Bioeffects and Therapeutic Applications of Electromagnetic Energy

BMG5330

Riadh W. Y. Habash, PhD, P.Eng

School of Electrical Engineering and Computer Science

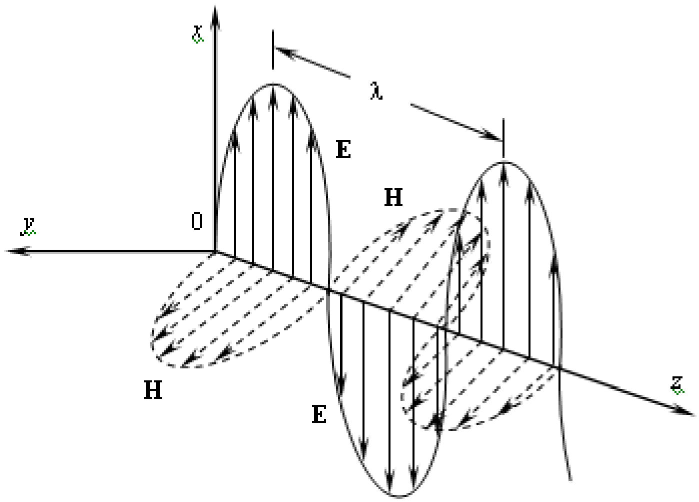
University of Ottawa

rhabash@site.uottawa.ca

The electromagnetic (EM) field is a physical influence (a field) that permeates through all of space, and which arises from electrically charged objects and describes one of the four fundamental forces of nature, ***electromagnetism***.

Electromagnetism is found almost everywhere. All EM fields are force fields, carrying energy and capable of producing an action at a distance. These fields have characteristics of both ***waves*** and ***particles***. This energy is utilized in various ways, though we still lack the full understanding of its fundamental properties.

Many inventions of the late twentieth century, ranging from everyday home and office appliances to satellite systems and mobile phones, are so important and so advantageous; we wonder how we ever lived without them.



General

- EM waves at low frequencies are referred to as EM fields and at very high frequencies are called EM radiation. The term EM field is generally used rather than EM radiation whenever wavelengths greatly exceed distances from exposure sources.

- EM fields at all frequencies make one of the most common environmental issues, about which there is a growing concern and speculation. EM fields are present everywhere in our environment but are invisible to the human eye.

- All populations are now exposed to varying degrees of EM fields, and the levels will continue to increase as technological inventions advance. These inventions have become an integral part of our modern life. We just need to know that they are safe.

Sources of Fields and Radiation

Low-Frequency Fields:

- Magnetosphere.
- Magnetic Resonance Imaging.
- DC Power Supply System.
- AC Sources including power lines, substations, and appliances.

Radio Frequency Sources:

- Generators.
- Transmission Paths including transmission lines, cables and waveguides.
- Antennas.

Bioeffects?

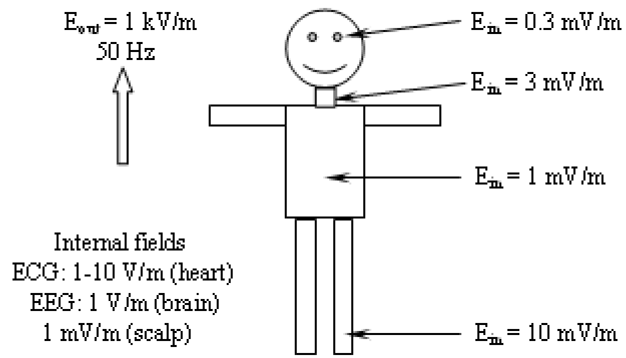
- A biological effect occurs when a change in the environment causes some noticeable or detectable physiological change in a living system. These changes are not necessarily harmful to health. For example, listening, reading, eating or playing will produce a range of bioeffects. However, none of these activities is expected to cause health effects.
- The body has sophisticated mechanisms to adjust to the various influences that encounter in the environment.
- But the body does not possess adequate compensation mechanisms for all bioeffects. Changes that stress the biosystem for long time may lead to a health effect.

Electromagnetic Interactions with Biosystems

- The basics of EM interaction with materials were elucidated over a century ago and stated as the well-known Maxwell's equations.
- The application of these basics to biological systems, however, is very difficult because of the extreme complexity and multiple levels of organization in living organisms, in addition to the wide range of electrical properties of biological tissues.
- The two most important health-related characteristics of EM fields are field strength and frequency. Extremely low frequency (ELF) fields can cause the generation of electric currents in the human body, while radiofrequency radiation (RFR) can lead to heating up of the body. The higher the frequency, the less deep the penetration of energy into the body, and the more superficial the heating effect is.

Part 1: Mechanisms for Electric and Magnetic Fields (EMF)

- There are several proposed mechanisms for the interaction of EMF fields with living systems. They can be grouped into induced fields and currents (a process called *coupling*), which varies greatly with frequency
  - Induced Fields and Currents
  - Thermal Noise
  - Endogenous Fields

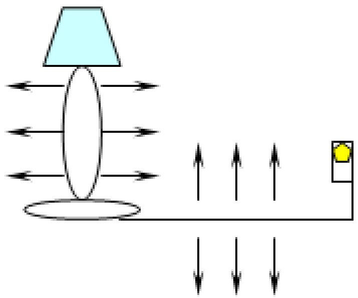


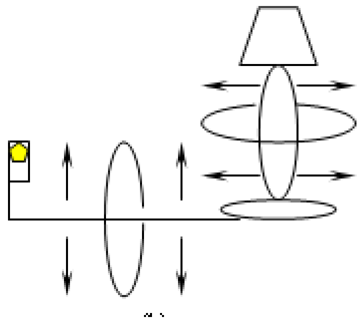
Electric Field Effects

- Polarization of Bound Charges
- Orientation of Permanent Electric Dipoles
- Drift of Conduction Charges
- Pearl-Chain Effects
- Electrorotation.

