Exposure Assessment of Extremely Low-Frequency Magnetic Field

Pilot Case-Control Study of Childhood Leukemia in the Czech Republic

(2005 – 2008)

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Purposes of the Studies

- **1. Exposure study of ELF MF.**
  - Objective: To estimate the exposures of children to power frequency magnetic field in the Czech Republic.
  - Purpose: To find out how many children in the Czech Republic are exposed to low frequency magnetic field above level 0.4 μT, hypothetically associated with increased risk of childhood leukemia.
- **2. Epidemiologic case-control (pilot) study of childhood leukemia.**
  - Objective: To evaluate an association between ELF MF exposures and the occurrences of childhood leukemia in the Czech Republic
  - Purpose: By these results to contribute to present knowledge acquired in West Europe and Overseas.
- **No similar studies have been accomplished in Middle and East Europe.**

Studies of ELF MF and leukemia

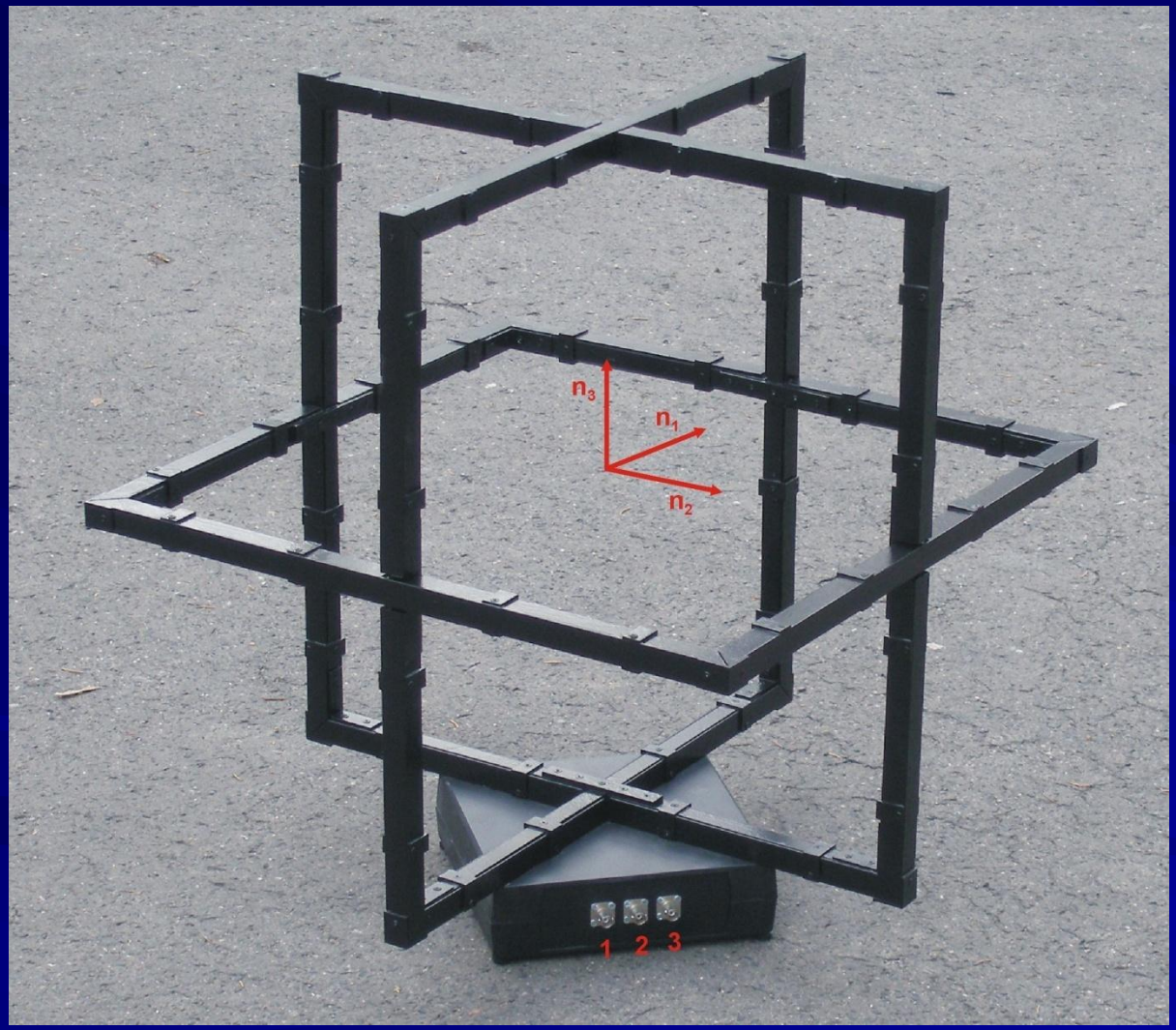
- **Three reasons of the studies:**
  - First: Publications providing results that exposures to ELF MF (50 Hz or 60 Hz) are weakly associated with increased incidence of leukemia in children.
    - This induced the International Agency of Research on Cancer (IARC) to classify ELF MF as a “possible carcinogen” (group 2B), in spite of some reports which did not confirm this suspicion.
  - Second: Data on EMF exposure of general public in countries of the former Eastern Europe have not yet been collected.
    - The types of housing have been for considerable time different in these countries in comparison to Western Europe and Overseas, ELF MF problems connected with possible health impairment were not included in the hygienic limits.
  - Third: The WHO recommendation characterized as „The further characterization of homes with high ELF exposure in different countries“ (published in 2007) encouraged this study (study started in 2005 - 2006).

