIFEX study[1], Röösli et al. [25] gave a report about the data collected by the subjects within the time period of a week. In fact, the aim of the analysis was how to deal with non-detects, i.e. measurement points below the sensitivity level (0.05 V/m) of the EME Spy 120[2]. The subjects wore the PEM at the belt or carried it in a backpack when on the move; they placed it close to their body when remaining at a location for a longer time, but not at exactly the same position for the whole week. As expected, the results (Table 2) showed an overestimation of the mean when missing data were replaced by the detection threshold (sensitivity limit). From the mean and median values it is clear that there is no frequency band dominating in the background radiation.

Table 2. Exposure data from 109 subjects in Basel (Röösli et al. [25])

Frequency band	Mean (V/m)	Median (V/m)	Maximum (V/m)
FM	0.07	0.05	0.41
TV3	0.06	0.05	0.16
Tetrapol	0.05	0.05	0.12
TV4/5	0.07	0.05	0.26
GSM900 uplink	0.11	0.09	0.25
GSM900 downlink	0.09	0.06	0.33
GSM1800 uplink	0.08	0.06	0.25
GSM1800 downlink	0.12	0.07	0.52
DECT	0.12	0.09	0.43
UMTS uplink	0.05	0.05	0.07
UMTS downlink	0.06	0.05	0.15
W-LAN	0.06	0.05	0.22
Total	0.23	0.19	0.57

[1] http://www.qualifex.ch

[2] This is a predecessor of EME Spy 121, but again with 12 different frequency bands.

The problem of sensitivity was also tackled by Thuróczy et al. [26] in their study, but with a different approach: they used 21 volunteers in Budapest who carried around a PEM which could discriminate between 9 frequency bands[3]. They calculated various quantities, like electric field strength statistics for various activity types or environments (home, bed, travel, work, other) and periods of time that the measured field fell into different exposure ranges (classes). In Table 3 the field statistics are shown for the registered frequency bands. It is clear that average exposure does not differ from that of the QUALIFEX subjects in Basel (Table 2), although maximum field values are quite larger in some cases. It is interesting to note that in the Hungarian study, exposure to the downlink frequency bands of cellular telephony networks is maximized during travelling (this activity corresponds on average to 11% of the daily time).

Table 3. Exposure data from 21 subjects in Budapest (Thuróczy et al. [26])

Frequency band	Mean (V/m)	Maximum (V/m)
FM	0.054	0.247
TV3	0.050	0.068
Tetrapol	-	-
TV4/5	0.055	0.529
GSM900 uplink	0.059	4.406
GSM900 downlink	0.060	1.147
GSM1800 uplink	0.055	2.513
GSM1800 downlink	0.055	0.555
DECT	-	-
UMTS uplink	0.050	0.060
UMTS downlink	0.050	0.076
W-LAN	-	-

Joseph et al. [27] used a completely different methodology to characterize personal exposure. Instead of recruiting several subjects of various ages and professions, they investigated 27 representative scenarios of activity and analyzed 95th percentiles of measured electric field strength. In this way they were able to draw conclusions for both different frequency bands and different living environments:

- Exposure to cellular telephony networks (GSM900, GSM1800 and UMTS downlink) was maximized during outdoor walking (maximum values of 0.52 V/m, 0.16 V/m and 0.11 V/m, respectively).
- In the office environment exposure is mainly due to WLAN services (up to 0.58 V/m) and DECT (0.33 V/m). However, these values should be identified as user exposure rather than background radiation because the subjects who participated in the measurement campaign wore the PEM.
- In rural areas exposure might in general be lower than in urban areas.
- The measured values for GSM900 downlink in an outdoor urban environment (daytime) correspond to a lognormal distribution with a median of 0.13 V/m. This type of distribution was also present in the data of all subjects from the QUALIFEX study [25].

In a newer analysis of exposure from the QUALIFEX study, Frei et al. [28] investigated the weekly exposure of 166 subjects (a total of 202 weeks logged, due to a repeatability study). They employed the robust ROS

[3] This was a DSP-090 from Antennessa (Plouzané, France) which is a predecessor to the EME Spy 120 of Satimo.

(regression on order statistics) method for points below the detection threshold of the EME Spy 120 by fitting a lognormal assumed distribution to the measured values to estimate the missing data. They excluded data during mobile and DECT phone calls by the subjects as they do not reflect the maximum exposure to the head of the person making the call [29]. Their results (Table 4) show that mean exposure is well below 1 V/m and that mobile base stations downlink frequencies contributed with a mean value of 0.13 V/m (this was the median for GSM900 downlink in the Belgian study [27]). As for the exposure at different times and locations, the authors concluded that:

- On workdays exposure was higher during the day (6 am - 10 pm) than at night.
- There was no difference in the mean exposure during workdays and weekends.
- Mean values of exposure at each location were calculated from all available measurements for the respective location. The highest mean values were recorded for train journeys, stays at the airport and rides on the tramway or bus.
- Contribution to the exposure from DECT phones becomes relevant indoors (home, workplace, friends' places).

Table 4. Exposure data from 166 subjects in Basel (Frei et al. [28])

	Mean	Median	95% quartile	Maximum
	(V/m)	(V/m)	(V/m)	(V/m)
Average	0.22	0.19	0.36	0.58
At home	0.19	0.13	0.35	0.68
Workplace	0.24	0.15	0.45	0.96
Daytime	0.25	0.22	0.41	0.63
Nighttime	0.17	0.10	0.30	0.72
Workday	0.22	0.19	0.36	0.54
Weekend	0.22	0.16	0.42	0.68

An exposure assessment study with PEM involving 377 participants (111 youths and 266 adults) was performed in the French cities of Lyon and Besançon by Viel et al. [30]. They used ten EME Spy 120 devices which registered the daily exposure of the subjects. Their total mean value is very close to that of Frei et al. [28] for the city of Basel. They also demonstrated (Table 5) that total exposure was higher:

- in urban areas (in agreement with [23] and [27]),
- during the day (in agreement with [28] but not with [23]),
- among adults (in agreement with [23] and [24] for the city of Munich), and
- when moving (travelling) (in agreement [26] and [28]).

An interesting observation of this study was that WLAN signals (total mean 0.038 V/m) were evenly distributed in the various environments, although one would have expected them to be present mainly indoors. The authors attribute this finding to the increasing number of access points in public areas and the use of such services either by the study subjects themselves or by bystanders.

