European Health Risk Assessment Network on Electromagnetic Fields Exposure

Report on the level of exposure (frequency, patterns and modulation) in the European Union

Part 1: Radiofrequency (RF) radiation

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1 Introduction

The main task of this WP is to estimate the distribution of amount and pattern of exposure of the public to radiofrequency (RF) electromagnetic fields (EMF) in the European Union. This will be achieved by data modeling, using as input the available information on exposure provided by *measurement campaigns*, *monitoring systems* and *audit of emissions* available in several Member States. The main conclusions of WP6 provide essential information for the risk identification and analysis as well as for the dose response evaluation of the human exposure to EMF. Further aim of the present work is to attempt creating *exposure categories* and classification within the population. In the evaluation of human exposure to EMF several possible classifications and clusters of exposure have been recognised such as: *indoor vs. outdoor*, *long term vs. acute*, exposure by *sources far from human body* (far-field exposure) vs. *sources close to human body* (near-field exposure). The classification by the *perception* of the exposure such as *voluntary* vs*. involuntary* exposure is also regarded, however this categorization does not have scientific basis or real exposure assessment.

Considering the relative diffusion of the various devices generating EMF at different frequencies, the available data are mainly at extremely low frequency, mostly generated by power lines and, especially, radiofrequency, mostly generated by broadcasting and radio base stations for telecommunications. Some more difficulties are expected for data on assessment of emissions at intermediate frequencies and wireless communication systems such as RFID, WiFi, WLAN, WiMax. However, the scientific and political interest on the emissions from these devices is increasing day after day and more data can be expected to be available in the next years.

In present document the human exposure to EMF fields is evaluated by *high frequency* and *low frequency* range. In each frequency ranges the public exposure was investigated by the *sources far from the human body* and the *sources close to the human body*. The European activities of the EMF exposure assessment, the general *trends of EMF exposure in the environment* and the expected exposure from the *new technologies* will also be discussed.

2 EMF exposure assessment in European countries

During the last decade intensive European activities have been recognized on the EMF exposure assessment in several countries of member states (e.g. France, Germany, Greece, Hungary, Italy, Slovenia, UK, Ireland) and also outside EU member states (in particular Switzerland). Most of exposure assessment studies were performed in the high frequency (RF) range mainly related to the mobile (wireless) technology. Several types of EMF exposure assessments were elaborated such as: radiation/exposure surveys and campaigns, personal exposimetry surveys, area radiation monitoring, exposure modeling and retrospective exposure assessment. Most of exposure models were related to epidemiological studies. These activities among different European countries are summarized in the Table 1 and Fig.1. by type and frequency range of the public exposure assessment.

Table 1. *EMF public exposure assessments in the European countries*

Country	Method of exposure assessment			
	Survey by in-situ measurements	Long term RF radiation monitoring system	Personal exposimetry	Modeling of exposure
Austria	RF	-	RF, ELF	RF, ELF
Belgium	RF	-	RF,	RF
Bulgaria	RF, ELF			
Croatia	RF	-	-	
Denmark	RF	-	-	RF
France	RF, ELF	RF	RF, ELF	RF
Germany	RF, ELF	RF	RF, ELF	RF, ELF
Greece	RF, ELF	RF	-	RF
Hungary	RF	-	RF, ELF	-
Ireland	RF	-	-	-
Italy	RF, ELF	RF	RF, ELF	RF, ELF
Netherlands	RF	-	RF	RF
Portugal	RF	RF	-	RF
Slovenia	RF, ELF	-	RF	RF
Spain	RF	-	-	-
Sweden	RF, ELF	-	-	RF, ELF
Switzerland	RF	-	RF	RF, ELF
UK	RF	RF	RF	RF, ELF

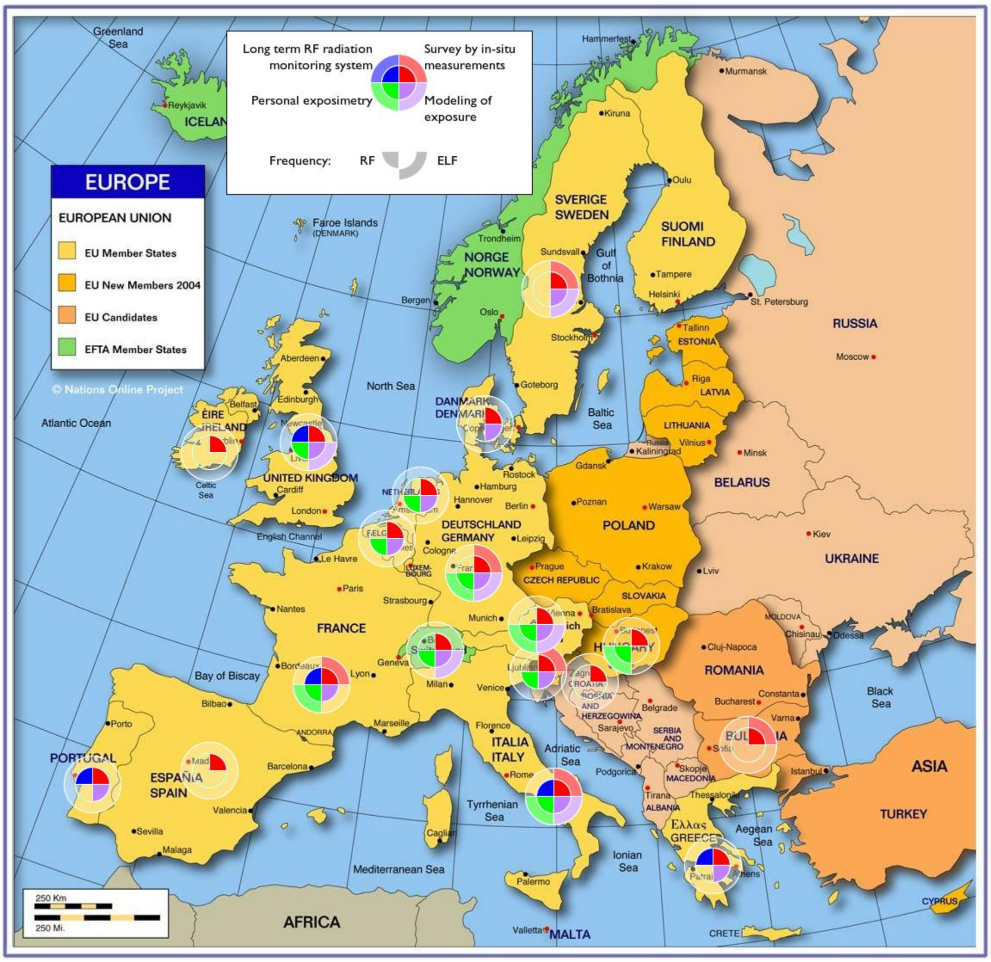

Fig.1. *EMF public exposure assessments in the European countries. The size of circles represents the level of activity on the corresponding exposure methods as: i) long term RF radiation monitoring systems, ii) survey by in-situ measurements, iii) personal exposimetry and iv) exposure modeling to RF and/or ELF range.*

3 Radiofrequency (RF) exposure assessment

The following review on the European exposure assessments is based on the classification of the sources such as: *body-far fixed sources* (sources far from the human body) and *body-close portable sources* (sources close to the body). The evaluation of public exposure to RF including both kinds of sources were considered based on scientific publications, national databases of exposure survey campaings, databases of national monitoring projects and exposure assessment performed within epidemiological studies in several European countries.