ELF MF exposure study

Devices and software

- **Three orthogonal coils connected to four-channel oscilloscope** type Tektronix TDS 3054 - Tektronix Inc., 14200 S.W. Karl Braun Drive, Beaverton, Oregon, USA. For main measurements.
- **The small (pocket) magnetometer** NoRad - NoRad Corp., 1160 E. Sandhill Ave., Carson, Calif., 90746, USA was used for personal measurement.
- **Software program Axum 7** (Mathsoft Engineering & Education, Inc., since 2006 Mathsoft) obtained from PTC Corporate Headquarters, 140 Kendrick Street, Needham, MA 02494, USA was used for processing the stored data from oscilloscope.
- Regression analysis, analysis of variance and correlation of the results were performed using **Excel** (Microsoft Corp., Worldwide, U. S. A.) and **Stata** (Stata Corp., Release 9, College Station, Texas, USA).

Measuring Equipment



Special-manufactured three orthogonal coils connected with oscilloscope by three shielded cables.

Three coils have the dimensions 540 x 600 x 540 mm and the effective areas 15.3 x 15.0 x 14.7 m^2.

Resistance is 10.6 - 11.0 Ω and self-inductance 6.6 – 7.2 mH in 120 Hz. The relative error of an electric-parameter measurement is about 5 %.

Data acquisition… three coils in action…

Methodology of exposure essessment

- Exposures have been assessed by:
  - calculation, i.e. from distance from electric wires, wire codes or calculation of historical fields,
  - measurement, i.e. spot measurements, long-term measurements and personal exposure monitoring
- Our exposure study
  - Main measurement - spot measurement
    - Short-term measurements on more sites
    - Chosen even though there are some drawbacks of this measurement strategy due to errors resulting from variability of magnetic fields.
  - Advantages:
    - Most of inhabitants didn't notice the measurement and therefore they weren't disturbed due to irrelevant misgiving and fear from magnetic field. Addresses have been kept in confidence for privacy protection.
    - An possibility of the oscilloscope recordings and hence the knowledge of its full frequency spectrum

Selection of measurement sites

- Site selection:
  - Different housing and schools were chosen, in different types of locations (i.e. big cities with more than 100 000 inhabitants, small towns and villages).

- Different constructions of buildings, typical for the CR
  - 3 categories (by type dwelling) in compliance with published housing statistics in the European Union
  - High-rise houses (built-up of concrete panels, generally with more than 4 floors and several tens of flats)
  - Multi-family houses (constructed of panels or bricks up to 4 floors with a smaller number of flats)
  - Family houses (generally single or double-storey houses, built-up of bricks or blocks with one or two flats)

High rise dwelling in the CR

Multi-family dwelling in the CR

Family dwelling in the CR

Spot measurement method

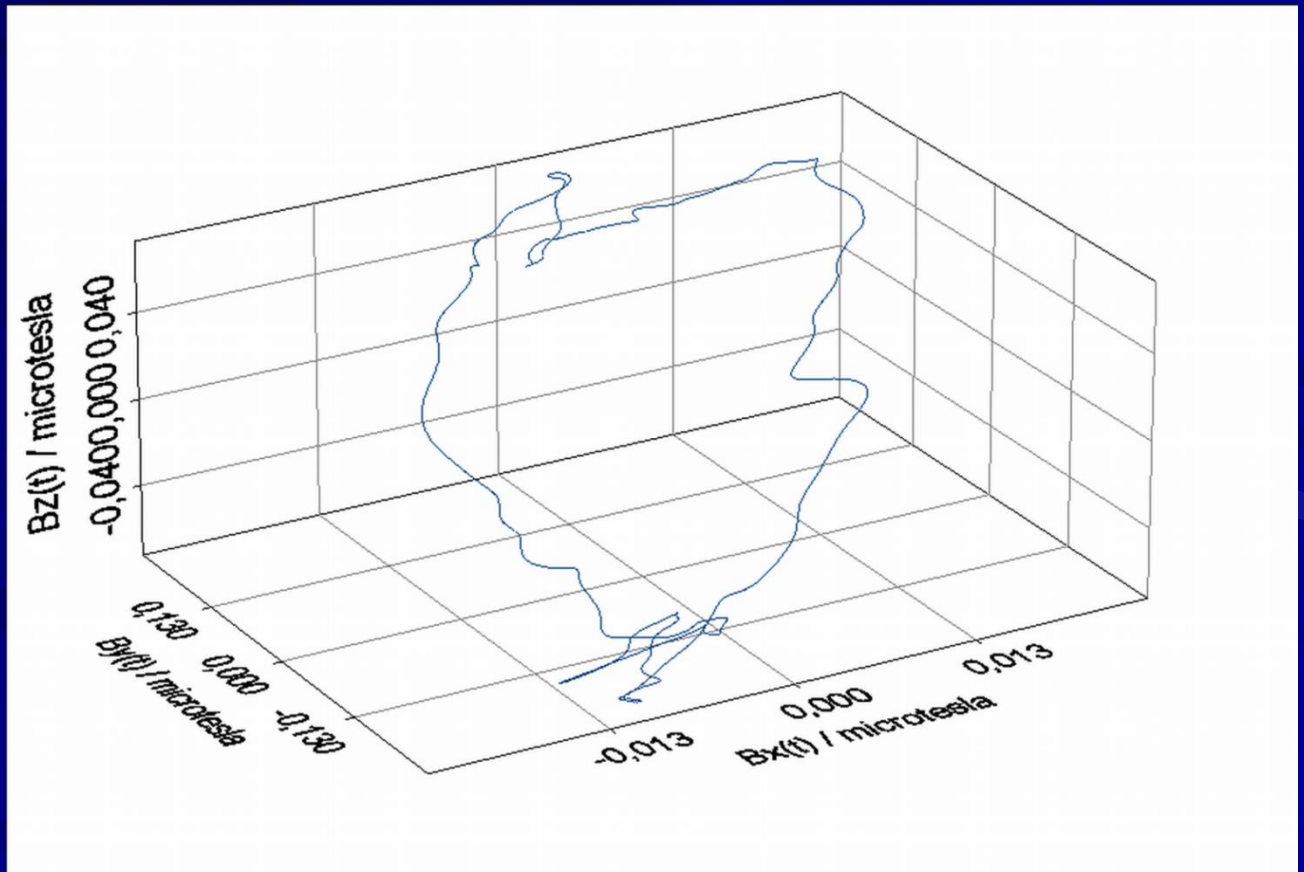
- Main measurements on the one site
  - 1 site = 1 house
  - Lasting from 15 to 45 minutes.
  - Performed on several places (from 3 up to 6 places) in immediate house vicinity (from 1 up to 5 meters).
  - These sampling locations were selected in random time of day
  - Accomplished minimally 1.5 meters over ground, because the ELF MF values directly above underground power lines are significantly higher than at any place beside or inside houses.