Table 5. Exposure data from 377 subjects in the French study (Viel et al. [30])

	Electric field intensity (V/m)
Total	**0.201**
Area	
Besançon	0.201
Lyon	0.202
Place of residence	
Urban	0.231
Periurban	0.201
Rural	0.156
Environment	
Home	0.200
Workplace	0.205
Transportation	0.215
Time	
Day	0.204
Night	0.197
Age category	
Youths	0.188
Adults	0.206

In a second French study about residential exposure, Viel et al. [31] focused on base stations and broadcast transmitters. The study was performed in the department of Doubs. A total of 184 day recordings with EME Spy 120 was analyzed. The authors found that the participants spent, on average, 14 h and 58 min (standard deviation: 3h and 36 min) at home, which is in good agreement with the amount recorded in the Hungarian study [26] (14 h). However, the maximum exposure was lower in this study and the authors attributed this difference to the inclusion of many subjects from rural areas in the study. Indeed, they showed (Table 6) that the maximum exposure depends on the geographical area and is lowest for rural areas. According to the authors, there were two distinct peaks in the residential exposure distribution with distance from the nearest GSM900 base station: one around 280 m (mainly in urban areas) and another one around 1000 m (mainly in periurban areas).

Table 6. Exposure data from 184 day recordings in French residences (Viel et al. [31])

Frequency band	Maximum electric field strength (V/m)						
	Mean	**Median**	**Minimum**	**Maximum**	**Urban**	**Periurban**	**Rural**
FM	0.17	0.05	0.05	1.43	0.31	0.15	0.06
TV 3	0.05	0.05	0.05	0.5	0.06	0.06	0.05
TV 4&5	0.07	0.06	0.05	0.26	0.08	0.08	0.06
GSM900 downlink	0.12	0.05	0.05	0.78	0.15	0.13	0.07
GSM1800 downlink	0.10	0.05	0.05	0.70	0.14	0.10	0.05
UMTS downlink	0.07	0.07	0.05	0.15	0.07	0.07	0.07

3.2.1.3 Limitations

There are several issues to be considered with the use of PEM for exposure assessment. In a feasibility study comparing the two commercially available PEM, Radon et al. [32] noted quite early that there was very poor correlation between the readings of the two devices. This is not surprising because there are several factors that could contribute to such a result:

- A PEM is prone to manipulation, e.g. a participant can deliberately put it at a highly exposed location (near a transmitter).
- There is always some out of band reception of the signals (poor selectivity) [24],[33],[34]. This response can be mistaken for real (as in [27] with DECT signals in outdoors environments), can be cleared from the data (as in [28] for the same signals) or just stressed in the data interpretation (as in [30] for UMTS signals). Moreover, traffic channels of base stations are not well detected [33].
- Isotropy is poor for both PEM when worn on the body [34],[35].
- The PEM interacts with the body and, therefore, measurements are affected. One major effect is shielding, which has been shown by several research groups to result in field underestimation both numerically and experimentally [35],[36]. In particular, the EME Spy 120 and its intended use (at the waist) was shown to underestimate depending on the body mass index (BMI) of the bearer [35]. This may have different implications in different environments (outdoors vs. indoors). However, it is possible to reduce this effect by mounting two PEM, one at the front and one at the rear of the torso [37].
- The sensitivity of a PEM is not low enough compared to the background radiation level. This leads to large quantities of non-detects (missing or censored data), which have to be treated properly. If these data points are replaced by the detection limit, an overestimation of the mean and an underestimation of the variance occur. Therefore, the approach of robust ROS introduced by Röösli et al. [25] seems to be the best solution. Nevertheless, the recording time above the detection limit [26] or detectable exposure [31] may also be suitable to characterize exposure.
- Finally, calibration of the PEM should be performed with the appropriate signals. The use of frequency-specific calibration factors resulted in a deviation of 18.9% upwards of the original mean, for which continuous wave signal was used in all frequency bands [28]. Moreover, regular calibration is also important [38] as there is a significant time shift in the response of the devices [28], which compromises the accuracy of measurements.

3.2.2 Spot (in-situ) measurements

3.2.2.1 Introduction

Several reports of spot measurements of background radiation can be found in the literature resulting from audits (mainly of base stations) and measurement surveys for compliance or exposure assessment efforts within epidemiological studies.

Spot measurements can be either broadband or frequency selective (narrowband). The former are easy to perform and are limited only by the frequency band in which the measuring equipment operates; by including an appropriate uncertainty analysis it is rather easy to assess the equivalent electric field strength of the whole band. However, such measurements cannot distinguish between the contribution to the background radiation at the spot of each electromagnetic application or frequency-band. In order to achieve this, the more expensive equipment necessary for frequency-selective measurements should be used. More about the equipment and procedures used for conducting spot measurements can be found in [39] and [40].

3.2.2.2 Results

The first results from a measurement campaign that investigated GSM exposure from base stations at a multinational level was performed in the framework of a Short Term Mission (STM) within COST 244bis [41]. The STM contained results from 371 measurements, 233 from Austria, 10 from France, 17 from Germany, 80 from Hungary and 31 from Sweden. Of these 371 measurements, only 346 were analyzed because 25 outdoor measurements were made in places where the public normally would not have access. Finally, only 152 measurements delivered information about the combined exposure of GSM900 and GSM1800. Among the results of the analysis, the following are of interest:

- The maximum electric field strength at single frequencies reached 2.24 V/m. The median value was 0.06 V/m.
- The maximum sum of all the levels in the GSM900 and GSM1800 band was 4.24 V/m and the median exposure 0.27 V/m. The variation in the total exposure was eight orders of magnitude.
- Inner and outer city levels were reasonably similar (median values of 0.39 and 0.34 V/m, respectively). There is a considerable difference between these and rural area exposures (median values of 0.05 V/m). The difference between inner city and rural exposure levels was confirmed both for outdoor ground levels (median 0.50 V/m in inner city, 0.06 V/m in rural areas) and for indoor levels close to windows (0.25 and 0.09 V/m, respectively).

The authors of the study concluded that:

- Detailed comparison of different sets of data is only possible if type and characteristics of the site as well as site selection criteria are matched.
- Variations in measuring methods and measuring uncertainties should be taken into consideration, but are not likely to explain the very large variations found in the results of the measurement campaign in each country.

In 2007 the Agence nationale des fréquences (ANFR) published [42] an analysis of the measurement campaign that had been carried out in France since 2001. About 10,000 measurements were considered. The measurements were classified into two time-periods (2001 - June 2004 and June 2004 - May 2007) because of changes in measurement protocol and site selection criteria (61% and 46% of the measurements were outdoors during the two periods, respectively). It is clear from Figure 1 that the values measured in France were higher than those during the COST 244bis STM campaign but still below 1 V/m. Moreover, the data from this analysis show an inverse picture with respect to environments, i.e. a slightly higher exposure indoors than outdoors for the mobile communication networks.

