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Abstract: [RF Safety Considerations for Body Area Network Applications]

Purpose: [To provide an introduction to the RF Safety Considerations for Body Area Network Applications]

RF SAFETY CONSIDERATIONS FOR BODY AREA NETWORK APPLICATIONS

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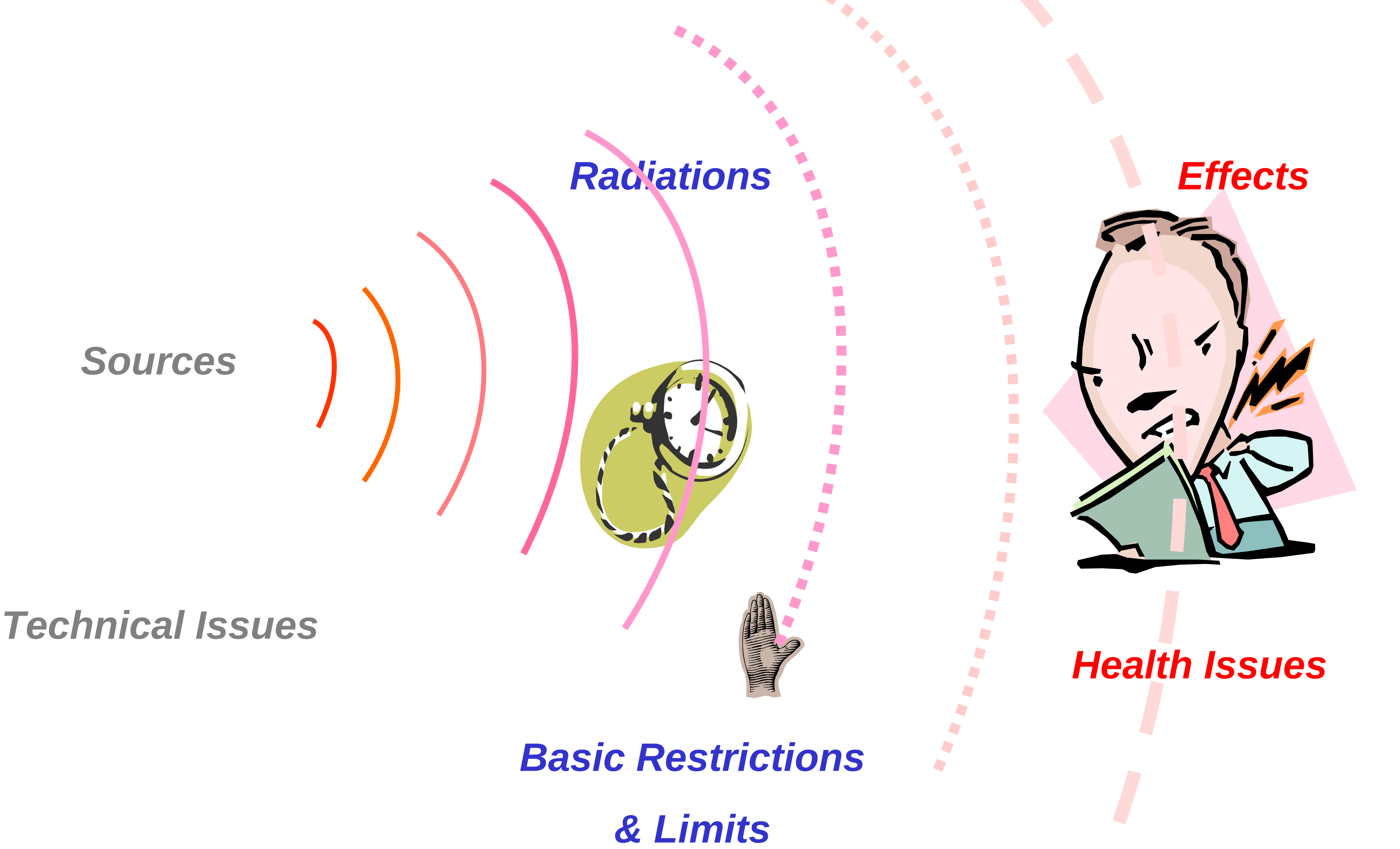
Content



Radiations
Effects
Sources
Technical Issues
Health Issues
Basic Restrictions
& Limits

Introduction

It has been known that high intensities of RF radiation can be harmful due to the ability of RF energy to heat biological tissue rapidly.

