ElectroMagneticFields (EMF) RF Human Hazards

5 May 2020

More information, Chapter 9 on EMF exposure of Mazar Wiley 2016 book on Spectrum Management

ITU intersector activities officer on RF-EMF and co-rapporteur ITU-D Question 7/2

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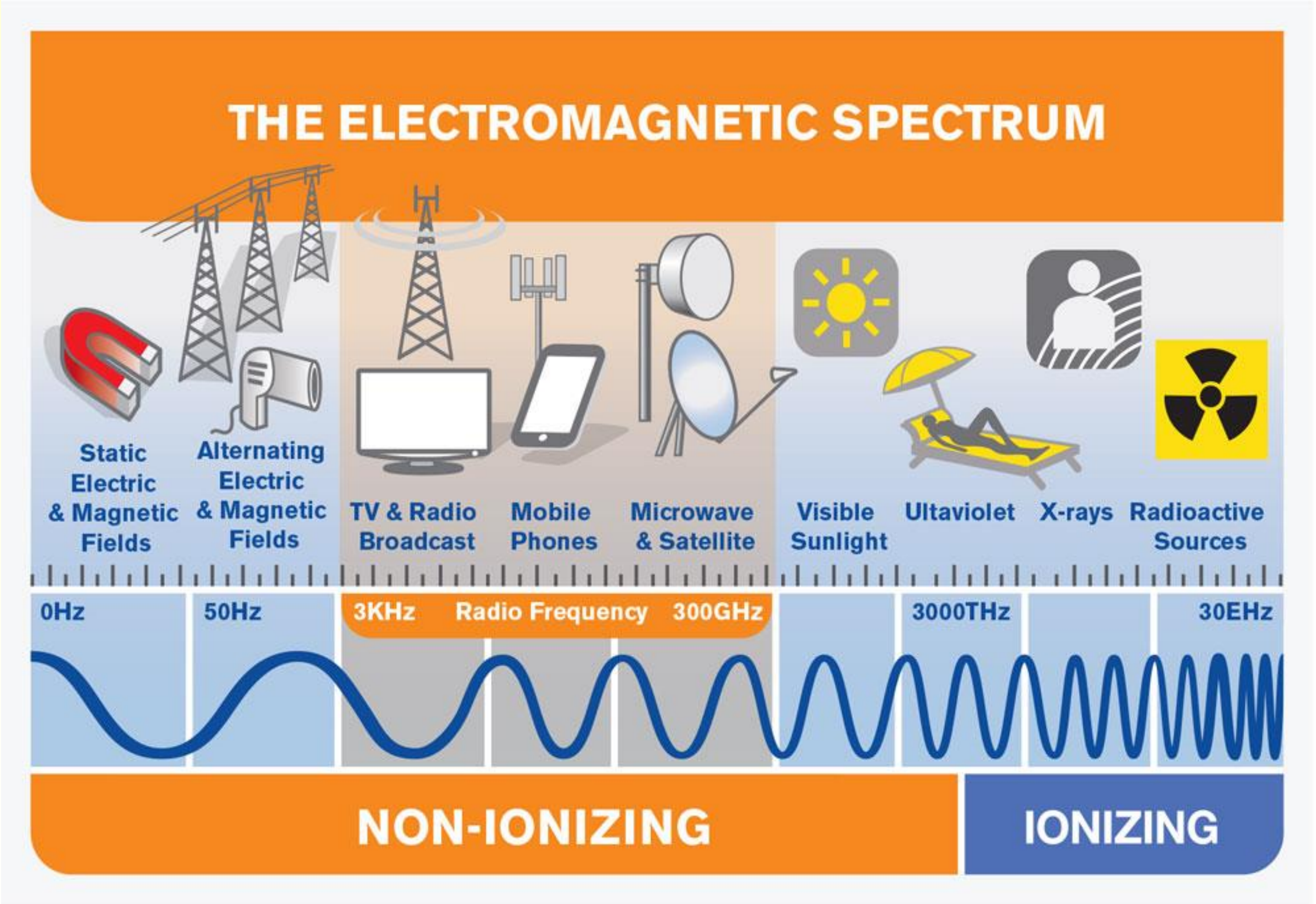
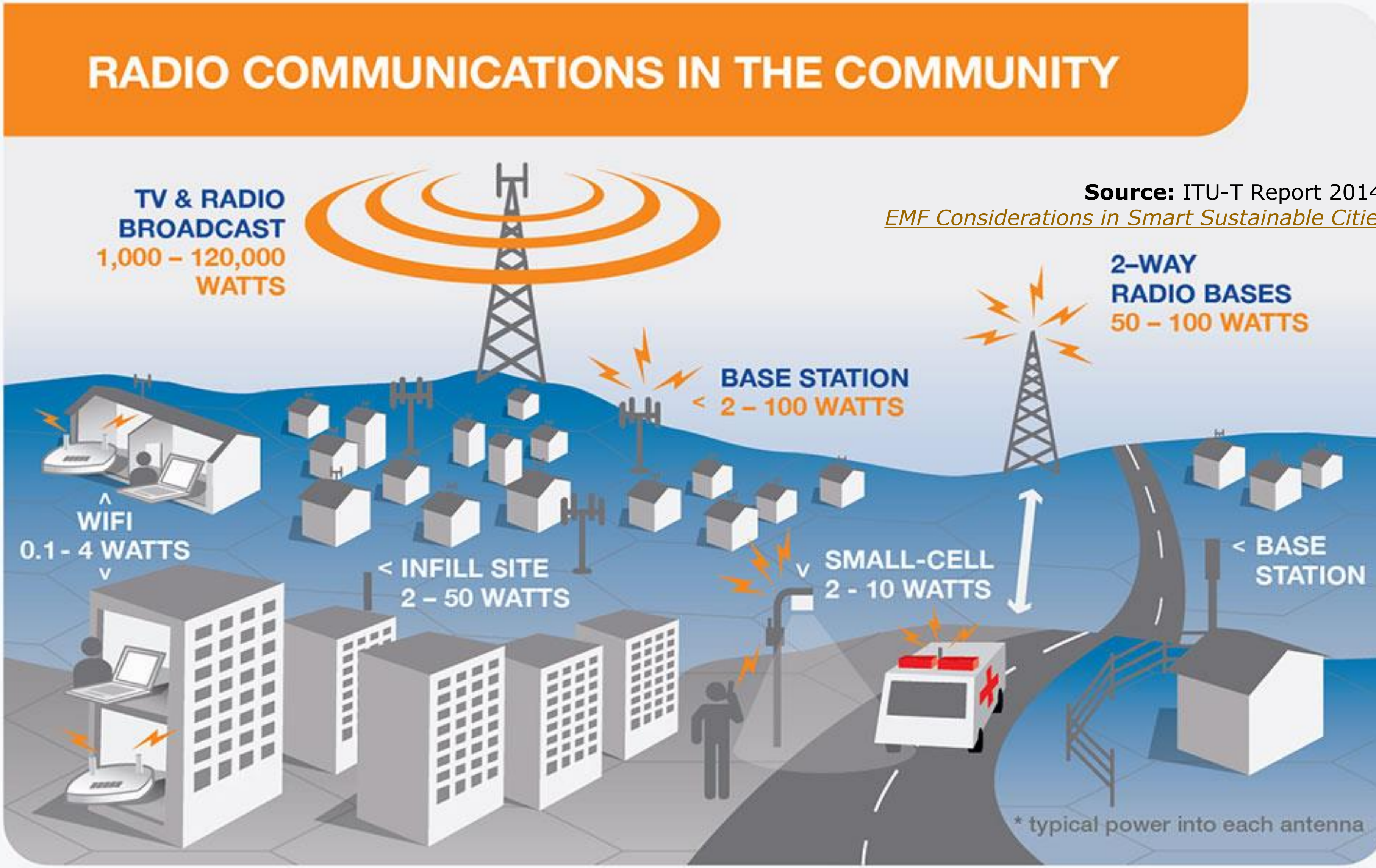
Dr. Haim Mazar (Madjar), ITU & World-Bank expert;
re-elected vice-chair ITU-Radio Study Group 5 (terrestrial services)



Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*



Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*

Ionizing and non-ionizing radiations

- Ionizing radiation (ionizing radiation) carries sufficient energy to detach electrons from atoms or molecules, thereby ionizing them
- Gamma rays, X-rays, and the higher ultraviolet part of the electromagnetic spectrum are ionizing, whereas the lower frequencies-ultraviolet, visible light (including nearly all types of laser light), infrared, microwaves, and radio waves are non-ionizing radiation

Ionizing and non-ionizing radiations; Planck–Einstein relation

- Planck's constant, denoted *h*, relates the energy carried by a photon to its frequency. A photon's energy is equal to its frequency multiplied by the Planck constant.
- The Planck constant $h = 6.62607015 \times 10^{-34}$ Joule/s.
- Planck–Einstein relation Energy = *hf*
- The electronvolt is the appropriate unit of energy and the petahertz the appropriate unit of frequency
- An electronvolt (symbol eV, also written electron-volt and electron volt) is the amount of kinetic energy gained (or lost) by a single electron accelerating from rest through an electric potential difference of one volt in vacuum.
- The numerical value of 1 eV in joules (symbol J) is equivalent to the numerical value of the charge of an electron in coulombs (symbol C)
- Under the 2019 redefinition of the SI base units, 1 eV equals $1.602176634 \times 10^{-19}$ Joule