Magnetic Field Effects

- Induced Currents
- Magnetic Biosubstances
- Radical Pairs
- Cell Membrane and the Chemical Link.

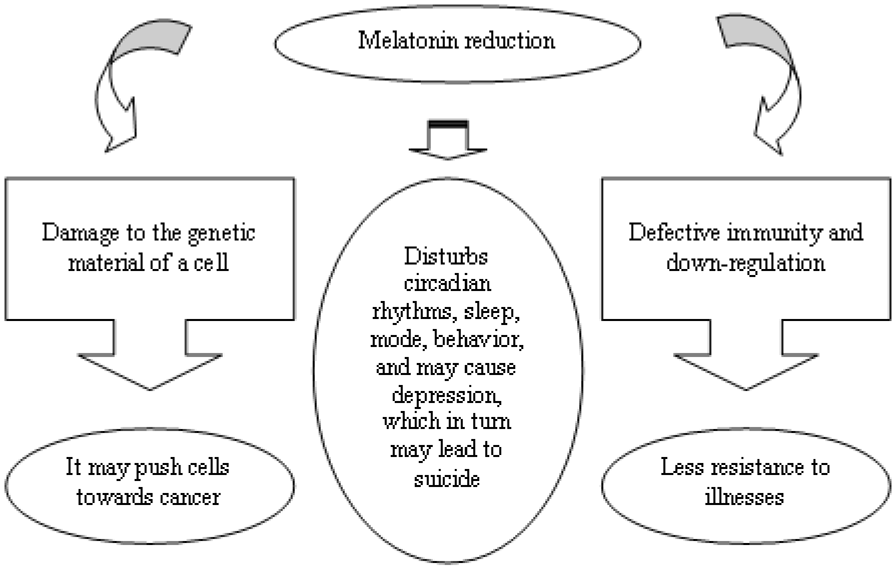




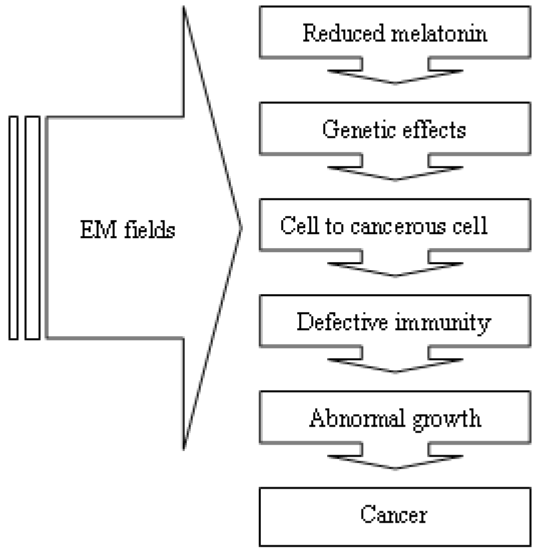
Biological and Health Effects

- Cells and Membranes
- Tissues
- Changes in Protein Conformation
- Changes in Binding Probability
- Absorption of Vibrational States of Biological Components
- Genetic Material
- Carcinogenesis
- Hypothesis of Melatonin
- Cancer
- Brain and Nervous System

Biological Consequences of Melatonin Reduction



Effects that may Lead to Cancer due to EMF Exposure



Guidelines for EMF Fields

Maximum Permissible Exposure (MPE) Values for EMF Fields

Year: Standard	Magnetic Field Safety Level	
1992: ANSI/IEEE	205 μT	
1993: NRPB	50 Hz: 1600 μT 60 Hz: 1330 μT	
1998: ICNIRP	**General Public** 83.3 μT	**Occupational** 420 μT
1999: The Swedish Standard	**Video Display Terminals** ELF (5 Hz-2 kHz): </= 0.2 μT VLF (2 kHz-400 kHz): </= 0.025 μT	
1999: Safety Code 6	**General Public** 2.75 μT	**Occupational** 6.15 μT
2002: ARPANSA	**General Public** 3 kHz-100 kHz: 6.1 μT	**Occupational** 3 kHz-100 kHz: 31.4 μT

0.1 μT = 1 mG

Epidemiological Assessment Studies

- Public concern over human effects of exposure to EMF is largely based on a series of key epidemiological assessment studies. Such studies identify the association between diseases and particular environmental characteristics.

- **Health Outcomes: Childhood Cancer and Leukemia; Breast Cancer; Adult Cancers; Cardiovascular Diseases; Neurodegenerative Diseases; Reproductive Toxic Effects.**

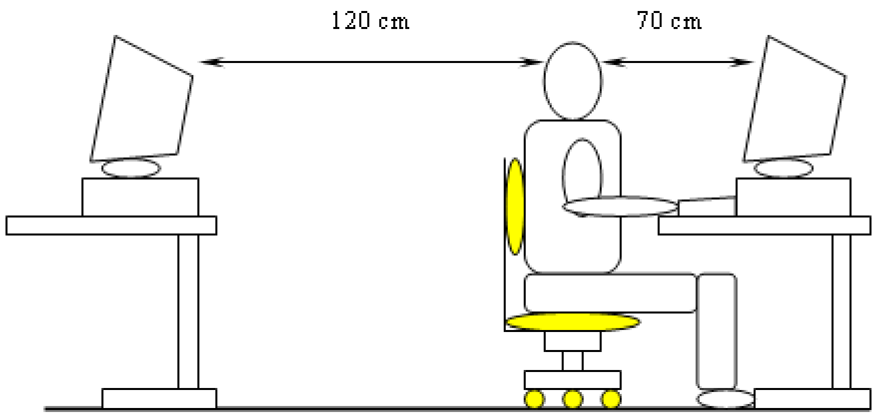
- Association between EMF exposure and health outcomes remains inadequate and inconclusive. Some studies have suggested a link between EMF and cancer, although the risks tend to be small by epidemiological standards. Childhood leukemia is the only cancer for which there is a statistically consistent evidence of an association with exposure to EMF above 0.4 μT. The evidence for a casual relationship is still inconclusive.

