Non-Ionizing Radiation

Spencer Pizzani, M.S., CIH
Bureau Veritas North America
spencer.pizzani@us.bureauveritas.com
Adapted from an original presentation by Wesley R. Van Pelt, Ph.D., CIH, CHP

© 2014 American Industrial Hygiene Association, New Jersey Section, Inc.
About the Presenter:
Spencer Pizzani, M.S., CIH

- Certified in Industrial Hygiene by the American Board of Industrial Hygiene
- Masters of Science in Occupational Safety and Health
- Over 7 years of comprehensive industrial hygiene experience in consulting
- Clients include USEPA, NYCDEP, USDOI and USPS, as well as major manufacturers.
- Specialties in Mercury remediation, disaster recovery, and hazardous waste management.
DISCLAIMER

The mention or depiction of products or instruments in this presentation are for informational purposes only.

They are not to be construed as recommendations or endorsements.

Most images are “courtesy” of images.google.com
Course Objectives

At the end of this course, you should be able to:

• Understand the components of the electromagnetic spectrum

• Identify industrial sources of non-ionizing radiation

• Identify hazards from non-ionizing radiation
Depth of Information

90 Minutes
90 Slides
No Penguins
What is Non-Ionizing Radiation?

- “Chemicals” and “Radiation”
- Not all radiation is transformed equal
- All kinds of radiation has uses
- Energy – governed by entropy
Intuition

This loud box is warm! We're friends now.
Electromagnetic Spectrum
Electromagnetic Spectrum
Frequency and Wavelength

\[ c = v \lambda \]

\( c \) = the speed of light \((\text{cm/sec})\)
\( v \) = frequency in Hertz \((\text{sec}^{-1})\)
\( \lambda \) = wavelength in \text{cm}
Medium Matters
Cherenkov Radiation is electromagnetic radiation emitted when a charged particle (such as an electron) passes through a dielectric medium at a speed greater than the phase velocity of light in that medium.
Electromagnetic Spectrum
But Wait…

- How can it have the properties of a wave as well as discrete units of energy?
Wave Particle Duality

Wave Theory: a propagating electric and magnetic field

\[ v = \lambda f \]

- \( f = \text{frequency, Hz} = \text{s}^{-1} \)
- \( v = \text{speed of wave, m s}^{-1} \)
- \( \lambda = \text{wavelength, m} \)

\( v = c = 300,000,000 \text{ m/s in vacuum (speed of light)} \)

Hertz = “cycles per second”
Propagating Electromagnetic Wave

Electromagnetic waves transport energy through empty space, stored in the propagating electric and magnetic fields.

Magnetic field variation is perpendicular to electric field.

A single-frequency electromagnetic wave exhibits a sinusoidal variation of electric and magnetic fields in space.
Properties of Waves
Wave-Particle Duality

Particle Theory: discrete packets of energy called photons.

Each photon has a kinetic energy, $W$

$$W = hf = 4.13 \times 10^{-15} \times f, \text{ eV}$$

$h = \text{Planck's constant} = 4.13 \times 10^{-15} \text{ eV-s}$

$f = \text{frequency, Hz} = s^{-1}$
Which model do hygenists use?

• Both have advantages

• Both are experimentally validated

• We need to use both
Really?

"I, at any rate, am convinced that He [God] does not throw dice."

~Albert Einstein on Quantum Mechanics

"Einstein, stop telling God what to do."

~Niels Bohr on Einstein's feeling about Quantum Physics

Niels Bohr, architect of the last mechanical model of the atom.
Recognition

- Recognition
- Evaluation
- Control
Radiation Is Everywhere
Radiation Is Everywhere

![Diagram showing the spectrum of radiation and its distribution in the atmosphere](image)
Science Fiction – For Now

10 years after everyone stops laughing
Electromagnetic Spectrum

**PERMEABLE ZONE**
Frequencies in this range are considered more valuable because they can penetrate dense objects, such as a building made out of concrete.

**Semi-permeable zone**
Difficult for signals to penetrate dense objects.

**Line-of-sight zones**
Signals in this zone can travel long distances, but could be blocked by trees and other objects.

Most of the white areas on this chart are reserved for military, federal government and industry use.

