

EFFECTS OF EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS ON HUMAN BEINGS

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Abstract

Since the early seventies, potential health risks from ELF (Extremely Low frequency electromagnetic Fields) exposure (50 Hz) have been extensively treated in the literature (more than 1000 references registered by WHO (World Health Organisation), 2007). After 30 years of worldwide research, the major epidemiological output is the possible modest increased risk (by a factor 2) of childhood leukaemia in case of a long exposure to an ambient magnetic flux density (B-field) higher than 0.4 μ T. However, this fact has not been confirmed by in vivo and in vitro studies. Moreover it has not been validated by any adverse health biological mechanisms neither for adults nor for children. International recommendations (ICNIRP, International Commission on Non-Ionising Radiation Protection) are currently, for general public, not to exceed a B-field of 100 μ T (50 Hz) and an E-field of 5 kV/m (50 Hz).

Herein, a rough overview of typical values of ELF fields will be presented followed by a brief literature survey on childhood leukaemia and ELF. The potential carcinogenic effect of ELF would be linked to electrical disturbances in cell behaviour. The major concern linking childhood leukaemia and ELF is thus to determine the response of bone marrow cells under ELF fields. With that purpose, transmembrane potential will be targeted and linked to the E-field at that level.

This paper is three-folded: (1) the electric interactions between ambient ELF fields and the body are studied both qualitatively and quantitatively. Different sources of internal E-field are analysed and classified according to their potential risk; (2) the hypothesis of contact current is detailed; (3) key actions to undertake are highlighted. Based on the current state of the art and some authors' own developments, this paper proposes simple low cost enhancements of private electrical installations in order to annihilate the major source of potential effects of ELF.

Keywords: Contact current – health – electromagnetic field – 50 Hz – electrical installation – residential home – biological concern

INTRODUCTION

50 Hz electric (E) and magnetic flux density (B) fields are linked to any human activity as electricity has become the best energy vector in many applications with a relatively high global efficiency from well-to-wheel approach. Particularly, the transmission and distribution of electrical energy is done with about 95% efficiency over thousands of kilometres. Figs. 1 and 2 show specific field values in Belgium for power lines (Hoeffelman *et al*, 2004). Of course, the loading of the line strongly influences the B-field value. The “max (calculated)” curve has been obtained for contingency limits (so called “N-1” situation), an extremely rare case. We recommend taking into account the yearly

mean values for health effect as long term exposure is concerned. The value of B-field may be higher for underground cables at zero location (just over the path), as cables are buried at about 1.2 meter under the ground (compared to distance from ground about ten times more for aerial power lines) but decreases much quicker compared to aerial lines because of the proximity of the three phases. More details about curves for power lines and cables can be found in standard IEC 62110.

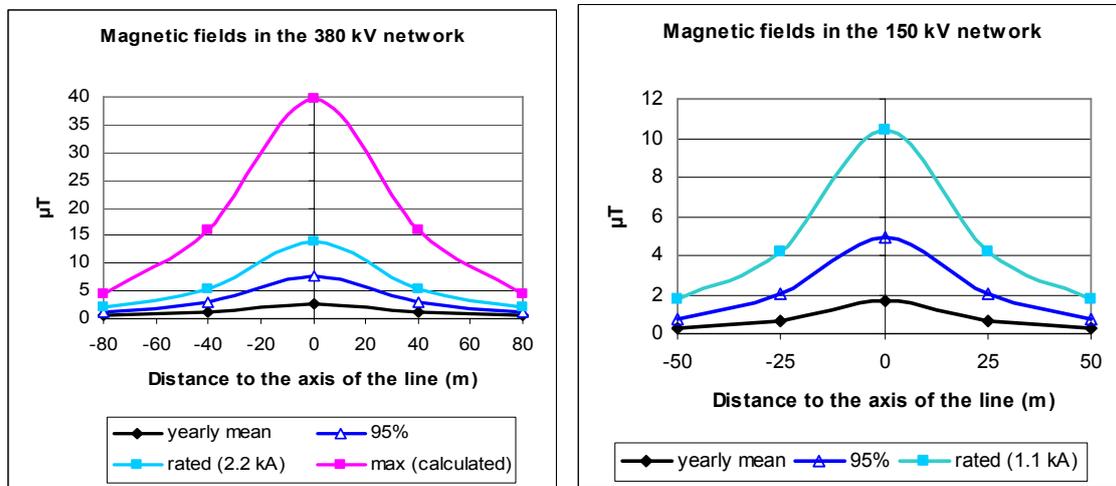


Fig. 1 Typical values for B-field in Belgium near HV lines as deduced from actual measurements (at 1.5 m above ground) and extrapolated to virtual values at different loading conditions (Hoeffelman *et al*, 2004).