- This is the principle by which microwave ovens cook food.
- Exposure to high RF power densities, i.e., on the order of 100 mW/cm^2 or more, can result in heating of the human body and an increase in body temperature.
- Tissue damage can result primarily because of the body's inability to cope with or dissipate the excessive heat.
- Under certain conditions, exposure to RF power densities of about 10 mW/cm^2 or more could result in measurable heating of biological tissue.
- The extent of heating would depend on several factors including frequency of the radiation; size, shape, and orientation of the exposed object; duration of exposure; environmental conditions; and efficiency of heat dissipation.
- Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects.

Frequency and Energy

The energy associated with electromagnetic radiation depends on its frequency

Frequency ↑ ⟶ Energy ↑

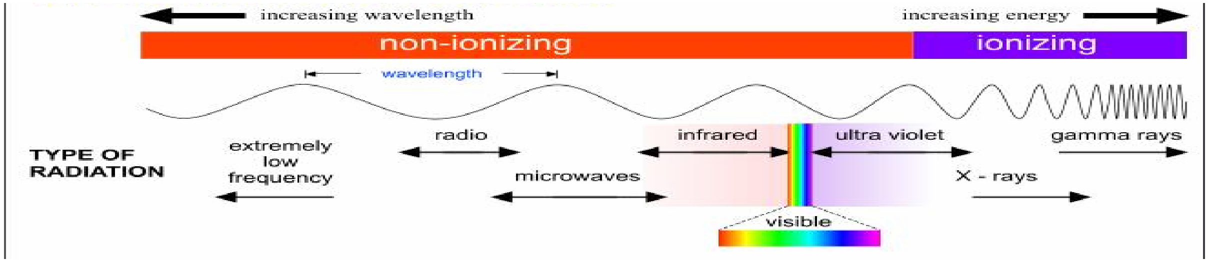
$E = h \times f$ (h Planck's constant)

- Therefore, x-radiation and gamma radiation, which have extremely high frequencies, have relatively large amounts of energy.
- At the other end of the electromagnetic spectrum, ELF radiation is less energetic by many orders of magnitude.
- In between these extremes lie ultraviolet radiation, visible light, infrared radiation, and RF radiation (including microwaves), all differing in energy content.

Ionizing Vs Non-Ionizing Radiation

- Ionization is a process by which electrons are stripped from atoms and molecules, producing molecular changes that can lead to significant genetic damage in biological tissue.
- In fact, X-rays and gamma rays are so energetic that they can cause ionization of atoms and molecules and thus are classified as "ionizing" radiation.
- Less energetic forms of electromagnetic radiation, such as microwave radiation, lack the ability to ionize atoms and molecules and are classified as "non ionizing" radiation.
- It is important that the terms, "ionizing" and "non ionizing," not be confused when referring to electromagnetic radiation, since their mechanisms interaction of the human body are quite different.

Further, Biological effects of (non-ionizing) RF radiation are discussed



Electromagnetic Field

- EM fields produced by an antenna can be described as having several components. Only one of these actually propagates through space. This component is called the *radiated field* or *the far field*.
- The strength of the radiated field does decrease with distance, since the energy must spread as it travels.
- The other components of the electromagnetic field remain near the antenna and do not propagate.
- There are generally two other components: the static field and the induction field; their strength decreases very rapidly with distance.
- The entire field—all of the components—near the antenna is called the *near field*. In this region, approximately one wavelength in extent, the electric field strength can be relatively high and pose a hazard to the human body.

Basic Restrictions

- Restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects are termed “basic restrictions” (ICNIRP).
- Depending upon the frequency of the field, the physical quantities used to specify these restrictions are;
  1- Current Density (J), (A/m^2)
  2- Current (I), (A)
  3- Specific Absorption Rate (SAR), (W/kg)
  4- Specific absorption (SA), (J/kg)
  5- power density (S), (W/m^2)
- Only power density in air, outside the body, can be readily measured in exposed individuals.

Relations Between Units and Frequencies

- Current density, J, in the frequency range up to10 MHz;
- Current, *I*, in the frequency range up to 110 MHz;
- Specific absorption rate, SAR, in the frequency range 100 kHz–10 GHz;
- Specific absorption, SA, for pulsed fields

  in the frequency range 300 MHz–10 GHz; and
- Power density, S, in the frequency range 10–300 GHz.

EM-Field and Absorption

- EM fields can be divided into four frequency ranges:
- Frequencies from about 100 kHz to less than about 20 MHz, at which absorption in the trunk decreases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs.
- Frequencies in the range from about 20 MHz to 300 MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g., head) resonances are considered.
- Frequencies in the range from about 300 MHz to several GHz, at which significant local, non-uniform absorption occurs.
- Frequencies above about 10 GHz, at which energy absorption occurs primarily at the body surface.