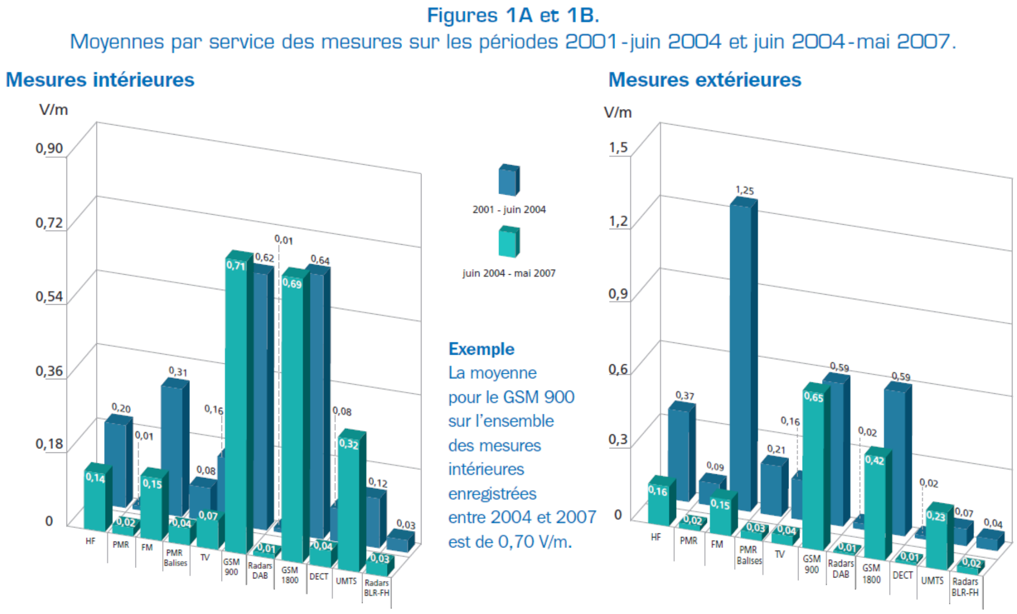

Figure 1. Mean values of electric field strength measured in France [42].

Expressed in terms of the ICNIRP reference level (Figure 2), the exposure was less than 10% in 97% of the measurements and less than 2% in the 75% of the measurements.

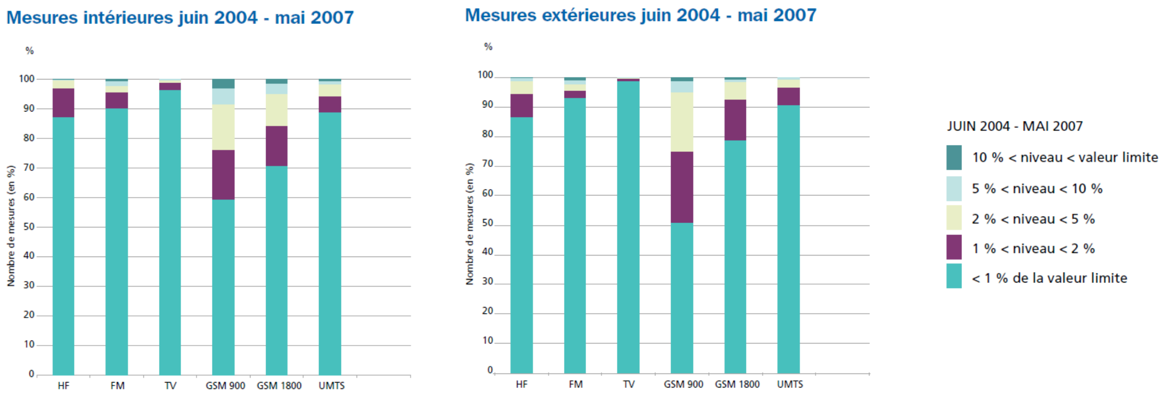

Figure 2. Distribution of exposure level (quotient) in the period 2004-2007 in France [42].

The results of the measurement campaign in Portugal within "the monIT project" [43] and the monitoring projects "Hermes" and "Pedion24" in Greece [44] are given in terms of the reference values in each country. The 2,280 measurements were conducted with broadband equipment in Portugal and showed that [45]:

- about 95% of them were below 1% of the ICNIRP reference level (Figure 3), i.e. below 20 mW/m^2 or 2.8 V/m,
- indoor measurements were on average higher than outdoor measurements, and
- exposure was higher in urban than in rural areas.

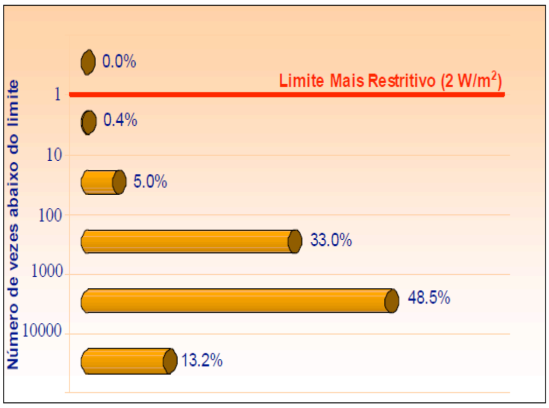

Figure 3. Global statistics of the broadband spot measurements performed in Portugal [45].

In Greece, the frequency selective measurements indicated that the total electric field strength from mobile phone base stations was at least 10 times lower than the national reference level, which means that all values were below 2.17 V/m (Figure 4). It is noted that the reference levels for equivalent power density in Greece are lower than the ones recommended by ICNIRP by 40%.

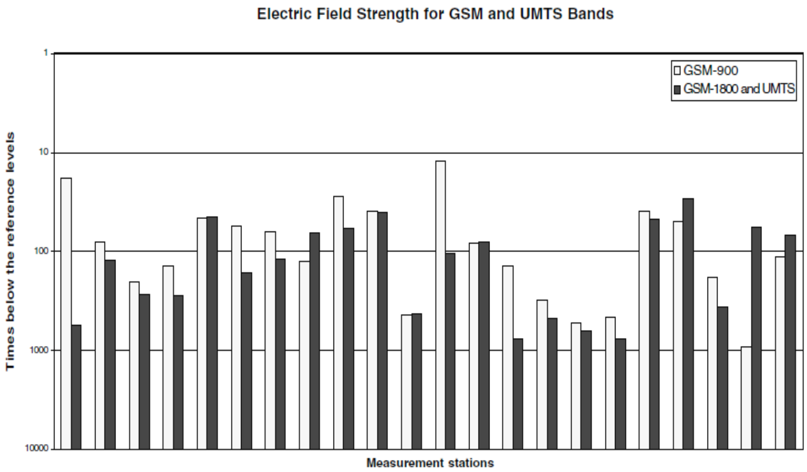

Figure 4. Measurement results for the downlink radiation of base stations in Greece [44].