3.1 Exposure assessment of sources far from the body: body-far fixed sources

The most of data on public exposure to RF radiation are available from the following types of exposure assessments:

- permanent (continuous) RF radiation monitoring systems
- on-site measurement campaigns
- personal exposimetry studies
- assessments by modeling the exposure from different sources supporting the epidemiological studies.

All exposure assessment studies intend to evaluate the public exposure to RF instead of the compliance test of RF devices such as radiation pattern of an antenna configuration or other RF transmitters.

3.1.1 Permanent RF radiation monitoring systems in EU countries

During the last decade several continuous RF radiation monitoring system have been introduced in the European countries. These survey programs are based on innovative monitoring systems for the continuous monitoring of radiation at radio frequencies, emitted to the environment by various sources, such as radio and television station transmitting antennas, mobile telephony antennas, radars, etc. The monitoring systems are used to monitor the levels of electromagnetic fields continuously, usually by using broadband equipment and/or frequency selective radiation probes. These monitoring programs aim to provide valid and up to date information to citizens about the results of these measurements. Such RF monitoring systems have been developed and installed in *Italy, Greece, Germany, Portugal, Malta, Slovenia* and *UK* (Table 2).

Monitoring networks have been established as tools in attempting to deal with public concerns about the potential health effects of non-ionizing electromagnetic radiation, however, there effectiveness has not been independently evaluated. The networks use to be consisting of the remote measurement stations (broadband or frequency selective) and one or more control unit(s). Each station communicates with the control unit via a public wireless. The control unit controls the remote units, stores the measurement data, and hosts the web site. The public can access the results through an Internet gateway. One part from these monitoring systems have on-site monitor device that works continuously (even until today), while others based on monitors moving from site to site providing exposure data during a certain period (Gotsis, 2008). For example in Italy within the monitoring campaign over almost 8000 monitored places (including schools, public buildings, private rooms) by more than 4 million total observed hours were performed during the last decade (Troisi, 2008).

__Table 2.__ Permanent RF radiation monitoring systems in Europe

Country	Name of the project	Number of sites	Year of starting	Number of measurement days	Homepage
Greece	HERMES	106	2002	continuous	http://www.hermes-program.gr/en/main.html
Greece	Pedion24	160	2006	continuous	http://www.pedion24.gr/en/index_en.jsp
Greece	FASMA	30	2008	continuous	http://www.fasmaprogram.gr/fasmaprogram_08_en.asp
Germany	EMF-Datebank	14	2007	continuous	http://emf2.bundesnetzagentur.de/
Italy	ARPA/Fondazione Bordoni	7792	2002	from 24 h to 2 weeks (replacing site)	http://www.monitoraggio.fub.it/,
Malta	Gardjola	10		continuous	http://gardjola.eng.um.edu.mt/emr/index.php
Portugal	monIT	144		~3 months/site (replacing site)	http://www.lx.it.pt/monit/index_en.htm
Slovenia	Forum EMS	~55		~1 month/site (replacing site)	http://www.forum-ems.si/merilna_kampanja_rezultati.html
Spain	Tech.Univ. of Valencia	15		continuous	http://www.smp.upv.es/
Switzerland	REMS-Network	25		~2250	http://www.e-smogmessung.ch/i4Def.aspx?Tabindex=0&TabId=50
UK	Cassiopea	110		~1 week/site	http://www.stroud.gov.uk/docs/cassiopea/cassiopea.asp

3.1.2 On-site RF measurement campaigns

On-site exposure measurement campaigns were elaborated almost in all European countries since the middle of 90th. These on-site (also called spot) measurement campaigns were performed by systematic planning process and also by on request of the public or local authorities. Most of them were focused on the exposure to RF of mobile phone base stations. One of the first campaigns was processed in *Germany* by RegTP (*Regulierungsbehörde für Telekommunikation und Pos, now: Federal Network Agency, BNetzAt*) in the years of 90s. The RegTP/BNetzA performed two series of measurements to assess the exposure of RF fields (1996/7, 1999/2000). Since 2003 they performed 2000 measurements per year (RegTP, IZMF, LUBW, LFU, homepages). The first series of survey was performed by broadband measurements than followed by frequency selective recordings which is a more sensitive method and may provide more exact results including the identification of the sources. Since 2003 the data are presented in the internet. Users both have access to transmitter locations, site certificates and measurements (EMF-Datebank, homepage). Similar measurement campaigns (audit, ad-hoc measurements and other studies) were elaborated during the last decade in several EU countries such as *Austria* (Garn, 1996, Neubauer, 2005, 2007), *Switzerland* (Altpeter, 1995, 2000), *France* (ANFR, homepage), *Greece* (GAEC, RCL AUTH, homepage), *Italy* (ARPA, homepage), *Ireland* (Ireland Report, 2009), *Hungary* (Thuróczy, 2006, 2008), *Malta* (Malta Communications Authority, homepage), *Portugal*, (MonIT project, homepage), *Slovenia* (Trecek, 2007), *Spain* (Paniagua, 2009), *Sweden* (Uddmar, 1999) and *UK* (NRPB, 2004, OFCOM, homepage). The first attempt for international measurement campaign was processed within the COST244bis project where six EU countries (Austria, Belgium, France, Germany, Hungary and Sweden) tried to harmonize their protocol in order to measure the RF exposure from mobile telephone base stations (Bergqvist, 2001). The first general review of the European exposure assessment activities was issued by the EIS-EMF Project (European Information System on Electromagnetic Fields Exposure and Health Impacts) conducted by JRC (Joint Research Centre) on behalf of DG SANCO (EIS-EMF, 2005).

