European Health Risk Assessment Network on Electromagnetic Fields Exposure

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

Part 2: Extremely low frequency (ELF) fields

Deliverable Report D4 of EHFRAN project

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1. Sources and source characterization

Time-varying electric and magnetic fields (EMFs) with a frequency below 300 Hz are defined as being extremely low frequency (ELF). The most prominent frequency in Europe is 50 Hz (often called power frequency) and its harmonics, mainly the third one. Electric trains are operated at 16.7 Hz in some EU countries, so public exposures at this frequency also have to be taken into account (WHO, 2007).

The main sources of exposure for the general public are from household and similar electric appliances, transmission power lines, transformer stations, the wiring of buildings and from electric transportation systems. Of these, the most important source are household electric appliances, and millions of these devices are used in everyday life. Exposures from these devices are localized and strongly depend on the distance from the appliance. The spatially most extended outdoor sources are high-voltage overhead power lines used for the transmission and distribution of electricity, including the feeder lines for electric vehicles like trams and commuter trains. There are approximately 360,000 km of overhead transmission power lines in the EU at voltages of between 110 - 400 kV (ENTSO-E, 2009, COM, 2003). A large country such as France, has approximately 47,000 km of these lines while a smaller countries like Hungary has approximately 3,000 km (Table 1).

Underground cables are also used to deliver electrical power. Approximately 2% of all electric power transport system is supplied by underground cables in Europe (ENTSO, 2009). The electric field at ground level is negligible because the cables are usually very close one another and the cables themselves are shielded with metallic sleeves. In addition, the magnetic fields from underground cables are usually significantly lower than those from an equivalent overhead line (Fig.1), but on the line of the route itself the field can be higher (ICF, 2003).

Low voltage electricity supply networks also produce magnetic fields. These systems are either wired in buildings, or placed on, or in, walls. The estimation of magnetic fields from these systems is difficult due to the large variation of system configuration..

Table 1: High-voltage power lines used in 27 different European countries

Country	*110-150 kV* (km)	*220-300 kV* (km)	*380-400 kV* (km)
Austria	6000	3760	2148
Belgium	3717	267	883
Bulgaria	n.a.	2745	2336
Cyprus	1227	-	-
Denmark	3954	260	1346
Estonia	3434	184	1541
Finland	15200	2400	3793
France	n.a.	25496	20869
Germany	n.a.	19000	18869
Greece	7745	-	2153
Hungary	157	1187	2000
Ireland	3611	1676	438
Italy	31158	12557	316
Latvia	n.a.	n.a.	1249
Lithuania	5000	1670	n.a.
Luxemburg	-	259	-
Netherland	6011	677	2003
Norway	10470	5257	2144
Poland	n.a.	7919	5274
Portugal	2400	2588	1235
Romania	n.a.	4096	4740
Slovakia	n.a.	962	1776
Slovenia	n.a.	328	508
Spain	20706	16351	15892
Sweden	15000	4435	10706
Switzerland	n.a.	5116	1597
UK	n.a.	13434	1052
Total EU25	135790	132624	104868

Various automobile components require electrical energy. This produces a low-frequency magnetic field in the cables and components that conduct the electricity. The frequency range is wide, from few Hz to kHz. The new hybrid cars may produce higher magnetic fields than those with only petrol or diesel engines (WHO, 2007).

EMFs of between 300 Hz and 100 kHz are defined as intermediate frequencies (IF). Sources of IF fields include computer and television screens containing cathode ray tubes, anti-theft devices in shops, toils including electric engines, and induction hotplates. Recently, others sources have appeared on the market ,such as compact fluorescent lamps (energy saving incandescent bulbs), and devices to allow inductive charging of batteries wirelessly by electromagnetic field (BIO Intelligent Services, 2010).

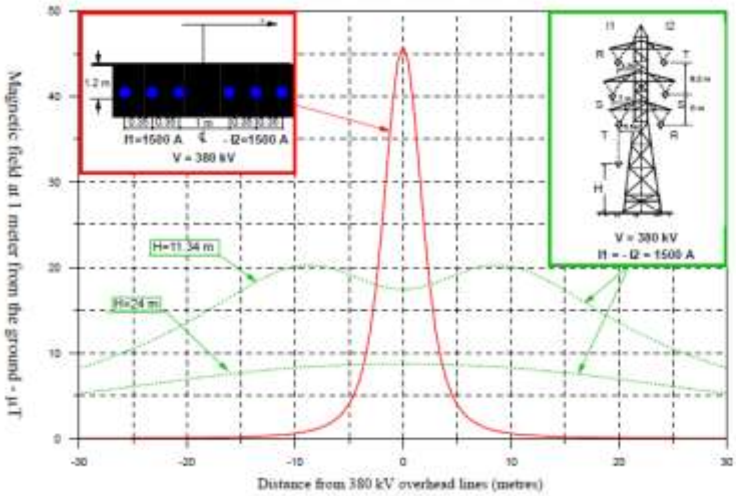

Fig.1 Examples of changes in magnetic fields with distance from a high-voltage underground cable (red) and a high voltage overhead power line, both operating at 380 kV (ICF, 2003)

