Managing the Health Risks from Workplace Electric and Magnetic Fields (EMF)

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Outline

• Basic EMF concepts
• Measuring lower frequency (60 Hz–100 kHz) EMF
• Managing health risks from lower frequency EMF:
  o Complying with exposure limits
  o Precautionary strategies to reduce possible cancer risks
• Overview of radio frequency (RF) hazards

EMF Concepts

• Lower frequency EMF in the electromagnetic spectrum
• Sources
• EMF definitions and characteristics
• Exposure metrics
• Biophysical mechanisms
5000 km
Extremely Low Frequencies (ELF)
60 Hz

Frequency is a major determinant of EMF’s biological effects.

High Magnitude ELF*
Sources

Transformer
Electrochemical cells
Transmission lines
Induction ladle furnace

Transformer
Metal welding

ELF = Extremely low frequencies (3 – 3000 Hz)
High Magnitude Intermediate Frequency (3 kHz – 10 MHz) Sources

- AM radio antenna
- RF ID scanner in warehouse
- **Induction** metal heat treating
- Electronic article surveillance

High Magnitude RF* Sources

- **Tower with FM radio & cell phone**
- **Radar**
- **Microwave drier**
- **Rooftop antennas**
- **Medical diathermy**
- **Dielectric plastic heat sealer**

*RF = Radio frequencies (30 MHz – 300 GHz)
EMF Properties and Units

- EMF are force fields emitted by electricity
- Electric fields ($E$) determined by voltage.
  - Units: Volts per meter [$V/m$]
  - Example: high-voltage power line
  - Shielding: shielded by most matter, esp. metal
- Magnetic fields determined by current.
  - Units:
    - ELF: $B$ (magnetic flux density) in microtesla [$\mu T$]
    - RF: $H$ (magnetic field strength) in amperes per meter [$A/m$]
    - Difference only in units: $B$ [$\mu T$] = $1.26 H$ [$A/m$]
  - Examples: welding, metal furnaces
  - Shielding: unabated by matter, except thick steel

EMF vectors over time
Trace of MF vector over four cycles near transformer

Vector Magnitudes:

From the earth:
Static Field (Bo): 314.23 mG
ELF Field (RMS): 3.36 mG
from the transformer.

Wobbles in the vector trace are due to harmonics.

Note on units: The obsolete “milligauss” (1 mG = 10 $\mu T$) is still used in the U.S.
Frequency Components

Transformer

Vector Magnitudes:
- Static Field (B₀): 314.23 mG
- ELF Field (RMS): 3.36 mG

Principle Frequencies
- Power Frequency for North America

Harmonics:
- Multiples of the fundamental due to non-linear components (rectifiers, etc.)

Frequency Spectrum
Transformer magnetic field
Exposure Metric

- **Definition:** a single number that summarizes a person’s exposure to an environmental agent.
- Essential for epidemiologic analyses and setting exposure limits.
- Successful metrics are derived from mechanisms related to health effects
- **Examples:**
  - dBA for hearing loss
  - Respirable fraction of aerosols for silicosis, black lung, etc.
  - Absorbed dose of ionizing radiation

Exposure Metrics for Lower Frequency EMF

1. **Root-mean-squared (RMS) vector magnitude**

   \[
   \text{RMS vector magnitude} = \sqrt{\frac{1}{T} \int_0^T \left| B_{AC}(t) \right|^2 \, dt} = \sqrt{B_x^2 + B_y^2 + B_z^2}
   \]

   where \( B_x, B_y, B_z \) are the RMS components.

   - Often called the “resultant”
   - Requires meter with sensors in the x, y and z axes
   - Not related to any biomechanism
**ELF Magnetic Field Measurements – 1**  
3-Axis Gaussmeters

- **Flat response:** 40-1000 Hz  
- 3 orthogonal (3D) induction coils ➔ isotropic probe  
- Spot measurements and personal monitoring  
- EMCALC software for statistics and graphing  
- Output called the “resultant”  
  \[ B_x^2 + B_y^2 + B_z^2 \]  
- TWA resultant calculated by data logging EMDEX models  

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**Mechanism for ELF EMF Neural Effects**

1. EMF induce internal electric fields.  
2. Which can stimulate nerves.  
3. EMF exposure limits keep internal currents from causing abnormal electrostimulation.