Effect of RF-Fields

- short-term, immediate effects

  health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and elevated tissue temperatures resulting from absorption of energy during exposure to RF radiation.

- Potential long-term effects

  such as an increased risk of cancer; ICNIRP concluded that available data are insufficient to provide a basis for setting exposure restrictions.

Why we Need to Measure SAR?

- Concern about health effects from radio frequency
- SAR is universally accepted as a measure of energy deposition
- Many regulatory agencies require radio transmitters to meet SAR limits

At the frequencies of operation of most wireless devices, the known health effects centre around tissue is heating. A measure of this heating effect is known as Specific Absorption Rate (SAR).

The SAR is determined from the relationship between E-field and the tissue properties, i.e.,

$$\mathbf{SAR = \sigma |E^2| / \rho}$$

where σ is the conductivity and ρ is the density.

RF Energy and Human Body

There are many factors that affect amount of absorption into the human body:

1- Dielectric composition

2- Size

3- Shape, orientation and polarization (The human body in a vertical position absorbs 10 times more energy in a vertically polarized field than in a horizontally polarized field.)

4- Complexity of the RF field

Whole/Local-Body SAR

- Whole-body SAR is restricted to avoid any problems associated with whole-body heating, such as heat stress.
- Localised SAR in parts of the body is restricted to prevent localised temperature rise in tissue.
- Localised SAR is the most relevant quantity for restrictions on exposure from wearable and hand-held devices (these are quite low power devices and there is not enough power available for whole-body SAR to be a concern). But if all the available power were to be deposited in the head, for example, the localized SAR in a small volume could be quite large.

Whole/Local-Body SAR

The SAR represents the amount of power deposited in body tissue divided by the mass of tissue that it is absorbed in. For example, a typical person might weigh 70 kg and, if they were close to a radio transmitter, they might absorb 0.7 watts of power in their whole body. The whole-body SAR is then 0.01 W/kg (0.7/70=0.01). If that same power is all absorbed in 1 kg of tissue, then the SAR in that localised 1 kg of tissue would be 0.7 W/kg. And if it were all absorbed in a tenth of a kg (100 g) the SAR in that 100 g would be 70 W/kg.

Human Body Thermoregulatory

- The human body has a very effective thermoregulatory system, and it can tolerate very short temperature rises. Because of this, SARs in the body can be averaged over 6 minutes. Within any 6-minute period the SAR can exceed the guideline level as long as the average during that time is below the guideline level.
- Different parts of the body have different thermoregulatory abilities (reflecting how deep they are in the body and the quality of their blood supply) so the averaging mass for SAR is different in different tissues.
- The limbs can tolerate higher levels than eyes, since the body's circulatory system (blood flow) acts as a coolant.

SAR Test

Under the FCC rules ,the FCC will require a SAR test for RF category “Portable” devices if the power exceeds;

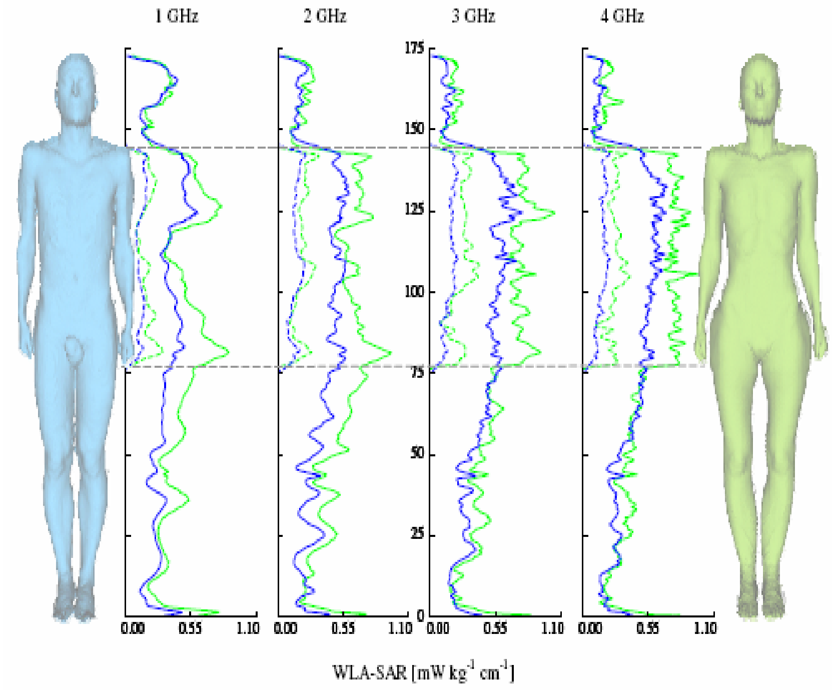
1- 60mW/f(GHz) if contact with antenna is allowed