2. Exposure assessment campaigns in Europe

Only a few countries, such as France, Germany, and the UK, have conducted large-scale assessments of public exposure to ELF fields.. In some European countries, assessments of exposure to ELF fields were performed that were limited to either a selected environment, a certain population (i.e. children, workers) or in a particular region of the country (i.e. in a specific town). Many of the studies with ELF magnetic fields were performed in support of epidemiological studies of childhood leukaemia. The aims of these exposure assessment studies were to estimate the level of magnetic field in case-control studies, and to classify participants into exposed and non-exposed groups regarding the levels of 0.4 µT and/or 0.2 µT, exposure categories suggested by pooled epidemiological studies (Greeland, 2000). Different methods of exposure assessments have been performed in Europe during the last decades including (i) indoot and outdoor spot measurements , (ii) personal (or individual) expositmetry, (iii) modelling exposures using the arrangement of wire systems, and (iv) measuring the magnetic fields around electric devices and household electrical appliances. So far, there has been no harmonized exposure assessment campaign on ELF within the EU , the exception being for those countries who are involved in the *International Study of Childhood Leukemia and*

Residences Near Electrical Transformer Rooms (Transexpo, 2010). Measurement studies were conducted to characterize ELF magnetic field exposure in apartments directly above a built-in electrical transformer, and in apartments in the same building that are located some distance from the transformer., It has been suggested that such an international study has a strong potential to provide new data by focusing on the population with high exposures and it has the added ability to evaluate selection bias. Several European countries are already involved in the project where the harmonized protocol looks feasible (i.e. Bulgaria, Finland, Hungary, Netherland, Italy, and Switzerland) and more are considering it (i.e. Portugal, Spain, Greece and Denmark).

2.1 Outdoor spot measurements in EU countries

Exposure measurement of ELF magnetic fields in urban environments has been performed in Spain, Italy, Sweden, Norway and in the UK. In Spain, spot measurements were evaluated in five cities. The average magnetic field was 0.2 µT in a range of 0 – 7.04 µT. (Paniagua et al., 2004, 2007). In Sweden, the ELF magnetic fields along certain stretches of sidewalk in the centre of Göteborg were mapped. About 50% of the investigated streets shows magnetic fields of the same order of magnitude. The median value of magnetic field was 0.2 µT (Lindgren, 2001). Similar surveys were conducted in Turin, a town located in the northwest of Italy, with approximately 1 million inhabitants. Measurements were made while walking at normal speed along an established path. Data were collected each 1.5 s, which corresponds to an interval of about 1.8 m. The measured data, consisting of more than 100,000 samples, did not follow a normal distribution, and showed an arithmetic mean (AR) of 0.19 µT, a median of 0.08 µT and a geometric mean (GM) of 0.06 µT (d'Amore, 2001). Between 2006 and 2008, outdoor and indoor measurement campaings were carried out in the town of Aosta in Italy,   . The highest outdoor measurement of 80 µT was measured against the wall of a transformer box, this reduced to 1.34 µT at 1 m from the wall (Bottura, 2009). In order to evaluate the seasonal variations due to power consumption, ELF magnetic fields were measured both during summer and winter In a city in Norway. Magnetic fields were mapped 1.0 m above the ground. In summer, less than 4% of the streets showed values exceeding 0.4 µT, but this increased to 29% and 34% on cold and on snowy winter days, respectively. The average levels were 0.13 μT (summer), 0.85 μT (winter, cold), and 0.90 μT (winter, snow), with the highest recorded value of 37 μT (Straume et al. 2008). The exposure of the general public from Belgian power distribution substations that transform the voltage from 11 to 0.22-0.4 kV were reported by Joseph et al. (2008). The magnetic field values were within the range of 0.025 to 47.4 μT. Average exposures of 0.4 μT were obtained at a minimum distance of between 5.4 m (average day) and 7.2 m (average year) . In the UK, the NRPB (now part of the Health Protection Agency) has performed measurements on 27 substations. Typical values at the perimeter fence were 10 μT for 275 and 400 kV substations , and 1.6 μT for an 11 kV substation. The mean field at the substation boundary was 1.1 μT, with a field of 0.2 μT up to 1.5 m from the boundary,(Maslanyj, 1996).