Regarding some samples of data by countries, for example in *Germany* within the second campaign in 1997 the locations nearby the base stations, and sensitive places (i.e. hospitals or schools) were investigated. The maximum and minimum measured RF power densities were 0,04 W/m^2 and 0,0000016 W/m^2, respectively. The mean value was 0,0052 W/m^2 and 0,0046 W/m^2 when not considering the extreme values (Bornkessel, 2004, 2005). In *Malta* on-site measurements of 55 randomly selected sites were performed during 2002. This survey was extended through 2003 and 2004 where about 50 new sites were audited each year (Malta Communication Authority, homepage). In *Spain* on-site measurements were performed in 3,818 locations at a maximum distance of 100 meters from a base station and included sites like 2,152 schools or similar buildings, 667 hospitals and 999 green zones parks and residential areas since 2002 (MITYC, homepage). The power densities obtained by these measurements were between a minimum value of 0,000081 W/m^2 and a maximum of 0,0118 W/m^2, which is quite small compared to the limits (4,5 W/m^2). In a *Spanish* case study the medium power density in outdoor urban area showed 0,000082 W/m^2. The frequency bands that most contributed to these levels were the three of mobile telephony with a 34,8%, those of FM and TV contributed to a lesser extent with 6,5% and 0,9%, respectively (Paniagua, 2009). In *Italy* innovative communication actions were combined with measurement campaign. The action was introduced in 2003 where a mobile EMF laboratory called “BluBus” and later “BluShuttle” cars were moving across the country equipped with a wideband portable RF field meter and an autonomous control centre. In each point a short monitoring campaign (lasting no more than half an hour) was performed (Troisi, 2008). To the end of 2009 the cars had over 50 000 km with more than 70 stops. According to the summary of these measurements more than 88% of recorded electric field strength were below 1 V/m, 8,1% between 1-3 V/m, 2,6% between 3-6 V/m and less than 0,3% above 6 V/m (BluShuttle, homepage). Within a large measurement campaign in *France* more than 20 thousands of site measurements were elaborated by ANFR (Agence Nationale des Fréquences) since 2001. All results of measurements are available for the public on the ANFR website (ANFR, homepage). More than 60% of measured total field were below 1

V/m, less than 0,1% above 20 V/m and around 2,8% between 6 V/m and 20 V/m. Currently a new project has been started in *France* called SAMPER running by ANR (l'Agence Nationale de la Recherche) where the aim is to deal with complex exposure situations such as a dense urban environment since it is impossible to simulate the exposure because of the lack of information about sources present and the exact properties of the various obstacles between the transmitter and given point in space (SAMPER, homepage).

Recently a large exposure assessment campaign was performed in *Austria* where the RF levels in the vicinity of mobile stations of the GSM and UMTS were measured by single measurement overall in 106 communities in 255 different measurement points. The measurement results were also published on-line recently (FMK, 2010). The most recent campaign was elaborated in three countries, *Belgium, Netherlands* and *Sweden* between 2009 September and 2010 April where at 311 locations (243 outdoor, 68 indoor) short term measurements (30 minutes per location) and at 14 sites long-term recording at least 4 successive days (2 weekdays and 2 weekend days) in 6 categories (rural, residential, urban, suburban, office, industrial) were performed (Joseph, 2010a). The main focus of this study was to measure the environmental exposure due to signals from GSM, UMTS, HSPA, LTE (Long Term Evolution, 4G), WiMAX and if present FM, DAB and DVB. The maximal total field was 3,9 V/m in residential environment mainly due to the GSM900 signal. The exposure was the lowest in the rural environment with median value of 0,09 V/m, while the urban, office, industrial, suburban and residential environment the median exposures were about 0,4-0,8 V/m. The exposure ratio (ER: the ratio between the maximal measured electric field value for the considered signal and the corresponding ICNIRP reference level) was from 0,5% (WiMAX) to 9,3% (GSM900). Regarding the emerging technology the ER were 2,3% of UMTS, 1,2% of LTE and 0,5% of WiMAX respectively. The contributions of power density by the considered technology were more than 60% from GSM900+1800, more than 5% from UMTS and less than 1% from LTE and WiMAX. The second highest contribution generated by DECT systems. The contribution was 15% in residential environment and 23,8% in suburban environments respectively. The contribution of FM, T-DAB, PMR, TV/DVB-T was less than 20% in all environments. Regarding the indoor versus outdoor exposure the GSM900+1800 is the highest contributor in both environments. The GSM900 has the highest contributions with 57,5% at outdoor and 42,4% at indoor environment. The DECT has higher contributions indoor with 28,9%. The contributions of broadcast systems have no much difference between outdoor and indoor exposures. FM signal and WiMAX have the lowest variations during time. The highest long term variations have the GSM and UMTS signals at weekdays. The variations are higher during daytime than during nighttime and lowest standard deviations are obtained in the rural environment (Joseph, 2010a).

Many countries upload their measurement results on the internet and/or publish the data in every year. Within these documents the contribution of different RF sources of the total exposure and/or the distribution of the measured field by exposure levels use to be evaluated. Some European countries have database on the location of radio stations which open for the public. In many cases the database of radio broadcast and communication stations are merged with the database of results of exposure measurement. For example in *Portugal* to verify the compliance, entities qualified to install and use radio-communications stations must present every year to the national radio-communications regulator a monitoring and measurement plan of the levels of electromagnetic fields arising from radio communication stations, requesting the approval afterwards. The results of these monitoring activities must be presented every three months to ANACOM (Autoridade Nacional de Comunicasoes) to the Ministry for Health, and to the municipal councils of the places where the radio-communications stations are installed (ANACOM, homepage). Similar databases are available in UK such as “sitefinder” and database of mobile phone base stations (UK Database, web), Spain (MITYC, homepage), France (ANFR antenna database, homepage), Germany (RegTP, homepage) and also in many EU countries.

In summary the general results of European site measurements surveys showed that more than 60% of measured total EMF exposure were below 1 V/m (~0,003 W/m^2), less than 1% above 6 V/m (0,095 W/m^2) and only less than 0,1 % were above 20 V/m (1 W/m^2) field strength (power density). The relevant recommended exposure limit for the public is in the range of 40-60 V/m (~ 4-10 W/m^2). The absorbed power in the human body is related to the power density in free space. No exposure data above the public exposure limit were obtained from these surveys. Otherwise contribution of the RF exposure from wireless telecommunication technology is continuously increasing and now is above 60 % of the total exposure. Looking the geographical distributions no noticeable differences between the EU countries, however the exposure levels and contribution of different sources showed differences in rural an urban area. Nevertheless the contribution of RF exposure from mobile technology is higher in the urban area than in rural. Interestingly no differences was found in the countries where the 1999/519/EC European Recommendations on the exposure limits of general public has been implemented comparing where stricter limits and/or additional precautionary measures are introduced (EU Recommendation, 1999). Namely the level of public exposure is independent from the exposure limit in the considering country.

3.1.3 Personal and micro-environmental RF exposimetry

Recently the attempts of the assessment of individual RF exposure (personal exposimetry) have been appeared in the RF surveys. The reasons of this approach were providing more exact data of personal exposure and reducing the uncertainty of the exposure assessment of the public. Moreover the personal exposimetry was also challenged by epidemiological studies where measurements of different RF-EMF sources at various places, long term measurements and measurements when the investigated person moving were requested. The on-site measurement studies have focused mainly on maximum exposure levels, as appropriate for assessing compliance with safety limits, but not on exposure patterns in the general population such as average personal exposure, time spent above a threshold or rate of change. These quantities would be more interesting for health risk assessment and also for epidemiological studies. The availability of RF-EMF exposure meters (exposimeters) for the last few years provides frequency selective exposure assessment means that personal RF-EMF exposure to multiple sources in the everyday environment can be more accurately assessed (Knafl, 2008, Mann, 2005, Neubauer, 2008, Röösli, 2010, Thomas, 2008). The applicability of the RF exposimetry in several studies have been demonstrated on different population samples in the European countries such as Austria, Belgium, France, Germany, Hungary, Netherlands, Slovenia, Switzerland and UK. During more than 3900 person-days more than 260 million measurement samples were recorded in the last five years by this technology in Europe (Table.3).