Toxicological/Laboratory Studies

- It seem that the energy associated with EMF environmental exposures is not enough to cause direct damage to DNA; however, indirect effects are possible by changing cellular architecture and metabolic processes within cells that might lead to DNA damage. Together, there is negative evidence against DNA damage and chromosomal effects at the EMF environmental levels.
- There is still not enough evidence to support the hypothesis that EMF exposure suppresses melatonin or cause an increase in cancer.
- Several investigations have indicated that ELF exposure has influence on the blood-brain barrier (BBB) permeability.
- In most studies, EMF exposure appears to have no effect on the immune system.
- Animal studies presented mixed results but no direct carcinogenic effects have been observed. Future research may focus on the role of EMF as a tumor promoter or co- promoter.

- # Suggestions to Minimize the Level of EMF

Determine sources of ELF fields. For example, a tri-axis Gauss meter could be used to determine the levels and locations of magnetic fields.
Use bundled and twisted power cable drops to reduce field generation.
Keep the drop, meter, service panels, and subpanels away from normally occupied rooms.
Place high load appliances such as electric dryers and electric hot water heaters away from bedrooms, kitchens, etc.
Avoid using devices such as alarm clocks or electric blankets near the bed.
As a last solution, use shielding techniques to reduce the level of fields. Shielding ELF fields requires either to divert the fields around the area considered sensitive to the magnetic fields or to contain fields within the source producing them.



Recommendations on Risk Assessment

- Risk assessment should be seen as an iterative process that notifies an overall conclusion as to health risk and consists of related activities incorporating both positive and negative information.

- A hazard identification resulting in a conclusion of weak or null effects, such as may be associated with ELF, will need to assign significant weight to animal cancer bioassays conducted under defined exposure conditions as well as to human epidemiologic studies.

- A default factor to account for possible age differences in sensitivity to carcinogenesis should be included in an ELF risk assessment.

- Lack of evidence of dose response and the apparent lack of DNA effect of ELF suggest that a safety factor may be most appropriate.

- An ELF risk assessment should permit at least provisional conclusions to be reached as to the limits of adverse health effects from exposure to ELF, and should also define efficient agendas for future research, actions, and risk communication aimed at clarifying uncertainties and answering public concerns.

Agenda for Future Research

- Looking to the future, further studies are required to address the following issues:

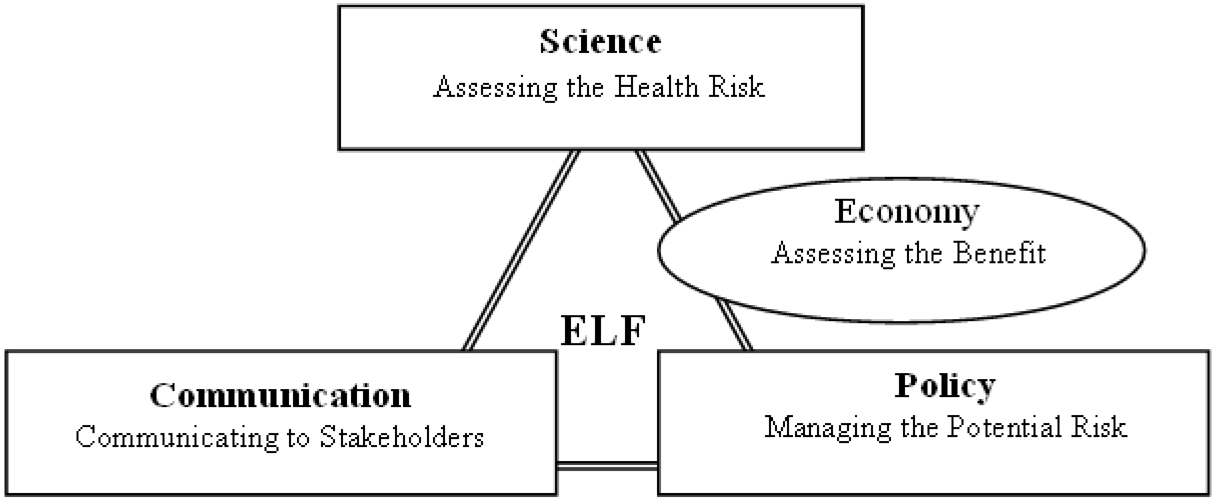
    - o Elucidation of the biophysical interaction mechanisms that may explain how the signal from the low–energy source could affect biological systems.
    - o Improved dosimetry to reduce uncertainties in exposure assessment.
    - o *In vitro* and *in vivo* studies on genetic effects, melatonin secretion, and tumorigenesis (with particular emphasis on characterization of dose–response relationships under a range of exposure conditions).
    - o Understanding the neurophysiologic implications of ELF.
    - o Epidemiological studies to clarify the relationship between ELF and cancer in children, particularly leukemia.

- In addition, work is also needed to better understand **public perception** of ELF risks, which can inform the design of risk communication strategies related to the management of ELF health risks.