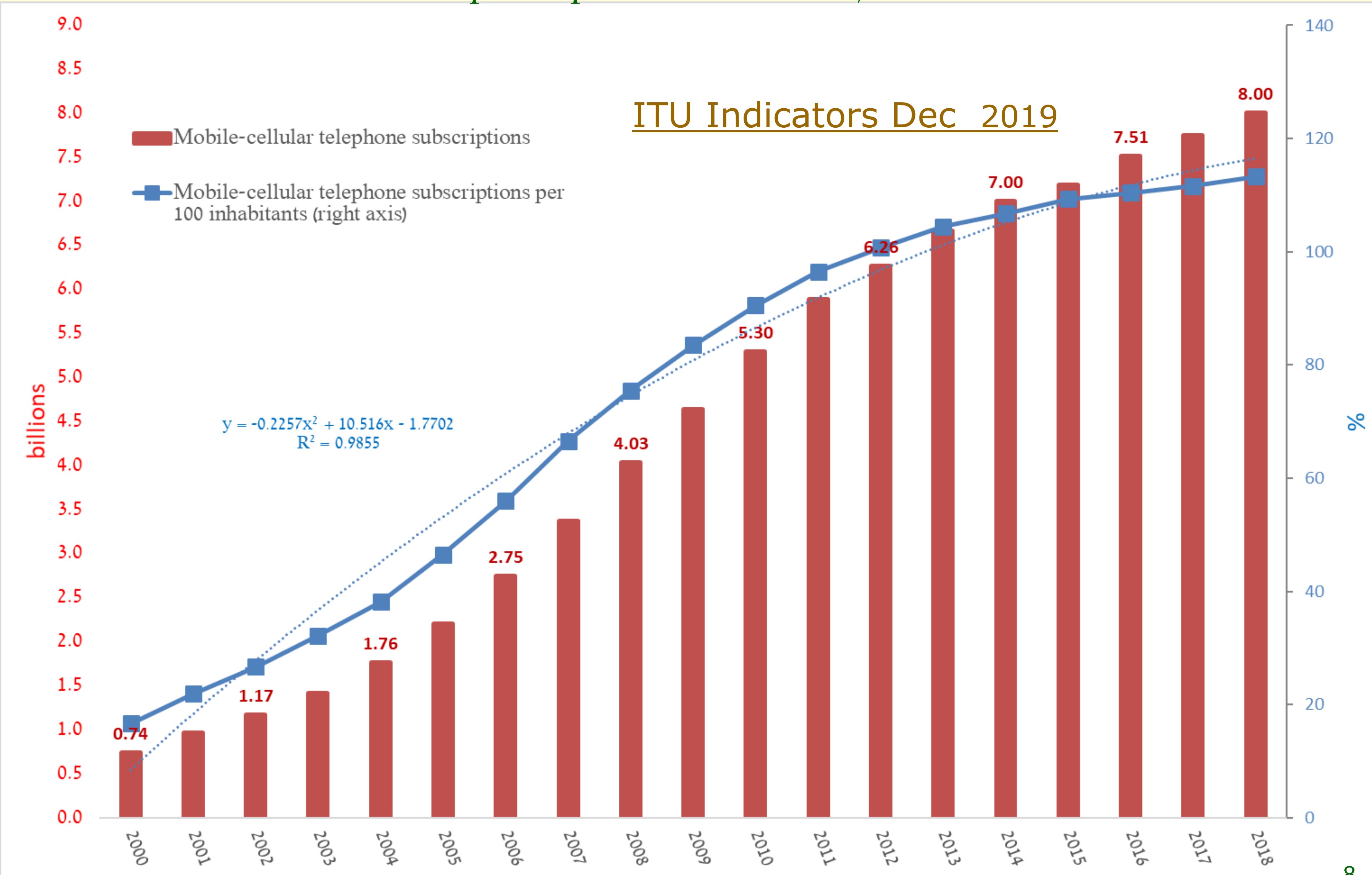
Ionizing Radiation

- The boundary between radiations is the photon energy between 10 eV (Federal Communications Commission FCC definition) equivalent to a far ultraviolet wavelength of 124 nanometers in the ultraviolet
- λ wavelength (m.)= $300x10^6/f$(Hz); f(Hz)= $300x10^6/124x10^{-9}$; as 1THz = 10^{12}Hz; f(THz)= $300x10^{-6}/124x10^{-9}=300x10^3/124=$ 2,419 THz; $2,419x10^3$ GHz
- The ITU Radio Regulations stop at 3,000 GHz; 3 THz; 0.01241 eV, 100 μM
- So, ionizing radiation is an electromagnetic wave propagating at light-speed, but not a radio-signal

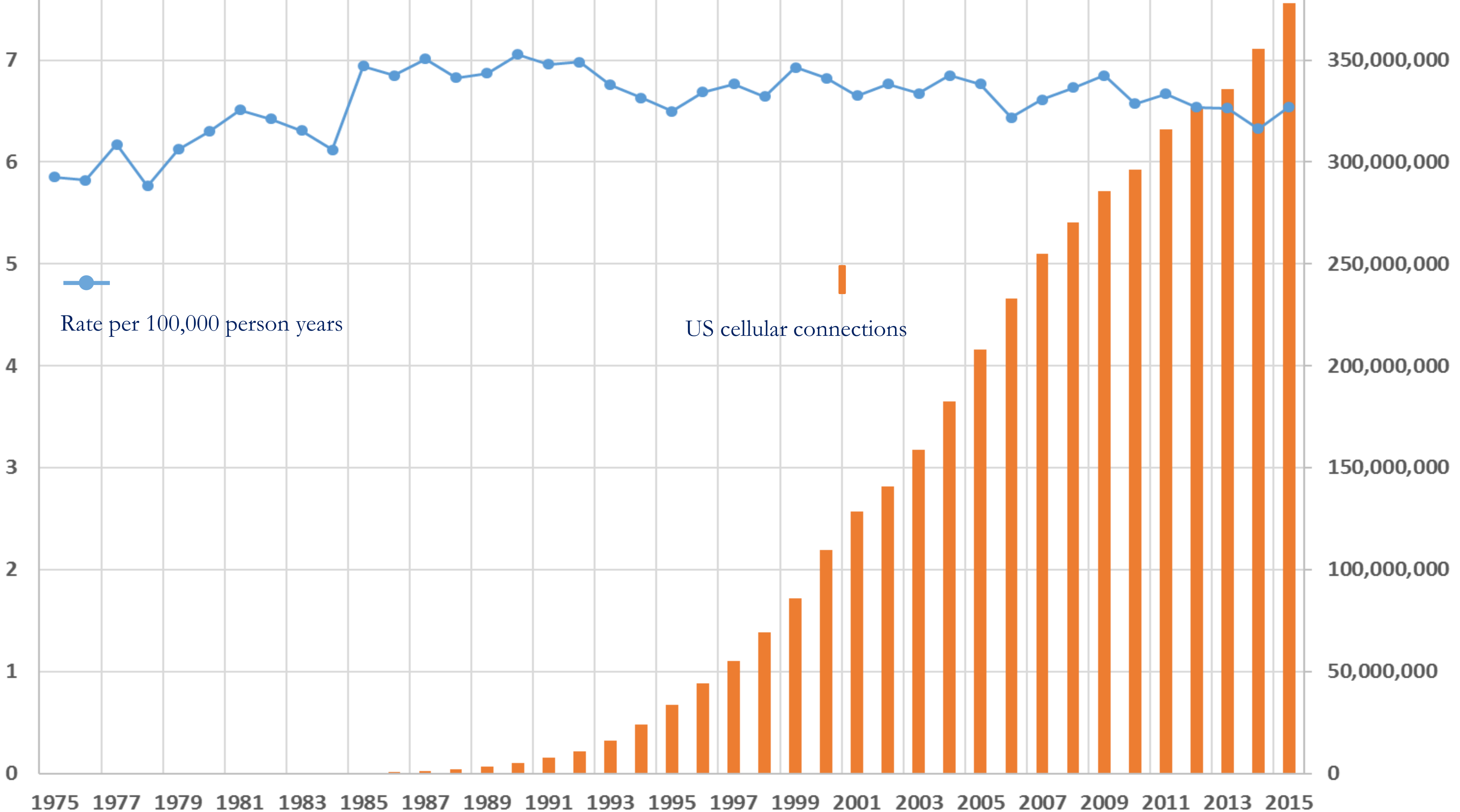
RF adverse effects: low-level effects

- No adverse effects have been established from low-level exposures despite 70 years of research
- No known interaction mechanisms
- No meaningful dose-response relationship
- Speculative
- Inappropriate for standard setting

Mobile-cellular telephone subscriptions (billions) & Mobile-cellular telephone subscriptions per 100 inhabitants, 2000-2018



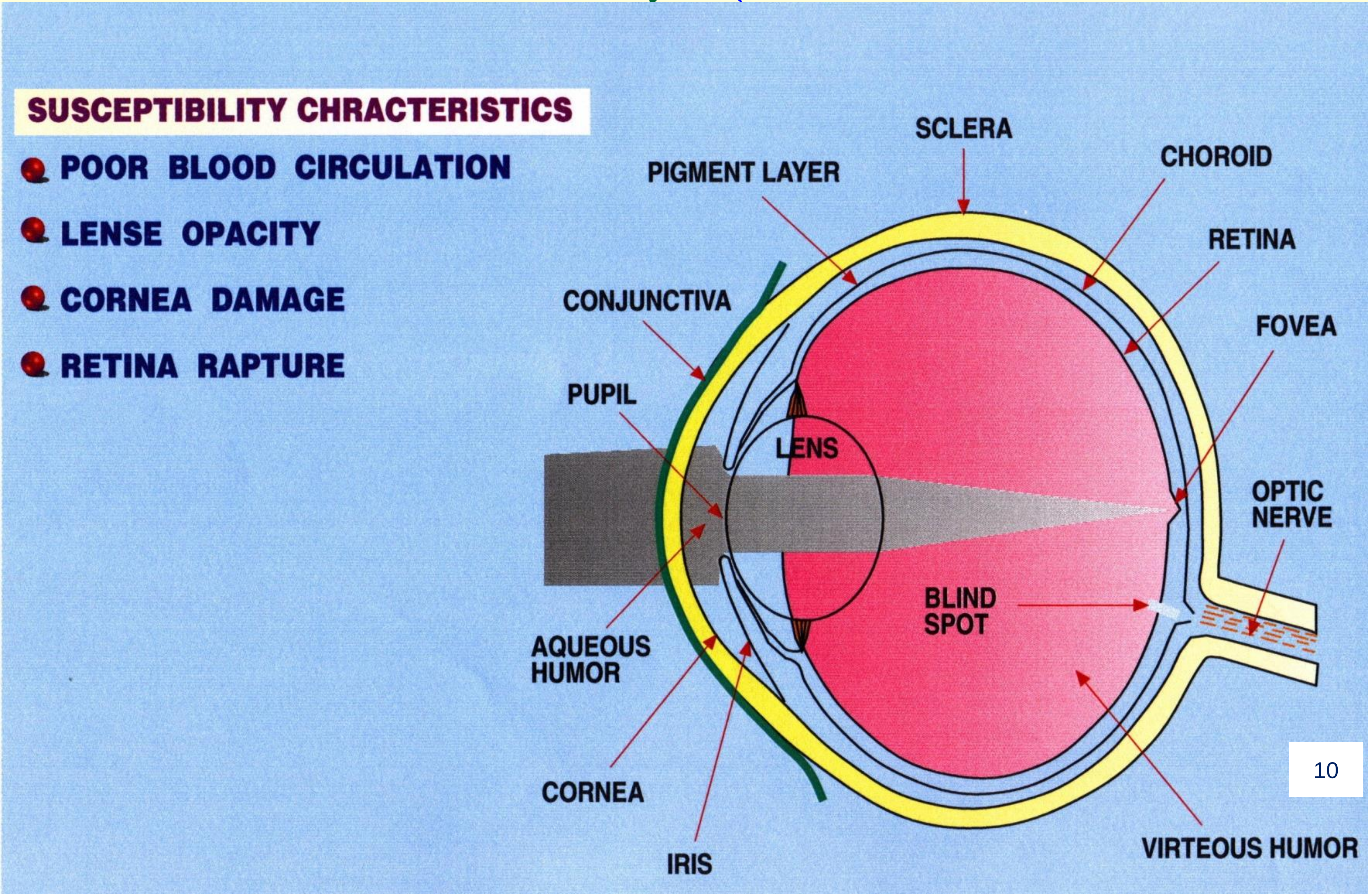
US brain cancer and mobile subscriber trends