Many measurements have been carried out around high-voltage power lines in order to map the spatial distribution of magnetic and electric fields. A large electricity pylon carrying a 380/400kV conductor produces a magnetic field of around 10 - 20 μT directly under the line, and an electric field of around 3 – 5 kV/m. These levels fall with distance from the sides of the line. For example, approximately 25 ms to the side of the pylon, the magnetic field is estimated to be below 5 μT, and the electric field is between 200 – 500 V/m. At a distance of 50 m, the magnetic field level was typically found to be below 1 μT, and less than 0.2 μT at 100 m . The value of magnetic field not only depends on the actual current in the line but also on the structure of wire system of the power line (WHO, 2007). While exposure assessment for magnetic fields is a major challenge, exposure assessment for electric fields is even more difficult and is less well developed. The main reason is that the ELF magnetic fields can penetrate into the body and pass through the non-metallic objects, but electric fields do not. Therefore, both measurement and calculation of electric fields in the presence of objects such as trees or buildings represents a difficult task (Kheifets, 2010).

In summary, the outdoor average ELF magnetic field in public areas in urban environments is around 0.05-0.2 μT, but higher values may occur directly beneath high-voltage power lines, at the wall of transformer buildings, and at the boundary fences of substations. In the case of the latter, the maximum field can reach up to 20 - 80 μT. The results of these surveys indicate that knowledge of urban background magnetic field levels is very important for a complete definition of general public exposure.

2.2 Residential and indoor exposure assessments

For residential exposure, the major sources of magnetic fields are household appliances, nearby power and high-voltage transmission lines, and domestic installations. Long-term exposures are mainly caused by power lines, transformer stations and domestic electrical wiring installations . In some cases exposures form electric trains also need to be considered. Power lines frequently cross built-up areas and these cause elevated magnetic fields in those homes that are situated under or near these lines (WHO, 2007, SCENIHR, 2009).

The largest campaign of residential exposure assessment was performed in Germany. with measurements of magnetic field at 50 Hz and 16.7 Hz made in 1,835 fixed-location residences. Fields were measured in children's bedrooms for 24 h. Median 50 Hz magnetic fields above 0.2 µT were found only in 1.4% of all homes. Higher magnetic fields were less frequently encountered: 0.3 µT was found in 0.4 % ,and 0.4 µT was found in 0.2 % of residences. The fields produced by high-voltage power lines (123 - 420 kV) were lower than expected, and the median magnetic field was above 0.2 µT in only 8 of 25 residences (32.0%) that were located 50 m or closer to the power line. Higher magnetic fields were measured in apartment buildings (Schüz et al, 2000).

In the UK, a week-long survey of power-frequency magnetic field measurements was conducted in 258 homes . The strongest identified factor influencing exposure at home was the presence or absence of overhead lines at voltages of 132 kV or above within 100 m of the home. The geometric-mean of time-weighted average field encountered was 0.208 µT within 100 m from the lines, and 0.054 µT not near to the lines. (Merchant, 1994). Similar studies were carried out in Austria with spot measurements at the bedside in 226 households. Average night-time ELF magnetic fields above 0.1 µT were obtained in 2.3% on households. Highest ELF electric fields were primarily due to the prersence of lamps beside the bed (maximum of 166 V/m). Highest ELF magnetic fields were attributed to the transformers of these devices (maximum of 1.03 µT) or high current of power lines (maximum of 0.38 µT). Simple reduction measures resulted in an average decrease to 0.023 µT for the magnetic fields and to 23 V/m for the electric fields. The most frequent reduction measures were removing or rearranging clock radios and transformers of devices, removing or rearranging bedside lamps, rearranging extension cables and multiple outlets, removing fuses or changing phase and neutral line (Tomitsch, 2010). In the UK, both electric and magnetic fields were measured in 549 homes within the United Kingdom Childhood Cancer Study (UKCCSI, 1999). In a follow-up study, 196 homes were identified and categorized into high (> 0.2 µT) and low (< 0.2 µT) exposure (Maslanyj, 2005). The possible sources of exposure were also analyzed. In 102 homes with fields estimated at or above 0.2 µ, exposure was attributed to the low voltage (0.4 kV) supply to the home.

In Sweden, ELF field measurements were performed in 100 houses, randomly selected to be in either urban areas or in the countryside. The study found that almost 90 % of the measured houses had magnetic fields below 0.2 µT, with a mean value of 0.11 µT and a median value of 0.05 µT. The magnetic field was found to be highest on the ground-floor in most of the houses as compared to middle or top floors. About 36 % of the houses had the highest magnetic fields on the ground-floor This was due to underground heating systems and the electric wiring in the houses. Total harmonic distortion was found to be high in some houses and the reason for this was the large amount of non-linear loads (Khan and Silva, 2010).

In Italy, to evaluate the background levels of magnetic fields, a survey was performed in different rooms of 37 houses with no nearby overhead power lines. The field levels were measured under “power-off” (i.e., household devices were turned off) and power-on (i.e., household devices in normal use) conditions. The average magnetic field level was higher in apartments (0.8 µT) than in houses (0.3 µT) (Anversa, 1995).