2- 120mW/f(GHz) if 2.5cm is maintained to the antenna

Difference Between Female and Male Models (WB-SAR)

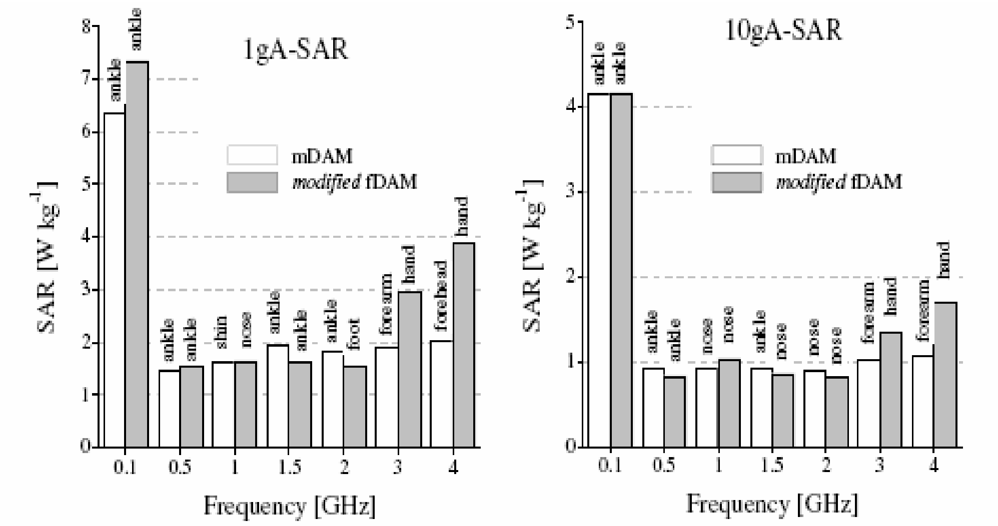
The body was separated into four regions:
(Total body volume 100%)

- Head and neck 7%
- Arms 9%
- Trunk 55%
- Legs 29%



The absorption of head and neck region does not seem to depend on gender. Remarkable differences have been found in arms, trunk and legs; in these regions (particularly in the thighs) the difference between thicknesses of subcutaneous fat is relevant.

Gender Effect on SAR



mDAM: male Dielectric Anatomical Model
fDAM: female Dielectric Anatomical Model

L Sandrini, A Vaccari, C Malacarne, L Cristoforetti and R Pontalti, “RF dosimetry: a comparison between power absorption of female and male numerical models from 0.1 to 4 GHz,” Phys. Med. Biol. **49** (2004) 5185–5201

It can be seen that below 3 GHz the maximum local SAR does not seem to depend on gender; from above 3 GHz, both 1gA-SAR and 10gA-SAR of the female model become larger than that of the mDAM.
This is hypothesized to be caused by the different posture of the hands (more spaced apart from the body for the modified fDAM than for the mDAM).
Maximum local SAR occurs in narrow and/or bony regions of the body where no subcutaneous fat layer is present. This explains why the gender differences reported for the WB-SAR were not found for maximum local SAR.

MPE Limits

(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/cm^2)	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	($900/f^2$)*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

(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/cm^2)	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	($180/f^2$)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

SAR Limits

- In most countries, for devices used at the head, torso or any part of the body (excluding the hands, wrists, feet and ankles), most standards (EN50360/1, ACA[1], ARIB[2]) set a SAR limit of 2 W/kg measured in a 10 g mass of tissue.
- The FCC sets a SAR limit of 1.6 W/kg measured in a 1 g mass of tissue.
- Because the 1 g tissue mass in which the RF energy is absorbed is much smaller than the 10 g mass, this leads to a much greater temperature rise, therefore, the FCC limit is effectively much tougher than the rest of the world.
- At 1800 MHz, a device that gives a SAR of 1.6 W/kg in a 1 g mass of tissue will typically give a SAR of 0.8 W/kg in a 10 g mass of tissue.