Although a large number of spot measurements have been performed in Germany for compliance reasons and in the UK in the form of audits, an analysis of them has not appeared in the literature until now. However, reports have been published which contain measurements from both countries. In the first report by Mann et al. [46], the power density from base stations was measured at 118 locations (around 17 installation sites). Total exposure assessment (30 MHz - 2.9 GHz) was carried out for 73 of the locations and it was found that the maximum exposure was 0.18% of the ICNIRP reference level, and median exposure was 100 times smaller than that. On the other hand, Bornkessel et al. [47] chose to investigate the exposure from 11 typical base station configurations. They found that maximum exposure for GSM and UMTS was at 5.4 and 5.1 V/m, or 12.8% and 8.4% of the ICNIRP reference level, respectively. The exposure range (highest to lowest) was 60 dB. The median exposure was measured at 0.72% and 1.75% of the ICNIRP reference level for UMTS and GSM, respectively. According to the authors, the highest exposures were measured in microcell scenarios (e.g. base stations mounted on the ceiling), where persons are closer to the antennas, even though the powers transmitted are very low. In contrast, very high mounted antennas often resulted in low exposures. The same conclusion was drawn by Cooper et al. [48] who examined public exposure from 20 GSM microcell and picocell base stations radiating between 1 and 5 W. They found that, at horizontal distances less than about 50 m from the antennas and at heights of 1.5 m above the ground, exposure near microcells was generally greater than exposure near macrocells. They attributed this finding to the lower mounting height of the microcell antennas and the broader beams produced by them in the plane of elevation. The maximum power density near any of the base stations was 8.6% of the ICNIRP reference level, i.e. in agreement with the German study [47]. The range of exposure was between 0.002 to 2% (5th to 95th percentiles).

In an attempt to validate their theoretical model, Bürgi et al. [17] performed 20 frequency-selective measurements in Basel and 18 in the rural region of Bubendorf. The results are shown in Table 7.

Table 7. Exposure data (average values) from a small validation measurement campaign in Switzerland (Bürgi et al. [17])

Frequency band	Basel (V/m)	Bubendorf (V/m)
Total	0.50	0.15
GSM900	0.16	0.10
GSM1800	0.42	0.04
UMTS	-	0.02
FM Radio	0.03	0.02
DAB	0.00	0.00
TV	0.03	0.04

The above group analyzed the results from a more extensive campaign of spot-measurements in the same area [49]. They consisted of data at street level ("street", 113 points), indoor measurements in the bedroom of participants in the QUALIFEX study ("home", 133 points), and the corresponding measurements in front of the windows of the bedrooms ("window", 131 points). For the "home" and "street" measurements the researchers used a seven-point stencil for averaging, with three points at the center of the room (point in the street) at different heights (1.1, 1.5 and 1.7 m) and another four at the level of 1.5 m and 1 m away from the central point. The average values for the electric field strength were 0.37 V/m at "street" level, 0.13 V/m in the "home" and 0.25 V/m at the "window". The main contribution in all three cases was from GSM1800. In the "street" GSM900 contributed about the same as GSM1800, whereas at the "home" and "window" points the contributions of GSM900 and FM were of the same order (15-20%).

Apart from the base stations of mobile communications networks, new applications have started to contribute to the background radiation. Digital broadcasting was evaluated in the work of Schubert et al. [20]. The authors have shown that the highest combined exposure from broadcasting systems was at 0.3% of the ICNIRP reference level. The median value of the exposure in terms of power density increased by about 6 times from the switchover from analogue to digital television, but it still remained very low, i.e. at 1.9 $\mu W/m^2$ (< 0.03 V/m).

Another source of background radiation that is becoming important for exposure, especially in indoor environments, is wireless local area networks (WLAN). After an extensive measurement campaign at 55 locations in Europe and the U.S., Foster reported [50] that the median value of the RF power density in the WLAN frequency range, when the laptop was not uploading/downloading a file and at a distance greater than 1 m from it, was 1.2 $\mu W/m^2$. In the case of the laptop communicating with the WLAN, the median value was one order of magnitude higher (16 $\mu W/m^2$) at 1 m distance. The maximum time-averaged power density values were 7 mW/m^2 and 1 mW/m^2, respectively. Compared with the total power density from all sources (frequency range 70-3,000 MHz; median: 60 $\mu W/m^2$; maximum 40 mW/m^2) it was clear that 'RF fields from WLANs in typical environments are far below exposure guidelines and in nearly all cases below other RF signals that are present in the same environments'.

Schmid et al. [51] have measured WLAN background radiation in six different exposure situations. Two of the considered scenarios comprised indoor installations (one in a coffee shop and another inside an airport terminal), where the radiation from both access points (AP) as well as mobile stations (clients) were considered. Another two scenarios at public places downtown, but outdoors this time, were examined (minimum distance to the AP antennas approximately 5 m). Finally, two cases in residential areas, where outdoor AP antennas were intended to supply indoor clients inside homes were considered (minimum distance to the AP antennas approximately 50 m). In case of outdoor scenarios only the field distributions caused by the AP were examined. The maximum spatial (measurements were conducted at five heights at each position) and temporal (burst) power density values are included in Table 8.

Table 8. Power density in exposure scenarios from WLAN (Schmid et al. [51])

Scenario	Minimum distance to AP antenna	Maximum spatial and temporal peak exposure (mW/m^2)	Maximum spatial and temporal peak exposure (V/m)
Coffee shop	0.2 m	183.0	8.31
Airport	3 m	1.86	0.84
Downtown location 1	5 m	0.1	0.19
Downtown location 2	5 m	0.34	0.36
Residential location 1	50 m	0.002	0.03
Residential location 2	50 m	0.004	0.03

Verloock et al. [52] assessed background exposure to WLAN access points for 222 locations (7 WLAN networks present) in office environments. They measured an average value of 0.12 V/m (95th percentile of 0.90 V/m). When the wireless sensor network test-bed was switched on, the previous values increased by about one order of magnitude.