In some European countries, 10/0.4 kV transformer stations are being installed in multilevel residential buildings. The built-in transformer stations elevate the magnetic field exposure in the rooms directly above the station. The source of magnetic field is mainly due to the distribution bars mounted on the ceiling of the room containing the transformer. The magnetic field reached as high as some tens of µT at the floor, but decreased to a few µT 1 m above from the floor. These results are consistent with a study performed in Hungary, where the mean magnetic field exposure of a number of rooms were characterized using five spot measurements made at a height of 1 m above the floort. The results of the measurements in 31 multilevel buildings showed that in the apartments just above the transformer station the mean exposure to 50 Hz magnetic fields was 0.98 µT, whereas in the apartments on other upper floors it was only 0.1 µT (Thuróczy, 2008). In another study (Szabó, 2007), time-weighted average

personal exposure in the apartment above the transformer were found to be 0.825 and 1.033 µT, for home and in bed respectively. In a Finnish study, the mean of spot measurements was found of 0.62 µT in the apartments immediately above transformers, 0.21 µT for apartments on the first floor, and 0.11 µT in apartments in other upper floors (Ilonen, 2008). Moving the distribution of bars/cables onto the floor can significantly reduce the exposure (by 3-10 times less) in the apartment above the transformer station. Similar studies have been conducted in Switzerland: the magnetic field was 0.59 µT on average in apartments that were either directly above the transformer or were in contact with the transformer room, but exposure was reduced to 0.07 µT in apartments which did not touch any wall of the transformer buildings (Röösli, 2010). Preliminary results from Bulgaria show that in the apartments above the transformers the average magnetic field was 0.4 µT, while on other floors it was 0.10 µT (Transexpo, 2010).
Data from various countries show that the geometric mean of spot measurements in homes do not vary strongly. In Finland, the geometric mean is 0.060 µT, and between 0.026 to 0.029 µT in Germany, 0.037 to 0.048 µT in Sweden, and 0.029 to 0.064 µT in the UK. There is a tendency to find higher fields in countries with lower distribution voltages. These data should, however, be interpreted with care, given great differences in the evaluation conditions (WHO, 2007).
Residential exposure from transport systems was surveyed in Lower Austria, where both 16.7 and 50-2000 Hz magnetic field exposure was measured for 8 h at the bedside of 226 residences. The arithmetic means were 0.0023 and 0.025 µT, respectively for the above mentioned frequencies (Tomitsch, 2010).

2.3 Exposure measurements of electric devices

For members of the public, the highest ELF fields are found in close vicinity of household and similar appliances, and these fields may reach up to few mT. However, these high fields are very localized and are limited to very short distances (less than some centimetres) from the surface of the equipment. According to SCENIHR (2009) the maximum possible exposure next to a specific source often differs by some orders of magnitude from the average for individual exposure. For assessment of compliance with exposure limits, the maximum possible exposure next to devices must be measured. Additionally, the exposure times are usually also limited for short-term use. The highest exposures in the ELF range occur during the use of electrical appliances that are held in close proximity to the body; for example, the use of electric razors or hair dryers (WHO, 2007).

In a survey of 50 homes in the UK, magnetic fields were assessed at various distances from domestic appliances, The 50 Hz fundamental and harmonic magnetic fields generated by 806 domestic appliances found in the houses were measured. Appliances were measured at standard distances and the magnetic fields were calculated from a mathematical model at 100 and 50 cm to remove room background contributions (Preece, 1997). The fields generated by a few appliances were in excess of 0.2 μT at a distance of 1 m: microwave cookers produced 0.37 μT; washing machines 0.27 μT; dishwashers 0.23 μT; some electric showers 0.11 μT; and can openers produced 0.2 μT. Of continuously operating devices, only three devices produced significant fields at 0.5 m: central heating pumps produced 0.51 μT, central heating boilers 0.27 μT and fish-tank air pumps produced 0.32 μT. Persons spent on average about 4.5 h per day in the kitchen, where the strongest sources of magnetic field were located (Preece, 1997). According to another survey from the UK, typical magnetic fields from underfloor heating systems of up to a few microtesla can occur at floor level, falling to a few tenths of a microtesla at 1 m above the floor. It ws found that the magnetic field depende on the configuration and depth of the cables, and the current flowing in them. Many systems draw current only overnight, using off-peak electricity, and relying on the heat capacity of the floor to provide warmth during the day (Allen et al, 1994).