Spot measurement method

- Additional measurements
  - To increase the credibility of exposure estimates from the spot measurements.
  - Some measurements was repeated in different seasons (to estimate seasonal, long-term variability)
  - Some of them were conducted continuously for several days at the same place (to estimate a short-term variability).
  - Parallel measurements were made beside and inside the houses (to estimate the differences of ELF MF values outside and inside the houses).
  - In addition, several measurements were performed in the vicinity of high voltage cables (220 and 440 kV)
  - Also a personal exposure measurement on a school child's body.

Result processing method

- Values of currents induced at the three coils were separately recorded in the oscilloscope memory.
- Vector of magnetic flux density B was constructed (calculated by Axum software) from the three stored components (from the three coils).
- From these data was calculated effective level of B(t) [microtesla]



Result processing method

- The individual results (B_{eff}) of measurements in the vicinity of houses showed the log-normal distribution. Therefore, the logarithmic data transformation was used (Stata software).
- The geometric mean (GM) was used as average value:

$$GM = 10^{AM}$$

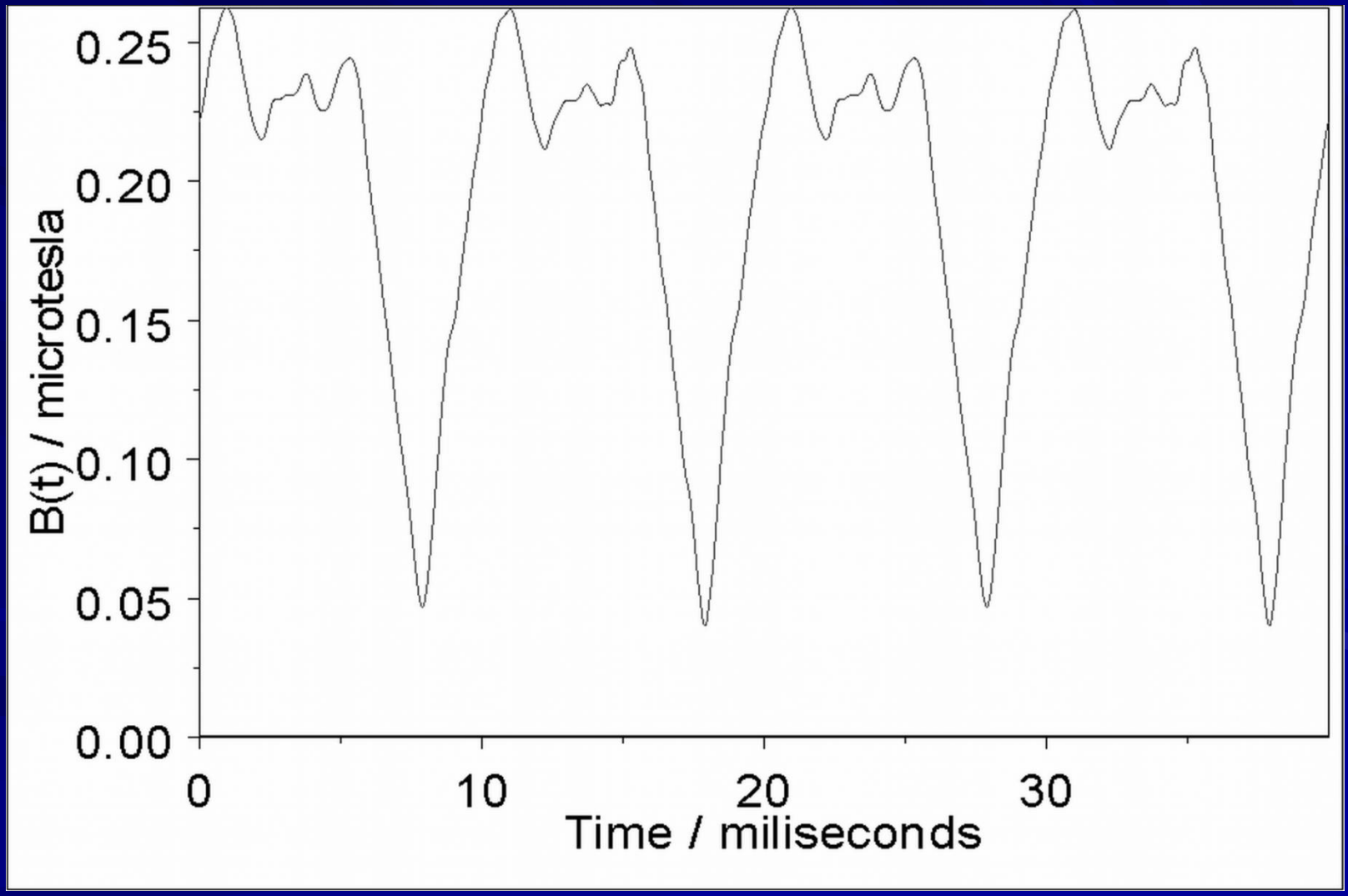
- The lower (L) and the upper (H) margin of variability has been expressed as

$$L = 10^{AM-SD} \qquad H = 10^{AM+SD}$$

- AM is arithmetic mean of logarithmic data,
- SD is standard deviation of logarithmic data;
- n is a count of data.