**Dose Metric:** Internal electric field $E$ [Volts / meter]
Magnetic Induction Mechanism
Analogy with an Electric Generator

- Static magnetic field
- Wire coil moves
- Oscillating field
- Head is relatively still

Both generate an AC electric field (AKA voltage).

Magnetic Induction and Frequency

What happens to the voltage when the generator spins twice as fast?

- Induced voltage proportional to frequency and magnetic field
  \[ E_{\text{internal}} \propto fB \]
Applied voltages can affect electrical structures

Neurons

Pacemakers

Applied voltage above threshold initiates action potential

Exposure Metrics for ELF Magnetic Fields

2. Safety limits

ICNIRP Reference Levels

1000 uT
Occupational Exposure Limits for ELF EMF

Outline

• Common features of ELF guidelines
  • Hazard basis for guidelines

• Guideline options

• Measuring compliance
  • Magnetic fields
  • Electric fields
  • Sampling strategies

Features of Safety Guidelines for ELF-EMF

• Basis is nerve disruption
  • Temporary visual effects (*magnetophosphenes*)
  • Impaired mental functioning

• Two-level limits
  o Basic restrictions
    • Internal voltage across a nerve – requires computer dosimetry
  o Reference levels
    • External exposure – use EMF meters
    • Other names: TLV, maximum permissible exposure

• Nerve disturbance from EMF ➔ frequency-dependent reference levels
  o Internal electric fields induced from external magnetic fields are proportional to $1/f$
  o Nerve response to an applied electric field has a hockey-stick behavior with frequency.
  o Combination of the two mechanisms gives reference levels that are flat at 50–60 Hz

Models derived from MRIs
Example of an Adverse Effect: Balance Effects from Time-varying Magnetic Fields near an MRI

- Double-blind experiments in tents near and far from an MRI.
- Standardized head movements in MRI’s fringe fields creates 2.5 Hz magnetic field exposures
- Balance test similar to a sobriety test for drunk drivers
- Sway measured by accelerometer
- Sway in high MF ≈ 5 glasses of beer


Occupational Exposure Limits for ELF MF

Existing standards/guidelines for magnetic fields

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Neurological basis</th>
<th>Magnetic field limit [µT] @ 60Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLV for Sub-RF MF</td>
<td>Magnetophosphenes</td>
<td>1,000</td>
</tr>
<tr>
<td>ICNIRP (International Commission for Non-Ionizing Radiation Protection)</td>
<td>Magneto</td>
<td>1,000</td>
</tr>
<tr>
<td>European Union Directive:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low action level</td>
<td>Magnetophosphenes</td>
<td>1,000</td>
</tr>
<tr>
<td>High action level</td>
<td>Adverse effects</td>
<td>2,000</td>
</tr>
<tr>
<td>IEEE (Institute of Electrical and Electronic Engineers)</td>
<td></td>
<td>2,710</td>
</tr>
</tbody>
</table>

- OSHA has no EMF standard
  - Website lists the TLV, IEEE and ICNIRP guidelines as enforceable under the general duty clause.
2. RMS Vector Magnitude in the Flat Response Region

Recommendation: Use resultant for ordinary AC sources.

Linear Response Region is more difficult
Sources in the Linear Response Region

300 Hz – 3kHz

**Induction Heat Treating**

Depending on the part’s dimensions and metal properties, frequencies can be in the linear response region.

**Metal Detector**

- Frequency Spectrum
- Waveform

Screening Method from IEEE Standard

*Option for single frequency fields in linear region*

1. Determine frequency and polarization from source properties.
2. Use a 3-axis meter that measures the resultant and has a bandwidth that encompasses the source’s frequencies.
3. Search for the maximum exposure over space and time.
4. If Upper Uncertainty Limit (UUL) < exposure limit, decide exposures comply with standard. Otherwise, consider a more accurate method.