Agenda for Policy Actions

- Risk assessment research is one of the costs of bringing new technologies into society. In recognition of widespread debate and conflicting views, particularly in the contexts of public health and environmental protection, government, scientists, and industry should take effective research and policy actions to address the concerns about potential health risks of ELF fields. These actions may include:
  - Public access to the most up-to-date research on biological and health effects associated with ELF fields.
  - Scientific risk assessment that goes beyond technical issues and identifies a need for psychometric approach including cognitive, emotional, and social demographic determinants of risk.
  - Thorough risk assessment and research projects with a potential to discover even the smallest of health risk with aims and results to be well communicated to all stakeholders.
  - Public participation in risk management actions taken in response to concerns about the potential health risks of ELF fields.
  - Adequate communication with individuals and groups on the various levels of scientific uncertainty.

Framework for Investigating the Potential Health Risks of Exposure to ELF Fields



Agenda for Risk Communication

- An effective risk-communication strategy will assist the community understanding the ELF health risk issues, and decision makers will be in a better position to make an informed decision and act on public concerns. The following questions will guide any proposed risk communication agenda:
  - How is the available scientific evidence being interpreted and how do these interpretations influence risk debate?
  - How is new scientific evidence used, or not used, in shaping public risk communication strategies related to the management of ELF health risks? What happens when the same evidence is communicated in a different way?
  - What role do public values play in perceiving ELF risk?
  - How can experts and decision makers build trust with the public for authentic public involvement in risk decisions that have an impact on their health?

A Step toward Reliable Risk Assessment

- One option to reduce actual and perceived risks to public, and to establish better foundation for trust and communication between interested parties, is to include the public as valid stakeholders in all phases of planning and routing of power transmission lines and the locations of substations. This may include adequate public representation on the relevant standard setting committees.

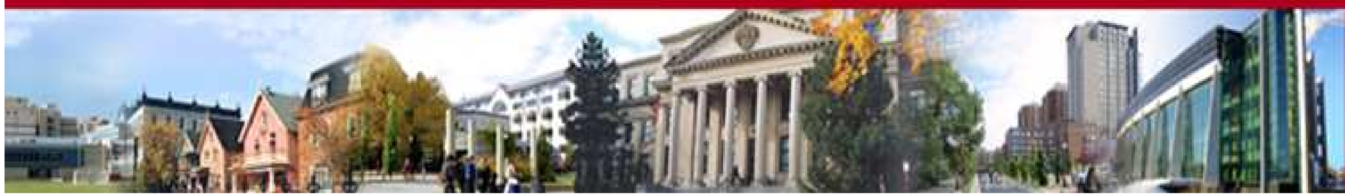
- Public membership on expert committees and in public submissions to those committees is very important. When all the information is said and actions are done, it is only by this process that the foundations for an accurate and reliable risk assessment for public can be implemented.

Part 2: Mechanisms for Radio Frequency Radiation (RFR)

- Biological effects due to exposure to EM radiation are often referred to as being thermal or nonthermal/athermal.

- Heating is the primary interaction of EM radiation at high frequencies especially above about 1 MHz. Thermal effects of EM radiation depend on the specific absorption rate (SAR) spatial distribution.

- Controversy surrounds issues regarding bioeffects of intermediate- and low-level EM radiation. First, whether the radiation at such low levels can cause harmful biological changes in the absence of demonstrable thermal effects. Second, whether effects can occur from EM radiation when thermoregulation maintains the body temperature at the normal level despite the EM energy deposition.



Chain of Events Leading from RF exposure to Disease

RF radiation

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Interaction: RF force induce currents

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Transduction: Modify tissues and membranes or ion currents
Not perceptible by cells; No amplification triggered

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Cell Signal: Signal cascade or amplification
Signal within normal variation; No functional consequences

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Biological Response: Changes in cell behavior
Sensory effects; Neutral effects ; No adverse effects

↓

Cell Dysfunction: Adverse Effects; **Progress Toward Disease**
Transient; Reversible .. No effect
Repair adaptation .. No effect
With reserve capacity .. No effect

RF Exposure Guidelines: SAR limits for RFR

Standard	Frequency Range	Whole Body SAR (W/kg)		Local SAR in Head (W/kg)		Local SAR in Limbs (W/kg)	
		Public	Occupational	Public	Occupational	Public	Occupational
ARPANSA	100 kHz-6 GHz	0.08 (6)	0.4 (6)	2 [10] (6)	10 [10] (6)	4 [10] (6)	20 [10] (6)
TTC/MPT	100 kHz-6 GHz	0.04 (6)	0.4 (6)	2 [10] (6)	8 [10] (6)		
Safety Code 6	100 kHz-10 GHz	0.08 (6)	0.4 (6)	1.6 [1] (6)	8 [1] (6)	4 [10] (6)	20 [10] (6)
ICNIRP	100 kHz-6 GHz	0.08 (6)	0.4 (6)	2 [10] (6)	10 [10] (6)	4 [10] (6)	20 [10] (6)
FCC	100 kHz-6 GHz	0.08 (30)	0.4 (6)	1.6 [1]	8 [1] (6)	4 [10]+	20 [10] (6)+
NRPB	100 kHz-6 GHz	0.4 (15)		10 [10] (6)		20 [100] (6)	
ANSI/IEEE	100 kHz-6 GHz	0.08 (30)	0.4 (6)	1.6 [1] (30)	8 [1] (6)	4 [10] (30)+	20[10] (6)+

( ) Averaging time in minutes.

[ ] Averaging mass in grams.

+ in hands, wrists, feet and ankles.