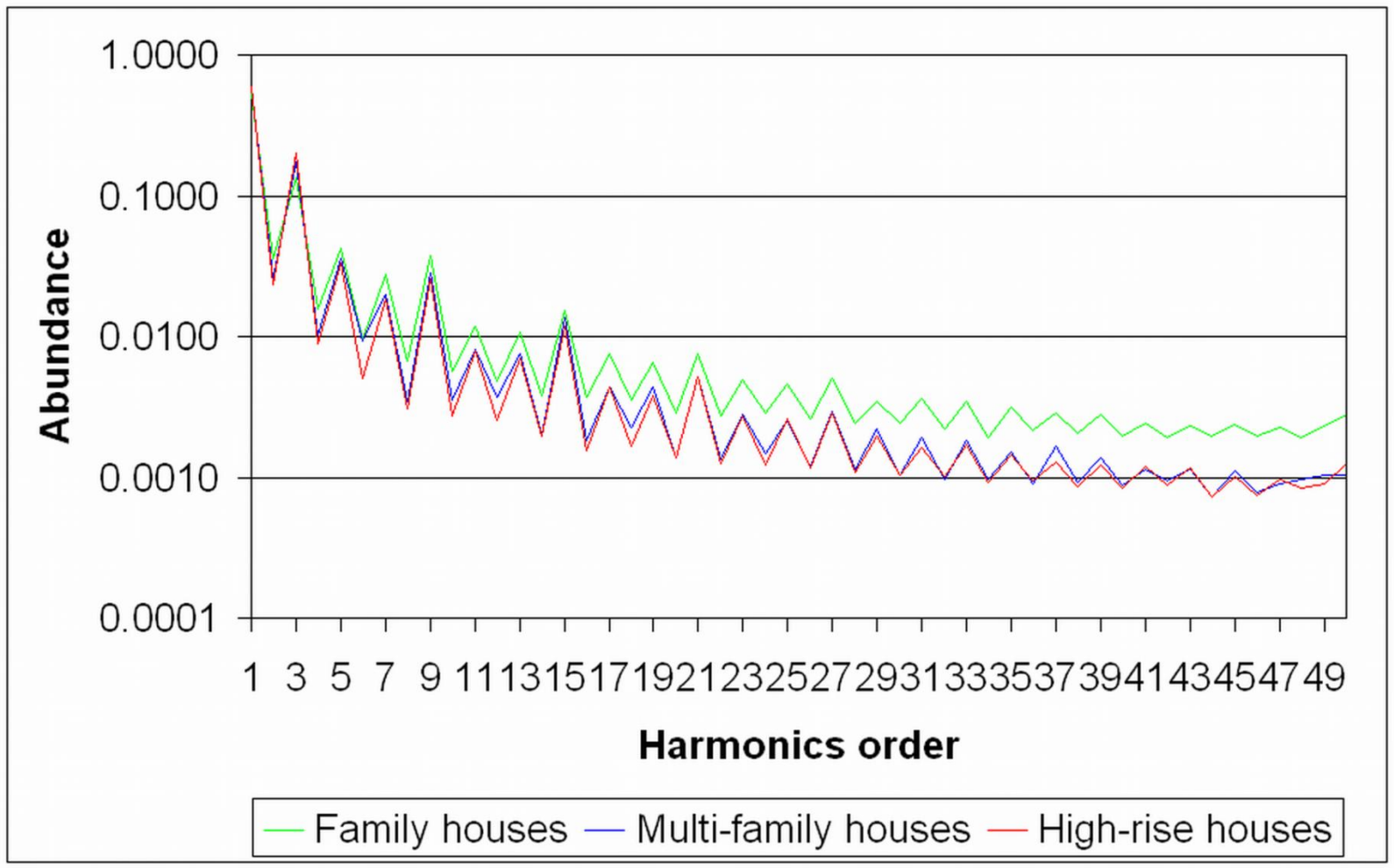
Results

- Magnetic induction values almost never gave a shape of an ideal 50 Hz sinusoid curve.