Overall, incidence data of the Surveillance, Epidemiology, and End Results (SEER) do not support the view that cellular phone use causes brain cancer

Based on CTIA and SEER data, and Inskip et al., 2010

the human eye (Moshe Netzer)



Monitoring of human exposure around the world: levels are very low, relative to ICNIRP reference levels

1. 2001 to 2004 (WHO 2007:30), UK conducted radio surveys at 289 schools with base stations on or near them. The highest compliance factor measured anywhere was 3.5 x 10^{-3} (= 12.2 x 10^{-6} of the power density), with the 90% of the schools having a highest compliance factor below 2.9 x 10^{-4} (**8.4 x 10^{-8}** power density) – which are very low values indeed. See also IARC 2013:58, fig. 1.11 specifies a cumulative distribution of exposure quotients corresponding to 3321 spot measurements made by OFCOM at 499 sites where public concern had been expressed about nearby base stations; the quotient values are median 8.1×10^{-6} of ICNIRP power density, ranging from the **5th percentile 3.0×10^{-8} to 95th percentile 2.5×10^{-4}**.
2. Two hundred randomly selected people in urban, sub-urban, and rural subgroups have measured on 2005–2006 in France (Viel et al. 2009; see also IARC 2013:114) for 24 hours a day, 184 daily measurements. At the GSM 900/1800 bands most of the time, the recorded field strength was below detection level (**0.05 V/m); 0.05 V/m is 3.63%** of the ICNIRP level at 900 MHz. 12.3% of measurements at the FM band indicate field strength above the detection threshold; the mean field strength was 0.17 V/m (Viel et al. 2009:552), the maximum field strength was always lower than 1.5 V/m. ANFR 2007 reveals that at 2004-2007, the average measurements are less than 2% of the field strength limit (less than 0.04 % of power density); more than 75% of the measurements were less than 2% of the field strength limit, regardless of the frequency band considered.
3. Ofcom published on February 2020 the results of recent measurements of EMF emissions close to sixteen 5G-enabled mobile phone base stations showing EMF levels at a total of 22 5G sites in 10 UK cities:
4. in 10 cities across the UK ; base stations support technologies in addition to 5G, including 2G, 3G and 4G:
    1. EMF emission levels from 5G-enabled base stations remain at small fractions of the reference levels for 1998 general public exposure in ICNIRP Guidelines (400–2,000 MHz) *f* (MHz)/200 (W/m^2), & 2– 300 GHz 10 (W/m^2)
    2. the highest level recorded being approximately 1.5% of the **power density** reference level.
    3. In all locations, the largest contribution to the measured levels comes from previous generations of mobile technology (2G, 3G, 4G).
    4. The highest level observed in the band used for 5G was just 0.039% of the reference level.

French ANFR, RF-EMF 2018 annual survey of over 2,500 public exposure measurements See ANFR Sept. 2018 abstract

Summerised results 2017: 90% of exposure levels measured in 2017 in rural areas are below 0.95 V/m.
* Values below the typical sensitivity threshold of the measuring devices, which equals 0.38 V/m

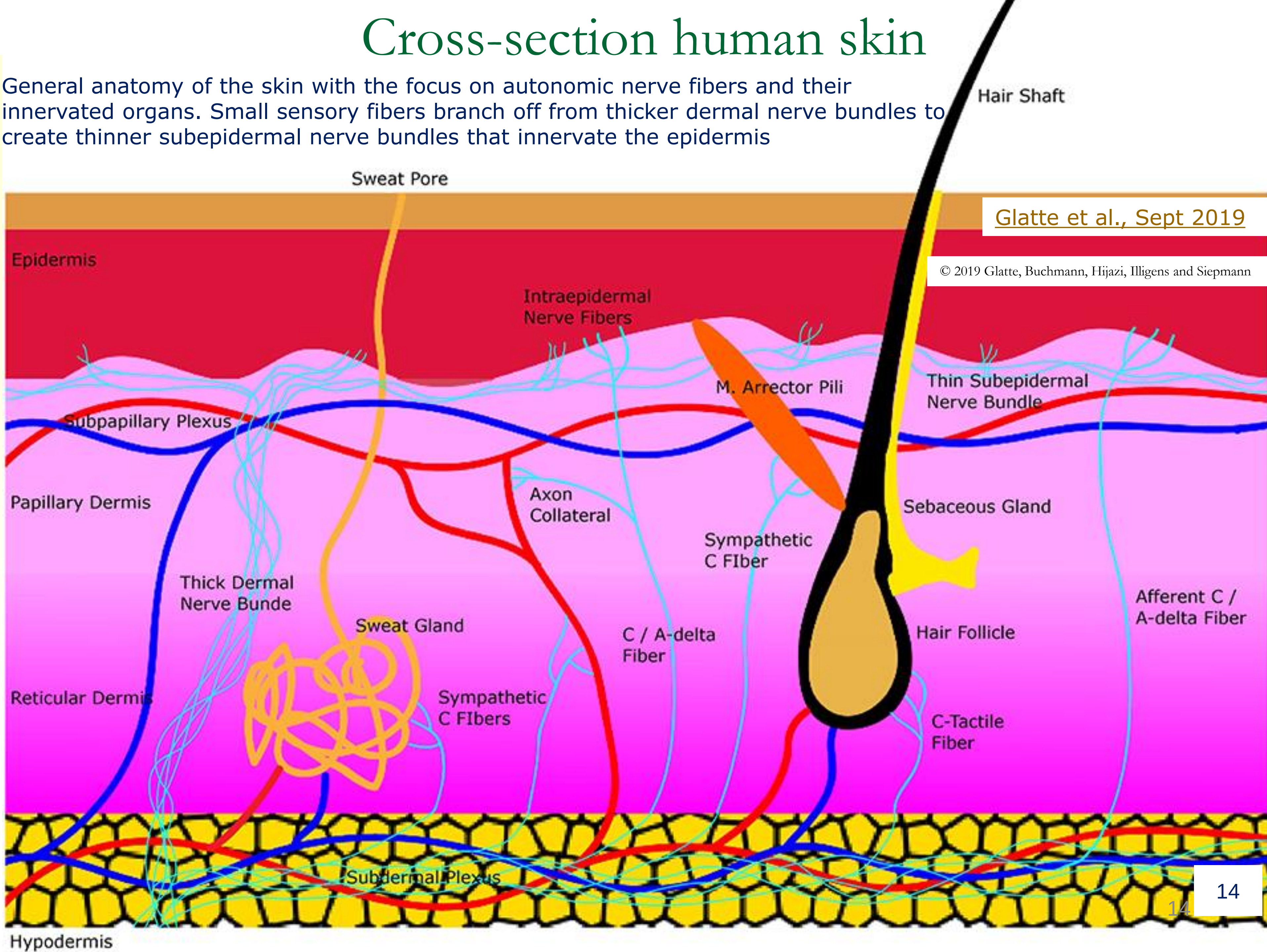
	Mesurements n°	**50% (median values)**	**90 %**	**99 %**	**Max**
Rural	425; 16 %	0,25* V/m	0,95 V/m	2,8 V/m	3,95 V/m
Urban	2166; 84 %	0,4 V/m	1,67 V/m	5,6 V/m	11,25 V/m
Indoor	1666; 64%	0,31* V/m	1,34 V/m	4,1 V/m	10,54 V/m
Outdoor	914: 36%	0,52 V/m	1,93 V/m	6,3 V/m	11,25 V/m
Total	**2591**	**0,36* V/m**	**1,57 V/m**	**5,5 V/m**	**11,25 V/m**

Questions to be raised

Compliance calculations and some periodic measurements are essential; however:
Why do we need to make so many nation-wide measurements?
May be ICNIRP reference levels are too liberal?

