Static fields:

highly exposed groups (MRI, NMR, electrolysis, etc), limited exposure assessment guidelines

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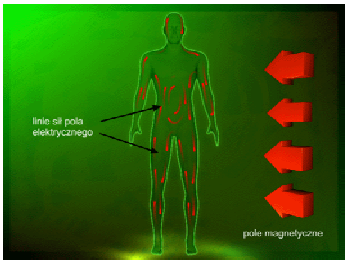
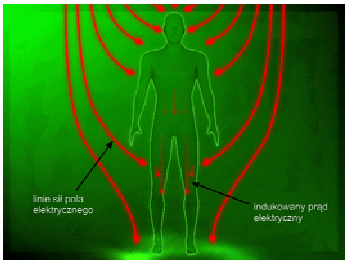
Human body exposure to time-varying EMF

- *B* and *E* fields penetrate the body
- time variability (d/dt) produce inside the body electric fields and induced currents
- induced fields/currents can cause nerve/muscle excitation





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Human body exposure assessment

e.g. Directive 2004/40/EC (workers)
assessment, measurements or calculations of EMF exposure

Action values - exposure level (*E* and *H*, *B*)
– **unperturbed fields** (measured without the presence of workers)

Exposure limit values - dosimetric quantities (J and SAR) – calculated with electrical properties of exposed objects and workplace components

Human body exposure to static EMF

- E_0 **fields not** penetrate the body
- B_0 **fields not** produce inside the **non-moving** body electric fields and induced currents
- time variability (d/dt) caused by the **movement of the body** in static fields produce inside the body electric fields and induced currents producing **occupational risk**

- **It is easy to measure** the unperturbed B_0 field, but it is not directly related with occupational risk
- In practice, **it is not possible to measure** the unperturbed E_0 fields and it is not directly related with occupational risk

Exposure to electrostatic field E_0

1) E_0 does not penetrate the human body (suppression over 10 orders of magnitude) and for that, this kind of exposure is neglected usually.

2) E_0 **removes small air ions from the indoor air.**

Nowadays the small air ions are considered a very weak environmental factor without significant influence on the human health and psychic performance.

But this attitude is based on experimental work which has been done with elevated air ion concentration.

Only a few papers consider the superoxied particles (some negative air ions) as important biological factor and the harmful effects of lack of negative ions on mice's health and the length of life.

- It needs more research with good methodology.

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Exposure to electrostatic field E_0

3) E_0 can induced **ESD** between the human body and conducting objects (including other human) ⇒ explosive hazards.

In some industrial cases, frequent discharges can cause **serious irritation of the skin**.

4) E_0 forces the elevated deposition of aerosol particles (air pollutions) onto the human skin, **including the radioactive radon daughters** – health effects are not recognized sufficiently.

TCO Development included that effect in restrictions of electrostatic potential of CRT VDU's.

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Biological and health consequences of exposure to static magnetic fields B_0 (#1)

- health effects of static magnetic fields are still under question, especially in case of chronic exposure of high level
- World Health Organization (WHO, 2006) *monograph 232 - Environmental Health Criteria - Static Fields* concluded that „**there is not sufficient scientific data for establishing health risk of static magnetic field exposure**"
- Short review is presented by IEEE *Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz*, Std.C.95.6, 2002

Biological and health consequences of exposure to static magnetic fields B_0 (#2)

- Physical effects of B_0 (**translation and orientation of charged molecules**) cause electrodynamic forces on moving electrolytes, and **effects on electron spin states** of chemical reaction intermediates
- Translation and orientation of molecular and cellular substances such as retinal rods, and some living cells have been experimentally observed in vitro in B_0 of high level (above 1 tesla (T)), in various materials - dia- and paramagnetic such as **hemoglobin, collagen, fibrin, and also on ferromagnetic particles such as magnetite**.
- Water distribution can be affected by high-gradient B_0 of high flux density (e.g., 8 T, 50 T/m; Ueno and Iwasaka 1994 - force up to 30% the force of gravity, but only about 1% of gravity in whole-body 4 T magnet).