Epidemiological Studies

- The epidemiologic evidence is not strong enough to the level required to conclude that RFR are a likely cause of one or more types of human cancer. This is attributed to weak design of the studies, lack of detail on actual exposures, limitations of the ability of studies to deal with other likely factors, and in some cases there might be biases in the data used.

- The current epidemiologic evidence justifies further research to clarify the situation. Moreover, since there are only a few epidemiological studies that examine the health risks associated with exposure to RFR, research at the cellular and animal level is needed to better understand this relationship.

Toxicological / Laboratory Studies

- The weight of evidence available indicates that, for a variety of frequencies and modulations with both short and long exposure times, at exposure levels that do not (or in some instances do) heat the biological sample such that there is a measurable increase in temperature, RF exposure does not induce (a) DNA strand breaks, (b) chromosome aberrations, (c) sister chromatid exchanges (SCEs), (d) DNA repair synthesis.

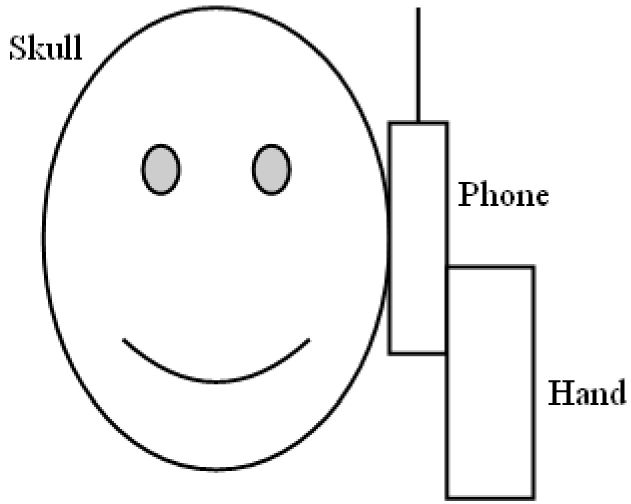
- There is little evidence to suggest that RFR is carcinogenic.

- It is important to note that modulated or pulsed RFR seems to be more effective in producing an effect. It can also elicit a different effect, especially on brain function, when compared with CW RFR of the same characteristics.

- An important area of research that needs further investigation is health risk associated with children's use of mobile phones.

Wireless Devices

Wireless transmitting devices include those operating in the cellular and personal communication networks, satellite communication services, and maritime communications. The above devices, especially handheld cellular phones, are of concern by the public. It is agreed that such devices should be subject to routine RF environmental evaluation prior to use.



Public Concern!

- The “precautionary principle” could be the right answer for an age in which technology is advancing and the impact of that technology may not be known for years. However, because of uncertainty in the medical and scientific communities concerning nonionizing radiation, it is recommended that law enforcement agencies implement a policy of “prudent avoidance,” including purchasing equipment with the lowest published maximum power densities.

- While uncertainty continues, it is fair to exercise some prudence in the use of cellular phones. It is, of course, the user’s choice as to whether they have a cellular phone in the first place and how much they choose to use it.

- Any technique or procedure that modifies the design, construction, or operation of the radiating system in order to prevent undesired radiation could be considered to be a radiation source control.

Trends in Electromagnetic Risk

- In spite of a vast array of studies investigating the association between EM fields and human health, a number of unresolved issues still remain. The unsolved issues continue to raise public concern that there could be some degree of risk from EM exposure. These concerns influence risk management and public acceptance of scientific health risk assessments.

- Reasonable risk management should be build on evidence stemming from both risk assessments and insights from social studies that investigate this concern through well organized research.

What is Needed?

- What is needed is greater public involvement in the risk-management decision making process, including both individuals and stakeholder groups.

- Participation in the development of an appropriate risk management strategy can go a long way towards the achievement of consensus solutions that enjoy the support of interested and affected parties, even if all participants do not fully understand all of the scientific complexities involved in the evaluation of risk.

- With technologically based risks, such as those that may be associated with EM fields, industry has a particular responsibility to take a leadership role in open participatory discussions on risk management strategies.

- As risk management options are debated, consideration will need to be given to level of risk that might be associated with exposure to EM fields and the attendant scientific uncertainty about EM risks.

Actions!

- Independent and unbiased research to further our understanding of the potential EM health risks.
- Transparency and full divulgence of data on EM emissions from various sources.
- Public access to the most up-to-date research on biological and health effects associated with EM fields.
- Scientific risk assessment that goes beyond technical issues and identifies a need for psychometric approach including cognitive, emotional, and social demographic determinants of risk.
- Thorough risk assessment and research projects with a potential to discover even the smallest of health risk with aims and results to be well communicated to all stakeholders.
- Public participation in risk management actions taken in response to concerns about the potential health risks of EM fields.
- Assessment impact of precautionary measures on public concern and the adoption of voluntary or mandatory policies.
- Adequate communication with individuals and groups on the various levels of scientific uncertainty.