In a German study, exposure to the magnetic fields from household appliances was quantified as net appliance-years of lifetime use and cumulative μT-hours, on the basis of measurements of appliances available in the published literature. Exposure was assessed on three different levels of precision: ever use, cumulative appliance-years, and average time of daily use (Behrens, 2004). Altogether, use of 8.454 appliances was reported in the structured interview of the 3,041 subjects. In total, 152,580 appliance-years were reported of which TVs had the greatest share (107,704 years), followed by microwave ovens (16,134 years), and electric blankets (10,375 years). The lifelong cumulated values were calculated from the questionnaire information on average time of daily use, the number of appliance-years, and estimated average magnetic field of the appliances. Electric alarm clocks and electromechanical digital alarm clocks showed the highest number of μT-hours of all appliances (7,688,126 and 2,854,417 µT-hours, respectively) followed by electric blankets (1,695,462 µT-hours) and TVs (498,152 µT-hours). For comparison, in the German study mentioned above, the measurements of magnetic fields from outdoor sources in residences exceeded 0.2 µT in only 1.4% of homes, with a mean value of approximately 0.04 µT (Schüz et al, 2000). Considering an average exposure of 12 h per day, a 10-year cumulative exposure would, therefore, add up to 1,752 µT-hours from outdoor sources in residences. Another example is the daily exposure of workers with 8 h working day and a 5-day working week, where cumulative exposure in 10 years would be roughly 6250 µT–hours (Kheifets 1997). These exposures are still way below the exposure caused by, for example use of an electrical alarm clock next to the bed assuming that a 10-year cumulative exposure would total 21,608 µT–hours. These data suggest that one third of the total exposure to magnetic fields can be attributed to personal appliance use (Behrens, 2004).

More than 1,000 electric appliances have been investigated in Austria regarding their emission of magnetic fields. It was found that complex frequency spectra measured from 5 Hz to 2 kHz are common and single frequency (i.e. 50 Hz) emissions are rare (Leitgeb, 2008a). Usually, the devices emit complex frequency spectra, particularly those with electronically switched power control and/or electric motors. Since exposure assessment requires frequency weighted sums, root-mean-square (rms) values are not appropriate for comparison with exposure reference levels (ICNIRP, 2010). This is because, rms-values considerably underestimate exposure compared to peak field values used for health risk assessment. Analysis of groups of devices showed a wide span of emission values of up to two orders of magnitude, with only weak associations to power consumption. Electric appliances usually simultaneously emit both electric and magnetic fields and expose almost the same body region. Since the sum of induced current densities is limited, one field component reduces the available margin for the other. It was found that many devices considerably exceeded the permitted reference levels and require a closer analysis to demonstrate conformity with basic restrictions (Leitgeb, 2008b, 2008c).

Within homes, house wiring and appliances (operating or just plugged in) are the most common sources of electric fields, and levels typically range between 1 and 10 V/m. Appliances can result in high electric field exposures and are on the order of a few hundred V/m near some appliances, though these fields diminish to the levels present from other sources after about one meter (Kheifets, 2010).

2.4 Exposure from transport systems

Relatively few studies have been conducted within the EU on the ELF exposure levels from transport systems such as trains, trams and hybrid cars. The maximum levels of recorded magnetic field strength are emitted at 50 Hz in a tram, 15.25–16.50 Hz in a train, and 12 Hz in a hybrid car (Halgamuge, 2010).

According to WHO (2007), peak magnetic fields of up to a few tens of μT have been recorded on the platform of a local city railway line. In France, measurements inside a high-speed train, and at a distance of 10 m outside the train, showed peak values around 6 to 7 μT during high-speed drive (Gourdon, 1993). In a Swedish study, field values in the driver cabin ranged from a few μT to over 100 μT, with mean values for a working day between a few μT to up to tens of μT depending on the engine. The measurements of magnetic field strength in the front of a train at floor level were in the range of 3.4–8.7 μT. In a tram, the peak magnetic field strength of 7.6 μT was recorded in the middle of the tram on the floor level when another tram passed in close proximity. The magnetic field strength near the floor on the outside of the tram reached up to 3.5 μT when a tram passed on the rail. Most of the field strength was in the range of 0.01–5.5 μT.

Cars are another source of ELF magnetic fields. The range of magnetic fields in a hybrid car was found to vary between 0.03-2.4 μT.. Low frequency magnetic fields (5-2000 Hz) in all four seats of seven stationary cars were determined with their engine and air conditioning running. Magnetic field averaged over the body were between 0.03-4 μT. At the left rear seat, a maximum magnetic field of 14 μT was measured at foot level (Vedholm, 1996). The Swiss Federal Office of Public Health (FOPH) commissioned a study in which the magnetic fields produced by car tyres were measured. Since the low-frequency magnetic fields are produced when the magnetic tyres rotate, measurements were made in cars travelling at 80 km/h. The magnetic fields were measured at frequencies of 5 to 2,000 Hz in 12 different cars. High values were measured in the foot area of the passenger seat and on the back seat. In 33% of the cars, values above 2 μT were measured; in 25% of the cars values were above 6 μT. However, these data are referring to old technologies (form about 15 years ago) and should be updated. The fundamental frequency of the magnetic fields is 10-12 Hz at a speed of 80 km/h. However higher harmonic frequencies were also measured (Stankowski, 2006, FOPH, 2009).

2.5 Personal ELF exposimetry

Monitoring the individual magnetic field exposure of a subject using a personal exposure meter (sometimes called a “dosimeter”) worn on the body is attractive because it captures exposure to fields from all sources and at all places the individual encounters. Since for all practical purposes, the human body does not perturbate the magnetic field at ELF frequencies, the recorded magnetic field may represent a reliable estimation of the real exposure levels. The values of magnetic field exposure recorded by personal (isotropic) meter tend to be higher than those derived from spot or long-term measurements in homes, because the device will measure the field from all sources (WHO, 2007).