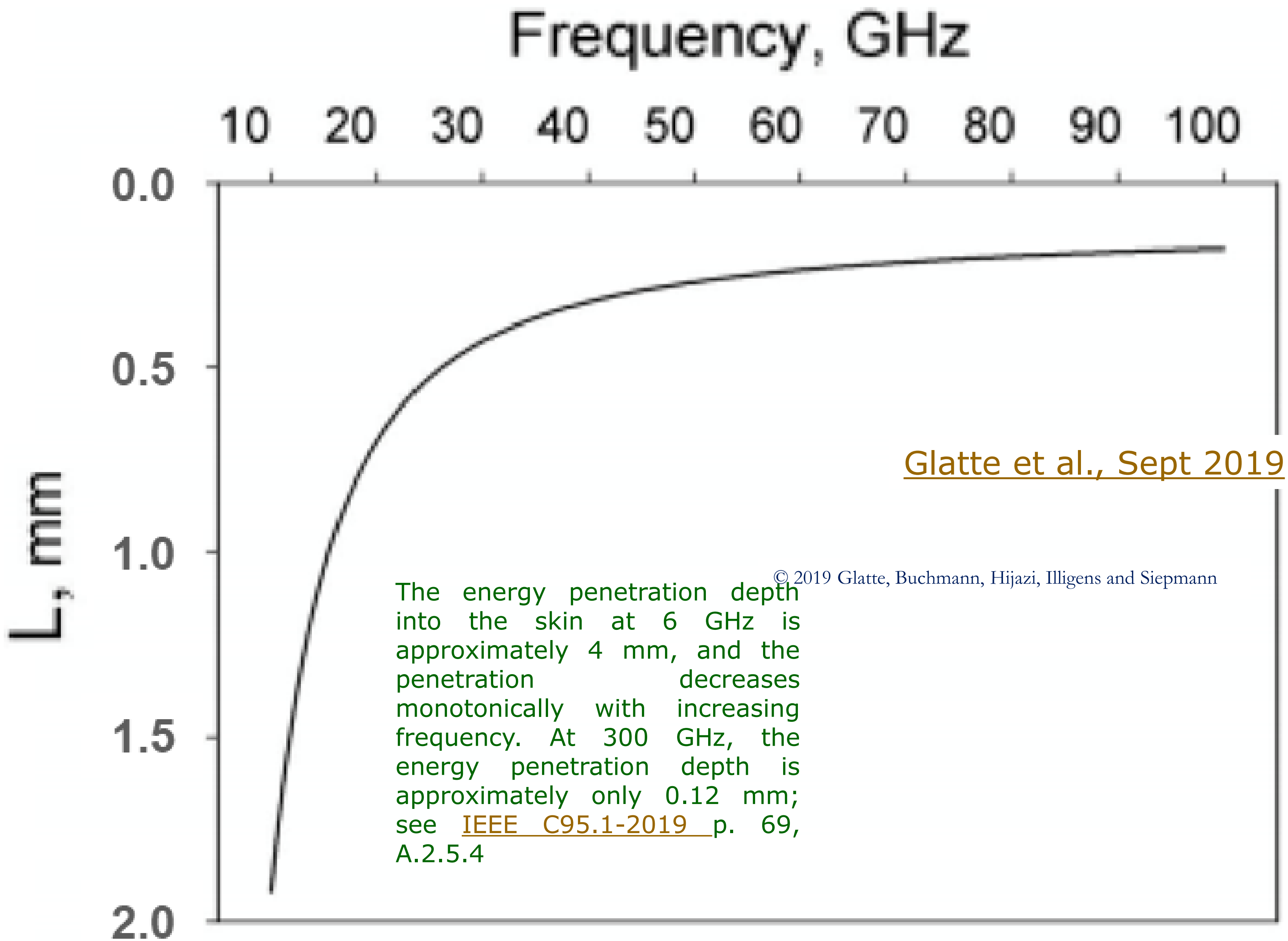
Cross-section human skin

General anatomy of the skin with the focus on autonomic nerve fibers and their innervated organs. Small sensory fibers branch off from thicker dermal nerve bundles to create thinner subepidermal nerve bundles that innervate the epidermis



Glatte et al., Sept 2019

mmWaves mostly absorbed in outer skin layers

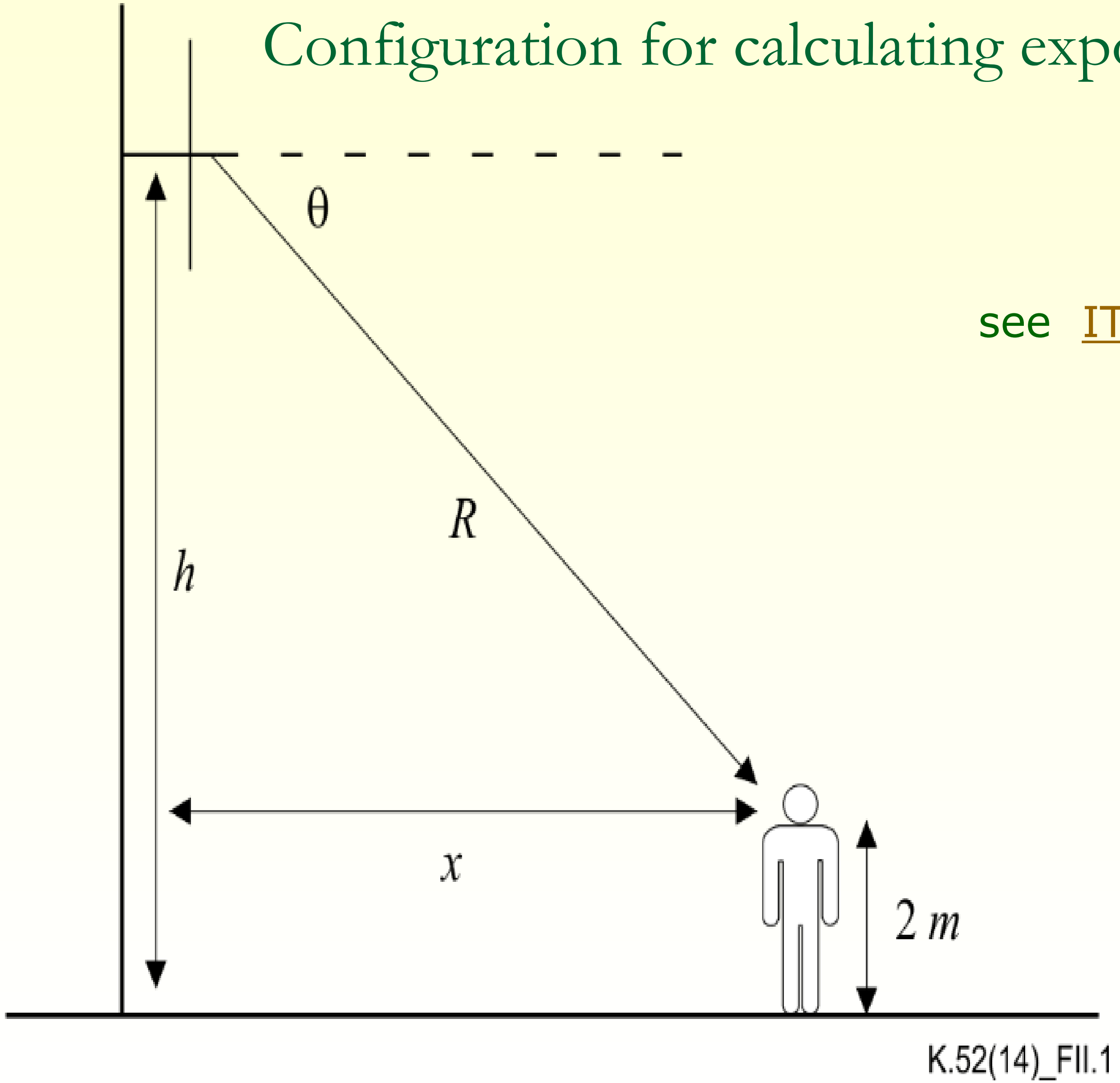


Glatte et al., Sept 2019

The energy penetration depth into the skin at 6 GHz is approximately 4 mm, and the penetration decreases monotonically with increasing frequency. At 300 GHz, the energy penetration depth is approximately only 0.12 mm; see IEEE C95.1-2019 p. 69, A.2.5.4

Dr.