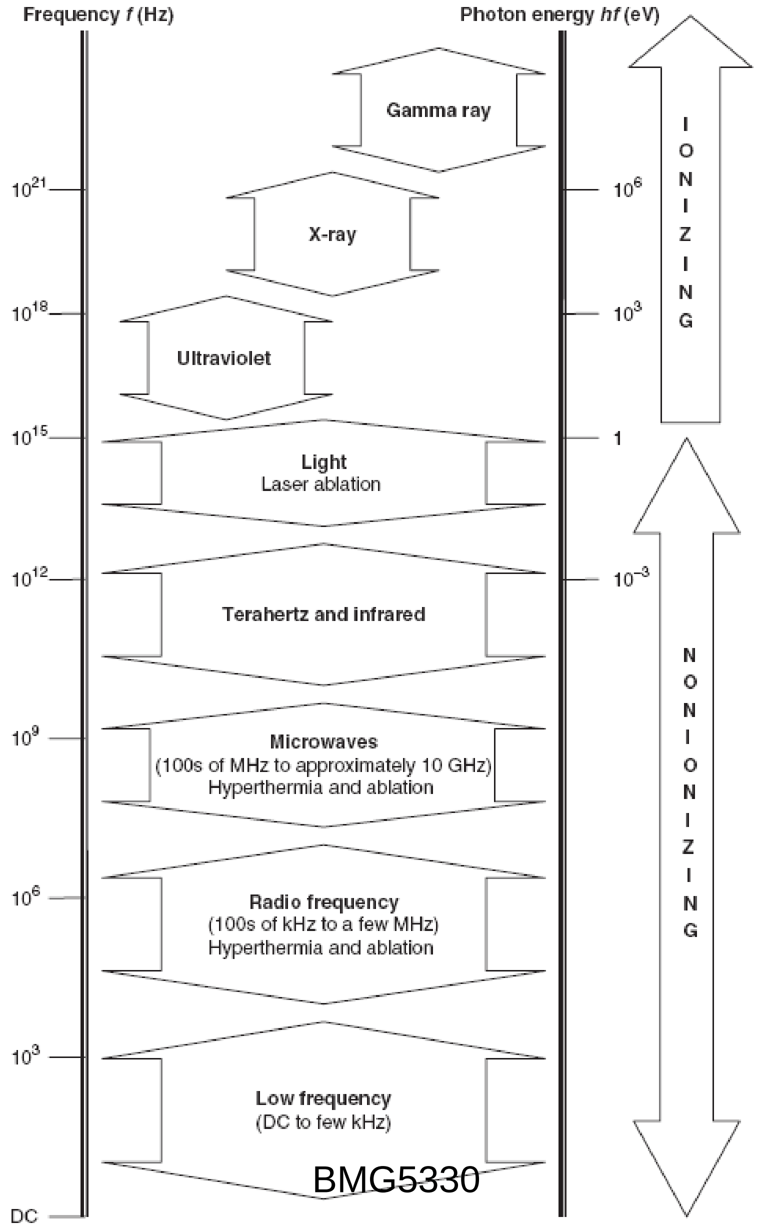
Health Risk! Summary

- As the development in science and technology advances and as we are enjoying a better quality of life, it is required from scientists to ensure that safety is not compromised. Scientist must be very careful in reporting their findings. Mistakes must be minimized and stopped at the first level of scientific research.

- In closing, I would like to summarize this part of this presentation and make a good reason to start the next part with this conclusion made by Professor C-K Chou:

"*After more than 50 years of studies looking for EM bioeffects, it is time for the bioelectromagnetics research community to clarify the identified gaps in knowledge on EM bioeffects as listed in the WHO research agenda and move on to study what EM fields can do for people. Dr. d'Arsonval would have been pleased to learn that what he started in the late 19th century on medical applications of EM fields holds promise for much fruit in the 21st Century*."

Therapeutic Applications



Thermal Therapy

Diathermia

Heating up to 41^{o}C with applications in physiotherapy for the treatment of rheumatic diseases.

Hyperthermia

The temperature of a part of the body or of the whole body can be raised to a higher than normal level (41-45^{o}C), which may allow other types of cancer treatments (radiation therapy or chemotherapy) to work better. This type of hyperthermia has applications in oncology for cancer treatment.

Thermal Ablation

Very high temperature (above 45^{o}C) can be used to destroy cells within a localized section of a tumor. This is commonly used in oncology for cancer treatment, in urology for benign prostatic hyperplasia (BPH) treatment and in cardiology for heart stimulations, and other areas.

Effect of Temperature on Biological Tissues

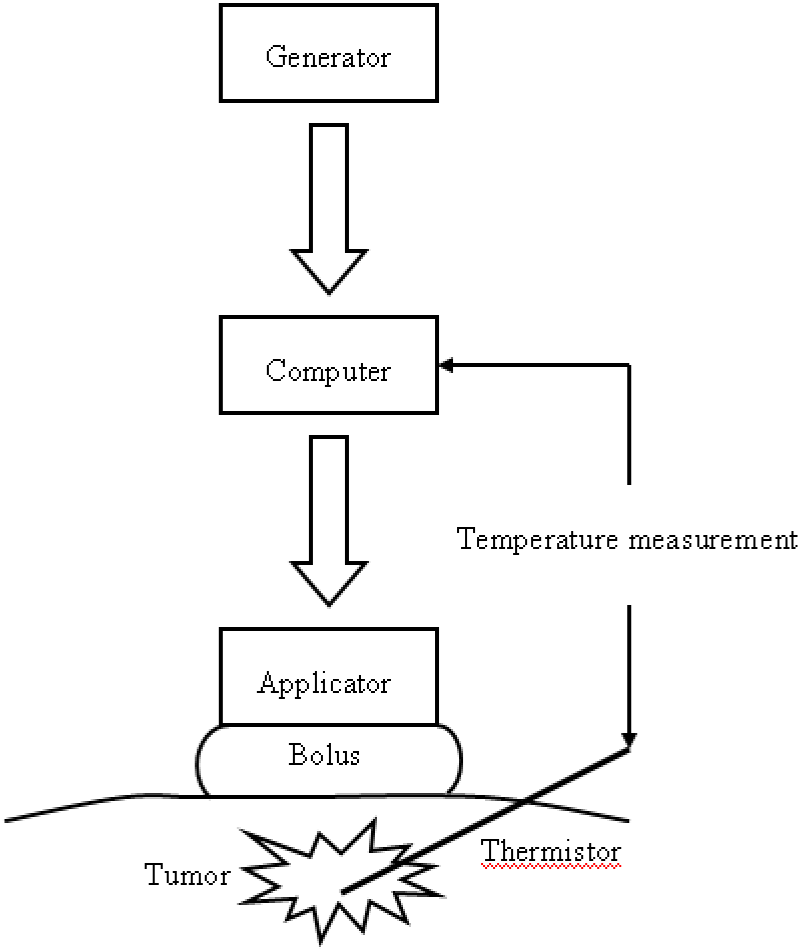
Temperature Range (°C)	Time Requirements	Physical Effects	Biological Effects
< −50	>10 min	Freezing	Complete cellular destruction
0–25		Decreased permeability	Decreased blood perfusion; decreased cellular metabolism; hypothermic killing
30–39	No time limit	No change	Growth
40–46	30–60 min	Changes in the optical properties of tissue	Increased perfusion; thermotolerance induction; hyperthermic killing
47–50	>10 min	Necrosis, coagulation	Protein denaturation; no subtle effects
<50	After ~2 min	Necrosis, coagulation	Cell death
60–140	Seconds	Coagulation, ablation	Protein denaturation; membrane rupture; cell shrinkage
100–300	Seconds	Vaporization	Cell shrinkage and extracellular steam vacuole
<300	Fraction of a second	Carbonization, smoke generation	Carbonization