Table 3*. Personal and microenvironmental RF exposimetry studies in the European countries*

Country	Recorded person-days	Estimated number of samples	Aim of the study	Publication	Comments
Austria	N.A.	N.A.	Evaluation of the device	Neubauer, 2008, 2010	Feasibility studies
Belgium	61	24 000	Exposure modeling	Joseph, 2010b	
France	377	2 500 000	Exposure assessment	Viel et al, 2008	2005-2006 two region
Germany	3000	2560 000 000	Exposure assessment, well being study	Thomas, 2008, a,b Radon, 2007	1500 children 1500 adolescent
Hungary	160	920 000	Exposure assessment	Thuróczy, 2008; Juhász, 2010	Adults, students, microenvironment in nursery schools
The Netherlands	103	>32 000	Exposure assessment	Bolte, 2008	Microenvironment exposure
Slovenia	51	66 000	Exposure assessment	Trcek, 2007; Valic, 2009	
Switzerland	166	650 000	Prediction of exposure	Frei,2009a,b	Recording 1 week per person
UK	10	50 000		Mann, 2005	
Total	3928	>260 000 000			

Nevertheless comparing exposure levels between countries using data from these first studies seems to be problematic due to the different types of measurement devices and/or different protocols and procedures of data analysis. Recently there is an attempt to harmonize these procedures for future studies (Röösli, 2010).

The general results of the personal exposure assessment show that the average RF level by personal exposures are lesser than the results from on-site measurements. According to the time analysis of the measurements, the individuals spent small fraction of the total measuring time above the detection limit of the exposimeter, that means less than 0,05 V/m (~0,007 mW/m^2) in average. Therefore robust regression on order statistics (ROS) method were have to be used calculating the arithmetic mean values including the none detect exposures (Röösli, 2008). According to the personal exposimetry data the averaged RF exposure is generally less than 0,2 V/m (~0,1 mW/m^2). The personal exposure measurements also showed that the contribution of exposure from mobile technology is in over 60 % of total RF exposure of the person (Frei, 2009a,b). For example in *France* according to the results of a personal exposimetry campaign shows that in the frequency range in the downlink of GSM 900 MHz, approximately 50 % of the measurement samples were below the detection limit (0,05 V/m). The same results in the GSM 1800 MHz and the 3G systems were 60% and 80% respectively (Viel, 2009). Also in *France* a trial of geostatistical estimation of electromagnetic exposure has been proposed providing an example of application of geostatistical methods combined with electric field recording with personal exposimeter to radio-electric exposure mapping (Isselmou, 2008). In a Swiss study (QUALIFEX project) the exposure on workdays was higher during daytime than night time (0,16 and 0,08 mW/m^2, respectively). Exposure levels and contributions of different sources at workdays and weekends were virtually the same (Frei, 2009a,b, Frei, 2010). Exposure levels were in general lower in private houses or flats than in offices and outdoors. At home, contributions from various RF sources were quite different between countries. Highest total personal RF-EMF exposure was measured inside transport vehicles although well below international reference levels. This is mainly due to mobile phone handsets. Mobile telecommunication can be considered the main exposure contribution to total RF-EMF in all microenvironments. Since the comparison between countries regarding typical exposure levels is lacking it is very much on the agenda comparing the mean exposure levels and contribution of different sources in specific environments among different European countries. This trial has been performed within five EU countries (Belgium, Switzerland, Slovenia, Hungary and The Netherlands). In each of these countries large measurement campaigns were performed using the same type of personal exposimeter. In all countries, exposure in offices was higher than in urban homes. One explanation for this might be that only daytime exposure was considered for offices as most people are at their offices during daytime, whereas in urban homes night-time measurements were also considered. It was shown that daytime values are in general higher than night-time values. In outdoor urban environments, mobile phone base stations (all countries) and mobile phone handsets dominate the exposure. Finally, exposure in all investigated countries is of the same order of magnitude. In all these countries there is a similar standard of living and the same RF-EMF sources and technologies (mobile phones, base stations, radio, TV/DAB) are present in similar amounts and densities (Joseph, 2010b).

3.1.4 Modeling of retrospective and predictive exposure assessments

Similar data were obtained from the exposure modeling and retrospective exposure assessments. These models generally support the epidemiological studies and provide long term retrospective exposure data and/or long term exposure predictions. However these data usually are valid for a selected population only (i.e. persons with certain diseases and their controls) these models may give valuable exposure assessment and can be considered (and extrapolated) to wide range of population. The most relevant data were obtained from the exposure modeling of population living around the radio and TV broadcast antennas. The exposure patterns of these fixed sources are more defined and the field strength generally depends on the distance from the antenna of the transmitter source (Fig.2).

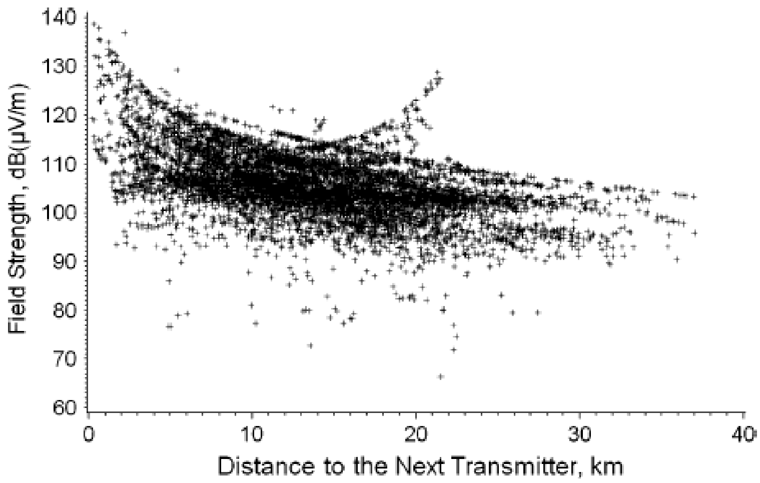

Fig.2. *Scatter plot of total radio frequency electromagnetic fields in relation to distance of study subjects' place of residence to the nearest main transmitter, Germany, 1984–2003. For example, 120 dB(µV/m) = 1 V/m. (from Merzenich, 2008)*

According to the validation by measurements in *German* childhood leukemia epidemiological study the distance from the antenna seems to be a good exposure proxy for a single transmitter only which uses the frequency bands of amplitude modulated radio, whereas it appeared to be of limited informative value in studies involving several transmitters, particularly if these are operating in different frequency bands (Merzenich, 2008, Schmiedel 2009). In this study 8,000 subjects and 20 years retrospective study period was evaluated. Recently in many countries terrestrial digital video (DVB-T) and audio broadcast (DAB) are going to replace the existing analogue broadcast systems. In *Germany* a measurement campaign was performed at more than 300 identical points, in a 'before' and 'after' switchover of this technology. The results of the measurement showed that the maximal exposure value for analogue TV in the 'before' measurement was 0,9 mW/m^2 and 6,5 mW/m^2 was 'after' measurement for DVB-T respectively. A comparison of analogue FM radio and DAB showed that FM exposure was higher with more than a factor of 10 (Schubert, 2007).