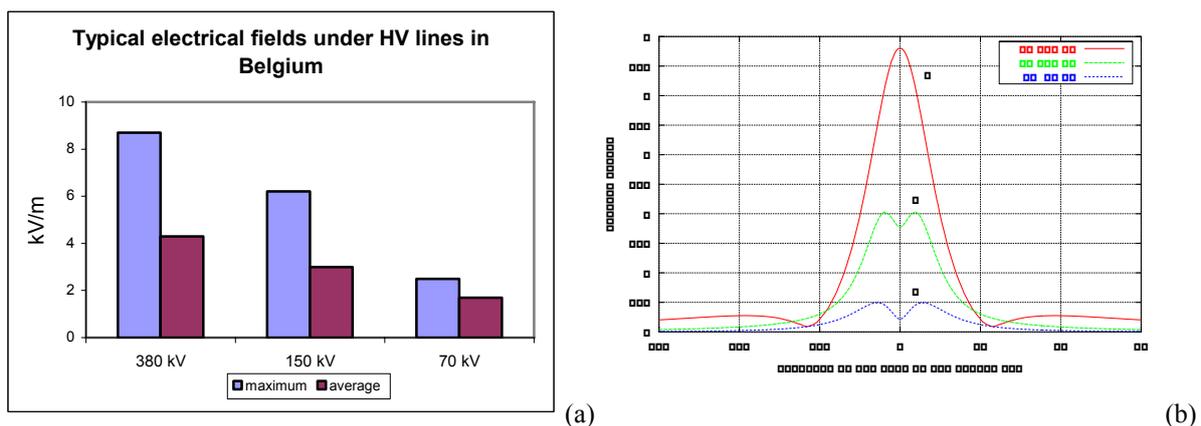


Fig. 2 (a) Typical values for E-field in Belgium near HV lines (mid-span) as deduced from actual measurements (arithmetic mean and max values) (Hoeffelman *et al*, 2004), (at 1.5 m above ground).
 (b) Typical E-field pattern near power lines (at 1.5 m above ground).

E- and B-field sources may also be residential installations as conductors going through the walls to the loads carry current (limited generally to max 25 A) and (generally phase to neutral) voltage (in Europe about 230 V). These two values are much lower (but their source is also much closer to human beings) than those imposed by major power lines and cables as the latter are managing the whole flux into several ten thousands kilometres of distribution line feeders. But a relatively strong B-field (several μ Ts) may be generated near the electricity counter or near large load in service, due to proximity, which is not the case in the middle of the rooms. Inhabitants are subjected to different ambient fields, depending on where their house is situated with respect to the power lines (most likely far). Fig. 3 shows the results of measurement campaigns in residential houses in USA and Belgium. The author's study (Fig. 3(a)), based on spot measurements in the middle of some rooms (and taking finally into account the median of these measurements for one home), has the following statistical characteristics: median 0.03 μ T, arithmetic mean value 0.12 μ T, geometric mean value 0.04 μ T.

The 24-hour exposition of children is of particular importance. Table 1 compiles the outputs of international studies (Foliart *et al*, 2001, WHO, 2007). These values have been obtained using dosimeters carried by the children all day long and placed closed to their bed during the night.

Very few children are exposed in average to residential 50 Hz B-fields that exceed the field level linked to an increased incidence of childhood leukaemia, viz only 1 to 2% are subject to field values higher than 0.4 μ T (WHO, 2007). The population living near power lines is exposed to higher values, about a few μ T for B and a few kV/m for E outside home; however the amount of people subject to such field levels is extremely limited. Also people living in the very

near proximity of an electrical installation (e.g. distribution transformer) may also be exposed to a few μT for distances smaller than about 5 m (as measured by the authors in many situations for distribution transformers up to 400 kVA). Farther than 5 m, the influence of the transformer can be neglected with regard to other sources. A side problem is linked to electric appliances, which may cause high fields. As stated by Leitgeb *et al*, 2008, the 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. Many devices exceeded significantly ICNIRP's reference levels (ICNIRP, 1998). A closer analysis is required to demonstrate conformity within reasonable limits.