Hyperthermia

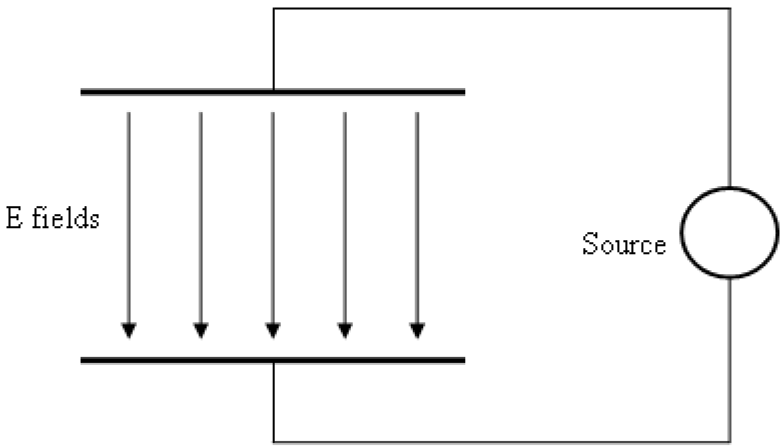
- Hyperthermia is an emerging therapy method in oncology. It has been an effective modality of cancer treatments, showing significant improvements in clinical responses for many patients.
  - Can be used alone, or
  - In combination with other treatment methods, such as surgery, chemotherapy, radiation therapy, and gene-therapy.

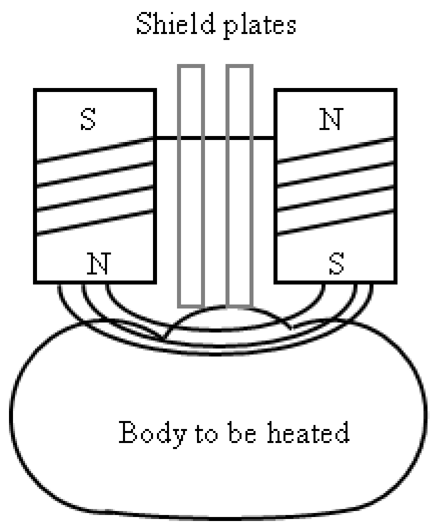
- The clinical exploitation of hyperthermia was and still hampered by various challenges including
  - High degree of interdependency between physiology and biology
  - Technical and clinical limitations
  - Standardization.