Biological and health consequences of exposure to static magnetic fields B_0 (#3)

- Electrodynamic forces on moving ions in blood vessels, generating an electric potential across the blood vessels (Hall effect) and theoretically a reduction of blood flow velocity (Tenforde 1992)
- 5 and 10% reduction in blood flow in the aorta was predicted for B_0 of 10 and 15 T, respectively, due to magneto-hydrodynamic interactions (Kinouchi et al. 1996)
- Related observations included a 0.2–3% change in blood velocity between 1–10 T (Dorfman; Keltner)

Biological and health consequences of exposure to static magnetic fields B_0 (#4)

- Experimental examination of the scale of biomedical effects of B_0 exposure are still under examination, frequently using electrocardiogram (ECG) technique
- In addition, **vertigo** and other sensations, as **difficulty with balance, nausea, headaches, numbness and tingling, phosphenes, and unusual taste sensations**, were recorded during movement in high field.

Biological and health consequences of exposure to static magnetic fields B_0 (#5)

The other investigated endpoint were:

- cognitive function, assessed during exposure using standard neuropsychological tests
- effects of exposure to fields of up to 8 T on heart rate
- respiratory rate
- systolic and diastolic blood pressure
- finger pulse oxygenation levels, and core body temperature.

Biological and health consequences of exposure to static magnetic fields B_0 (#6)

- **The exposed volunteers moved very slowly (one or two feet over a few seconds, followed by a 15–30 s pause, taking overall about 3–4 min for high field units) into the magnet bore in order to avoid the transient, movement-induced sensations described above.**
- **Nevertheless, nine subjects reported sensations** of dizziness, and two reported a metallic taste, assumed to be due to electrolysis of metallic chemicals in the subjects' teeth fillings (Schenck et al. 1992).
- **Normal worker's movements in the vicinity of magnets are much faster.**

Biological and health consequences of exposure to static magnetic fields B_0 (#7)

- IARC (2002) notes that two somewhat dated studies (Neurath 1968; Ueno et al. 1984) report that exposure to B_0 of 1 T with high spatial gradients (10–1,000 T/m) can adversely effect the development of frogs and toads, but notes that most studies indicate a lack of effect of B_0 exposure
- **With B_0, reactions under laboratory conditions include a 17% increase in human cardiac cycle length at 2 T (Jehesen et al.)**
- **The authors suggested that the observed effect is probably harmless in healthy subjects, but that its safety in dysrhythmic persons was not certain.**

  Such question is very important in the case of health examination for workers, who are going to start or continue MRI scanners operation

Highly exposed workers

???

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B_0 versus occupational exposure limitations

Examples of limitations from:	Whole body		Limbs		Cardiac stimulators and implanted electronically activated devices
	Whole working day	Ceiling value	Whole working day	Ceiling value	
ICNIRP guidelines, 1994	200 mT	2 T	not fixed	5 T	0.5 mT
EU directive, 2004	200 mT	not fixed	not fixed	not fixed	mentioned but not fixed
IEEE standard, 2002	500 mT	500 mT	500 mT	500 mT	mentioned but not fixed
ACGIH, 2005	60 mT	2 T	600 mT	5 T	0.5 mT

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EMF Exposure Limitation (Directive 2004/40/EC) – inversely proportional to frequency

	Static Magnetic Fields	Power frequency magnetic fields (50 Hz)	Intermediate frequency magnetic field (1 kHz)
workers	200 mT Action Values only	0.5 mT Action Values and Exposure Limit Values (induced current density)	0.04 mT
flying objects	3 mT	no danger	no danger
cardiac peacemakers	0.5 mT	0.1 mT	0.1 mT

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E_0 versus occupational exposure limitations

- limited arguments
- how to define overexposure?
- exposure guidelines – 25 – 60 kV/m?

- dielectric materials production
- DC HVPL

  - Modern monitors (CRT and LCD) **not** produce elevated E_0 fields

EMF Exposure Limitation – inversely proportional to frequency Overexposure prediction

	Static Magnetic Fields	Power frequency magnetic fields (50 Hz)	Intermediate frequency magnetic field (1 kHz)
Workers exposure limitation	200 mT	0.5 mT	0.04 mT
in the distance of **100 cm** from current of	1000 kA	2.5 kA	0.2 kA
in the distance of **15 cm** from current of	160 kA	0.4 kA	0.03 kA

MRI equipment

Nuclear magnetic resonance (NMR) involving absorption and re-emission of radiofrequency (RF) radiation by nuclides (protons) in a static magnetic field.