Signals in this zone can only be sent short, unobstructed distances.
AM Radio Tower
Antenna Complex
Satellite Dish Antennas
Arecibo Observatory Radiotelescope
FAST - China
(Five hundred meter Aperture Spherical Telescope)

Figure 1: Left: FAST optical geometry, right: FAST 3-D model
Very Large Array (New Mexico)
For those of us who are not radio astronomers
Cutting Edge

Ivanpah
R+D into Nanomaterials

Vantablack

99.96%
RF Heat Sealer
RF Heat Sealer

Works by exciting polar molecules

Concentrated RF energy (3 kHz to 300 GHz) melts plastic together

Mostly used on PVC, but can be applied to many blends

Products include packaging, inflatables, and framings where fastening is impractical (due to weight or component material properties)
RF Heat Seal
Small RF emitters
ICDs and Pacemakers

2. Typical of modern implantable cardioverter defibrillators (ICDs) and pacemakers are the Medtronic InSync II Marquis (left) and the InSync III (right).
Magnetic Resonance Imagers
Functional Magnetic Resonance Imagers

“YES”
“NO”

Control

Patient
Blue Light Therapy
Military Lasers
Evaluation

Recognition  Evaluation  Control
Frequency-Specific Health Effects

Electromagnetic Fields 0-300 GHz
- Static Magnetic
- Sub-RF Magnetic
- Sub-RF and Static Electric
- RF and Microwave

Optical
- Light and near-IR
- UV
- Lasers
Special Clauses

Medical Device Wearers

Hazardous Projectiles

Induced Charges

*Transient Sensory Phenomena

**Flow Charts and TLV Referrals
Frequency-Specific Health Effects

Watch your terminology!

- Flux Density
- Power Density
- Field Strength

Not interchangeable!

Same for units.
Ultraviolet Light

- UV effects cornea of eye
  - photokeratitis (Welder’s flash)
- Chemical sensitizing agents
- Sun burn of skin (erythema). Skin cancer.
- UV produces ozone in air
- Ozone in stratosphere absorbs UV <0.29 um

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
<th>Wavelength, um</th>
<th>Energy, eV</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum UV</td>
<td>UV-C</td>
<td>&lt; 0.16</td>
<td>&gt; 7.7</td>
<td>highest energy</td>
</tr>
<tr>
<td>Far UV</td>
<td>UV-C</td>
<td>0.16-0.28</td>
<td>7.8-4.4</td>
<td>germicidal</td>
</tr>
<tr>
<td>Middle UV</td>
<td>UV-B</td>
<td>0.28-0.32</td>
<td>4.4-3.9</td>
<td>sunburn</td>
</tr>
<tr>
<td>Near UV</td>
<td>UV-A</td>
<td>0.32-0.40</td>
<td>3.9-3.1</td>
<td>black light</td>
</tr>
</tbody>
</table>
Ultraviolet Light

TLV for UV

TLV in J/m² is very dependent on wavelength.

TLV range 30 – 1,000,000 J/m² in 8 hrs

Additional TLV: \( \lambda = 0.315 - 0.400 \, \mu m \) (UVA)

- irradiance of 1 mW/cm² exposures > 1000 s
- radiant exposure of 1 J/cm² exposures < 1000 s
# Energy and Power

<table>
<thead>
<tr>
<th>Energy</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joule</td>
<td>Watt</td>
</tr>
<tr>
<td>Joule = Watt * second</td>
<td>Watt = Joule/second</td>
</tr>
<tr>
<td>Also referred to as “work” or “amount of heat”.</td>
<td>Rate at which electromagnetic energy is radiated, absorbed, or dissipated.</td>
</tr>
</tbody>
</table>

Example: Energy radiated from a 100 Watt light bulb for one second.  
Example: 100 Watt light bulb

Example: Your monthly electric bill is in “kilowatt-hours.” This is a unit of energy.
Infrared Radiation

• $\lambda = 0.7 \, \mu\text{m} \text{ to } 1000 \, \mu\text{m}$

• Sources
  – sun
  – heated materials
  – incandescent bulbs
  – furnaces
  – welding arcs, plasma torches
  – lasers