Reference: IEEE Recommended Practice for Measurements and Computations of EMF Exposures, 0 – 100 kHz (2010)
IEEE Compliance Decision Strategy

Exposure limit

UUL < EL
Employer in compliance

LUL > EL
Inspector can cite

UUL > EL
Employer might get more data

Improve exposure data:
1. Better metric
2. Better instrument
3. Dosimetry

UUL = upper uncertainty level; EL = exposure limit; LUL = lower uncertainty level

Most accurate metric for EMF exposure limits: *Meter with “Shaped Time Domain” Filter*

1. Filter starts with ICNIRP limit
**Meter with “Shaped Time Domain” Filter**

2. Flip ICNIRP limit to create a filter

![Graph](image1.png)

**Meter with “Shaped Time Domain” Filter**

3. Measurement of multi-frequency field

![Graph](image2.png)
**Meter with “Shaped Time Domain” Filter**

4. Readout is the sum of filtered frequency components as a percent of the standard.

![Graph showing frequency response and ICNIRP standard](image)

**Gaussmeter with Filtering Capability**

- 3-axis probe
- Bandwidth 1 Hz – 400 kHz
- Dynamic range up to 80 mT
- Analysis modes:
  - Field Strength (RMS magnitude or peak vector magnitude)
  - Filters for ICNIRP and other standards
    - Shaped Time Domain (STD) mode
- Limitations:
  - Expense
  - Sequential multiplexing

![Gaussmeter image](image)
Precautionary strategies for the Possibly Carcinogenic rating for ELF Magnetic Fields

Outline

• Meaning of Possibly Carcinogen to Humans rating by IARC and WHO
• Exposure metrics and risks to workers from ELF-MF
• Precautionary measures to reduce possible cancer risks
• Messages for persuade industrial hygienists, managers and workers to adopt precautionary measures

Problem

• Magnetic fields at extremely low frequencies (ELF=3-3000 Hz) are Possibly Carcinogenic to Humans
  • Based on epidemiology:
    • Childhood leukemia with home exposures
    • Brain cancer and leukemia from occupational exposures
  • Animal studies inconclusive in 2007
    • New mouse study of ELF MF and ionizing radiation
  • No proven mechanism
    • New findings here also
• WHO’s Environmental Health Criteria on ELF-MF:
  “low-cost precautionary procedures to reduce exposures [are] reasonable and warranted ...”
• However, precautionary methods for reducing workplace exposures are lacking
Resolution

- NIOSH risk assessment of cancers from occupational ELF-MF [Bowman et al. 2012]
  - Risk of dying prematurely decreases by 0.32% ± 0.29% per 1 μT reduction in TWA magnetic field resultant
  - Reducing TWA exposures above 0.3 μT can be cost-effective

Precautionary strategy: Low cost measures to reduce TWA

NIOSH Project
Managing possible cancer risks

- Evidence too weak for regulations.

- World Health Organization recommends reducing magnetic field exposures as a precaution
  - Precautionary Principle

- Strategy: Reduce magnetic field TWAs
  - Cost-effective methods developed for Dutch work places
Participating Dutch companies and their strong ELF magnetic field sources

<table>
<thead>
<tr>
<th>Company</th>
<th>Equipment and Equipment Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR car refitting plant</td>
<td>Magnetic fault testers, induction heaters, induction furnace, arc welding</td>
</tr>
<tr>
<td>Auto body plant</td>
<td>Spot resistance welding, arc welding, electric power center</td>
</tr>
<tr>
<td>Plastics company</td>
<td>Chlorine electrolysis cells, rectifier room, electric power center</td>
</tr>
<tr>
<td>Paper mill</td>
<td>Generator, transformers, large motors, arc welding, electric fork lift</td>
</tr>
</tbody>
</table>

Tools for Designing Controls

- Personal monitoring with task log
  - High exposure tasks
  - Duration of exposure
- Spot measurements
  - Identify sources
  - Fall off with distance
- Basic IH principles:
  - distance, time, reps
- Modeling

![Graph showing magnetic field strength decay with distance for induction heater]
### Precautionary measures

**RR car refitting plant**

<table>
<thead>
<tr>
<th>Source</th>
<th>Exposure reduction measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction furnace</td>
<td>Install remote control</td>
</tr>
<tr>
<td>Handheld fault tester</td>
<td>Purchase lower emission model</td>
</tr>
<tr>
<td>Metal induction heater</td>
<td>Increase distance when operating</td>
</tr>
<tr>
<td>Arc welder</td>
<td>Do not run cable over the shoulder</td>
</tr>
</tbody>
</table>