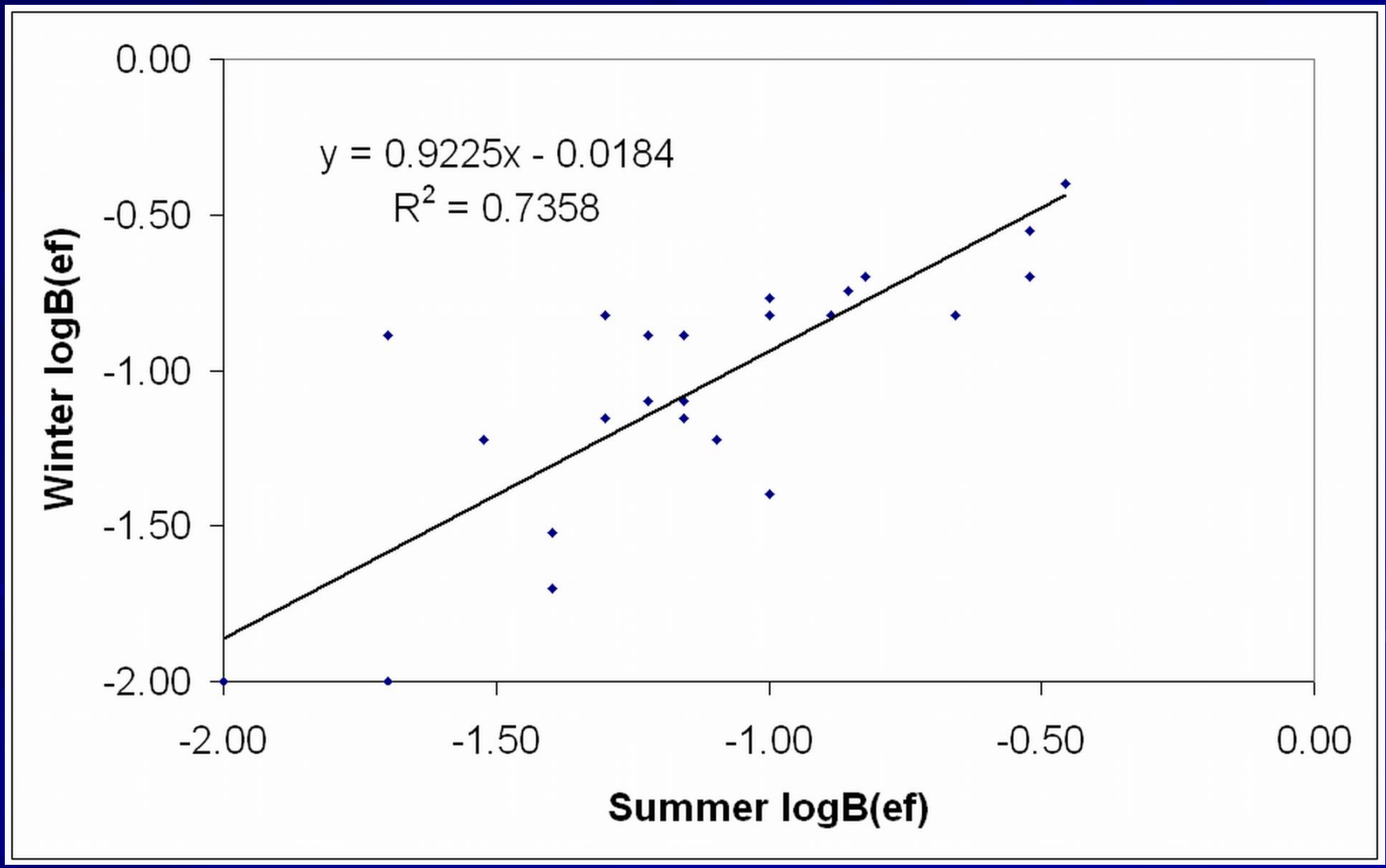
Results

- Relative ELF MF average levels of higher harmonic frequencies in proportion to the 1st (fundamental 50 Hz) harmonic for each of the three types of housing.