The field strengths inside the house are always lower depending on the frequency and the construction of each house. In the European houses the indoor power density values use to be approximately 10 times lower than outdoor. The range of the exposure of the population is very wide approximately 40 dB (covering the range of 10 000 in power density) with 0,17 V/m (0,08 mW/m^2) at 50% cumulative percent of distribution. Similarly in *Switzerland* according to the exposure models validated by measurements, the calculated averaged field strength on the street was 0,45 V/m (measured 0,37 V/m), the indoor level was 0,12 V/m (measured 0,13 V/m) respectively (Bürgi, 2009).

In another *German* study the applicability of a model to estimate radiofrequency electromagnetic field strength from mobile phone base stations in households was evaluated with technical data of mobile phone base stations available from the German Net Agency. Dosimetric measurements were performed in an epidemiological study participating more than 1300 households. The results of this measurements show that indoor exposures in 61% of the households were below the sensitivity threshold of the dosimeters (0,05 V/m). The average measured value of field strength (power density) was 0,072 V/m (~0,014 mW/m^2) the value calculated by the exposure model was 0,076 V/m (~0,015 mW/m^2). In this study the upper 10th percentiles (above of both outcomes were defined as the 'higher exposed' groups(Breckenkamp, 2008).

By similar approach in *Switzerland* the objective of the study was to develop a prediction model which can be used to predict mean RF-EMF exposure from different sources for a large study population in epidemiological research. For the development of the exposure prediction model they used measurements over one week of 166 volunteers carrying a personal exposimeter (Frei, 2009a), combined with information from questionnaires as well as modeled RF-EMF from fixed site transmitters at the homes of the volunteers (Bürgi, 2008, 2010). It should be noted that simulation studies showed that personal exposimeter measurements underestimate true exposure due to the impact of the body. For GSM 900 the average degree of underestimation by the exposimeter was 0,76, and for UMTS 0,87; for FM no underestimation was found, the ratio was 1. In the case of WLAN the degree of underestimation was more pronounced, the ratio was 0,64 (Neubauer, 2008, 2010).

In *France* a city-wide experiments will be started in 2010 reducing the RF emitted power of base stations with decreasing the exposure to electromagnetic fields in the environment of 17 cities, to see if this is technically and financially feasible. The mapping of exposure level will be performed by frequency selective personal RF exposimeters in parallel computing the reduction of RF exposure by mathematical computer modeling (COMOP Project, 2009).

3.1.5 Dosimetric considerations of far field exposure

The absorption of RF radiation in the far-field exposure assessment of the human body (called dosimetry of RF exposure) taking place more importance during the last decade. Recent results show that for adults, compliance with reference levels ensures compliance with basic restrictions, but concerning children models the whole-body-averaged SAR (Specific Absorption Rate) goes over the fundamental safety limits up to 40% (Conil, 2008). The ICNIRP also notes that there has been considerable advance in dosimetric investigations. According to the ICNIRP statement released on this issue, for bodies shorter than 1,3 m in height (corresponding approximately to children aged 8 y or younger) at the recommended reference level the induced SARs could be up to 40% higher than the current basic restriction under worst-case conditions in the frequency range 1-4 GHz. The ICNIRP concludes that this is negligible compared with the large reduction factor of 50 (5,000%) for the general public (ICNIRP, 2009). It is well known that the smaller the size of the human body phantom relative to wavelength, the higher the whole-body SAR. According to a similar study in Belgium the whole-body averaged SAR for a realistic (multipath) exposure exceeds the worst-case single plane wave exposure in approximately 10% of the exposure samples (Vermeeren, 2008). On the contrary in very recent results under multipath exposure (regarding to the real exposure conditions) the whole body exposure decreasing around 30% compare to the plane wave radiation (Kientega, 2010, MULTIPASS, homepage).

Another important dosimetric approach is the whole body SAR estimation in real exposure conditions. Statistical evaluation of the whole-body SAR in a human body phantom in a realistic exposure environment has been developed and the results shows that the whole-body SAR in a complex environment complies with the ICNIRP basic restriction when the averaged field over the human body is equal to the ICNIRP reference level (Vermeeren, 2008). In another research personal electromagnetic field measurements were converted into whole-body SAR for exposure of the general public assessed by personal RF exposimetry (Joseph, 2008, 2010c). The highest total whole body SAR was found at 1-year-old child, with 11,5 µW/kg (at 0,48 V/m). All other values were many times below the basic restriction of 0,08 W/kg (80 000 µW/kg) for the general public according to the EU recommendations.

By using realistic data on personal RF-EMF exposure and mobile phone use from a population based cohort study in Switzerland (QUALIFEX Project) the whole body averaged SAR (WBA-SAR) was compared from various near-field (i.e. mobile phone) and far-field sources (i.e. base stations, broadcasts) of the everyday environment (Lauer, 2010). The induced WBA-SAR caused by far field sources sums up to 561 nW/kg. In comparison, an average mobile phone user causes a self-induced WBA-SAR of 2µW/kg, when using the GSM 900 service exclusively. Using GSM 1800 or UMTS causes an induced WBA SAR of 1,26µW/kg and 12,6 nW/kg, respectively. The WBA-SAR of an average mobile phone user is dominated by the use of his or her own mobile phone when a GSM 900 or GSM 1800 phone is used. However, for a UMTS phone the far-field sources feature the dominant contribution to the WBA-SAR (Lauer, 2010).

3.2 Exposure assessment of RF sources close to the body: body-close portable sources

3.2.1 Mobile phones

The exposure assessment of RF sources close to the human body needs dosimetric evaluation due to the complex RF electromagnetic field nearby the RF devices. The most important device producing the highest exposure to RF of the public are the mobile phones (also called cellular phone or handy-phone). Other portable RF wireless devices which also can be proximate to the body expose the body by many time less exposure than mobile. The penetration of mobile phone across Europe is beyond 100% in many countries and Europe leads in mobile penetration worldwide (Fig.3,4).