Most of the personal exposimetry studies were performed using the same type of device (EMDEX-II or EMDEX-PAL) both in Europe and elsewhere.. Therefore the results derived from different studies in various countries are comparable. Personal ELF exposimetry studies have been performed in a number of European countries in the last decade, including Germany, France, the UK, Denmark, Switzerland, Austria, and Hungary. The largest studies were conducted in Germany, France, and Switzerland.

In Germany, individual magnetic field measurements at 50 Hz and 16.7 Hz of 1,952 people selected from the Bavarian population were performed between 1996 and 1997. The mean of the 1,952 individual means was 0.101 µT and that of the individual medians was 0.047 µT at 50 Hz. Only 2,4% of the subjects showed individual medians higher than 0.2 µT. Fields exceeding 100 µT at 50 Hz were measured in 31 persons. The total time with such extreme exposures only amounted to about 21 min, which was less than 0.001% of the total time for all measurements (5.3 years). For persons living next to railway lines, the mean individual magnetic field at 16.7 Hz was calculated to be 0.156 µT, and the mean individual median was 0.102 µT (Brix, 2001).

In Switzerland, a study with 552 volunteers was performed over 24 h period in order to assess typical levels of 50 Hz magnetic fields and to identify the main causes for elevated field levels,. The participants were selected from different professions and areas of northern Switzerland. The daily averages were found to be below 0.2 µT for 75 % of the volunteers and for only 3 % of the cases this value was above 1 µT. The data showed an almost lognormal distribution (Stratmann, 1994).

Exposure to 50 Hz electric and magnetic fields for 24 h was measured for 301 volunteers in Denmark. Electric and magnetic fields were measured with personal dosimeters, and the mean values were calculated for work and non-work periods. The magnetic field exposure in residences away from power lines was 0.04 µT, and in residences near power lines was 0.29 µT (Skotte, 1994). According to a recent study in Austria, the median exposure form both ELF and radiofrequency fields in residential areas were measured for 226 individuals. The magnetic and the electrical field components of the night-time ELF exposure close to the bed were 0.02 µT and 26.2 V/m, respectively, and 25% of the measured (Tomitsch, 2010). The feasibility of measuring exposure to ELF magnetic fields in the UK Adult Brain Tumour Study was examined in 81 individuals in the UK. Exposure data were collected for 3-4 consecutive days. Data were collected over a total of 321 days, including non-occupational periods. There were no statistically significant differences between the populations in exposure during travel and domestic periods. The average daily exposure was 0.13 µT while exposure for domestic periods was 0.08 µT. The results showed occupational exposure to be the main determinant of overall exposure (van Tongeren, 2004).

In 2006, the French Ministry of Health initiated a large study of personal exposure of the French population to 50 Hz magnetic fields (called the EXPERS Study). The objective was to collect a database of 1000 children (0-14 years) and 1000 adults. The exposure data were collected during three measurement campaigns between 2007 and 2009. The arithmetic mean (AM) and geometric mean (GM) were 0.09 µT and 0.02 µT for children, and 0.14 µT and 0.03 µT for adults, respectively. Exposures for the out of sleep periods were 0.05 µT (AM) and 0.02 µT (GM) for children, and 0.10 µT and 0.03 µT for adults. The percentage of children with a 24 h mean exposure higher than 0.4 µT was 3.1% (AM), and 0.2 % (GM). The highest exposures for adults represented 11 individuals , with a 24 h mean exposure higher than 1,54 µT (AM), and 0.26 µT (GM). It was found that most of these high exposures were caused by placing the dosimeter very close to a clock radio during the night or close to an electric appliance with a transformer. Taking into account the exposures out of the periods of sleep, 11 children (1.1%) had a mean exposure higher than 0.4 µT (AM), and 2 (0.2%) (GM). The mean 50 Hz magnetic field exposures were higher for adults than for children. The children were more exposed inside the home than outside, while the opposite was true for adults. At home, both adults and children were more exposed during the day than during the night (Bedja, 2008, 2010; Magne, 2010)

In general, measurements of personal exposure are higher than the background fields measured away from appliances, largely because of the extra contributions of additional appliances and any other sources within the home. The ratio of average personal exposure to average field away from appliances varies from 1.0 to 2.3, with an average of 1.44 (WHO, 2007).