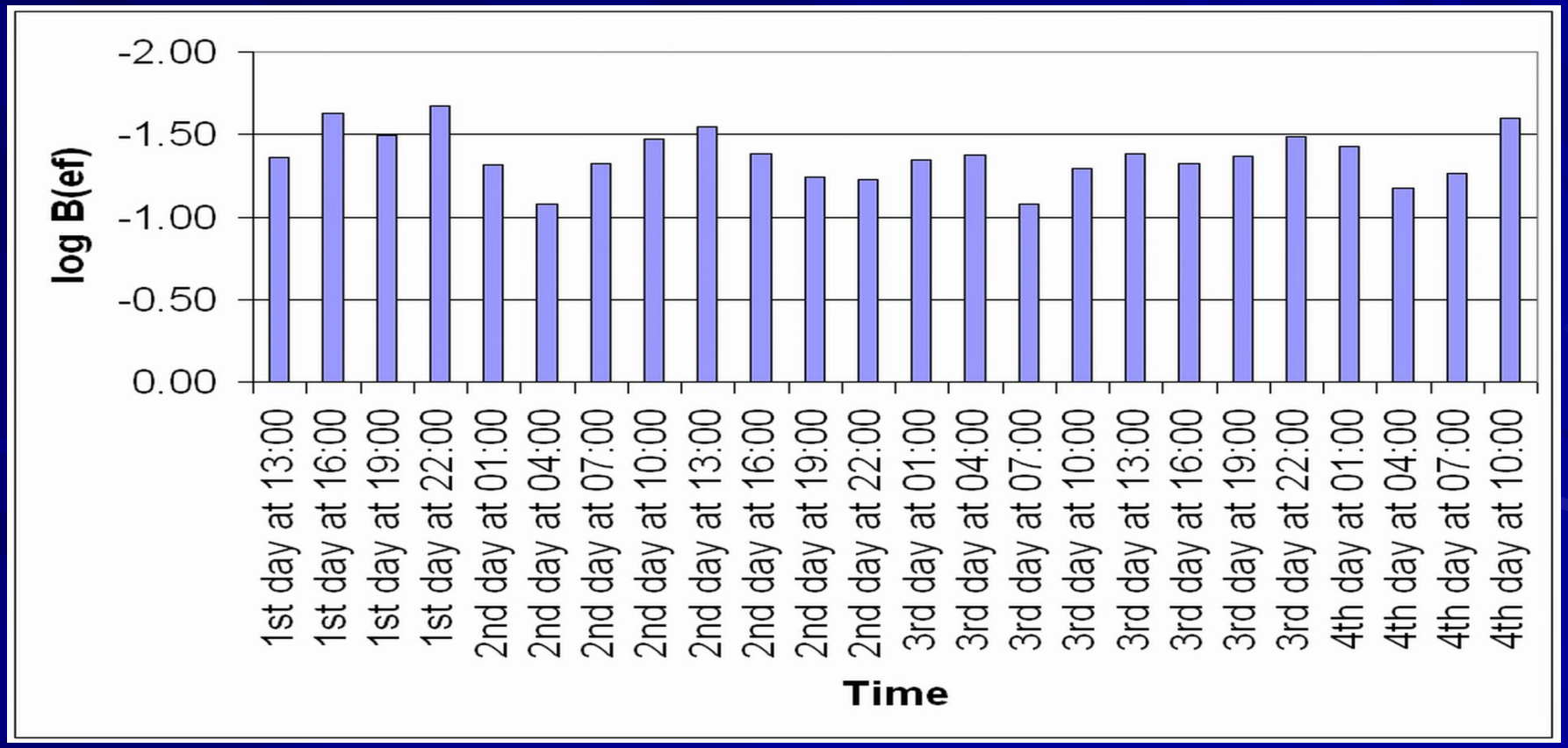
Results

- Seasonal variability of spot measurement results (29 - sites)



Results

- Variability of spot measurement results during a day and in different days
- Relative standard deviations were approximately:
- ±35 % inside and ±31 % outside for high-rise houses (2 houses)
- ±41 % inside and ±35 % outside for family houses (2 houses)



Results

- Differences in ELF MF measurement results beside and inside the houses.
- Parallel measurements in randomly selected places (2 houses of each type, i.e. 12 measurements).
- Geometric mean of the ELF MF values for selected:
  - high-rise houses 0.122 μT outside and 0.147 μT inside,
  - Multi-family houses 0.184 μT outside and 0.161 μT inside,
  - family houses 0.038 μT outside and 0.045 μT inside

Results

- Personal exposure
- Measurement of daily (24-hours) exposure was performed by two ways
  - Directly measured personal exposure (pocket magnetometer)
  - Stationary spot measurements in various places of a typical living environment (i.e. at home or in a flat, on the way of the child to school, at school, i.e. in classroom and corridors, and outside of house).
- Direct measurement on 12 years old school boy
  - Average value of 2 repeated 24-hour directly measured personal exposure was 0.094 μT
- Calculated daily personal exposure was 0.100 μT
  - He spent 18 hours at home (spot measurement 0.072 μT) or around the house (spot measurement 0.075 μT) and 6 hours at school (spot measurement 0.181 μT).

Results

- Measurements in the vicinity of power lines
- Reported results from the wires of 220 kV / 440 kV respectively :
  - directly under wires 2.46 μT / 3.33 μT.
  - 30 meters from the wires 0.89 μT / 1.13 μT.
- The efforts to acquire data of the number of houses located in the vicinity of very high voltage power lines in CR were not successful.

Results

- Main measurements - spot measurements beside houses using oscilloscope recording

Type of housing	High-rise houses	Multi-family houses	Family houses
Number of measured sites	55	35	73
Geometric Mean	0.236 μT	0.203 μT	0.072 μT
Variability (L – H) *	0.097 – 0.577 μT	0.095 – 0.432 μT	0.026 – 0.198 μT
Distribution in the CR **	33.8%	56.6%	9.7%
Weighted average	0.193 μT		
Variability (L – H)	0.084 – 0.442 μT		

•- the expression of variability (L – H)

*•** - distribution in the Czech Republic means how much inhabitants live at the mentioned types of housing (FIHF, 2006)*

Results

- Distribution of ELF MF exposure levels in the Czech Republic
- According to EU statistics:
  - 33.8% of total dwelling stocks of CR are in high-rise dwelling
  - 55.6% are in the multi-family dwellings, i.e. in houses with three and more flats.
  - Most of the last are probably multi-family houses (more detailed statistics is not available), because family houses have mostly up to two flats (two-dwelling buildings are not included in the above-mentioned statistics). It can be estimated, that one or two family dwelling represent only 9.7 % of total dwelling stocks in CR.

Exposure distribution	Category * <0.1 μT	Category * (0.1 - 0.2) μT	Category * (0.2 - 0.4) μT	Category * >0.4 μT
Percent of population	19.7%	27.6%	28.3%	24.4%

**** - the categories are divided according to WHO.***

Discussion

- WHO published ELF MF values in Western Europe and Overseas - geometric means (0.025 – 0.07) μT.
- Results obtained in this study are higher (0,072 – 0.236 μT).
  - This higher level may be due to a different manner of housing in CR, with considerable proportion of high-rise and multi-family houses with relevant electric wiring and lines.
  - In addition, panel houses have steel-concrete framing. Estimated geometric mean of ELF MF levels is 0.236 μT for high-rise houses and 0.203 μT for multi-family houses.
- Geometric mean of effective ELF MF levels of family houses had an estimated value of 0.072 μT and is statistically different.
  - Only results for family houses are consistent with values published by WHO. Approximately three times higher exposure has been found in other types of housing in CR (i.e. in high-rise houses and in multi-family houses).

Discussion

- Differences among the average contents of higher harmonic frequencies for each type of housing were small, but statistically significant.
  - We have no explanation for the slightly higher relative content of the basic frequency 50 Hz, third harmonic frequency 150 Hz and lower relative content of remaining frequencies beside the high-rise and multi-family houses.
- Presented results of ELF MF spot measurements had a considerable stability.
  - Regression analysis of winter and summer data shows no statistically significant differences, while their correlation is significant.
  - Short-term variability of spot measurements at the same location during several days was relatively low (max 41%)
  - These facts shouldn't significantly influence the applicability of the spot measurement results on longer-term period. Therefore we suppose that the results of spot measurements can be used for long term exposure assessment.