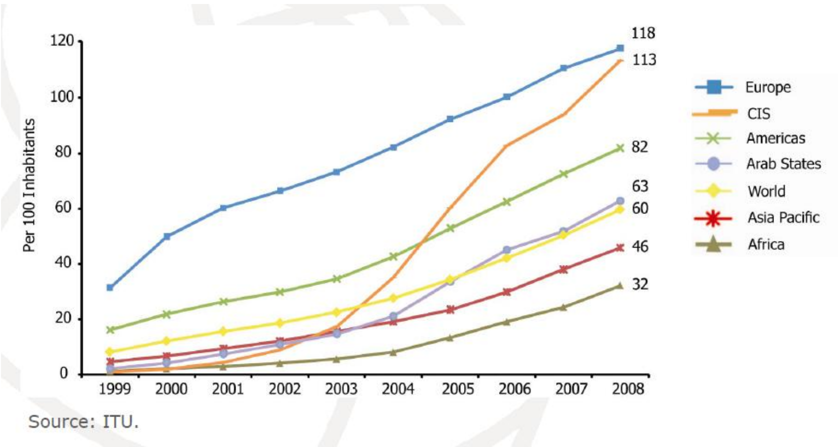

Fig.3. *Penetration of mobile phones per 100 inhabitants in the World (ITU, 2009).*

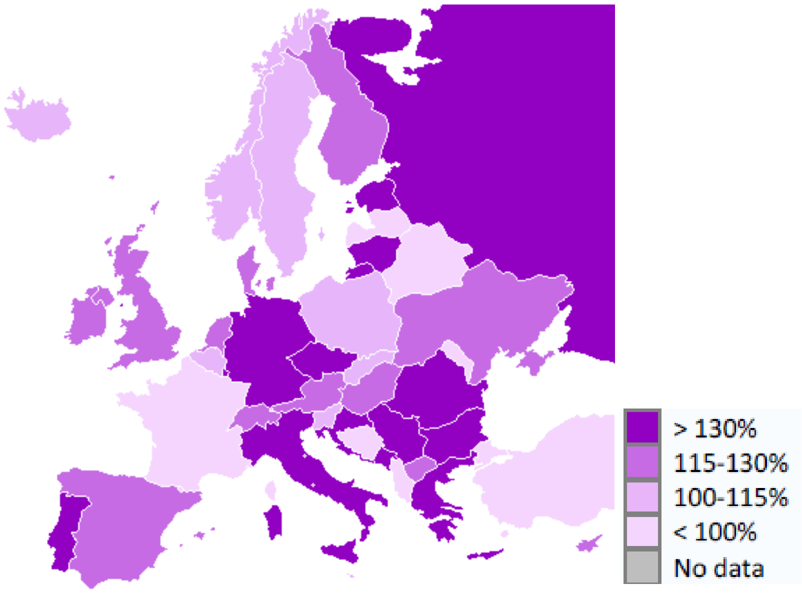

Fig.4 *Mobile phone penetration in Europe 2009 (from Wikipedia)*
Data are also available from International Telecommunication Union (ITU, 2009)

The averaged local exposure in the head induced by the mobile phone is considerably higher than that of the far field sources such as base stations and broadcasts sources. For example, the spatial peak SAR value in the brain during usage of a mobile phone can reach 1 W/kg which is more than five orders of magnitude larger than the corresponding value in a person exposed to an incident field of 1 V/m (corresponds ~ 1 μW/kg), for whole body averaged SAR levels of about 10 μW/kg, approximately corresponding to >0,5 V/m incident plane wave exposure. Estimating the cumulative exposure, about 30 min of mobile phone use corresponds to 1 day exposure from far field source at an incident level of 1–2 V/m (Neubauer, 2007). However the EU limit of permissible SAR in the head is 2 W/kg, the real life exposure to RF fields from mobile devices is less than the results of compliance tests. According to a study in Switzerland, the compliance tests of more than 600 mobile phones frequently used in the European countries produced between 2000 and 2005 and (Fig.5) at maximum radiated RF power provided a Gaussian distribution with around 1 W/kg peak frequency of maximum SAR measured according to EN standard in liquid head phantom (Kühn, 2007). Similar studies were performed in Germany with 0,8 W/kg peak. The most important variation of the output RF power emitted by GSM phones is due to the network parameters and mainly due to the adaptive power control (PWC) and discontinuous transmission (DTX) technique. PWC technique allows a power reduction of the power emitted by the handset. Therefore, close to a base station with an unobstructed communication path between handset and base station antenna, the emitted power of a GSM handset can be very low, while far away or due to shielding by buildings, the power may be constantly on the highest level (Wiart, 2000). The efficiency of power control depends on the technical parameters and systems of operators that can be different by the countries. The cumulative dose may also be affected by the radiation effectiveness of the phone, network coverage, environmental and user factors. In general the communication technology is a strong predictor of exposure from mobile phones. Different technologies can have a strong impact on the actual exposure, such as a factor over 100 between GSM and UMTS systems (Gosselini, 2010). Limited data are available about these differences within the EU countries so far.

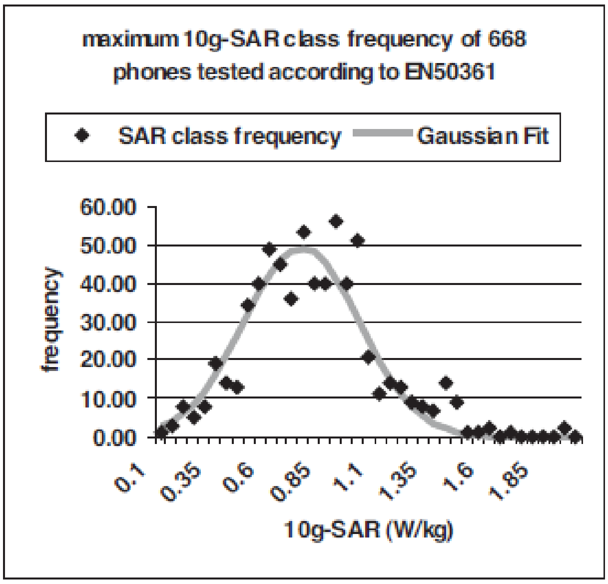

Fig.5. *Statistical distribution of maximum 10g SAR measured for 668 mobile phones in Switzerland according to EN50361 from years: 2000 – 2005 (from Kühn, 2005, 2007).*

According to the exposure assessment of epidemiological studies and the information from the operators, the phones in GSM mode work 30-50% of time in maximum power, while in 3G mode only 1 % of time. The largest exposure assessment study among the mobile phone users worldwide was performed within the INTERPHONE case-control epidemiological study (Berg, 2005, Cardis, 2007,). This population-based case–control study started in 2000 and is conducted according to a common core protocol in 13 different countries including eight European countries (Cardis, 2007, 2008, 2010). The exposure duration of mobile phone (duration of call) in the validation study of INTERPHONE shows that the average duration of call in Europe is approximately 500 min/month (~ 16 min/day). These data is different by countries, for example lower data were obtained in Germany and UK, higher data in Italy, Finland and Israel respectively. The number of calls and duration of calls can be a sufficient parameter to estimate the cumulative power emitted by the handset of a cellular telephone. Nevertheless some data shows that a high number of phone calls are operated at maximum power levels. For GSM900 maximum power is transmitted when establishing the connection with the base station and then PWC becomes active. Thus, with a longer duration of a call, the cumulative power increases only slowly. For example averaging the data over a sliding window of 6 min width in France gives a mean value of 25% of the maximum emitted power for a GSM900 phone (Wiart, 2000). The same is not true of 3G/WCDMA or other new mobile technologies. (Andersen, 2010). According to the Swiss QUALIFEX study the average mobile phone call time of the participants was 25,6 minutes per week. The average output power was 133 mW of GSM 900 mobile phone, 62,2 mW of GSM 1800 and 650 µW of UMTS phone (Frei, 2009a,b).