Spot measurements determine control's position  

Cable crossing the body

### Precautionary measures

**Auto body plant**

<table>
<thead>
<tr>
<th>Source</th>
<th>Exposure reduction measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc welding</td>
<td>Do not run cable over the shoulder</td>
</tr>
<tr>
<td>Manual spot welding</td>
<td>Re-design process</td>
</tr>
<tr>
<td>Robotic spot welding</td>
<td>Electric-work-only zones</td>
</tr>
<tr>
<td>Power center</td>
<td>Electric-work-only zones</td>
</tr>
<tr>
<td>Other jobs</td>
<td>Training on EMF hazards and exposure reduction</td>
</tr>
</tbody>
</table>

Control: Place metal parts into jig and step back to weld
## Precautionary measures

*Plastics plant*

<table>
<thead>
<tr>
<th>Source</th>
<th>Exposure reduction measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine cell hall</td>
<td>Electric-work-only zones</td>
</tr>
<tr>
<td></td>
<td>Install video cameras to decrease inspections</td>
</tr>
<tr>
<td></td>
<td>Turn surrounding cells off during repairs</td>
</tr>
<tr>
<td>Power center</td>
<td>Electric-work-only zones</td>
</tr>
<tr>
<td>Rectifier room</td>
<td>Electric-work-only zones</td>
</tr>
<tr>
<td>Other jobs</td>
<td>Training on EMF hazards and exposure reduction</td>
</tr>
</tbody>
</table>

![Electrolysis cell hall](image)

### Rectified Magnetic Field

<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Magnetic field (mT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Electric-work-only Zones in the electrolysis cell hall**

- **34 μT**
- **90 μT**
- **87 μT**
- **27 μT**

**Work practices for electric-work-only zones**

- First prepare all tools
- Step out of zone for other tasks
- Do not take any safety risks.

**Decrease time in high field areas**
Worker Training Presentations for Dutch study

• *Train the trainer* model

• **Outline**
  • What are magnetic fields?
  • Health risks
    • Proven ➔ European limits
    • Possible ➔ precautionary measures
  • How worker can reduce exposure

![Risk gauge shows workers their cancer risks](image)

Magnetic field’s main health effects

• **Brain function**
  • Disruptions from very high exposures

• **Cancer**
  • Possible brain cancer and leukemia risks
Magnetic fields from AC electricity may possibly cause cancer

- Epidemiology studies with thousands of workers
- Leukemia and brain cancer increase with the time-weighted average (TWA) exposures to magnetic fields.
- Uncertainty (error bar) is due to errors in epi studies.

Effects on exposures – Paper mill

- -72% reduction
- Welder 0.83
- Electrician 0.44
- Mechanic 0.21
- Paper mill 0.20
Lessons Learned – Controls

- Low-cost measures can substantially reduce TWA magnetic field exposures
- Measures designed with basic IH principles + monitoring and walkthrough data
- Developed models for setting boundaries on electric-work-only & no-go zones
- Workers easily trained to identify high-field sources

Lessons Learned – Barriers to Acceptance of Precautionary Measures

- Controversy over science
- Not a regulation
- Other hazards are higher priority
- Reluctance to raise cancer issue with workers
- Different paradigm than OEL compliance
- Health benefits to economy, not company
- Telling workers about cancer and EMF may create fear

**Lesson:** Message needs improvement.
Communication Strategies for Precautionary Measures
Strategies suggested by health communication research

1. Managers
   - $5,100 ± $4,000 benefits to society per 1 μT reduction
   - Increase employee trust; perhaps improve labor relations

2. Industrial hygienist and occupational physicians
   - Increased life span = 2 weeks per 1 μT
   - A science-based response to worker concerns about cancer
   - Distinguish between:
     - Proven hazards → OSHA exposure limits eliminate risks
     - Possible carcinogen → Precautionary measures reduce risks

3. Workers
   - Risk gauges show risk reduction from decreased TWA
   - Risk reduction measures shown to abate fear of diseases
     - Studies with pandemic flu, NOT cancer and EMF

Designing precautionary messages for workers about MF’s possible cancer risks and exposure reduction measures.