Magnetic Resonance Imaging (MRI) use NMR phenomenon for 3D imaging.

EMF sources:

- magnets - typically from 0.5 T to about 3 T (7 T)
- diagnostic coils emitting pulsed modulated RF fields of 20-120 MHz (280 MHz)
- gradient coils emitting pulsed magnetic fields, in pulse sequences harmonised with RF pulses

Diagnostic use of MRI units
MRI health care staff activities (#1)

- attending while patient's access and lay down on the imaging table
- diagnostic RF coils positioning on the imaging table or patient's body
- **plugging-in/off the RF coils cables into the supplying socket**
- MRI table positioning for finding it's geometrical position and put in/out it into/from magnet
- attending while patient is getting off from the imaging table
- contrast injecting

Exposure to static fields

30-150 cm from the housing

2-15 minutes per patient

MRI health care staff activities (#2)

- Occasionally in case of old types of MRI systems, during the course of examination, workers were tuning manually RF coils placed inside the magnet. This activity sometimes lasts a few minutes
- In the case of certain types of examination, some pharmaceutical components, e.g. contrast are injecting into the patient (usually placed inside the magnet). In many cases injection is made by nurses, even if the use of infusion pumps is technically possible. These activities last of 1-2 minutes – **it can be executed during pulsed fields emission and cause time-varying fields exposure!**
- **In some medical centres diagnosed patients are assisted by medical staff during the examination – very rare practice!**

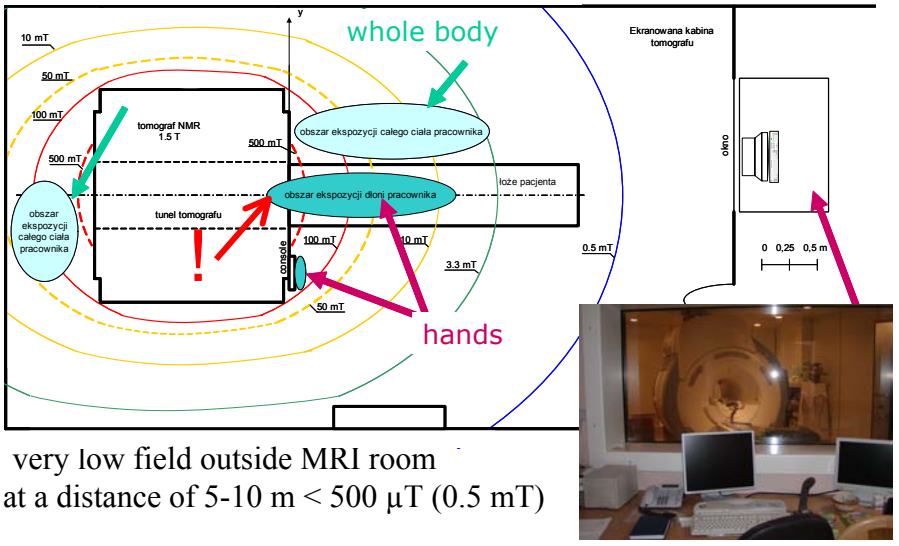
MRI health care staff activities (#3)

- Occasionally workers' exposure can be caused also by emergency situations
- Cleaner-workers can be also exposed to high level of static magnetic fields inside imaging room because permanent and superconductive magnets are always switched on