The field strength and distribution of SAR within the head are dependent on the phone design and the communication system. The influence of the hand was mainly present for the UMTS communication system, since in GSM the average output power in dominated by peak power excursion during handovers (Gosselin, 2010). It is important to emphasize that at distance 10 cm from the mobile phone the absorbed power in the head decreasing more than 10 times comparing assessed close to ear. At 40 cm in front of the head the maximum SAR over 10g is close to 1% of the SAR touching the phone to head (Gati, 2009).

3.2.2 Short range wireless devices (DECT, WiFi, WLAN, Bluetooth)

The normal operation for short range wireless devices and cellular phones fundamentally differ. Usually, exposure from DECT (cordless phone technology), Bluetooth and WLAN and WiFi devices is generally smaller than from cellular phones however present for a longer exposure period. The largest and comprehensive studies were reported by IT'IS Foundation in *Switzerland* on the exposure and dosimetry of short range wireless devices, body worn devices and base station wireless data communication devices in home and office environments (Kühn, 2005, 2007). Another study conducted by the in *Germany* reports on the measurement of exposure by the WLAN infrastructure in classrooms of university and in *Austria* where reports on exposure measurements from a notebook with integrated WLAN modules. In four cities of Germany the power density in different spots close to public WLAN 802.11b facilities was measured. The results showed a great spread of the power densities measured, ranging from some µW/m² to 23 mW/m². They concluded that the exposure of WLAN reduces rapidly with distance from the source and that at a distance of about one meter from the WLAN-Card the emission ranges from 15 to 20 mW/m² (Eddelbüttel, 2002). Similar studies were performed in *Italy*, *UK* and in *Romania* on the exposure assessment of WiFi technology indoor and the classroom of schools (Liberti, 2010, Miklaus, 2009, Peyman, 2007). A study from in *Croatia* reports on far-field measurements of DECT signals at different distances (1,5 m; 4,5 m; 5,5 m) from the DECT base station and also with the base station behind a wall (Simunic, 2000).

Considering the power levels of these short range wireless devices for DECT telephone a peak power of 250mW and for WLAN (802.11b) a peak power of 100mW is permitted. However the average output power of DECT handsets can be less than 10mW (Kühn, 2005, 2007). Additionally, in contrast to, for example, GSM cellular phones, DECT handsets are in general of larger size. Consequently, the position of the transmitting antenna can significantly vary in relation to the head.

Exposures from DECT handsets are rather low, i.e., below 0,1 W/kg. The maximum exposure of WLAN and highest power of Bluetooth device (class 1) can lead to levels similar to those of mobile phones, i.e., in the range of 0,1 - 1W/kg, on the other hand under normal operational circumstances these devices are operated at lower output power (Fig.6). The Bluetooth mobile headset devices operate at higher frequency than GSM and 3G mobile phones, they produce very low level SAR less than 0,005 W/kg. The Bluetooth USB dongle devices can produce higher SAR touching the body, but the uses of these devices are in general not operated as close to the body. The maximum exposures within a radius of one two meters of these transmitters corresponds to typical exposures inside apartments close to mobile phone base stations.

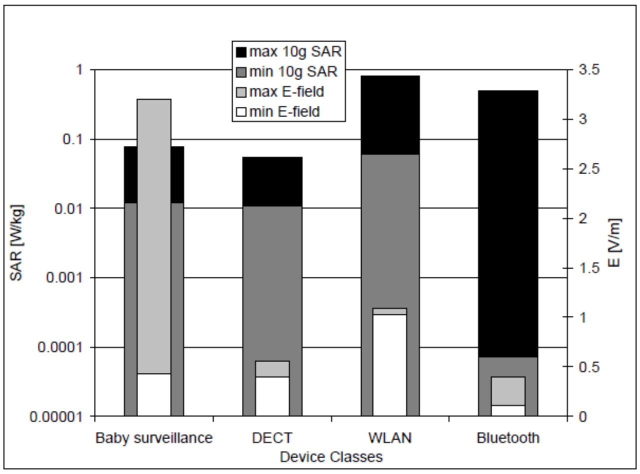

***Fig.6**. Overview of maximum and minimum measured E-fields (1m distance) and maximum and minimum determined 10g SAR of different device groups (from Kramer, 2005)*

The maximum electric field strength at 0,5 m distance from the base station wireless data communication devices varies between 0,6-4 V/m with corresponding maximum peak SAR with touching position 1,6 W/kg for the access point and 0,5 W/kg for PC cards respectively while but 5 cm from SMC access point the maximum SAR can be around 0,05 W/kg. It can be summarized that the dominant source of near-field exposure remains the cellular phone. However, the average SAR values for cellular phones can be reached by some home and office devices. In worst case situation the PDA showed peak spatial SAR values above the 2

W/kg limit. However the PDAs used to be keeping in the hand; therefore the 4 W/kg limit has to be applied (Kramer, 2005).

The wireless mice and wireless keyboard of PCs operate at 20-40 MHz frequency range that is lower than other wireless systems. These devices transmit RF radiation if they are under operation (moving, clicking or typing). The measured SARs were below 0,005 W/kg (detection limit) the electric field strength were also low 5 V/m around at 5 cm from the keyboard and ~2-5V/m at the fingers moving the mouse respectively (Kramer, 2005). For baby surveillance devices that are operated at 40-800 MHz, the determined 10g SAR is comparable to DECT handsets and is 10 times lower than cellular phones. It must be mentioned that under normal conditions a baby phone is not operated close to the body, but at approximately 0,5-1 m distance. The manuals of these devices generally recommend choosing a distance above 1 m.

It is also interesting to compare the exposure from short range wireless devices with exposure from body-far (outdoor) sources. Typical values inside buildings at distances up to 100m from GSM base station sites are in the range of 0,1-1V/m. Consequently, the electric field exposure caused by wireless home and office devices is in the range of exposure from a base station operated in close vicinity to an office or apartment (10-200m). However, with the growing the penetration of the wireless devices in home and office the exposure by a set of these devices will be necessary to assess the combined exposure (Kühn, 2005, 2007).