[1](ACA: Australian Communications Authority)
[2](ARIB: Association of Radio Industries and Businesses)

SAR Limits

(A) Limits for Occupational/Controlled Exposure (W/kg)

Whole-Body	Partial-Body	Hands, Wrists, Feet and Ankles
0.4	8.0	20.0

(B) Limits for General Population/Uncontrolled Exposure (W/kg)

Whole-Body	Partial-Body	Hands, Wrists, Feet and Ankles
0.08	1.6	4.0

- Whole-Body SAR is averaged over the entire body.
- Partial-Body is averaged over any 1 g of tissue defined as a tissue volume in the shape of a cube.
- Hand, wrist, Feet and Ankle is averaged over any 10 g of tissue defined as tissue volume in the shape of a cube.
- Above 6 GHz, SAR limits are not applicable and MPE limits for power density should be applied at 5 cm or more from the transmitting device.

SAR Limits (Different Standards)

Exposure Guideline		SAR (W/kg)
NRPB (Public & workers)	Whole body	0.4
	Head	10
	Trunk	10
	Limbs	20
IEEE (Uncontrolled Environments)	Whole Body	0.08
	Head, Torso, Limbs	1.6
(Controlled Environments)	Whole Body	0.4
	Head, Torso, Limbs	8
ICNIRP (Public)	Whole Body	0.4
	Head, Trunk	2
	Limbs	4
(Occupational)	Whole Body	0.08
	Head, Trunk	10
	Limbs	20

Heat

How much heat delivery is 0.4 W/kg?

SAR of 0.4 W / kg will melt an ice cube (0°C) to water (0°C) in 10 days.

Densities & Electrical Properties of Tissues

- Low Frequency

  ε_r large, σ small
- High Frequency

  ε_r small, σ large

		900 MHz		1800 MHz	
Tissue	ρ (kg m^{-3})	ε_r	σ (S m^{-1})	ε_r	σ (S m^{-1})
Skin	1126	39.59	0.693	38.40	0.999
Tendon	1151	46.72	0.951	45.23	1.367
Fat/yellow marrow	943	4.786	0.053	4.51	0.067
Cortical bone	1850	12.61	0.172	11.93	0.302
Cancellous bone	1080	18.62	0.308	17.79	0.469
Blood	1057	55.48	1.868	54.18	2.283
Muscle	1059	60.73	1.198	57.03	1.840
Grey matter	1035.5	51.80	1.009	47.79	1.525
White matter	1027.4	37.77	0.665	36.58	1.081
Cerebro-spinal fluid	1000	68.29	2.426	67.39	2.842
Sclera/cornea	1151	51.79	1.192	52.69	1.683
Vitreous humour	1000	67.90	1.686	67.19	2.092
Nerve	1112	33.36	0.606	32.09	0.867
Cartilage	1171	40.62	0.828	38.24	1.241
Tongue/thyroid	1059	56.29	1.087	54.07	1.599
Cerebellum	1035.5	49.74	1.066	47.98	1.441
Oesophagus	1126	40.33	0.818	37.07	1.153

SAR in Adults and Children When Using a Mobile Phone @ 2.2cm

	Peak SAR (W kg^{-1})	Max SAR$_{1\,g}$ (W kg^{-1})	Max SAR$_{10\,g}$ (W kg^{-1})	SAR$_{wh}$ (W kg^{-1})
Adult	4.21	2.35	1.44	0.02
88%	3.84	2.06	1.32	0.03
78%	3.36	1.72	1.20	0.04

250 mW @ 900 MHz

	Peak SAR (W kg^{-1})	Max SAR$_{1\,g}$ (W kg^{-1})	Max SAR$_{10\,g}$ (W kg^{-1})	SAR$_{wh}$ (W kg^{-1})
Adult	4.56	2.74	1.45	0.008
88%	4.63	2.76	1.43	0.011
78%	4.93	2.71	1.35	0.015

125mW @1800 MHz

Higher whole body SAR is observed for the lower frequency while higher local absorption is obtained at 1800 MHz. This ratifies that field penetration is higher at 900 MHz, as expected.

The lower frequency has twice the radiated power of the higher frequency.

M. Martınez-Burdalo, A. Martın, M. Anguiano and R. Villar, "Comparison of FDTD-calculated specific absorption rate in adults and children when using a mobile phone at 900 and 1800 MHz," Physics in Medicine and Biology, Phys. Med. Biol. 49 (2004) 345–354

Placing a Medical BAN Devices with Respect to the SAR

Where to place it:

- ✓ In-Body
- ✓ On-Body
- ✓ Off-Body
  - near to body (< 2.5cm)
  - far from body (> 2.5cm)

Sources

NRPB: National Radiological Protection Board

ICNIRP: International Commission on Non-Ionizing Radiation Protection

IEC: International Electrotechnical Commission

CISPR: International Special Committee on Radio interference

NCRP: National Council on Radiation Protection

IEEE: Institute of Electrical and Electronic Engineers

WHO: The International EMF Project

Thank you
For
Your Attention