Other non-medical exposed groups

- Technicians repairing the magnets
- Manufacturer's staff

Exposure to static fields from magnets

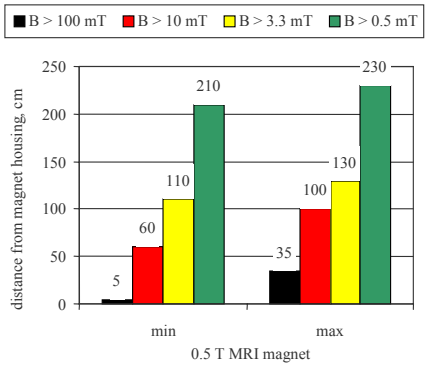


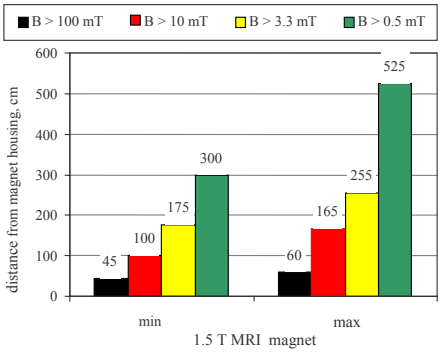
- very low field outside MRI room
- at a distance of 5-10 m < 500 μT (0.5 mT)

Exposure to static fields from magnets

in the case of performing professional activities very close or inside the magnet's bore, workers can be exposed to fields of level of patient's exposure !!! (up to 1-2 (3) T), e.g. during adjusting or plugging in RF cables of treatment coils, or device cleaning

Spatial distribution of static fields of various MRI devices





0.5 T **1.5 T**

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Static magnetic field of workers' exposure

- no need for higher worker's exposure from higher field unit

Activities types	Health care staff exposure level, mT / MRI unit type	
	relatively high field superconductive magnet - closed (bore)	
	1 T	1.5 T
plugging-in/off the RF coils cables into the supplying socket and console use - hands exposure	50-200 up to 1000*)	20-500 up to 1500*)
maximum field existing on the accessible for workers cover of magnet	350	250-600

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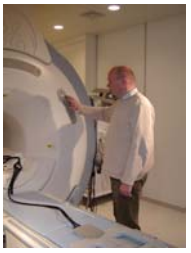
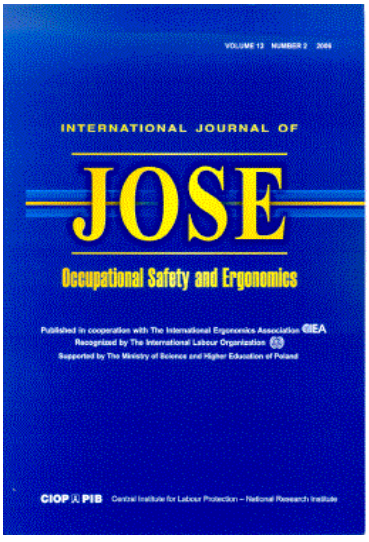
Exposure reduction

- reduction of the workers' exposure level is possible when it is possible to operation in the distance from the magnet no less than 0.5 m (requirement for MRI device design! – no possible to change construction in the hospital)
- workers' training should also present them methods for exposure reduction





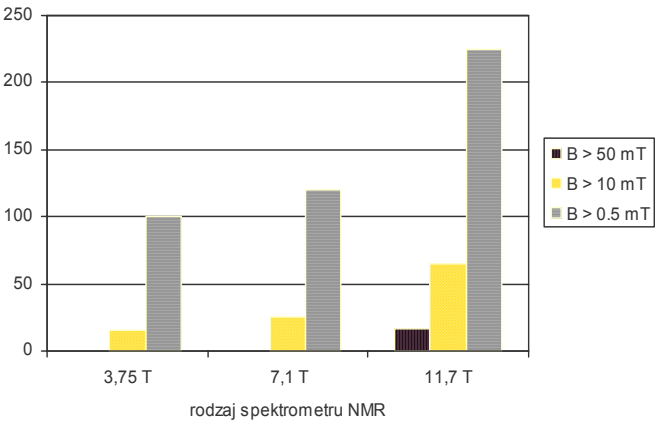
More detailes:

Karpowicz J., Gryz K. - Health Risk Assessment of Occupational Exposure to a Magnetic Field From Magnetic Resonance Imaging Devices,

International Journal of Occupational Safety and Ergonomics (JOSE), 2006, vol. 12, No. 2, 155-167.