3. Typical ELF exposures in the ambient outdoor and indoor environment of the population

Several reports have been published in the last few years on typical population exposures to ELF fields, including the relevant exposures from different sources (WHO, 2007, SCENHIR, 2009, BIO Intelligent Services, 2010). The highest magnetic fields can be found close to several domestic appliances that incorporate motors, transformers, and heaters. Such exposure levels are very local and decrease rapidly with distance from the appliance, plus exposure form these sources is not constant . German data suggest that one third of the total cumulative exposure to ELF fields can be attributed to personal appliance use. Some data on individual exposures are also available from epidemiological studies. WHO summarised measurement studies in the ELF range conducted until 2007. In all studies, the majority of studied persons were exposed to magnetic field levels below 0.1 μT (73.6- 89.9 %), but a few (0.5-4.5%) had exposure levels above 0.3 μT (based on arithmetic means). Geometric means were only available for a small number of studies, but more than 90% had exposures of more than 0.1 μT and 0.4-1,2 % had exposures of more than 0.4 μT. The electric field component was more difficult to assess as it is more susceptible to shielding and perturbation by conduction bodies (WHO, 2007). Regarding individual exposure, only a few percent of the European population are exposed to levels above a median magnetic field of 0.2 μT in their homes (SCENIHR, 2009).

According to the epidemiological studies on childhood leukemia, the differences between the average field strengths to which “highly exposed” and “less highly exposed” individuals in a population are subjected are not great. The typical average magnetic fields in homes appear to be about 0.05–0.1 μT. In pooled analyses of childhood leukemia studies, magnetic fields of 0.4 μT have been used as a high-exposure category, but these differ by factors of only 2 or 4 from those in a low exposure category, and ideally these categories should be higher by at least one order of magnitude. Those in the high exposures category can be found only above apartments with built-in transformers . In theses apartments, exposure can be around 0.5-5 μT (Transexpo, 2010).

Several fixed installed sources are operated in outdoor environments. Prominent examples are high-voltage transmission lines operated between 110 and 400 kV at 50 Hz. The average magnetic field measured directly beneath overhead power lines can reach 30μT for 765-kV lines, and 10 μT for the more common 380-kV lines. The exposure of people under the line can typically reach values of 2 to 5 kV/m for the electric field strength. The magnetic field produced depends on the current on the line; so fields up to 20-40 μT are possible, but are usually lower. It is important to note that such exposure levels occur only directly below the lines; exposure decreases with the square of distance to the lines. In addition, intermediate voltage transmission lines (10 kV to 30 kV) and distribution lines (400 V) have to be considered; exposure levels are in such cases much lower. Typical values from these lines can reach 100 to 400 V/m and 0.5 to 3 μT

According to an estimate in Italy, the percentage of the population that is exposed to magnetic fields above 0.2 μT that are generated by power lines is around 0.54% (~300,000). The largest fraction comes from 132/150 kV power lines (0.31%), the lowest from the 380 kV (0.08%) (Anversa, 1995). Similar studies have been conducted in the UK and Denmark (Olsen *et al*., 1993, Swanson, 1999, UKCCSI, 2000). Extrapolating these data to the whole of the EU (which consists of about 500 million inhabitants), it is estimated that approximately 2.7 million inhabitants could be exposed above 0.2 μT due to the power lines. While it is likely that elevated magnetic field levels can be measured in homes close to power lines, the actual magnetic field level depends on the power load of the lines, which is depends on the individual power line and time, and therefore the distance to a power line is not a perfect indicator of magnetic field exposure. According to most studies, power lines are a major source of exposure for less than 1% of the population. It appears that average exposure over 24 hours is usually well below 0.1 μT, and the proportion of the general population exposed to average ELF magnetic fields above 0.2 μT is small, i.e., between 1-5%; average exposures to magnetic fields exceeding 1 μT are exceptional but may occur in residences immediately beneath high-voltage power lines or those with transformers in their basements. These field may alo occur in certain occupations, e.g., among electric welders, electricians, electric power engineers, or locomotive engineers. Substations and power plants are usually not accessible to the general public except in the case of apartments with built-in transformers. In case of underground cables, the electric fields can be neglected; the distribution of the magnetic field is different compared to overhead power lines. Underground cables can produce higher magnetic fields directly above them than an equivalent overhead line, since the physical distance from the underground cable to the surface of the the ground is smaller. For example, 400kV cables can produce over 30 μT at ground level,falling to 10 μT at 2 m above the ground (see Fig.1). The magnetic field also falls very rapidly with distance from the side of the cable (ICF, 2003).

Security or anti-theft devices in shops and other premises, as well as low frequency RFIDs, are common sources of exposure to intermediate frequency (IF) fields (i.e., between 10 KHz to about 10 MHz). While customers may be transiently exposed, some shop assistants may be exposed throughout their working day especially if they are required to work close to these installations. It is possible that the reference levels for exposure of the general public might be exceeded in the immediate vicinity of some of these devices. However, no large-scale systematic measurement surveys have been undertaken, and there is little monitoring of compliance with protection guidelines once the devices are installed. Most other significant sources of EMF exposures are occupational. Visual display units containing cathode ray tubes are still common sources of exposure and they produce magnetic fields in both the ELF and the IF range, in the order of 0.001 to 0.05 μT. Radio transmitters operated in the long-wave range (30 kHz to 300 kHz) can cause exposure in the IF range with levels above the ICNIRP recommendations , and therefore safety measures are implemented for both the general public and workers (BIO Intelligent Services, 2010).