Configuration for calculating exposure at ground level

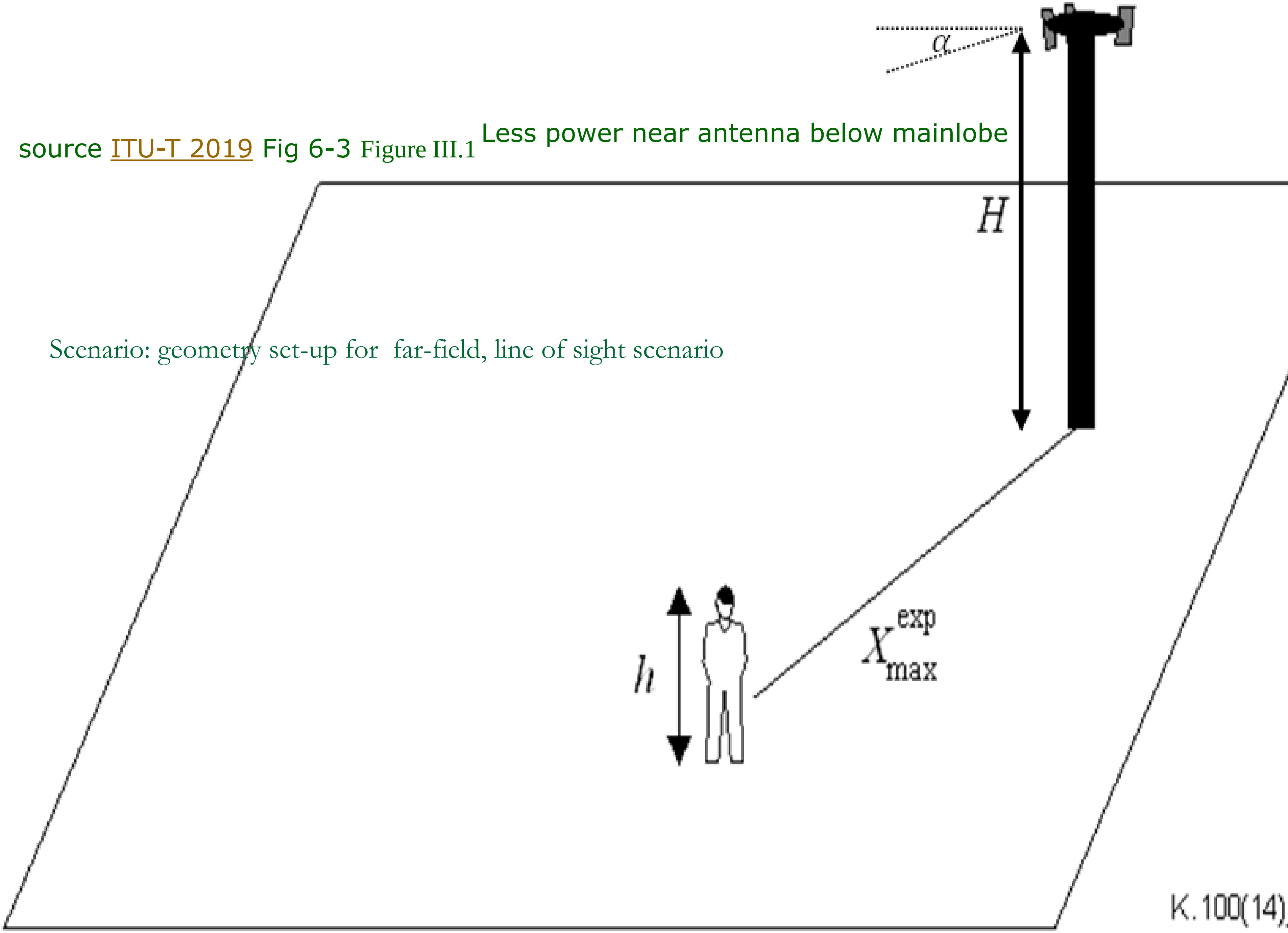


see ITU-T 2018 K.52 Fig II.1

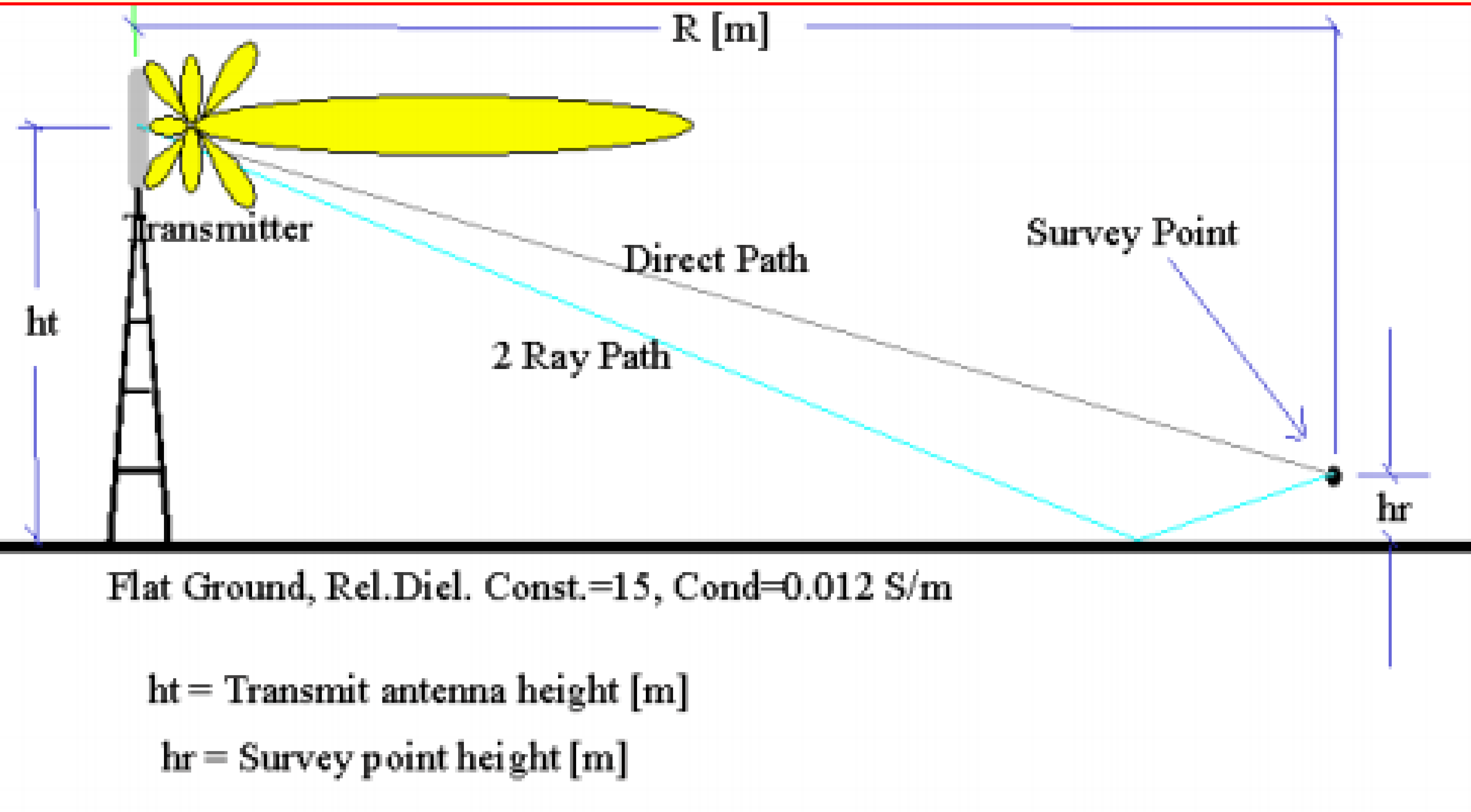
source ITU-T 2019 Fig 6-3 Figure III.1

Less power near antenna below mainlobe

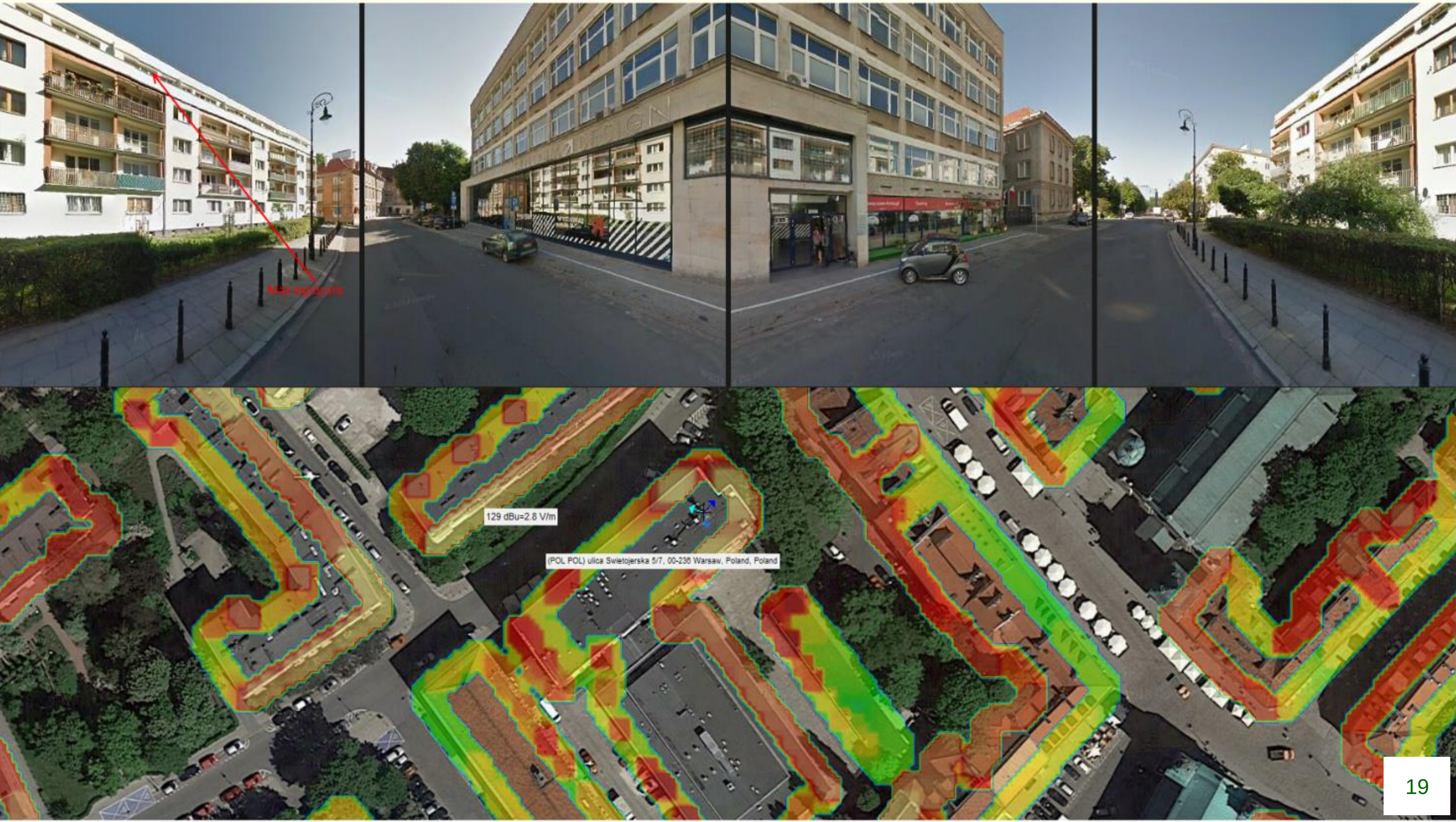
Scenario: geometry set-up for far-field, line of sight scenario