NMR spectrometers – static magnetic fields exposure

Static magnetic field – Directive 2004/40/EC compliance



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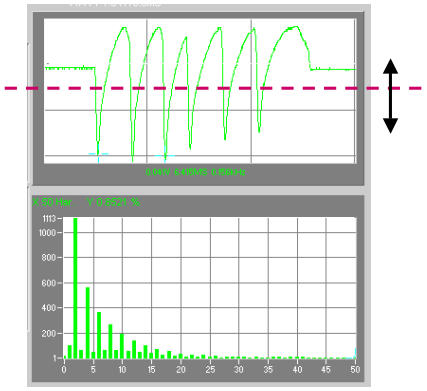
Rectification – so-called DC current supply static magnetic fields exposure + time-varying exposure



DC component + even harmonics (50 Hz or higher basic frequency)

Various DC/AC ratio!!!

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Electrolytic installations

DC (rectified currents, 3-phases) - **10-300 kA**
(DC component + time-varying from rectification 50-300 Hz, possible also higher frequency components)

Static magnetic field – Directive 2004/40/EC compliance, but hazardous for cardiac pacemakers, possible magnetic memory destroy and flying objects in the case of extremely high current

Time varying exposure – possible overexposure

Possible active and passive shielding

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DC Welding devices

DC (rectified currents, 1- or 3-phases)
- up to **100 (1000) A**

- (DC component + time-varying from rectification 50-300 Hz, possible also higher frequency components up to high kHz range!)

Static magnetic field
– Directive 2004/40/EC compliance,
but hazardous for cardiac pacemakers, possible magnetic memory destroy and flying objects hazards very rare

Time varying exposure – possible overexposure

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CONSLUSIONS

- **MRI was identified as the potential source of the highest exposure of workers**
- No serious adverse health effects from the whole-body exposure of healthy human subjects up to 8 T have been reported in the literature, **but also no epidemiological studies have been performed yet** to assess possible long term health effects in patients, workers, or volunteers.
- Only few informative studies have been performed using exposures above 2 T.

CONSLUSIONS

- There are many gaps in knowledge of biological effects and interaction mechanisms of MRI-related electromagnetic fields with tissues.

- It is very confusing against the growing up the use of static magnetic fields in medicine, which lead to exposures of patients and workers to very high fields, even significantly exceeding the level of scientifically investigated exposure results (4 to 8 T).

CONSLUSIONS

- In the case of very specific occupational situation of medical staff operating MRI scanners, **additional attention should take notice of the occupational risk assessment**
- **Further investigations and exposure assessment should include the safety of patients from non-error work ability of medical staff and safety requirements preventing hazards from "flying metallic objects"**

» **Exposure assessment should allow multi-level analysis of exposure pattern, harmonized with various approach to exposure limitations**

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„Murphy's law"

Worker takes always 'the worst case" of EMF source operation!!!

!!!

!!!

Good engineering is the most important for worker's safety

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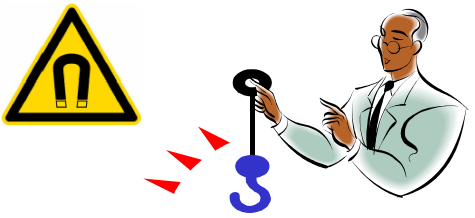
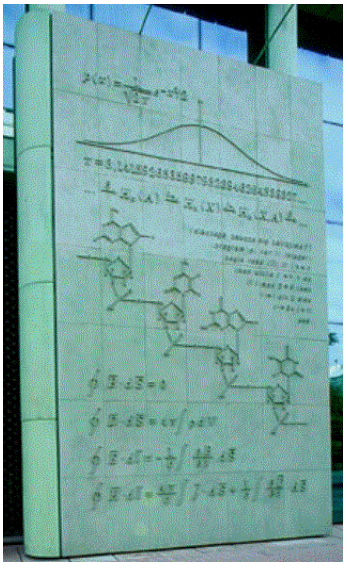
„cost-effective” (magic) static fields assessment

$E_0 > 3$ kV/m – „moving hair”



$B_0 > 3$ mT – „flying objects”



Thank you for your kind attention!

Static fields

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