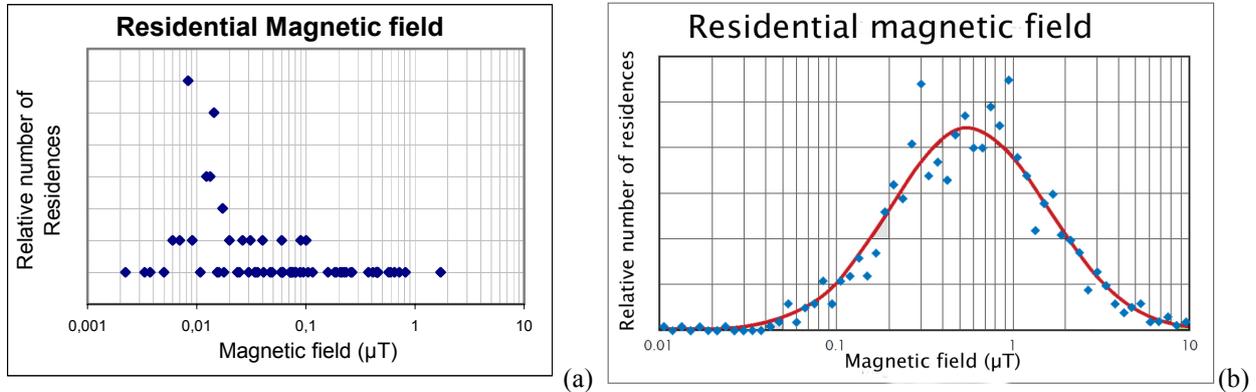


Fig. 3 Residential magnetic fields in (a) **Belgium** (author's study, 90 homes currently) (in μT , $1\text{mG} = 0.1 \mu\text{T}$) and in (b). USA (Syfers. 2006, taken from EPRI 1000 homes study) (in mG)

Table I: Magnetic flux density field exposure of children

Study	Country	Age range (years)	N	24-hour-weighted average mean (μT)	24-hour-weighted average $\geq 0.2 \mu\text{T}$	Geometric mean (μT)	Geometric standard deviation	Median (μT)
Zaffanella <i>et al</i> , 1998	USA	<18	138	0.106	12.3%	0.077	2.19	0.069
Kaune <i>et al</i> , 1994	USA	< 8	29	0.13	14.3%	0.105	1.89	n/a
Kaune <i>et al</i> , 1994b	USA	<18	31	0.14	13%	0.097	2.46	n/a
Linnet <i>et al</i> , 1997	USA	<15	615	0.104	11.4%	0.077	2.09	0.072
McBride <i>et al</i> , 1999	Canada	<14	329		12.8 %			
Decat <i>et al</i> , 2005	Belgium	<15	491	0.10 (home) 0.05 (school)	12%	0.05 0.03	2.60	0.07 0.04
Brix <i>et al</i> , 2001	Germany		1952		8.6%	0.064	2.41	

PART 1. ELECTRIC INTERACTIONS BETWEEN AMBIENT ELF FIELDS AND BODY - QUALITATIVE AND QUANTITATIVE APPROACHES

1.1. Potential origins of biological effects

At 50 Hz and with the considered field levels, there are neither thermal effects nor any ionising radiation effects (WHO, 2007; WEB.13). Induced heat has been evaluated (WEB.13), for 100 μT and 1 kV/m 50 Hz ambient, near a very small fraction of μW (compared to endogenous 100 W generation). Electromagnetic fields can only influence human body through biological mechanisms, though. When people are exposed to electric and magnetic fields created by power systems, imperceptible electric currents are induced in their bodies (see part III). There are a lot of biological interactions linked to endogenous alternative currents in the body, as electrocardiogram or electroencephalogram may easily show. The frequency content of the body signals is below 50 Hz (Alpha rhythms from 8 to 12 Hz, Beta rhythms 13 to 30 Hz, others (Delta, Theta) at much lower frequencies). The most well known signal is heart beat around 1 Hz. In general, these signals are extremely complex and far from being completely understood. Signals are exchanged between cells owing to the change of TMP (transmembrane potential). And this may be one source of disturbance due to non-endogenous signal (WHO, 2007, page 94; Wang *et al*, 2005; Chiu *et al*, 2005). TMP may be disturbed by the internal E-field in the tissues and the latter is thus a key value to estimate potential disturbances. Concerning leukemia, *the internal E-field in the bone marrow is essential*. The spontaneous opening and closing of voltage-gated channels

cannot occur for internal E-field lower than 10 mV/m (WHO, 2007, page 101). Chiu & Struchly, 2005 determined that a local body internal E-field of 1 V/m (1000 mV/m, hundred times the WHO threshold) can produce 0.2 mV across the gap junction connecting two bone marrow stromal cells. These cells orchestrate hematopoiesis that includes lymphocyte precursor cellular proliferation (LeBien, 2000; Bertil *et al*, 2001). Thus, internal E-field, whatever the source, must be over several tens of mV/m to observe a potential biological effect (which obviously would not necessarily imply adverse health consequences). There is nowadays no biological evidence indicating that this level of internal E-field within the bone marrow is either carcinogenic or stimulates the proliferation of initiated cells.

There is a secondary issue, concerning the duration of application of the “disturbance”. Up to now, we have no clear answer to that. Certainly a few seconds exposure would have no biological consequences as the auto-regulation mechanism is able to control most external attacks. Taking this phenomena into account, there are few ways to study transient short time effects, like ESD (electrostatic discharge) and electromagnetic transient (due to switching impulse, lightning impulse...). We do not know if there is a dose-response effect and how to combine different excitations at different time. More research on the subject is needed. Current investigations on epidemiological observations are based on mean 24 h exposure. A minimum of 8 h corresponding to sleep time is particularly concerned and thus bedrooms are the location where precautionary measures could be taken. It must also be pointed out that it is extremely easy, for laboratory purposes, to apply a given E-field to Petri boxes with appropriate biological material. Unfortunately, only few labs performed such experiments.