Future plans

- Recommendations to be developed for dissemination as a NIOSH publication and companion website.
- Review and approval process:
  - Internal and external scientific reviews
  - Stakeholder reviews
  - Public comments
- Several years before final publication

Overview of RF hazards
Health Hazards from RF / Microwaves

• Effects of tissue heating
  • Behavior and cognitive disruption
  • Cardiovascular – *microwave illness*
• Birth defects and developmental abnormalities
• Cataracts
• Burns, especially from hand contact

• Nonthermal effects
  • Many reported but none proven
  • Elevated brain cancer risks from 10-yr+ cell phone use
    • *Possible Human Carcinogen* -- IARC, 2011

RF Occupational Exposure Standards – 1

• Based on acute animal studies
• Based on whole body SAR of 0.4 W/kg
• Frequency dependent
• Duration - 6 min averaging time
• Include induced and contact currents
RF Occupational Exposure Standards – 2

- IEEE C95.1-2005
- OSHA - existing regulation obsolete; uses IEEE under general duty clause
- ACGIH TLV
- FCC - uses a hybrid of IEEE and NCRP
  - regulates all non-military RF transmitters
  - regulates emission limits for cell phones, other telecommunications devices
- FDA - consumer and medical product emissions standards
  - microwave oven; medical diathermy, MRI units

Question: RF Occupational Overexposure

An electrician was assigned to relocate a small RF antenna (for a paging system) from the elevator shaft of a hospital to the roof.

He was told NOT to de-energize it, and worked very close to it for hours in the process.

He subsequently suffered headaches, tachycardia, chest and neck soreness, pain in his ears, and other symptoms.

Are these health problems RF-related?
Answers: Electrician RF Overexposure

- Prior health status was good
- Experts at OSHA, FCC, NIOSH agree on likelihood of RF overexposure to upper body
- Health effects are plausible from degree of exposure
- No authoritative decision for worker compensation on his injury
- Rooftop antennas are still a big problem


RF EMF and Cancer

- IARC’s possibly carcinogenic rating was based on cell phone epidemiology, especially the INTERPHONE study [2010] and its follow-up analysis by Cardis et al. [2011]

- In Cardis et al., a significant dose-response (p=0.01) was found with brain cancer and cumulative energy from cell phone radiation absorbed per kg of tissue (= SAR * time) at the tumor site 7+ years before cancer diagnosis.
Reflections on the INTERPHONE study of cell phones and brain cancer by J. Bowman (2011)

- Doubling of gliomas in people who used cell phones for over a half-hour a day over ten or more years.
- Gliomas are a relatively rare cancer which strikes 6 – 8 people per 100,000 every year – far less than the 68 cases of lung cancer per 100,000.
- The radiation received from a cell phone can be greatly reduced by using it away from the head by:
  - Texting,
  - Speaker phone option,
  - Ear buds
  - Bluetooth®


Reflections on the INTERPHONE study of cell phones and brain cancer by J. Bowman (2011)

- People absorb far more RF radiation from a cell phone held to the ear than from
  - Wi-Fi,
  - portable phones,
  - wireless computer networks,
  - cell phone towers,
  - all other wireless devices (outside of a few workplace sources).
- Cell phones and all other wireless consumer devices comply with all safety standards which protect against RF’s proven health hazards.
- The greatest risks from cell phones are their distractions while people are driving cars or doing other potentially hazardous activities.

Final thoughts

• Many similarities between RF and ELF EMF
  • Exposures fall off with distance from source
  • Proven effects and consensus guidelines for high short-term exposures
  • Possibly carcinogenic with moderate long-term exposures – CONTROVERSIAL!
  • Precautionary measures for the cancer possibilities both reduce TWA

• COMING ATTRACTION: INTEROCC study of brain cancer and occupational RF exposures
  • INTERPHONE spin-off with 7 countries
  • Large study population (1,939 glioma and 1,822 meningioma and 5,404 controls)
  • Detailed personal interviews of EMF sources
  • Novel exposure assessment methods give individualized exposure estimates
  • RF cancer risks should be submitted for publication in the next year

Resources

– Institute of Electrical and Electronic Engineers. *Recommended Practice for Measurements and Computations of EMF Exposures, 0 – 100 kHz. IEEE Std. C95.3 (2010)* http://my.nps.edu/documents/103425239/106393247/C95_3_1-2010.pdf/67574b02-c77c-4c0b-8027-986e6e6a9c78
– Bowman et al. Possible health benefits from reducing occupational magnetic fields. (2013) http://dx.doi.org/10.1002/ajim.22129
– Cardis et al. Risk of brain tumours in relation to estimated RF dose from mobile phones: results from five Interphone countries. (2011) http://dx.doi.org/10.1136/oemed-2011-100155