Discussion

- Significant differences were not found between average ELF MF levels beside and inside houses.
  - But the distribution of ELF MF levels within the houses was not uniform.
  - This finding confirms the idea that measurements in the immediate outside vicinity of houses are representative for exposure inside houses (of course except very short term exposures from electric appliances or close to incoming electric power lines in the building). This is supported by some studies which used distances between dwelling and outside power lines to calculation of ELF MF exposures inside houses.
- Substantial difference has not been found between the result of personal exposure measurement and the calculated time-weighted average from the spot measurements.
  - 24-hour personal exposure average 0.094 μT corresponds with WHO published data (0.042 - 0.134 μT). This result was slightly higher than spot measurement in the vicinity of houses (0.075 μT). The reason of found higher personal exposure level was probably 6 hour-presence in higher ELF MF exposure (0.181 μT) at the school.
  - Real ELF MF exposures for children living in family houses can be probably slightly higher than ascertained by spot measurements.

Discussion

- Short-term ELF MF exposures in vicinity of an electric appliance or in vicinity of underground power lines shouldn't affect the long-term exposures (exposure maximum is a few minutes).
- However, high long-term exposures can occur in the vicinity of very high voltage lines.
  - Measured levels under power lines correspond to published data, but number of exposed persons on a long-term basis in the vicinity of very high voltage was not available.

Conclusion of the ELF MF exposure study

- Because the dwellings in CR is different in comparison with Western Europe (for example in Great Britain only 2.4 % of dwelling is in high-rise buildings - 33.8 % in CR, 18.7 % dwelling is in multi-family houses - 55.6 % in CR), it was ascertained, that exposures above 0.4 μT, which are associated with slightly increased risk of childhood leukemia, can be expected up to 24 % of children (i.e. about 400 000 of 1 700 000 children) in the Czech Republic.
- These exposure values are higher than published data from industrial countries of Western Europe and Overseas, where is estimated that maximum 4 % of children is exposed by level above 0.3 μT, and maximum 2 % is exposed by level above 0.4 μT on a long-term basis.
- Whether these increased exposures mean some enhancement of childhood leukemia incidence in CR is solved in the epidemiological study.

Pilot case-control epidemiological study

Childhood Leukemia*
(25 – 35% of all neoplasmas in infancy)

- Acute childhood leukemia - absolute majority
  - Lymphatic (ALL) appr. 75 - 80%
    - By morphology - L1(most frequent), L2, L3 types
    - By B a T cells
      - Early Pre-B 57%-65% ALL
      - Pre-B 20%-25% ALL
      - B-Cell 2%-3% ALL
      - T-Cell 13%-15% ALL

  - Non-lymphatic – myeloid (AML) appr. 15 - 20%
    - From immature cells (except lymphoblastes) M0 type
    - From myeloblastes (immature granulocytes) M1, M2, M3 types
    - From monoblastes (immature monocytes) M4, M5 types
    - From erythroblastes (immature erthrocytes) M6 type
    - From megakaryoblastes (immature plateletes) M7 type
- Chronic childhood leukemia (CLL, CML) – rare cases

*According to American Cancer Society 2003 and WHO 2004

Causation of leukemia

- The exact causes of leukemia creation are unknown
- Decisive action:
  - Gene mutation, expression and reparation
    - The role of oncogenes and tumour suppressor genes (TSG) at mitosis
  - Chromosomal translocation (80% 11q23)
    - Possibility the oncogenes activation and TSG disconnecting
    - But ALL, AML will develop in only some ones with the translocations
  - DNA mutations and translocations aren't usually inherited but acquired.

Causation of leukemia

- Elmg fields can't be direct causes of structural changes (energy is too low !).
- Risk factors:
  - Ionising radiation (e.g. X and gamma ray)
  - Roles of the infections
    - Increasing risk have been found in a mixed population (new cities, suburb)
    - Two events – first prenatal (inception of the translocations), second postnatal (relates with early protection against infections)
  - Cancerogenic substances (e.g. benzen)
- **Is ELF MF a risk factor ???**

Methodology of epidemiology

Unpaired selection

	cases (sick)	controls (healthy)
exposed children	**a**	**b**
unexposed children	**c**	**d**

Paired selection

	exposed controls	unexposed controls
exposed cases	W	X
unexposed cases	Y	Z

Relative risk (RR) = (a/(a+b)) / (c/(c+d))

- risk ratio of exposed and unexposed people

Odds ratio (OR) = ad / bc (case-control study) nebo **X / Y**

- odds ratio of exposed and unexposed people

Epidemiologic Studies in the World Childhood Leukemia and ELF MF

- Descriptive studies
  - Enhanced incidence near high voltage power lines (Li et al. 1994, 1998)
  - Earlier and enhanced incidence on the sites with earlier installation electric wires in the first half 20th century. (Milham, Ossiander 2001)
- Cohort study (only one)
  - 17-year observation, found weak enhanced incidence (statistically insignificant) (Verkasalo et al.1993)
- Case-control studies
    - Canada (Mc Bride et al. 1999) OR=1,6 (0,65-3,7) >0,4μT
    - Germany (Michaelis et al. 1998) OR=2,0 (0,26-15) >0,4μT
    - New Zealand (Dockerty et al. 1999) 0case/0control >0,4μT
    - UK (UKCCSI 1999) OR=1,0 (0,30-3,4) >0,4μT
    - USA (Linet et al. 1997) OR=3,4 (1,2-9,5) >0,4μT
    - Sum calculated field studies OR=2,1 (0,93-4,9) >0,4μT
  - **Pooled metaanalysis up to 2002** **OR= 2,0 (1,3 – 3,1) >0,4μT**
  - **WHO-IARC 2002** **ELF is possibly carcinogenic to humans**
  - New studies
    - Japan (Kabuto et al. 2006) OR=4,7 (1,14-19,7) pro >0,4μT
    - UK (Draper et al. 2005)-calculation distances from power lines 132-400kV RR=1,7 (1,13-2,53) do 200m