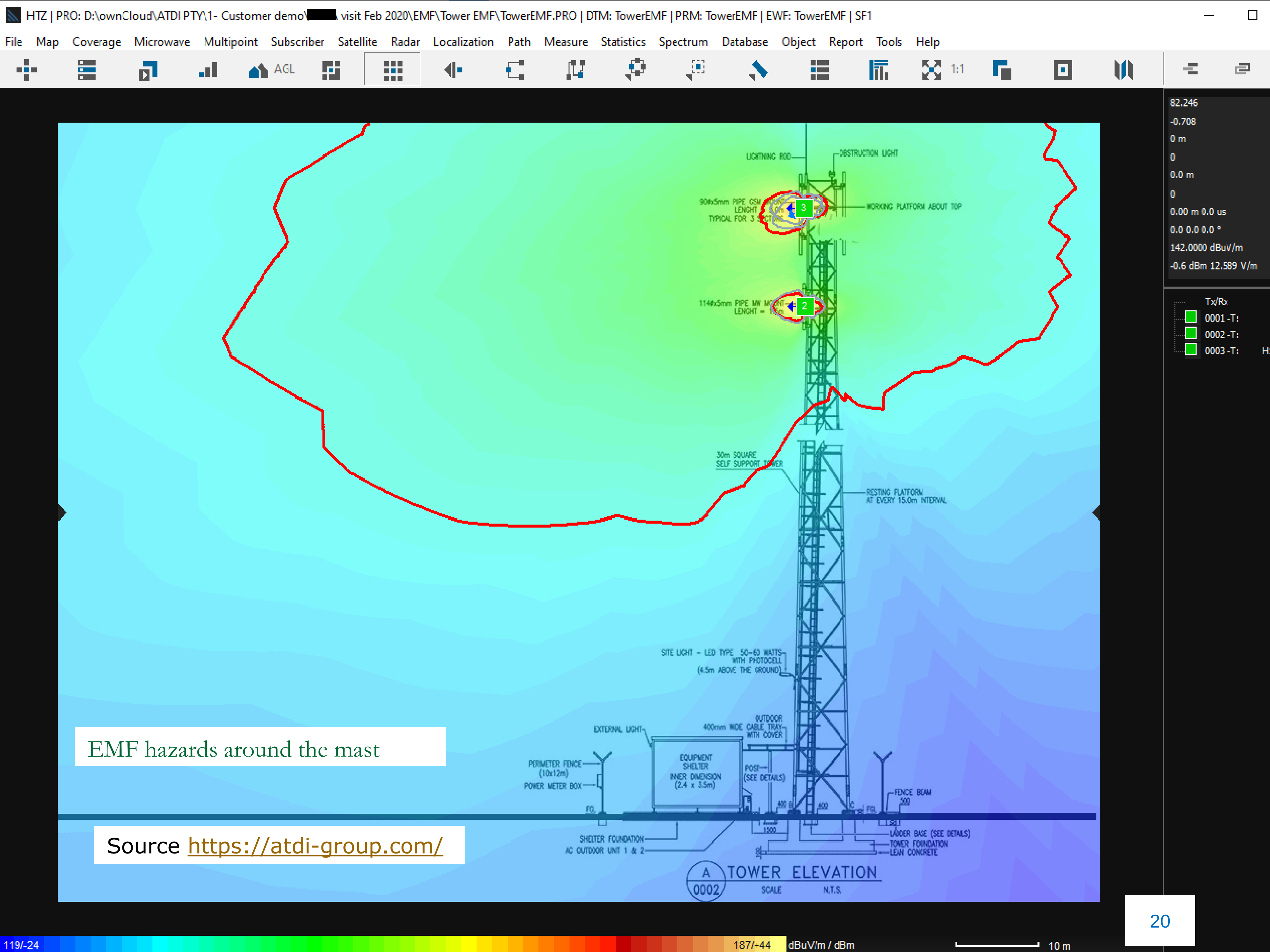


Far-field Scenario



ATDI 3D coverage analysis, to find max exposure locations

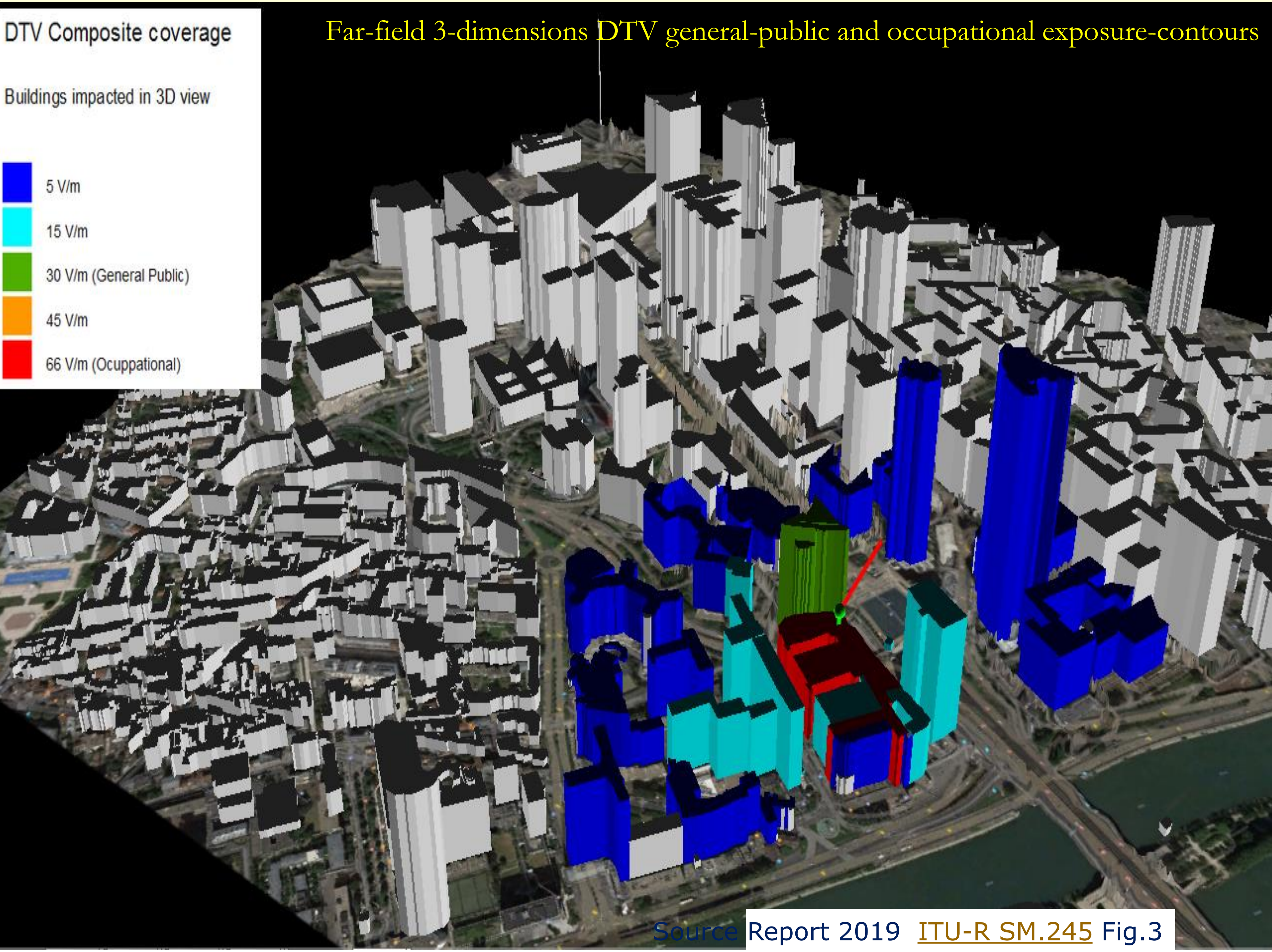




EMF hazards around the mast

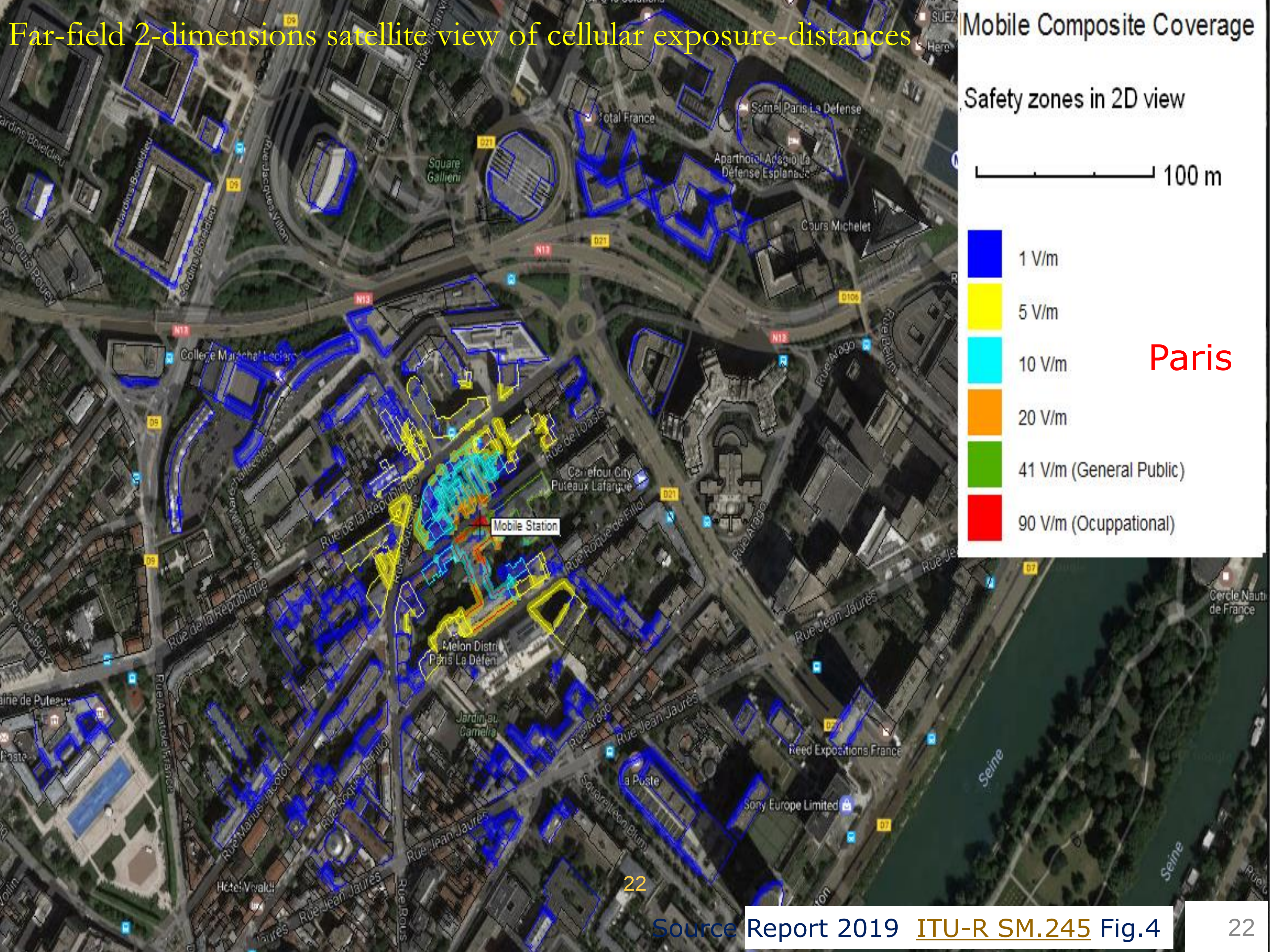
Source https://atdi-group.com/

Far-field 3-dimensions DTV general-public and occupational exposure-contours

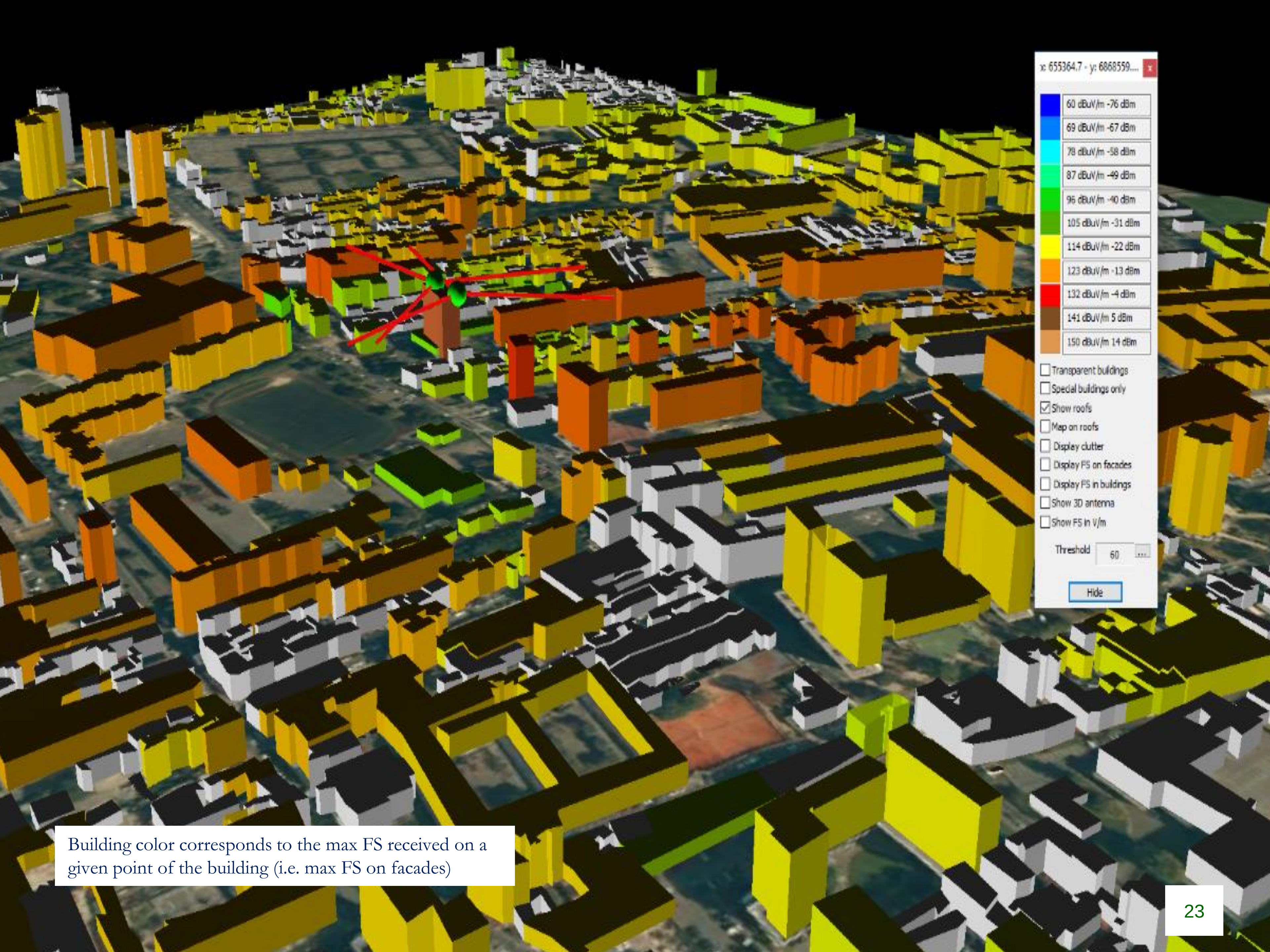


Source Report 2019 ITU-R SM.245 Fig.3

Far-field 2-dimensions satellite view of cellular exposure-distances

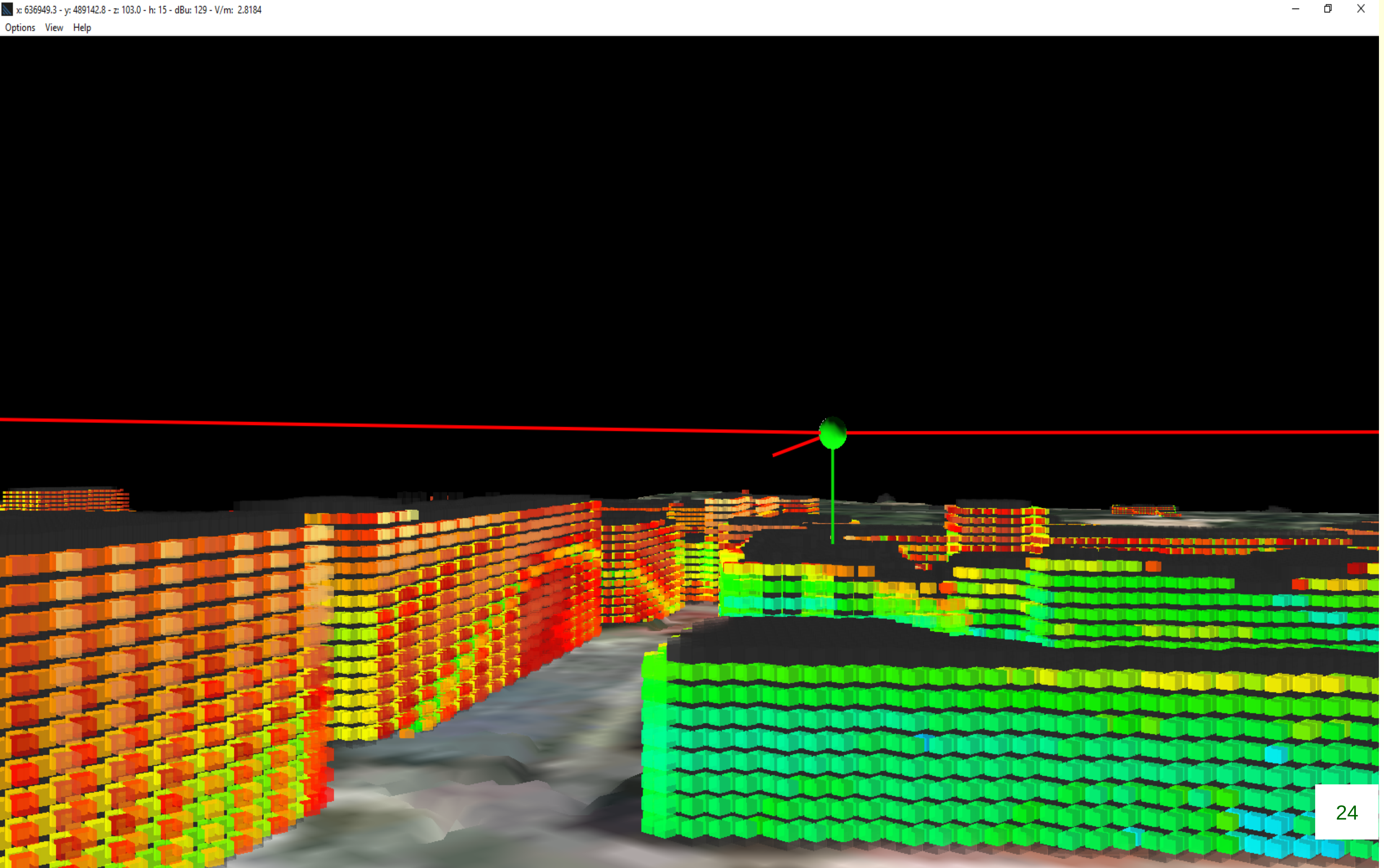


Source Report 2019 ITU-R SM.245 Fig.4



Building color corresponds to the max FS received on a given point of the building (i.e. max FS on facades)

3D coverage calculation on building facades (1 m resolution X,Y,Z)



Example: Human Hazards- thresholds

1. On April 2020 at 400-1500 MHz, the allowed ICNIRP 1998 (is revised in April 2020, see ICNIRP 2020) and EU Power Density for the general public is: ***f* (MHz)/200 [W/m^2**]

2. Europe follows ICNIRP 1998 levels; but: SUI (0.01 ICNIRP for BTS), Italy (0.03 ICNIRP) and Slovenia (0.1 ICNIRP)

3. US & Canada limit is 4/3 higher: ***f*(MHz)/150 [W/m^2]**

4. US & Canada threshold on terminal's SAR is **1.6 W/kg** (5/4 more risk averse). ICNIRP & EU limit is **2.0 W/kg**