• Detectors
  – thermocouple, photomultiplier, MIRAN (Single beam infrared spectrophotometer)
Infrared Radiation

• Biological Effects
  – eye damage: iris, cornea, lens, retina
  – glass blower’s cataract
  – heating of skin
Visible / Illumination

- Visible: $\lambda = 0.4$ to $0.7 \mu m$ (or $1 \mu m$)
- Rods peak efficiency $0.510 \mu m$ (dim light)
- Cones peak efficiency at $0.555 \mu m$ (daylight)
- Fovea proximity
- Eye will adjust to intense light
- Short pulsed intense light: flash blindness
- High intensity light may cause retinal burns
- Blue light hazard (photochemical retinal damage)
Visible / Illumination 1

- **Source of light**
  - *luminous flux = lumen*
    - 1 Lumen = 1 candela * steradian (square radian - SI)
    - A 100 watt light bulb emits about 1700 lumens.
    - Luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light.
    - A measure of the total "amount" of visible light in some defined beam or angle, or emitted from some source.
  - *luminous intensity = candela*
    - 1 Candela = 1 lumen / steradian
    - A 100 W light bulb emits about 120 cd
    - Originally the amount of light from a candle!
Visible / Illumination 2

• Arriving at surface (illumination)
  – luminance = candela/m²
  – illuminance = lumens/m²

• Glare
  – bright light in the visual field (direct or reflected)
Lasers

“Light Amplification by Stimulated Emission of Radiation”

• Types
  – crystal (e.g., ruby, alexandrite, Nd:YAG)
    • (neodymium-doped yttrium aluminium garnet; Nd:Y$_3$Al$_5$O$_{12}$)
  – glass (e.g., Nd-glass)
  – gas (e.g., He-Ne)
  – diode
  – dye
Lasers
“Light Amplification by Stimulated Emission of Radiation”

- Characteristics of laser light
  - coherent (in phase, parallel beam)
  - directional (not radiant)
  - monochromatic (single frequency)

- Visible or invisible

- CW, Pulsed, Q-switched
Lasers

- **Biological Effects**
  - eye damage
    - visible = pigment of retina
    - UV = cornea
    - near IR = cornea
    - far IR = cornea
  - skin damage
  - acute exposure only (effects from chronic exposure rare)

- **TLV**
  - MPE in J/cm² or W/cm²
  - depends on frequency, duration, limiting aperture and target organ
Lasers

• Classification
  – Class 1: no damage, exempt
  – Class 2: visible lasers with low potential for eye injury
  – Class 3: intrabeam viewing of direct or specular reflection may cause eye damage
  – Class 4: direct or diffuse reflection may cause eye injury; direct beam may injure skin or cause fire

ANSI Z136 – Different Scheme
Specular and Diffuse Reflection

(a) Specular reflection

(b) Diffuse reflection

Copyright John Wiley & Sons
Lasers

• Regulations
  – FDA (CDRH), manufacturers
  – ANSI, (ANSI Z136.1 – Safe Use of Lasers)
  – ACGIH, TLV

• Safety Considerations
  – interlocks
  – goggles, optical density
  – restricted access, signs
  – limit reflective surfaces
  – enclose beams
Lasers

- Nominal Hazard Zone (NHZ)
  - Calculated or Measured
  - Exposure above the Maximum Permissible Exposure
Lasers Goggles
Laser Goggles – Optical Density

• Optical Density of Goggles
  – attenuation of a laser beam through a partially transmitting medium
  – OD can be very frequency dependent

\[ \text{OD} = \log_{10}(E_0/E) \]

\( E_0 = \text{beam irradiance, } W/cm^2 \)
\( E = \text{irradiance penetrating medium, } W/cm^2 \)

e.g., goggles with an OD of 3 would reduce the laser irradiance at the eye by a factor of 1000.
Laser Power Sources
Aircraft VFR Hazard
Beam Divergence
Summary