3.2.2.3 Limitations

The main problem of spot measurements is that they present only an instance in time of the electromagnetic environment. In order to assess maximum or worst-case exposure, it is necessary for some frequency bands and applications to have information from the provider of the corresponding services. Another issue with spot measurements is averaging and which value best represents exposure in a location. There are already measurement standards and recommendations for investigating compliance with exposure guidelines in-situ, which assume averaging in the volume of the human body, but it is not clear that this procedure gives values which correlate to personal exposure [35], especially in the presence of a dominant signal coming from an arbitrary angle.

3.2.3 Continuous monitoring

3.2.3.1 Introduction

Continuous monitoring is achieved with the installation of broadband or frequency selective field probes at fixed locations for a given period of time. The location can be changed and the probes can be moved to a new position after some time, depending on the objectives of the measurement campaign. The field probes have to fulfill some specific technical characteristics that enable them to operate unattended under variable environmental conditions, mainly outdoors (e.g. lightweight, large variations in temperature and humidity, autonomous power supply, remote control). Currently, several such devices are commercially available from Narda Safety Test Solutions GmbH (Pfullingen, Germany), Satimo (Brest, France), E.I.T. s.r.l. (Rome, Italy) and Rohde & Schwarz (Munich, Germany). Most of them measure the electric field in the frequency range between some kHz to about 3GHz.

Although a large number of monitoring networks have operated in Europe, only a few results have reached the open literature and these are mentioned below.

3.2.3.2 Results

The main advantage of continuous monitoring is that it can provide information about the time variation of the background radiation. In Portugal [45], the results from 109 field probes, which measured continuously for at least three months at each location, are shown in Figure 5 (for the typical daily variation) and Figure 6 (for the probability density function of the variation between maximum and average values). It appears that the most probable daily variation is 1.38.

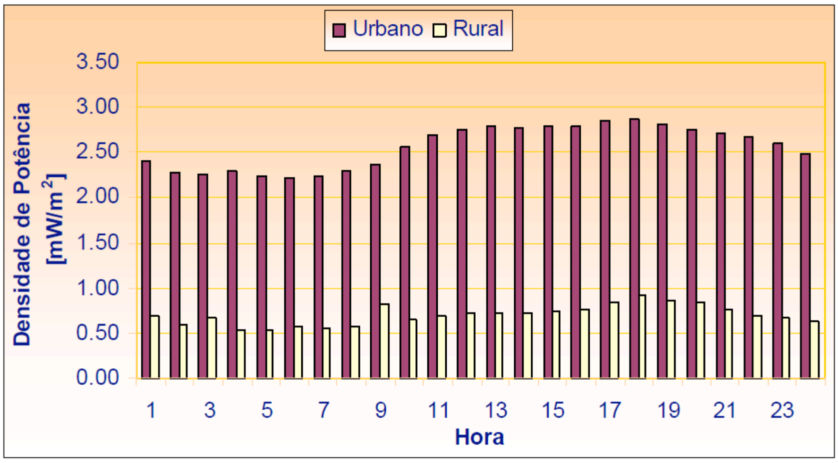

Figure 5. Typical daily variation in the monitoring network in Portugal [45].

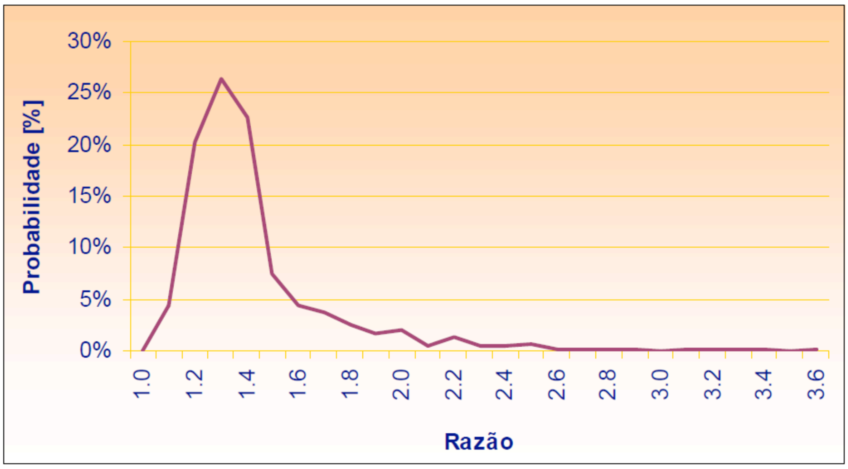

Figure 6. PDF of the variation between maximum and average values from 109 stations in the monitoring network in Portugal [45].

Similar results for the daily variation of the background radiation were published from the data of 60 monitoring stations in networks in Greece [53]. The stations were divided (according to spot-measurements) into two classes, i.e. those for which the FM contribution was highest and the ones for which the GSM signal component was highest. The intra-daily variation was then calculated as a percentage difference between the maximum and minimum electric field strength recorded. One can easily deduce from Figure 7 (for the second class) that the most probable intra-daily variation is 0.35. Assuming that the minimum and maximum values are present for the same fraction of the day, it is easy to conclude that the variation between maximum and average power density is about 1.32, which is in agreement with the value from Portugal.

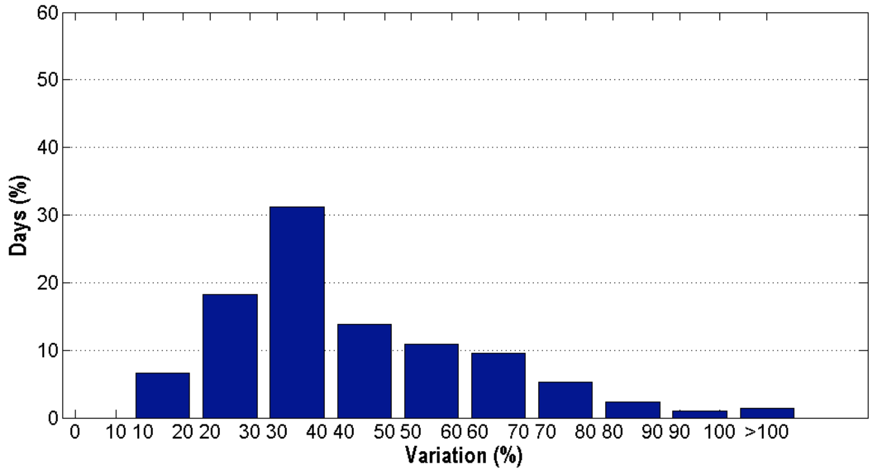

Figure 7. PDF of the variation between maximum and minimum electric field strength values from 60 stations in the monitoring network in Greece [53].