1 May 2020, representative general population/ uncontrolled exposure reference levels

<table>
<tr><th></th><th>PD 1,000 MHz (W/m^2)</th><th>SAR (W/kg)</th></tr>
<tr><td>USA</td><td rowspan="2">f/150 =6.67; 133/%</td><td>1.6, averaged over 1g tissue</td></tr>
<tr><td>Japan</td><td rowspan="2">2.0 , over 10 g</td></tr>
<tr><td>ICNIRP1998; IEEE 2005; AUS; NZL; EC Directive 004/40/EC</td><td rowspan="2">f/200 =5; 100%</td></tr>
<tr><td>Korea</td><td rowspan="2">1.6, averaged over 1g tissue</td></tr>
<tr><td>Canada</td><td>$0.02619f^{0.6834}$ =2.94; 59%</td></tr>
<tr><td>China</td><td>0.4; 8%</td><td>2.0 , over 10 g</td></tr>
</table>

ICNIRP guidelines for limiting exposure to electromagnetic fields (100 KHz TO 300 GHz)

Published in: Health Phys 118(5): 483–524; 2020; DOI: 10.1097/HP.0000000000001210

ICNIRP reference levels are critical for compliance assessment

Tables 5 and 6 detail reference levels for exposure, averaged, to electromagnetic fields (EMF) from 100 kHz to 300 GHz (unperturbed rms values). The four ICNIRP figures appear in the additional material from the ICNIRP website, which are clearer, but could not be included in the Health Phys publication. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other. Figure and Figure disregard ICNIRP 2010.