1.2. First potential source of internal E-field: the human body response to direct effect of ELF fields

As just explained, the inside body locally induced internal E-field (due to either external E- or B-field) is of particular interest because it is related to the stimulation of excitable tissues.

Alternative external E-field, vertically oriented (near ground) in typical situations, induces alternative current paths (mainly vertical) in the body. Indeed alternative external E-field is strongly influenced by the presence of a body. As a body is much more conductive than the surrounding air, charge distributions appear on its surface. The internal E-field is then quasi-null due to the joint effect of the external field and the induced surface charges. At low frequencies (50 Hz), there is a permanent migration of charges which produces an alternative current *within* the body. As these charges, and hence the current, depend on external conditions, there exist an internal E-field which corresponds merely to an ohmic voltage drop due to the resistivity (inverse of the conductivity) of the body parts. The so called “electrostatic induction current” follows more or less vertical paths through the body, some through the bone marrow. In fact the E-field inside the body is about six orders of magnitude (1 million times) smaller than the external E-field: kV/m outside, mV/m inside. The order of amplitudes in the bone marrow (see later for further details) is of about 10 mV/m for a body embedded in an external E-field of 10 kV/m.

Alternative external B-field induces a current in the body and thus an internal E-field (given by Ohm’s law) as in any conductive material. External B-field, horizontal in typical situations, induces current loops in the body. The order of amplitudes (see later for further details) of induced internal E-field is 1 mV/m for external B-field around 100 μ T.

Both these values (due to E- and B-field) can be combined. The resultant is an internal E-field of some mV/m.

Could external ELF fields be directly linked to biological effects? This is unlikely in a typical situation in Belgium, even below a 400 kV power line (the maximum power line voltage level in Europe) at its maximum load transfer (typically 2.2 kA), or even over a 150 kV underground cable at its maximum load transfer (typically 1.1 kA). Indeed these lines, as stated above, generate a maximum of rated B-field (2.2 kA for 400 kV power lines) of 15 μ T and a maximum of E-field of 9 kV/m, thus creating a combined value of *internal* E-field lower than 10 mV/m. Even lower if we consider the recommended annual average values, for health effects. A literature review of human beings in these situations is discussed in section 1.4 in order to better quantify the internal E-field.

1.3. Other source of internal E-field: the contact currents

To limit the existence of internal E-field to external E-field and/or B-field is not exhaustive. There is another source which has been first pointed out by Kavet *et al*, 2000, 2002, 2004, 2005; Bowman *et al*, 2006: the contact current. When a person simultaneously touches two conductive objects that are at different potentials, a so-called contact current flows through his/her body. This is something very common though and most of the time we do not even notice. Indeed the current is so weak that it is under the human level current perception, near 0.5 mA (Hilert *et al*, 2002; Leitgeb, 1998). For instance, when taking a shower or a bath, you need to touch the faucet handle, the spout or the water stream. A voltage (50 Hz value) may appear between the object in contact (with one hand for example) and your feet. As your body has an impedance close to 500-3000 Ω , just 100 mV, allows a current of 0.2 mA to flow through the body during the contact (depending on the source impedance). That current may flow through the body via the easiest paths, like the bone marrow with a high conductivity, particularly for children. That current creates local current densities and thus generates also internal E-field. Dawson *et al*, 2001 estimated that a 50 μ A exposure produces about 650 mV/m in 5% of the bone marrow (bone marrow conductivity not uniform) in the lower arm of an 18 kg child, 4-year old (more details in section 1.4).

The origin of the contact voltage is manifold. It may arise from either return current in the grounding system and/or as a result of Faraday induction in any circuit, including electrical circuit, metallic circuit. The latter can be influenced by the proximity of power lines and even can propagate far away owing to particular metallic ducts and/or earthing networks in dense habitat. With a contact current of 0.1 mA, the order of amplitudes of the E-field in the bone marrow (see later for further details) is several hundreds of mV/m for the arm and several tens of mV/m for the spinal backbone.

Contact currents can give rise to possibly hazardous internal field levels higher than the established safety threshold (ref: part 1.1) and seems thus to be a potential source of biological effects. This contact current, which may induce relatively large internal E-field, cannot be detected by most of the population as its level is lower than the perception level, though, except for hypersensitive people. Furthermore, the occurrence of contact currents is relatively limited, but when they appear, that may happen for several hours every day, which is particularly delicate for foetus, babies or small children. It must also be pointed out that there is no epidemiological evidence linking the risk of childhood leukemia and contact currents. Nevertheless, such epidemiological study would be particularly difficult to be performed due to the complexity of the measurements involved.