The measured variation of electric field strength maximum to median values in Belgium [54] obtained with a spectrum analyzer during a period of 7 days was in the range of 1.27 to 1.96 (median: 1.52) for GSM and 1.41 to 1.85 (median: 1.41) for UMTS. However, the number of locations investigated in this study was small (only 5 sites) and it is difficult to extract safe statistical information about the variation in all environments.

In contrast, the variation of the hourly average from 24 monitoring stations in Switzerland [49],[55] was less than 20% for GSM background radiation (in most cases less than 10%). This disagreement could be attributed to the fact that, for example, background radiation levels in Greece are higher (mean in urban areas: 1.86 V/m [53]; median of all stations: 1.8 V/m, mean of all stations 1.578 V/m [44]), probably due to higher GSM radiation (smaller number of base stations). This could lead to a larger variation within the day as there would be a larger variation in traffic density.

3.2.3.3 Limitations

It is obvious from the above that the information extracted from continuous monitoring depends on the endpoint of the measurement campaign, i.e. the selection criteria of the monitoring station locations. If the latter are placed in the vicinity (or in line of sight, LOS) of base station antennas, then higher variations with time can be observed. However, these variations are not necessarily representative of the time behavior of the field in a wider area. Furthermore, there is a need for continuous measurements indoors in order to also assess time variation there.

3.2.4 Measurements synopsis

The literature review has shown that there is no harmonized way of reporting measurement data for exposure, even for the same measurement methodology. However, an attempt was made to include common information from published results in Table 9. It is clear that with respect to background radiation:

- PEM measurements of downlink transmissions give a lower exposure estimate than spot measurements.
- DECT fields measured with PEM are higher than those measured with spot measurements, probably because PEM also measures user exposure during a call.

Table 9. Presentation of results for exposure assessment of background radiation (the values are in V/m)

		FM		GSM900 downlink		GSM1800 downlink		DECT		UMTS downlink		WLAN	
method	ref.	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max
PEM	25	0.07	0.41	0.09	0.33	0.12	0.52	0.12	0.43	0.06	0.15	0.06	0.22
PEM	26	0.05	0.25	0.06	1.15	0.06	0.56			0.05	0.08		
PEM[§]	27		0.31		0.52		0.16		0.33		0.11		0.58
PEM	31	0.17	1.43	0.12	0.78	0.10	0.70			0.07	0.15		
spot[§§]	42	0.31		0.62		0.64		0.08		0.12			
spot[§§]	42	0.15		0.71		0.69		0.04		0.32			
spot[§§]	42	1.25		0.59		0.59		0.02		0.07			
spot[§§]	42	0.15		0.65		0.42		0.01		0.23			
spot[§§]	17	0.03		0.16		0.42							
spot[§§]	17	0.02		0.10		0.04				0.02			

[§]The values from this study are not maximum but 95th-percentile; they were treated here as maximum for the sake of comparison. [§§]The values for GSM and UMTS reported in these publications include most probably both uplink and downlink; here it is assumed that uplink transmission does not contribute much to the measured value.

3.3 Short-range and indoor communication devices

3.3.1 Introduction

This section contains a report on the measurements of electric and magnetic fields around short-range and indoor communication wireless devices, like wireless computer networks, DECT telephones, bluetooth devices and RFID. These devices are of special interest to the current project and are therefore considered separately. Moreover, they contribute both to background radiation and to user exposure.

3.3.2 Results

Kühn et al. [56] reported on the exposure from various low-power wireless network devices (Table 10). The group of measured apparatuses included 3 WLAN (802.11b) access points, 4 bluetooth devices (power classes 1, 2 and 3), 4 DECT telephones, baby surveillance devices and 3 wireless computer peripherals (keyboard, mouse). It is clear that the measured maximum electric field strength even at the distance of 1 m was comparable to (if not larger than) the typical exposure from base stations of cellular networks.

Table 10. Maximum measured electric field strength in the vicinity of low-power wireless devices [56]

Device type	Peak output power (mW)	Frequency range (MHz)	Max. E-field (V/m) @ 20 cm	Max. E-field (V/m) @ 100 cm
Baby surveillance	500	40 - 863	8.5	3.2
DECT*	250	1880 - 1900	11.5	2.9
WLAN (802.11b)	100	2400 - 2484	3.9	1.1
Bluetooth	100	2402 - 2480	3.1	1.0
PC peripherals	10	27 - 40	<1.5	<1.5

* Extrapolated maximum for asymmetric transmission mode (fixed part only)

The above results were confirmed by Schmid et al. [57] who added devices from other applications, such as remotely controlled toys.

Table 11. Maximum measured electric field strength in the vicinity of low-power wireless devices [57]

Device type	Product no.	Frequency (MHz)	Peak output power (mW)	Max. E-field (V/m) @ 100 cm	Max. E-field (V/m) @ 300 cm
Baby surveillance	1	40.7	10	0.04	0.03
	2	446	500	1.09	0.41
	3	864	10	0.45	0.14
	4	2450	—	0.40	0.11
Wireless headphone	1	864	—	0.14	0.04
	2	864	10	0.35	0.10
DECT cordless	1 (BS)	1880-1900	250	3.61	1.29
phone systems	1 (MS)		250	1.24	0.44
	2 (BS)		250	2.69	1.50
	2 (MS)		250	1.93	0.77
Remotely	1	27	—	0.50	0.15
controlled toy	2	27	—	0.40	0.05
	3	27	—	0.40	0.10

In a recent study [58] concerning electric field strength in the vicinity of laptops using WLAN (14 devices measured in an anechoic chamber and transmitting at the highest bit-rate), it was found that the maximum value at 1 m from the laptop varied between 0.72 and 1.31 V/m, in agreement with [56].

The results of the various reports on measurements of short-range and indoor communication devices are summarized in Table 12.

Table 12. Presentation of measurement results for short-range and indoor communication devices

Device type	Ref.	Max. E-field (V/m) @ 100 cm
WLAN laptop	50	1.62
WLAN laptop	58	1.31
WLAN access point	56	1.10
DECT base station	56	2.90
DECT base station	57	3.61
DECT handset	57	1.93

3.4 Incident fields dosimetry

3.4.1 Introduction

The reference levels for electric and magnetic fields included in guidelines or standards have been derived for plane wave exposure of homogeneous spheroids. Plane wave exposure assumes that the electric field distribution is uniform at the location of the scatterer and in its absence. In reality, however, the situation is completely different because of multipath propagation. The electromagnetic field at the space occupied by a scatterer, like the human body, results from the superposition of several plane waves with different polarization and phase. Modeling such a situation of 'heterogeneous' exposure is a scarce subject in the literature. Neubauer et al. [59] mention that, considering a simple homogeneous ellipsoid as the scatterer simulating the human body, the exposure from two opposite incoming plane waves at 1GHz can be shown to lead to a heterogeneous field distribution, which causes a whole-body SAR (normalized to the incoming electric field) 6% higher compared to single plane wave exposure at the same frequency. Therefore, Neubauer et al. [59] investigated both the whole-body and partial-body (10g) SAR for heterogeneous exposure conditions in two different scenarios. They concluded that plane wave exposure does not represent worst-case exposure conditions: when the electric field strength arising at plane wave exposure is compared to the electric field strength averaged over the volume of the human body occurring during multipath exposure, 12% of all heterogeneous cases examined represent worse exposure conditions than plane wave exposure for whole-body exposure at 946 MHz, 15% at 1840 MHz, and 22% at 2140 MHz.