3.3 Trends of the RF exposure – future technologies

The exposure level in the living area is continuously increasing. According to the results of the first measurement campaign in several cities in USA, the average exposure level in urban areas in 1975 was approximately 0,05 mW/m^2 (Tell, 1977). In 1998 similar survey was elaborated in Sweden where the RF exposure level in the urban area was ~ 0,5 mW/m^2 (Uddmar, 1998). Recent results from the survey measurements in dense populated areas in Greece show ~ 10mW/m^2 averaged power density, 3,9mW/m^2 in urban areas and 1,3 mW/m^2) in rural areas (Manassa, 2009). While the measurements in US in 1975 show that the principal sources of radio-frequency radiation are from signals in the broadcast bands, nowadays more than 60% of RF the exposure radiated by the wireless telecommunication devices. This trend seems to be continuously increasing. The major part the RF public exposure comes from *mobile and wireless portable devices*, not from the fixed transmitters. Based on this fact researchers are currently working to develop a new technology that would allow to harvest and convert ambient electromagnetic radiation from phone antenna or other RF wave source to electricity so that the mobile device can be continuously powered up for longer talk time without the need of recharging. Reducing the emitted RF power of base stations may result in an increase in the number of base stations to provide services to mobile devices with limited sensitivity. Industry estimates suggest that decreasing the RF power by a factor of ten will require two and a half times more base stations for the same level of service.

Regarding the trend of development of new wireless technologies, the new design is moving toward the “Quality of Services, (QoS)” that operates “focusing area” instead of “covering area” in the wireless services, Access Point (AP) instead of base station (BS), “relaying” and not “endnote” systems (Gati, 2009). By the adaptive data rate the downlink sources will not have power control as was used in the GSM systems. The introducing of LTE system may generate maximum +10% increasing of the environmental exposure levels with very high capacity and speed services. Due to the request of higher capacity and higher speed of data transfer the frequency range of wireless technology will be increasing beyond 5 GHz. For example the frequency range of WiFi (nowadays is 2,45 GHz) will be increased up to 60 GHz in the WiGig (Wireless Gigabit) technology providing 10 times faster service than the highest WiFi (WiGig, homepage). High data rate induces a higher power levels but not necessary a higher exposure due to the different positioning of the device than the position of mobile phones (Gati, 2009). New technologies called Wireless Body Area Networks (WBANs) are deployed for higher data rates. Recently the Ultra-wideband (UWB) technology is foreseen as one of the main candidates for the wireless technology. Main advantages of UWB are potentially high data rates, low power consumption and restricted levels of emitted power due to very short and low-power impulse signals between 3 and 10 GHz (Klemm, 2006, Chen, 2006). The RFID (Radio Frequency Identification) systems are also increasing worldwide. Generally the indoor RF exposure seems to be increasing faster than outdoor exposure due to the increasing of home and office wireless devices. Therefore, in the very near future the background exposure in everyday life situations will exceed exposures from base stations and broadcast stations (Kramer, 2005).

4 Conclusions

- A number of RF exposure survey and/or modeling has been performed in EU member states since 2000. There are four main type of exposure assessment have been introduced in the European countries such as *i)* permanent RF radiation monitoring systems, *ii)* on-site measurement campaigns, *iii)* personal and micro-environmental RF exposimetry and *iv)* modeling of retrospective and predictive exposure. There are different activities of RF exposure assessment within the member states nevertheless the highest activities could be recognized in France, Italy, Germany, Spain and UK.
- The general RF exposure level of the population from the fixed RF sources including LF/MF broadcast, VHF broadcast, UHF TV and telecommunications is very low. The range is between 0,01-1 V/m in Europe that is many times below the exposure limits of EU recommendations. The results of exposure measurements show that more than 60% of recorded total EMF exposures were below 1 V/m, less than 1% above 6 V/m and only less than 0,1 % were above 20 V/m field strength. The relevant European recommended exposure limit for the public is in the range of 28 V/m to 87 V/m. Otherwise the contribution of the RF exposure from wireless telecommunication technology is continuously increasing and now is above 60 % of the total exposure.
- Looking the geographical distributions, no noticeable differences are between the EU countries (or difficult to recognize), however the exposure levels and contribution of different sources showed differences in rural and urban areas. Nevertheless different technologies can have a strong impact on the actual exposure, such as a factor over hundred for example between GSM and UMTS. Limited data are available about these differences within the EU countries so far.
- The major part the RF public exposure comes from mobile and wireless portable devices, not from the fixed transmitters. The cumulative dose may also be affected by the radiation effectiveness of the phone, network coverage, environmental and user factors.
- The indoor RF exposure seems to be increasing faster than outdoor exposure due to the widespreading of home wireless devices. This will considerably increase the complexity of epidemiological studies. The dominant source with respect to local and cumulative exposure will, however, be the cellular and portable phone.
- Regarding the exposure classification from the point of view of risk analysis, four main categories can be recognized: *i)* intermittent variable local exposure; *ii)* intermittent variable low level exposure; *iii)* continuous variable low level exposure and *iv)* continuous determined low level exposure (Table 4.).

Table 4. *Classification of RF public exposure*

Exposure classification	***Description, main sources and relevance of risk evaluation***
Intermittent variable local exposure	- Highest level of exposure category including mostly the mobile and wireless handsets (body-close portable devices). The exposure levels are highly variable and local. The exposure is intermittent. The levels of exposure are below the recommended European exposure limit (2 W/kg), but the local maximum may close to the limit. The most characterstic exposure unit is the SAR (W/kg). - Typical sources: mobile handsets (GSM, 3G), DECT phones, other wireless handsets. - This category is the most important for some risk evaluation studies.
Intermittent variable low level exposure	- Medium level of exposure category including mostly the indoor wireless portable and fixed devices. The exposure levels are variable, inhomogeneous, local and/or whole body. The exposure is intermittent, the mean and maximum exposure levels are well below the recommended European exposure limits. The most characteristic exposure units are the electric and magnetic field strength or under special conditions the SAR. - Typical sources: WiFi, WLAN, wireless and Bluetooth USB dongle devices, other wireless portable devices. - This category has limited importance for risk analysis, but under some conditions (i.e. children exposure from WiFi, baby surveillance systems) may be relevant for investigations.
Continuous variable low level exposure	- Low level of exposure category including mostly the fixed outdoor sources of wireless telecommunication systems (mobile base stations, body-far fixed sources). The exposure levels are variable in space and time. The exposure is continuous, whole body and the mean and maximum exposure levels are many times below the recommended European exposure limits (typically less than 1 V/m). The most characteristic exposure units are the electric and magnetic field strength. - Typical sources: mobile telephone base stations (GSM, 3G, LTE), WiMAX base stations. - This category has very limited importance for risk analysis except the investigations of long-term changes exposure to RF of general population.
Continuous determined low level exposure	- Low level of exposure category including mostly the fixed outdoor sources of TV and radio broadcasts systems. The exposure levels are variable, but better determined in space. The exposure is continuous, whole body and the mean and maximum exposure levels are many times below the recommended European exposure limits. The frequency range is wide from kHz to GHz. The most characteristic exposure units are the electric and magnetic field strength. - Typical sources: radio and TV broadcasts systems, other continuous radio communication systems. - This category has been studied previously for risk analysis therefore has limited importance for investigations except of certain cohort epidemiological studies.

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