Local Hyperthermia

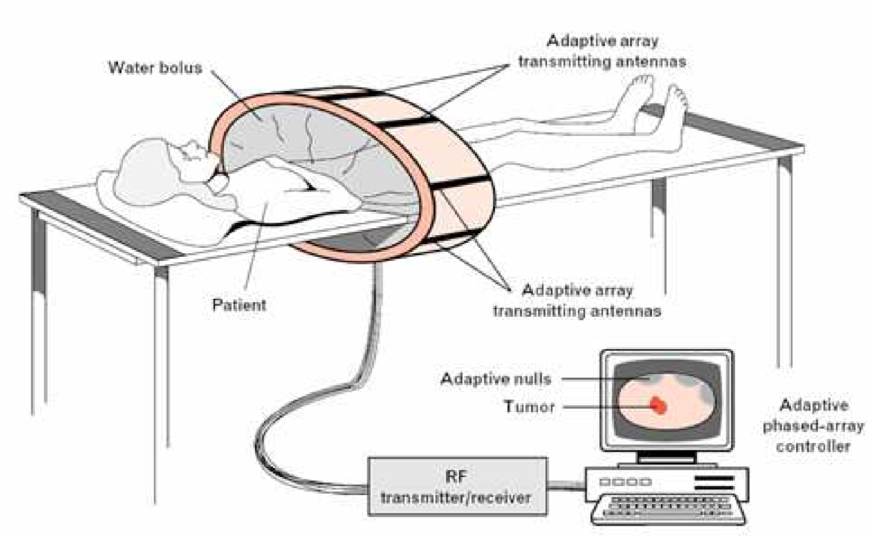


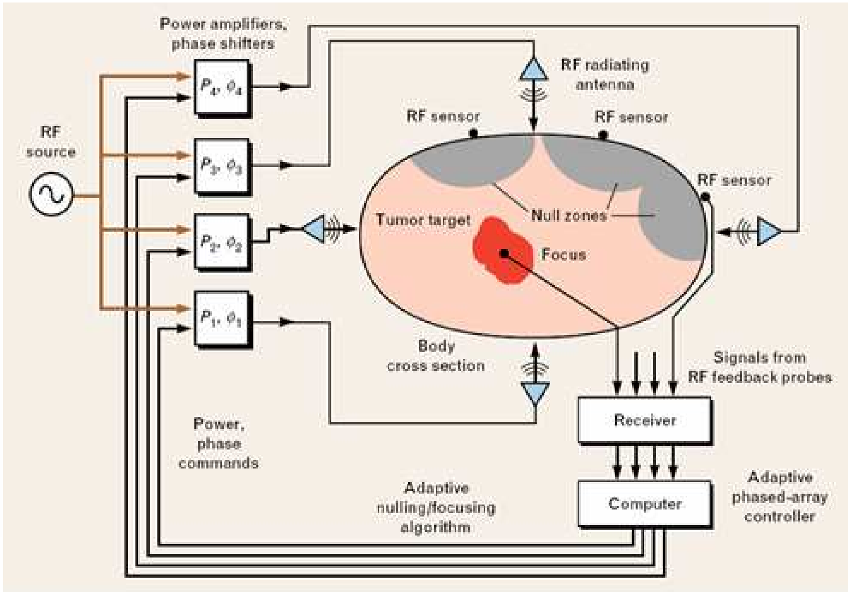
Capacitive and Inductive Hyperthermia





Hyperthermia with Radiative Devices





Ablation Techniques

- The term “ablation” is defined as the direct application of chemical or thermal therapies to a specific tumor (or tumors) in an attempt to achieve eradication or substantial tumor destruction.

- The methods of ablation most commonly used in current practice are divided into two main categories:
  - Chemical ablation (ethanol and acetic acid that induce coagulation necrosis and cause tumor ablation , and
  - Thermal ablation (RF, Microwave, Laser).

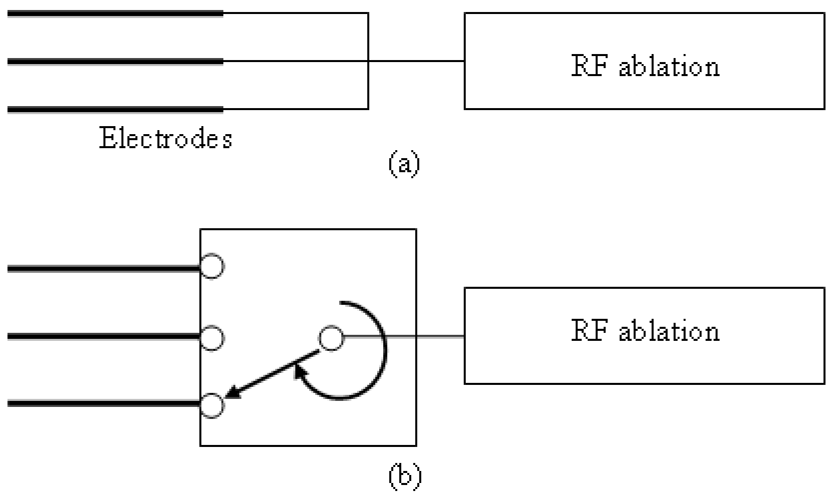
- Thermal ablation can be an alternative to risky surgery, and sometimes it can change a patient from having an inoperable tumor to being a candidate for surgery.

Clinical Applications

- Cancerous (malignant) tumors in the liver
- Benign prostatic hyperplasia (BPH)
- Renal cell
- Breast cancer
- Lung cancer
- Bone tumors
- Cardiac Diseases (arrhythmias: abnormal focus of electrical activity or an abnormal conducting pathway within the heart)

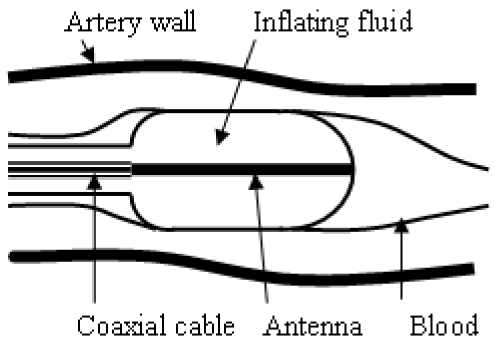
(a) Set-up for simultaneous power application

(b) Set-up for rapidly switched power application method

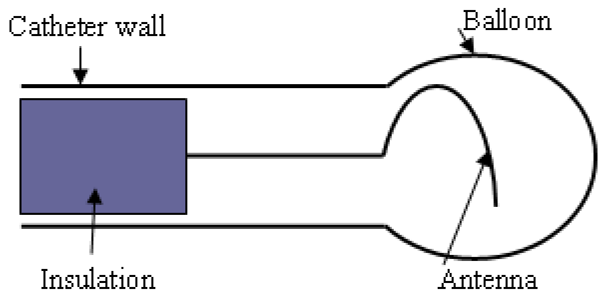


Microwave Ablation

Microwave Balloon Angioplasty



Microwave Ablation Catheter



Future Research

- Accurate modeling of the electrical and thermal characteristics of biological tissues.
- Realistic modeling of the cooling effect of large and medium blood vessels.
- Determining the parameters (frequency factor and energy) of the thermal damage function for different types of tissues (hepatic, breast, cardiac, etc.).
- Technological advances in electrode and generator design.
- Better understanding of methods to ensure adequacy of tumor necrosis.
- Conducting research on new histological markers of thermal injury.