Reference Levels and Exposure Limits

ICNIRP, EMF guidelines, Health Physics 74, 494-522 (1998)

It saves against the adverse effects of a induced electric current in body

European power frequency	**50Hz**		
	Electric field (V/m)	Magnetic field (μT)	Induced current density (A/m^2)
Public exposure limits	5 000	**100**	0,002
Occupational exposure limits	10 000	500	0,01

Childhood Leukemia in the Czech Republic

Statistics of childhood leukemia	0-4 years	5-9 years	10-14 years	Sum
1998-2003 mean count of children per year	458 421	563 627	645 635	1 667 682
1998-2003 mean count of new diseases per year	26,1	18,0	16,2	60,3

Case-control epidemiologic study

- Hypothetical statistic significance and the necessary count of cases and controls
- **Therefore the pilot study ! Our number of cases and controls is lower.**

Unpaired selection	Cases	Controls	OR	CI (95%)
Exp+	20	20	2,25	1,15 – 4,41
Exp-	80	180		
Pair selection	**Control, Exp+**	**Control, Exp-**	**OR**	**CI (95%)**
Cases, Exp+	5 pairs	30 pairs	2,0	1,04 – 3,89
Cases, Exp-	15 pairs	40 pairs		

Pilot case-control study

- Selection of cases
- Children <15 years old with any form of acute leukemia diagnosed by authorized physicians (diagnoses C91 – C95).
- The 82 cases were found (diagnosed between 2001 and 2006).
  - Two big specialized hospitals (of 6 totals) came into line of cooperation. More patients was not available, because some hospitals refused any cooperation by reason of personal data protection.
  - Quality of leukemia diagnostics in the CR is high; therefore the identification of "cases" can be regarded as reliable and specific. According to attainable dates from the Institute for Sanitary Information and Statistics, the average annual incidence of the disease in the CR between the years 1998 and 2003 was $3.25.10^{-5}$, which represents 54.2 new cases of leukemia yearly [UZIS, 2007].
- Data available only at the hospital documentations.
  - needed number of diagnosis, dg date, sex of child, birthday and **address.**

Pilot case-control study

- Selection of controls
- The 81 controls from the same documentation
  - Children treated in the hospital through an accident or another disease
- Pair selection – 79 pairs (for the first time in the ELF MF studies)
  - Pair consisting one sick and one healthy child at the same age and sex (increases the influence of age and sex)
  - Similar locality of living - dwelling (partly remove the confounding factors – environmental factors)

Exposure assessment

- From the exposure study.
- Each house (dwelling) complies with a case or control.
- From these data was calculated odds ratio (OR) and confidence interval (CI).

Results

- Exposure assessment results
- 14 cases and 15 controls were exposed $\geq$ 0.4 μT.
- 68 cases and 66 controls were exposed $<$ 0.4 μT .
- 9 pairs (cases $\geq$ 0.4 μT, controls $<$0.4 μT)
- 10 pairs (cases $<$0.4 μT, controls $\geq$ 0.4 μT)
- Remaining 56 pairs were exposed $<$0.4 μT and 4 pairs were exposed $\geq$0.4 μT.

Results

- Epidemiological data results

Number of observed subjects	**79 pairs**	**82 cases** **81 controls**
Odds Ratio (OR)	**0.900**	**0.906**
Confidence Interval (CI)	**0.366 – 2.215**	**0.406 – 2.023**

Discussion

- The pair controls for our study were chosen as the most appropriate for treating the bias and confounding factors.
- Epidemiologic studies are generally known for the pair selection decrease a negative influence with:
  - An uneven distribution of the illness in population
  - Age and sex
  - Environmental factors
- The pair selection has also a higher statistic significance with lower number of children (cases and controls).
- Therefore the validity of the study is higher, than if a not paired control method has been used.

Discussion

- Retrospective exposure assessment (see exposure study) would have mean a minimal uncertainty, because only the cases diagnosed in immediate past (years 2001 – 2006) were considered, while the appropriate exposures were measured as soon as possible (in 2006 – 2008). The delay of an exposure measurement in comparison with diagnosis date has been 5 years at the most.
- The number of cases and controls didn't achieve needed level and therefore there couldn't be expected significant odds ratio , but the pilot study hasn't any small tendency to a correlation (though insignificant) between ELF MF and the childhood leukemia occurences.

Conclusions of the epidemiological study

- Though the low number of cases was taken to the study (likewise in the previous foreign studies), not even insignificant slight higher occurrence of childhood leukemia (OR=0.9, CI=0.366 -2.215) has not been observed with regard to higher ELF MF exposures in the Czech Republic.
- According to WHO, the OR = 2 (CI = 1.3 – 3.1), derived from the pooled analyses, describes a risk (probability) of childhood leukemia with elevated exposure to ELF MF. It would mean approximately 20 new cases yearly due to the ascertained higher exposures in the Czech Republic. This has not been confirmed in our study, the occurrence of childhood leukemia is not higher as in other countries.

- Thank you for your attention