1.4. Evaluation of internal E-field in the bone marrow for ELF fields and contact current cases

From 1996, many authors evaluated *internal* E-fields in different configurations (Barchanski *et al*, 2006; Struchly *et al*, 1996, 2005; Dawson *et al*, 1997, 1998, 2001, 2002, 2003; Dimbylov, 1998, 2000, 2005; Cech *et al*, 2007, 2008; Caputa *et al*, 2002; Jart *et al*, 1998). Currently, we are not aware of any measurements done inside the body of a living human, thus results are obtained by numerical simulations. Different human models can be found worldwide, from children to adults, and including even pregnant women. Available software allows accounting for detailed models of the whole body, with different electrical characteristics (e.g. conductivity, permeability) for the different tissues. Finite difference and finite element models are mostly used. The 3-D model is discretized in so-called “voxels”, of about 3 mm size. Sources may be initial B-field, or E-field or both, or contact current between any parts of the body. The output of interest for our purpose is, namely, the internal E-field in the bone marrow. The conductivity of the bone marrow (yellow and red marrows) varies with age. Most common values stated by Reilly, 1998 go from 0.05 S/m to 0.2 S/m (foetus).

Table II: Different models found in the literature, sources and observed effects (50 Hz or 60 Hz)

	Model	External sources	Effects
Dawson, 1997	voxel of 3.6 mm for man of 76 kg, 1.77 m	E field 10 to 20 kV/m	~20 mV/m in bone marrow (current density of 1 mA/m ²)
Dawson, 1998		B-field 1 μT	~10 μV/m in bone marrow
Hart & Gandhi, 1998		E-field of 10 kV/m B-field of 33 μT	~3 mV/m in spinal liquid
Dawson, 2001	virtual child (18 kg, 1.1 m)	contact current of 0.1 mA	up to 500 mV/m in arms up to 45 mV/m in spinal backbone marrow
Caputa, 2002	“Brooks man” (104 kg, 1.8 m)	B-field of 1 μT	0.02 to 0.29 mV/m in bone marrow
Dimbylov, 2005	“Naomi” (60 kg, 1.63 m)	B-field of 1 mT	6 to 48 mV/m in bone marrow
		E-field of 1 kV/m	3 to 56 mV/m in the bone marrow
Cech, 2007 and 2008	“SILVY” pregnant women 30 weeks (89 kg, 1.8 m)	B-field of 100 μT	3 mV/m in the foetal bone marrow (current density of 0.6 mA/m ²)
		E-field of 5 kV/m	20 mV/m in foetal bone marrow (current density of 3.3 mA/m ²)
		Combination of both	20 mV/m in the foetal bone marrow (current density of 3.5 mA/m ²)

Eventually, the calculated effects of E-field, B-field and contact currents may be summarized as follows: (1) as the “material” is considered as linear, the internal fields are directly proportional to the external fields; (2) an E-field of 10 kV/m generates an internal E-field of about 30 mV/m in the bone marrow (adult); (3) a B-field of 100 μT gives rise to an internal E-field of 1 mV/m in the bone marrow (adult); (4) a contact current of 0.1 mA produces an internal E-field up to 500 mV/m in the arm for adult and up to 1500 mV/m for foetus.

Based on previous physical observations, we may argue the following:

1) Concerning external E-field and/or B-field effects on the E-field in the bone marrow: the WHO considers 10 mV/m as a basic minimum level able to potentially disturb biological mechanism (WHO, 2007, page 116, “...based on current evidence threshold values around 10-100 mV/m seem more likely”); the maximum E-field (just under a 400 kV line) is close to, and most generally lower than, 10 kV/m; the maximum B-field (just under a 400 kV line) is close to 20 μT.

Then, the external E-field and B-field can be disregarded as a direct source of childhood leukemia. Indeed, E-field in critical situations, i.e. close to a threshold value, is very much influenced inside home by the walls, metallic tubes or plates; values as high as 10 kV/m are not found in residential houses. It is just a few tens of V/m, what means 1000 times lower than the potential threshold.

2) Concerning contact currents effect on internal E-field bone marrow: contact currents may induce a significant internal E-field in the bone marrow and must be more deeply investigated.