Power Sources is #1

Engineering Controls Dictated by Class

PPE in Conjunction With Controls

Invisible Lasers Harder to Control
Microwave Radiation 1

• Electromagnetic Spectrum Range

\[ \lambda = 1 \text{ m to } 1 \text{ mm} \]
\[ f = 300 \text{ MHz to } 300 \text{ GHz} \]

• Sources
  – radar
  – satellite communications
  – UHF television
  – microwave ovens
  – diathermy equipment
  – industrial heating and drying
Microwave Radiation 2

• Biological Effects

$\lambda < 3$ cm, absorbed in skin

3 – 10 cm, penetrate 1-10 mm

$\lambda > 10$ cm, can reach internal organs

$\lambda > 100$ m, does not penetrate body
Microwave Radiation 3

- **Biological Effects**
  - heating effects
  - cataracts at > 100 mW/cm²

- **TLV**
  1 mW/cm², 30-100 MHz
  greater at other frequencies
  based on Specific Absorption Rate (SAR) of 0.4 W/kg
Microwave Radiation 4

• Detection
  – diode rectifier
  – thermistor, thermocouple

• Microwave Ovens
  1 mW/cm², at 5 cm from surface
  5 mW/cm², at 5 cm from surface throughout life of oven
  an FDA performance standard
Electromagnetic Spectrum

Non-Ionizing

“Radiofrequency Radiation”
Radiofrequency Radiation

- $\lambda = 0$ to $300$ MHz
- SAR = Specific Absorption Rate, W/kg
- thermal effects seen at SAR of 4 W/kg and higher.
- TLV
  - set at SAR of 0.4 W/kg
  - frequency dependent
  - 1 mW/cm$^2$ at 30-100 MHz
    - greater at other frequencies
### Radiofrequency Exposure Limits

**Specific Absorption Rate (SAR)**

<table>
<thead>
<tr>
<th>Occupational/Controlled Exposure (100 kHz - 6 GHz)</th>
<th>General Uncontrolled/Exposure (100 kHz - 6 GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.4 W/kg whole-body</td>
<td>&lt; 0.08 W/kg whole-body</td>
</tr>
<tr>
<td>≤ 8 W/kg partial-body</td>
<td>≤ 1.6 W/kg partial-body</td>
</tr>
</tbody>
</table>

Table 2. *FCC Limits for Localized (Partial-body) Exposure*
### Radiofrequency Exposure Limits

**Measured Fields - Occupational**

---

**Table 1. FCC Limits for Maximum Permissible Exposure (MPE)**

(A) Limits for Occupational/Controlled Exposure

| Frequency Range (MHz) | Electric Field Strength (E) (V/m) | Magnetic Field Strength (H) (A/m) | Power Density (S) (mW/cm²) | Averaging Time $|E|^2, |H|^2$ or S (minutes) |
|----------------------|----------------------------------|----------------------------------|-----------------------------|------------------|
| 0.3-3.0              | 614                              | 1.63                             | (100)*                      | 6                |
| 3.0-30               | 1842/f                           | 4.89/f                           | (900/f²)*                   | 6                |
| 30-300               | 61.4                             | 0.163                            | 1.0                         | 6                |
| 300-1500             | --                               | --                               | f/300                       | 6                |
| 1500-100,000         | --                               | --                               | 5                            | 6                |
# Radiofrequency Exposure Limits

Measured Fields – General Population

## (B) Limits for General Population/Uncontrolled Exposure

| Frequency Range (MHz) | Electric Field Strength (E) (V/m) | Magnetic Field Strength (H) (A/m) | Power Density (S) (mW/cm²) | Averaging Time $|E|^2$, $|H|^2$, or $S$ (minutes) |
|-----------------------|----------------------------------|----------------------------------|---------------------------|---------------------------------------------|
| 0.3-1.34              | 614                              | 1.63                             | (100)*                    | 30                                         |
| 1.34-30               | 824/f                            | 2.19/f                           | (180/f²)*                 | 30                                         |
| 30-300                | 27.5                             | 0.073                            | 0.2                       | 30                                         |
| 300-1500              | --                               | --                               | f/1500                    | 30                                         |
| 1500-100,000          | --                               | --                               | 1.0                       | 30                                         |

f = frequency in MHz

*Plane-wave equivalent power density
Radiofrequency Exposure Limits - Magnetic Fields