Starting in 2009, certain types of incandescent light bulbs have been withdrawn from the market in the EU and elsewhere. However, compact fluorescent lamps that are among the candidates to replace them, produce IF electric fields much higher than any other device or appliance previously available to the general public. Energy saving lamps produce fields at about 30-60 kHz. These frequencies vary slightly between different lamp types. As with other electrical appliances, they also generate

ELF fields (Dürrenberger, 2004). Results of measurements of the electric fields showed that the maximum electric field strength in the 1.2–100 kHz frequency range in close proximity to the lamps was higher than 42 V/m for all tested lamps. In nine cases from 17, the field strength exceeded 87 V/m, and the highest measured value was 216 V/m (Bakos, 2010). The induced current density of all investigated bulbs at a separation of 20 mm were within the ICNIRP guildlines , mostly with large margins. However, based on the observed large variations between the bulbs, it cannot be concluded that energy saving bulbs are intrinsically compliant with the ICNIRP recommendations (Jagadish, 2010).

4. Conclusions

- A number of exposure surveys and/or modeling studies have been performed in EU member states at power frequencies since 1980 with many conducted before 2000. No systematic surveys have been carried out on other low frequencies or at intermediate frequencies. There are four main type of ELF exposure assessment that have been performed in European countries *i)* outdoor spot measurements of electric and magnetic fields (in the area of high-voltage electric power lines, outdoor city area), *ii)* indoor spot and/or permanent recording of ELF magnetic fields with modeling of retrospective exposure, *iii)* measurement of ELF fields in proximity to household and other electric devices, including cars and transport systems, *iv)* personal exposimetry by personal exposimeters. Throughout the EU, individual member states have undertaken different amounts of activity, with the highest activity in France, Italy, Germany and the UK.
- The general ELF exposure level of the population is very low, between 0.01 and 0.1 µT. Approximately 0.5 % of general population are exposed continuously to levels above 0.2 µT from the fixed outdoor ELF sources (i.e. high-voltage power lines, lines of transport systems). Elevated ELF exposure (up to a few µT) can be seen in apartments above built-in line transformers.
- Looking at geographical distributions, no noticeable differences are seen among the different EU countries.
- The major part the ELF public exposure comes from electric household devices that are everyday used by the general public, but in this case the duration of

exposure is very limited. For cumulative exposure, approximately one thrd of the total exposure can be attributed to personal appliance use.

- The exposure to EMFs beyond 50 Hz and up to some kHz have not been examined systematically so far. No exposure assessment studies on general population have been performed in the EU. Some studies on exposure and compliance of devices have been conducted on energy saving lamps, security systems, cars and transport systems.
- The exposure levels for both electric and magnetic fields in areas accessible to the general public are below the reference levels set by ICNIRP for limiting exposure. These reference levels are dependent on the frequency of the field. Regarding 50 Hz fields, the ICNIRP reference level for the electric field is 5 kV/m and the reference level for the magnetic field is 200 μT (ICNIRP, 2010). The EU issued a recommendation in 1999 concerning restrictions on the exposure of the general public to electric and magnetic fields. These restrictions are 100 μT for magnetic fields and 5 kV/m for electric fields (EU, 1999). These values are recognized in many EU countries, but some national or local governments have issued their own exposure guidelines.
- Regarding the classification of exposure to 50 Hz fields from the point of view of risk analysis, three main categories of exposure can be recognized: *i)* intermittent variable local exposure; *ii)* continuous elevated level of exposure and *iii)* continuous low level background exposure (Table 2.). No clear classification is available for all other frequencies .

Table 2. *Classification of ELF public exposures*

Exposure classification	***Description, main sources and relevance for risk assessment***
Intermittent variable local exposure	- Highest level of exposure category, including the exposures from household electric devices. The exposure levels are highly variable and local. The exposure is intermittent and limited in time. The levels of exposure are below the recommended European exposure limits but the local maximum may be close to, and in some cases could be higher that the EU reference levels reaching up to few hundreds of µT. Typical sources: household appliances, some transport systems. This category is considered in the risk assessment studies of general public exposure to ELF that have been performed so far.
Continuous elevated level of exposure	- Medium level of exposure category including exposures from built-in transformers, and high voltage power lines within 20-50 m. The exposure levels are variable. The mean and maximum exposure levels are well below the recommended European exposure limits, reaching up to few µT. - Typical sources: built-in transformers, substations, and high voltage power lines. - This category has importance for risk analysis, when epidemiological studies on childhood leukemia are considered.
Continuous low level background exposure	- Low level of exposure category as the background of todays electromagnetic environment. The exposure is continuous. The mean and maximum exposure levels are many times below the recommended European exposure limits and are in the range of 0.01-0.1 µT. - Typical sources: low-voltage wiring systems, continuously operating household electric devices. - This category has very limited importance for risk analysis.

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