PART 2. THE CONTACT CURRENT HYPOTHESIS - A DEEPER ANALYSIS

2.1. Origin of contact currents in residential homes

2.1.1. Definition of contact current

The contact current is a current flowing through the body that appears when two members of the body are in contact with two metallic parts subject to a different potential. It is thus linked to a potential difference called contact voltage. The contact current cannot be simply calculated as the ratio between the "open circuit" contact voltage and the body impedance. In fact, the whole electric circuit behind the two contact points (Thevenin equivalent) has to be considered. Indeed, the voltage source behind the two contact points has an internal impedance which may be huge and in that case, no significant current would be generated. Therefore, a suitable evaluation of such risk requires two measurements: (1) the open circuit voltage and (2) the short-circuit current value. For practical reasons, the short-circuit measurement is replaced by the measurement of the voltage applied at a very high resistance (in practice, the body impedance is taken in the range 0.5 to 3 k Ω) placed between the two contact areas. In many cases, this second measurement gives a quasi-null value, which means that the internal global impedance of the circuit is extremely large (several M Ω), thus with no consequence (too low contact current). The contact current is not related to the electrostatic discharges (ESD). The latter is a transient current (a few ns) due to charge equilibration between two "objects". In this paper, this phenomenon is not taken into account. ESD is generally considered as no source of any long-term pathologic consequences, despite its very disturbing, but instantaneous effect.

2.1.2. Grounding systems in residential distribution circuit

Ground and neutral are closely related. Ground provides a low impedance path to earth to prevent the appearance of transient hazardous voltages. Normally, a grounding conductor does not carry current. Neutral is a circuit conductor that may carry current and which is usually connected to ground. The basic rule in a distribution circuit is that neutral is mostly isolated from ground. The neutral is often connected to the earth at the transformer or substation which supplies the low voltage line. Every time the neutral conductor is earthed, the neutral current can divert out of the line into the earth itself (through e.g. water pipes) and return to the transformer via a different path (closing the circuit). Any diverting current out of the neutral, inside home, is susceptible of generating potential contact currents, as they give rise to contact voltage at any location (particularly on water arrival, radiator, earth plug...). Another source is linked to faulty house wiring or faulty appliance. This case occurs roughly in 20% of the homes and provokes an unintended phase connection to the earth. In some network, too large diverting current from phase to earth will force the differential protection to open the circuit, this last being generally tuned at 30 mA on water rooms and about 300 mA at the origin of the electrical installation. So contact current up to either 30 mA or 300 mA can flow freely without any action of the protection. This allows fault current to divert out of the line. This current limit has been imposed by regulation, taking into account safety aspects linked to potential heart hazard. Establishing a lower limit is not possible as most installations have some diverting current and such a reduction of the differential protection would cause frequent circuit interruptions every day.

2.1.3. Origin of contact current

The contact current sources may either come from external source (like B-field and E-field induced by power lines, cables, transformers, etc., Fig. 4(a)) or internal source (treated later on) (Fig. 4(b)). A contact voltage may then appear, typically between faucet and water evacuation. Depending on the material used for ducts, bathtub, heating system, etc. The internal impedance of the global circuit seen from the two contact points may be low enough to allow significant contact currents to flow through the body. In Fig. 4 (b), the net load current (resulting from any load inside home) coming back to the distribution feeder may divert at the panel where the local earth is linked to the neutral. As water pipes are also linked to the earth, any load current may partially divert to the earth and water pipes, creating thus systematic contact voltage. In both cases, the proximity of power lines (as shown on Fig. 4 (a)) may induce a voltage in any existing circuit, including earthing and any metallic ducts. That voltage has to be superimposed to the further explained case. Obviously, the induced voltage in the circuit loops depends on their size and orientation with regard to the power line B-field. This may be a potential link between the B-field and possible effects on human.

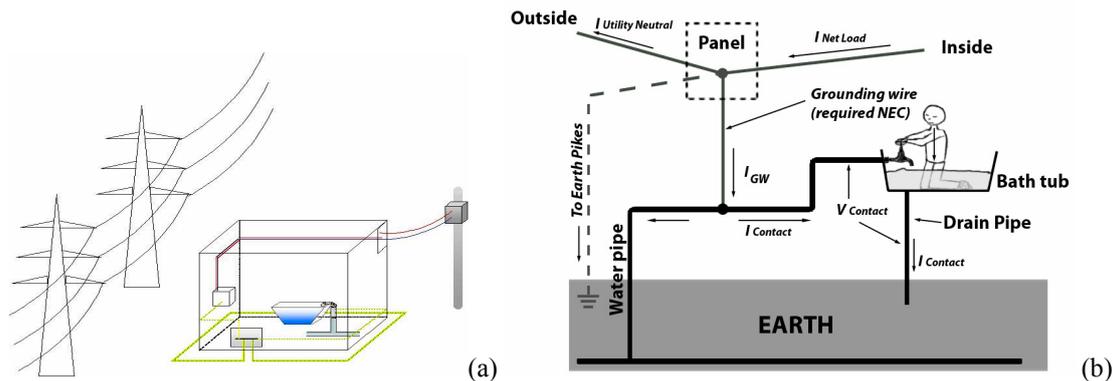


Fig. 4 (a) Typical model to evaluate induced voltages and currents in homes near power lines (b) US typical TN-S residential connection, including water pipe links. $I_{\text{net load}}$ is the net current load coming “back” from the load in the “neutral” conductor (active conductor not drawn).