Similar investigations have been performed by other researchers. Vermeeren et al. [60] took a statistical approach to examine whole-body SAR under multipath exposure of a simplified homogeneous human phantom (spheroid) in specific environments (e.g. urban, macrocell; urban, microcell; indoor, picocell; outdoor-indoor). They showed that for the urban, macrocell environment (frequency 950 MHz) the whole-body SAR was below 0.023W/kg at an averaged field level of the ICNIRP reference value (42.38 V/m) for 99% of the investigated cases in the above four environments. Their methodology allows for very fast calculations in complex environments. It has also been extended by the same group [61] to the calculation of whole-body SAR from PEM measurements. One question, however, which arises for the above methodology is how representative of the real human anatomy spheroid phantoms are.

3.4.2 Issues of interest

There are, however, some points, which have attracted the attention of regulators and policy-makers due to the increasing public concern, and these include the exposure of special population groups like children and pregnant women. Several recent numerical studies with both scaled and anatomical models of children exposed to plane wave radiation [62]-[69] have revealed that the ICNIRP reference levels are not conservative in the

GHz range, i.e. the whole body averaged SAR basic restriction of 0.08 W/kg is exceeded. Of great interest is the work of Dimbylow et al. [64] with the University of Florida newborn voxel phantom. This shows that the basic restriction whole body SAR is breached for the ICNIRP reference levels in a wide range of frequencies (700 to 2450 MHz).

Concerning pregnant women, several numerical studies with both simplified and realistic fetal and embryonic models [70]-[73] have been conducted. However, all of these studies were focused on the SAR induced in the fetus or embryo with respect to the ICNIRP reference levels in order to verify their conservativeness, whereas a thorough thermal analysis similar to that of Hand et al. [74] would be more appropriate. Modeling the thermoregulation of the fetus, as well as obtaining gestational-age-specific data of its dielectric properties, are two issues that need to be studied further before a final decision on fetal exposure can be reached. Moreover, realistic models at different gestational ages are needed.

4 User Exposure

4.1 Mobile phones

4.1.1 Introduction

The exposure of mobile phone users has been the subject of a vast number of published studies, which cannot be reviewed here due to space and scope limitations. Both numerical and experimental dosimetry of mobile phones are well documented in several books [39], [75]-[78]. Nevertheless, the case of children exposed to mobile phone radiation has been the subject of a long controversy, and prenatal exposure has already seen the publication of contradicting epidemiological studies on neurological development [79],[80].

4.1.2 Issues of interest

Unfortunately, there is no literature on the exposure assessment of pregnant women from mobile phones, even though the placement of the device in a bag carried next to their belly is a common habit among pregnant users. However, the issue has attracted the attention of many groups. For a long time there has been a dispute on the absorption pattern of electromagnetic energy in the heads of children. Quite recently a study was published which puts this subject into a new frame. Christ et al. [81] concluded that with respect to the effect of age-dependent tissue parameters for testing compliance with safety standards:

- Age dependences of dielectric tissue properties did not lead to any systematic changes of the peak spatial-averaged SAR (psSAR) for all configurations analyzed in the paper (two adult and four children models, two generic and one CAD phone models, ‘touch’ and ‘tilt’ positions).
- The geometrical properties of the head did not have a systematic impact on the psSAR, i.e. a correlation between the size of the head and the peak spatial SAR could not be established. Differences were merely due to individual anatomical properties.
- In all investigated cases, the current methods for compliance testing proved to be conservative.

With respect to the exposure of particular tissues and brain regions the authors concluded that, in general and on average, children suffer a higher exposure of their brain regions than adults. This higher exposure is due to differences in anatomical proportions. For the exposure of the surface of the brain, the current density distribution or the near field of the cell phone must be regarded. This is of particular importance for the interpretation of epidemiological studies and for research on non-thermal effects. In more detail, they found that:

- The exposure of regions inside the brains of young children (e.g. hippocampus, hypothalamus, etc.) can be higher by more than 2 dB–5 dB compared to adults. This should be considered in the design of volunteer (human provocation) studies.

- The exposure of the bone marrow of children can exceed that of adults by about a factor of 10.
- The exposure of the eyes of children is higher than the exposure of the eyes of adults. Regarding thermal effects, however, this does not represent a problem as the exposure of the eyes by mobile phones is very low, i.e. less than −10 dB compared to the psSAR.
- Because of differences in their position with respect to the ear, brain regions close to the surface can exhibit large differences in exposure between adults and children. The cerebellum of children can show a psSAR more than 4 dB higher than the local exposure of the cortex of adults. It should be noted that these differences strongly depend on the current distribution of the phone.
- Tissues or regions that have a similar distance to the phone for adults and children, such as the pineal glands, do not experience age-dependent exposure.

4.2 Short-range and indoor communication devices

4.2.1 Introduction

In this section an attempt is made to describe the user exposure of short-range and indoor communication devices. Although it is difficult to distinguish between background radiation and user exposure for such devices, the following report mainly contains SAR measurement results that have appeared in the literature for such devices, concerning either their typical (intended) use or worst-case situations.

4.2.2 Results

4.2.2.1 RFID readers

Radiofrequency identification (RFID) technology is gaining acceptance in many applications in different environments, ranging from industrial spaces and logistics warehouses to hospital rooms. Unfortunately, not many studies exist in the literature about the exposure of the population, either workers or the general public, to RFID reader devices.

The measurements performed in Sweden [82] for readers operating at 13.56 MHz on local public transportation vehicles have revealed that at a distance of 10 cm the magnetic field strength (H) was 0.4 A/m, i.e. higher than the ICNIRP reference level of 0.0073 A/m for the general public. Only at distances a little greater than 20 cm did the magnetic field reduce to values lower than the reference level. In order to test whether the basic restrictions were exceeded, the Swedish Radiation Safety Authority conducted a SAR measurement performed by the German test house IMST GmbH for a worst-case condition, i.e. a person leaning against the reader. This measurement showed that local SAR was 0.1 W/kg, which is well below the basic restriction of 2 W/kg for the general public.