Figure 1. FCC Limits for Maximum Permissible Exposure (MPE)

Plane-wave Equivalent Power Density

- Occupational/Controlled Exposure
- General Population/Uncontrolled Exposure
Extremely Low Frequency RF Radiation

- ELF = 0 - 300 Hz
  - includes 60 Hz power frequency
  - power lines
  - electrical appliances
  - VDTs (~60-80 Hz)
  - typical home or office has 60 Hz magnetic field of ~0.5 milliGauss (mG)

- Lymphoma, leukemia and brain tumors in several epidemiological studies. Other studies show no effect. Effect, if any, is small.

- NCI (1997) study says “no cancer from ELF”
ELF
## Extremely Low Frequency RF Radiation

<table>
<thead>
<tr>
<th>International Commission on Non-Ionizing Radiation Protection (ICNIRP) Recommendations for Maximum Exposure to 60 Hz Magnetic Fields</th>
<th>Magnetic Field Strength, mG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure Characteristics</strong></td>
<td><strong>Occupational</strong></td>
</tr>
<tr>
<td></td>
<td><strong>General Public</strong></td>
</tr>
</tbody>
</table>
Inverse Square Law

- Applies to any point source emitting isotropically.
- Intensity is proportional to the inverse of the square of the distance.
- \( I_2 = I_1 \left( \frac{x_1}{x_2} \right)^2 \)
# Inverse Square Law

<table>
<thead>
<tr>
<th>Distance</th>
<th>Dose Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10,000</td>
</tr>
<tr>
<td>2</td>
<td>2,500</td>
</tr>
<tr>
<td>3</td>
<td>1,111</td>
</tr>
<tr>
<td>4</td>
<td>625</td>
</tr>
<tr>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>6</td>
<td>278</td>
</tr>
<tr>
<td>7</td>
<td>204</td>
</tr>
<tr>
<td>8</td>
<td>156</td>
</tr>
<tr>
<td>9</td>
<td>123</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>83</td>
</tr>
<tr>
<td>12</td>
<td>69</td>
</tr>
<tr>
<td>13</td>
<td>59</td>
</tr>
<tr>
<td>14</td>
<td>51</td>
</tr>
<tr>
<td>15</td>
<td>44</td>
</tr>
<tr>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>18</td>
<td>31</td>
</tr>
<tr>
<td>19</td>
<td>28</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>
Field Dynamics

• **Gain**: increase in power output resulting from antenna geometry

• **Near Field vs Far Field**
  - Near field: unpredictable. All fields must be measured.
  - Far field: predictable. Calculations for one field may suffice.

Near vs. Far Field determined by Frequency and Distance
- Calculation of hazard distance possible.
Field Measurements

- Probes may provide E field, H field, or both at once.
- Directional or isometric.
- Do not include static magnetic fields (Hall effect Gaussmeter needed).
Field Measurements

Fiber Optic Cable
The Usual Suspects
The Usual Suspects

![Warning Sign: Strong Magnet]

- Can be harmful to pacemaker wearers and others with medical implants.
- Stay clear!
- Keep tools and other metal objects away. This magnet is strong enough to pull them out of your hand or can cause you to lose your balance and fall.
- To avoid damage, keep magnetic media such as computer disks, credit cards and tapes away.

Failure to follow this warning can result in serious injury.
The Exam

Focus on principles, not calculations

Know specific instances of non-ionizing radiation

Datachem

Small number of questions on narrow scope

Principles of hazards more important than magnitudes
Questions?

If you can’t explain it simply, you don’t understand it well enough.

– Albert Einstein
Bibliography / References

• ANSI S136.1 – Safe Use of Lasers


• IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz, IEEE std C95.7 – 2005.

• GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC, AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz), International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1998.

• ON LIMITS OF EXPOSURE TO ULTRAVIOLET RADIATION OF WAVELENGTH BETWEEN 100 nm AND 400 nm (INCOHERENT OPTICAL RADIATION), PUBLISHED IN: HEALTH PHYSICS 87(2):171-186; 2004