The part of the contact voltage (and contact current) due to power lines may be quantified by numerical simulation. Most significant contact currents (larger than a few tens of μA) are due to bad installations. This will be confirmed later on by the absence of correlation between B-field and contact currents, as recently evidenced in a 90-home measurement campaign in Belgium. Further measurements are still performed to improve the data base size and are under investigation.

Following remarks concerning contact currents may finally be detailed:

- 1) There are rules of installations which force all metallic tubes (water feed, gaz, domestic hot water heating installation...) to be linked to the earth switch (or breaker). This last is very often missing in installations older than 1981 (Belgium).
- 2) If no earth link exists for some loads (e.g. washing machines, hair dryer), the partial loss of insulation on active circuit will give rise to some voltage on the machine metallic parts.
- 3) In the last cases, a voltage exists on some metallic parts and, when a human being touches it, a new return path for the current appears: through the body impedance and impedance from the feet to the earth and finally back to the transformer. The body contact resistance to ground is very small in case of nude humid feet, as may be the case in bathrooms, the corresponding contact current may be quite high; yet no protection would open any circuit below a certain level.
- 4) Human being impedance is in the range of 0.5 to 3 $\text{k}\Omega$ (voltage dependent). If there are no other impedance in series, a contact voltage of 50 mV is enough to obtain a 0.1 mA contact current.
- 5) The most obvious sources of contact current are (i) the faucet to the drain in shower and bath, which would limit body impedance to its minimum near 500 Ω and (ii) contact with machines or radiator to the feet on a wet surface.
- 6) Sources of contact current exist also in the environment of power lines, for example, when touching a pylon or a car. Voltage difference occurs between these large metallic objects and the feet. But these situations are rare and cannot be considered as long-term exposure.

2.2. Contact current in Belgian residential homes: level and protection

Fig. 5 shows the authors' recent overview on 90 randomly chosen houses in Belgium. The mean level of contact current is limited to tens of μA . However several hundreds of μA have been detected in some of these houses: 6 houses out of the 90 considered have contact currents higher than 100 μA . The measured contact currents and internal B-field in the Belgian residential homes is shown in Fig. 6. Up to now and from the authors' study, no correlation has been observed in Belgium between the contact current level and the B-field.

In Belgium (governmental statistics by FPS Economy, DG Energy), there are about 4 million residences (either house or apartment). They can be classified as: (1) type 1: 1.7 million very old-fashioned (before 1945); (2) type 2: 1.5 million old-fashioned residences (1945 to 1981); (3) type 3: 800.000 residence post-1981 (year when national RGIE regulations appeared). The experience of an authorized company shows that, about 50% of Type 1 residences have no earthing. Most of the rest have at least one kind of earthing, but only 50% of them have a differential at 300 mA at the origin of the installation. Belgian residential park has mainly a TT scheme. But in some large areas (Bruxelles, Charleroi), there are still installations with an IT scheme (WEB.12). It is known by certification utilities that Belgium park of residential houses and apartments have about 40% of bad earthing, but only part of it may be subject to relatively large contact currents. This is most probably due to the non-conductive tubes used more and more in the installations. In modern installations, conductive tubes for water and gas have disappeared. In older installations, such conducts are progressively substituted. Therefore, most of the described problems will be clearly reduced in the coming years.

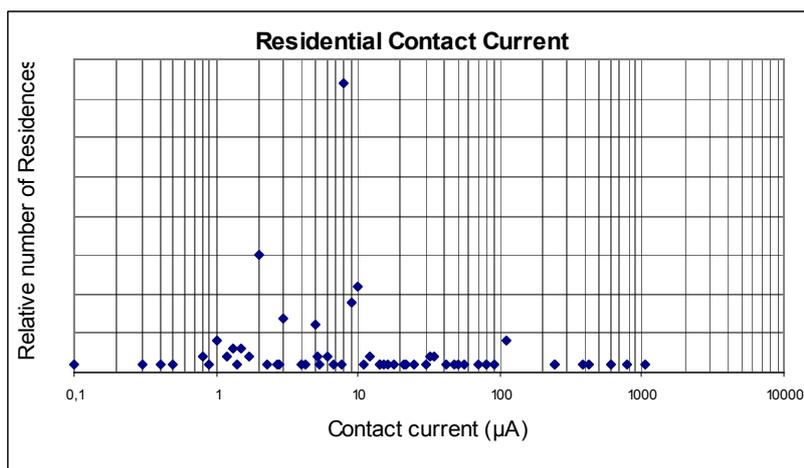


Fig. 5 Contact current level in residential park in Belgium (90 homes), authors' study.