Arumugam and Engels [83],[84] calculated with the FEM that, when an RFID reader antenna operating at 915 MHz with 1 W output power was placed 10 cm in front of the face, both the FCC (1g averaged SAR) and the ICNIRP (10g averaged SAR) basic restrictions were exceeded.

Hong and Yun [85] performed the exposure assessment for two numerical models of adults (Korean male and Duke of the Virtual Family Project) next to an RFID reader for various heights and distances. They found that the ICNIRP basic restriction of the 10g averaged SAR was exceeded only for the Korean model at contact with the antenna (distance of 0 cm from it).

4.2.2.2 Communication devices

Kühn et al. [56] measured the SAR of short-range communication devices (Table 10) touching a flat phantom, which is considered a worst case situation. The values of the measured peak spatial-averaged SAR are shown in

in

Table 13.

Table 13. Maximum measured SAR values from short-range communication devices [56]

Device type	Max. SAR (W/kg) - averaged over 1g	Max. SAR (W/kg) - averaged over 10g
Baby surveillance	0.115	0.077
DECT	0.087	0.052
WLAN (802.11b)	1.93	0.81
Bluetooth (Class 1)	1.31	0.466

In a specific study about the exposure from hands-free kits, Kühn et al. [86] reported that for three wireless hands-free models of power class 2 the measured peak spatial averaged SAR (averaged over 1 or 10 g) was below the sensitivity of the measurement equipment, i.e. below 0.005 W/kg.

Guterman et al. [87] investigated the SAR distribution in the user of a laptop connected to a wireless local area network for various antenna configurations. They used a homogeneous generic numerical phantom with dielectric properties at 2.44 GHz, which correspond to an average material made of 85% muscle and 15% fat. They found that the maximum peak spatial average (10g) SAR occurred in the hand of the user for the side patch location (on the laptop screen) and had a value of 0.4 W/kg. For an inverted-F antenna used in the PCMCIA slot of the laptop the peak spatial SAR reached a value of 2.74 W/kg in the wrist of the user. The authors claim that, although this value is large, it was calculated for an output power of 1 W from the antenna, whereas in a realistic environment the laptop antenna would operate with a power of 10 mW, leading to a hundred times smaller peak spatial SAR. It is worth mentioning here that the use of homogeneous numerical phantoms for such calculations presents the limitation of being unable to predict enhancements in absorption due to tissue stratification [88].

5 Critical points in standards/guidelines

Volume averaging of SAR has been a problematic issue for guidelines and standardization committees in near-field exposure. In the radiofrequency/microwave range the main health effect to be prevented is tissue heating. One would therefore expect that a spherical volume of tissue could be chosen for SAR averaging, since heat diffuses almost isotropically inside the tissue in the absence of large blood vessels. On the other hand, if a biologically relevant thermal effect were to be mitigated, the choice of a contiguous tissue volume of the same organ, which is usually distinctly blood-perfused with its own vascular network, would be another reasonable alternative. It has already been shown that SAR averaging in contiguous tissue volumes gives higher values both in simple as well as realistic numerical phantoms. Stevens and Martens [89] estimated an increase of up to 38% in the maximum SAR calculated in an irregular coherent volume compared to the SAR value resulting from a cube completely embedded in the tissue. Van Leeuwen [90] reported values of SAR averaged in arbitrary volumes that were up to 80% larger than the values calculated from 1g and 10g tissue cubes. Finally, Lee and Pack [91] proposed a new method for averaging SAR in contiguous volumes, which resulted in values up to 10% higher than the cube method.

However, the correlation between temperature rise and mass-averaged SAR is a more complicated matter that does not depend solely on the averaging volume (either shape or quantity). Hirata et al. [92] and Samaras et al. [93] have shown that tissue composition is more important for this correlation. In fact, the dominant factor is heat diffusion, i.e., the higher the blood perfusion rate, the smaller the heating effect of electromagnetic radiation and the smaller the SAR averaging mass, which must be used to maximize the correlation with temperature elevation. All the above points should be carefully considered if any change of dosimetric quantities (basic restrictions) in standards is attempted.

6 Conclusions

- Exposure assessment of the general public to electromagnetic radiation of wireless network devices requires the use of a combination of modeling and experimental techniques.
- Continuous monitoring in the environment has shown that there is variation of the electric field strength between day and night. This variation is not the same for all countries and it can be in the order of 20% to 30%. The main contribution to this variation comes from the GSM system.
- Continuous monitoring has also indicated a difference in exposure between urban and rural areas, with the exposure being higher in the former than in the latter.
- The diurnal changes in exposure as well as the differences with place of residence (urban vs rural) are also supported by PEM measurements.
- PEM data should be used with caution due to technical specifications. In particular, the most important thing to keep in mind is the way calibration is performed, the shift in operating characteristics with time and the inadequate discrimination between neighboring frequency ranges. PEMs should not be employed to evaluate exposure from wireless devices used by the bearer.
- In-situ (spot) measurements are not very useful for specific exposure assessment unless they are combined with continuous monitoring, PEM measurements, georeferencing or modeling (calculations). However, they can provide a good estimation of worst case exposure at 'hot spots'.
- Not enough data exist in the literature about indoor exposure, or about the new wireless devices which have begun to be established in the home and office environments. More research should be done for the characterization of these environments where people spend more than 60% of their time.
- Short range communication and indoor communication wireless devices can result in electric fields at a distance of about 1m comparable to or larger than those of GSM base stations (see Table 9 and Table 12). The only difference is that the latter type of exposure concerns the whole body.
- User exposure from mobile phones remains higher than from other short range communication devices. However there is still not much information about emerging uses such as WiFi cameras, headsets etc.
- RFID readers in contact with the human body can result in large SAR values that may exceed mobile phone exposure.
- Baby surveillance devices operate in a wide frequency range (40-2450MHz). However, in the current project only such devices working with the DECT and 802.11 shall be considered because they can form a simple network (two-way communication).
- In near-field dosimetry there is a lack of information about prenatal exposure. Research should focus on several situations that lead to exposure of the embryo due to use by pregnant women.
- In children it is significant to investigate tissue specific exposure, especially in view of recent results about the SAR values in the bone marrow of young mobile phone users.
- Open scientific issues still exist which prevent an accurate use of temperature as the dosimetric quantity (basic restriction) in standards.

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