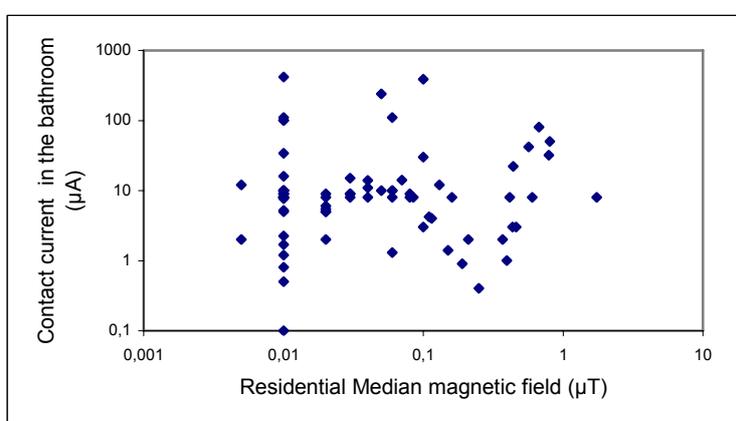


Fig. 6 90-home authors' study in Belgium. Maximum contact current versus median B-field in each home.

PART 3. KEY ACTIONS TO UNDERTAKE

Let first summarize the facts:

- 1) The values of external E- or B-field are never high enough to induce a corresponding internal E-field in the body (direct effect) higher than the biological threshold limit fixed from 10 mV/m to 100 mV/m (WHO, 2007, p116) for ELF fields (50 Hz).
- 2) Some houses of the Belgian residential park may have significant, yet non perceptible, contact currents, which may induce internal E-field in the bone marrow over the threshold. The time of exposure is limited, though.
- 3) Contact currents may appear either from ageing and/or bad installations and/or from the proximity of power lines and other large load installations.
- 4) There is currently no scientific evidence of any adverse health effect of ELF fields but a potential actor may be linked to a significant contact current.

Based on former observations and analyses, should we apply the so-called "precautionary principle" (PP) based on epidemiological observations, with potential correlation to health effect, based on the sole ambient B-field? What can be advised to avoid contact currents?

Residential park in countries like Belgium (with either a TT or IT system for distribution network), **must** all have a link between earthing of the electrical installation and metallic circuits like water and gas conducts. This is a simple, no/low cost measure that is imposed to new installations (since 1981) but rarely fulfilled in old installations. Houses where plastic tubes are used for water and gas do not need such links. Obviously a compliant installation, including earthing is imperative as well as differential protection. Certification companies can help to verify the installation efficiency and conformity. Particular situations (apartment located above or in the vicinity of a substation) may find local ways of protection (such as B-field screens) to limit contact current by induction into circuit loops.

For those particularly sensitive to EM fields and for houses with no self protection (no metallic parts in the structure), in-house E-field in situation just next to 400 kV power lines, may easily be reduced. The installation of a simple very thin sheet of metallic material on their roof (inside) would annihilate external effects on their in-house E-field and limit it to the in-house generated field. The modern anti-lightning roof protection (a rough meshed network on the whole roof, linked to the ground), if any, may also serve to that aim.

4. CONCLUSIONS

Exposure to external ELF electric and magnetic fields induces electric fields inside the body. As mechanisms become only plausible with fields above certain strength, in agreement with NIEHS, we just fix a minimum of several tens of mV/m of internal electric field inside bone marrow. This level is required to be able to discriminate from inherent random noise. In Europe, such a level of internal E-field cannot be due to direct effect of any ambient ELF magnetic or electric field generated by high power lines or cables. However such a level of field can be provoked by particular contact currents that depend on the local electrical installation. Simple modifications of these installations may easily help to limit and/or avoid contact current level in any residence.

Following WHO recommendations, it is thus strongly advised:

- To enforce wiring regulations to reduce unintentional ground current, while ensuring safety.
- To do more research to assess the capability of residential electrical grounding and plumbing practices to give rise to contact currents in residences.
- To adopt low cost precautionary measures to reduce exposure and do not compromise the health, social and economic benefits of electricity.

There is a considerable potential to reduce fields without loss of performance of many electric appliances in every day life, which has to be recommended.

Last but not least, large epidemiologic studies pointing out a possible moderate increase of the risk (factor 2) for ALL in small children, being based on external B-field higher than 0.4 μ T, have few chances to have had looked at the appropriate data (external B-field) as that data is, for sure, a negligible direct effect for potential adverse health effects. It must nevertheless be admitted that there are no other clear data to easily look at. The replica of the conclusions by different studies is nevertheless disturbing. It suggests that indirect links, like contact current could be a hypothesis to take into account. That may be consistent with some domestic distribution rules in some countries. But in a situation like in Belgium, a fortiori with proposed changes in the give rise to installations, there will be no way to find any effect, direct or indirect, due to the B-field.

This paper, based on both a literature survey and authors' own measurements, seems to orientate research in another direction, first suggested by Kavet *et al*: everybody should have his/her installation verified and modified to ensure conformity, if necessary before looking for an external source of the problem. However, manufacturers and power line owners should also carefully study how to reduce ambient fields at any frequency.

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END NOTE

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