ICNIRP 2020: Table 1. Quantities and corresponding SI units used in these guidelines

Quantity	**Symbol**	**Unit**
Absorbed energy density	U_{ab}	joule per square meter ($J\ m^{-2}$)
Incident energy density	U_{inc}	joule per square meter ($J\ m^{-2}$)
Plane-wave equivalent incident energy density	U_{eq}	joule per square meter ($J\ m^{-2}$)
Absorbed power density	S_{ab}	watt per square meter ($W\ m^{-2}$)
Incident power density	S_{inc}	watt per square meter ($W\ m^{-2}$)
Plane-wave equivalent incident power density	S_{eq}	watt per square meter ($W\ m^{-2}$)
Induced electric field strength	E_{ind}	volt per meter ($V\ m^{-1}$)
Incident electric field strength	E_{inc}	volt per meter ($V\ m^{-1}$)
Incident magnetic field strength	H_{inc}	ampere per meter ($A\ m^{-1}$)
Specific energy absorption	SA	joule per kilogram ($J\ kg^{-1}$)
Specific energy absorption rate	SAR	watt per kilogram ($W\ kg^{-1}$)
Electric current	I	ampere (A)
Frequency	*f*	hertz (Hz)
Time	*t*	second (s)

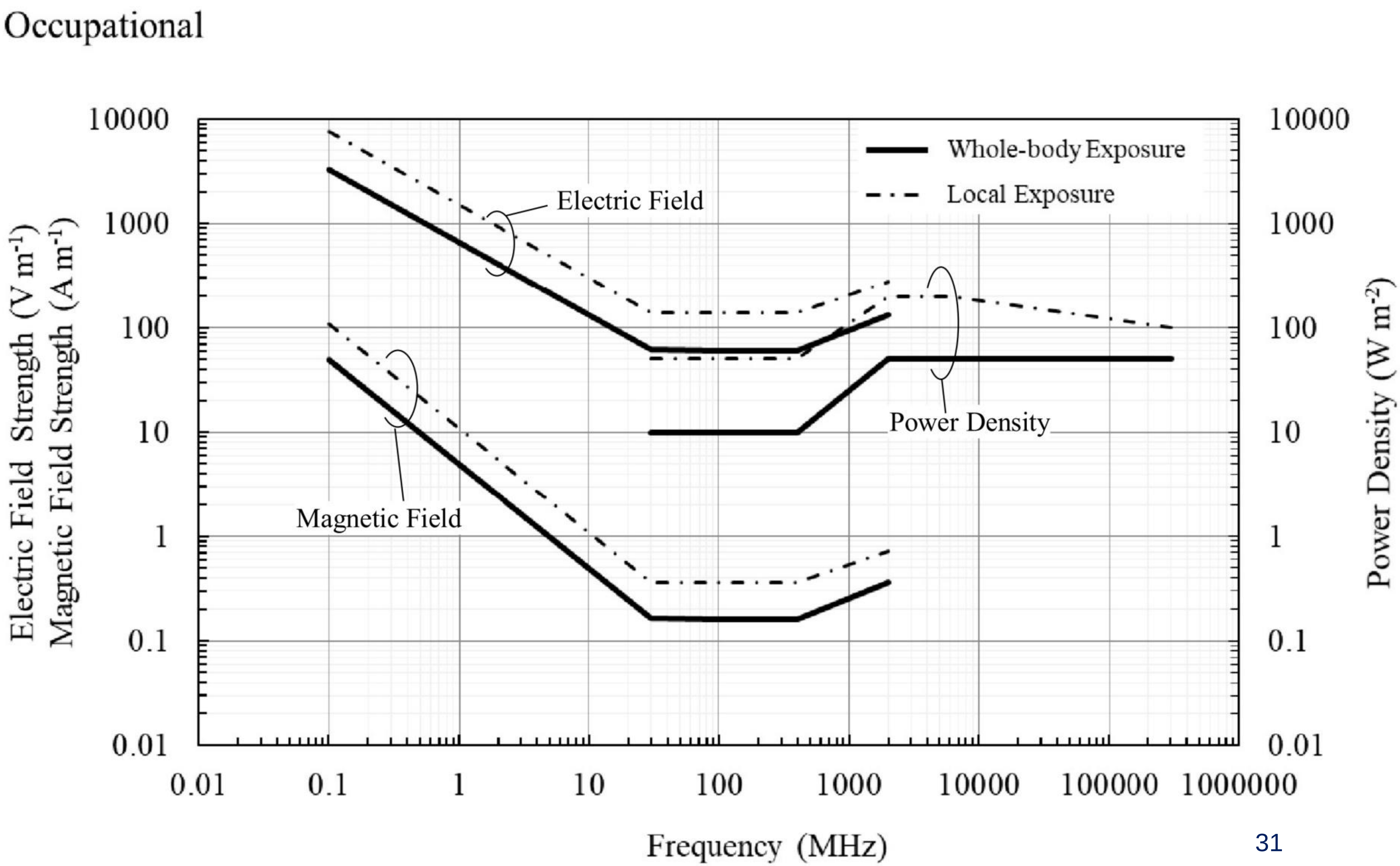
ICNIRP 2020 EMF for occupational & general public exposure, based on Table 5, p. 495: averaged over **30 minutes** and the **whole body**

Exposure scenario	Frequency range	Incident E-field strength (V/m)	Incident power-density (W m^{-2})
Occupational	0.1 – 30 MHz	$660/f_M^{0.7}$	NA
	>30 – 400 MHz	61	10
	>400 – 2000 MHz	$3f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	50
General Public	0.1 – 30 MHz	$300/f_M^{0.7}$	NA
	>30 – 400 MHz	27.7	2
	>400 – 2000 MHz	$1.375f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	10

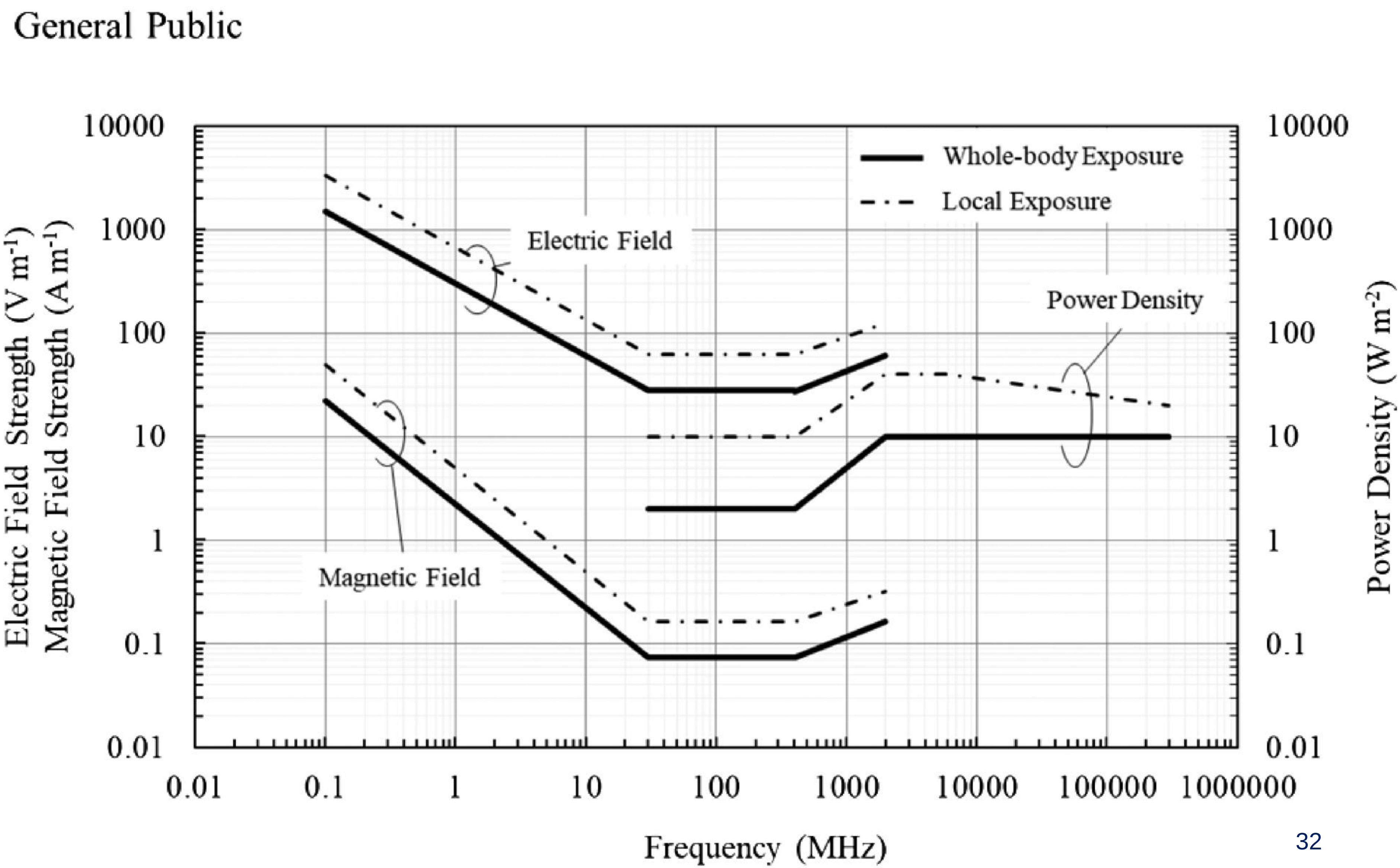
ICNIRP 2020 EMF for occupational & general public exposure, based on Table 6, p. 496:
local exposure, averaged over **6 minutes**

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$1504/f_M^{0.7}$	NA
	>30 – 400 MHz	139	50
	>400 – 2000 MHz	$10.58 f_M^{0.43}$	$0.29 f_M^{0.86}$
	>2 – 6 GHz	NA	200
	>6 – <300 GHz	NA	$275/f_G^{0.177}$
	300 GHz	NA	100
General Public	0.1 – 30 MHz	$671/f_M^{0.7}$	NA
	>30 – 400 MHz	62	10
	>400 – 2000 MHz	$4.72 f_M^{0.43}$	$0.058 f_M^{0.86}$
	>2 – 6 GHz	NA	40
	>6 – 300 GHz	NA	$55/f_G^{0.177}$
	300 GHz	NA	20

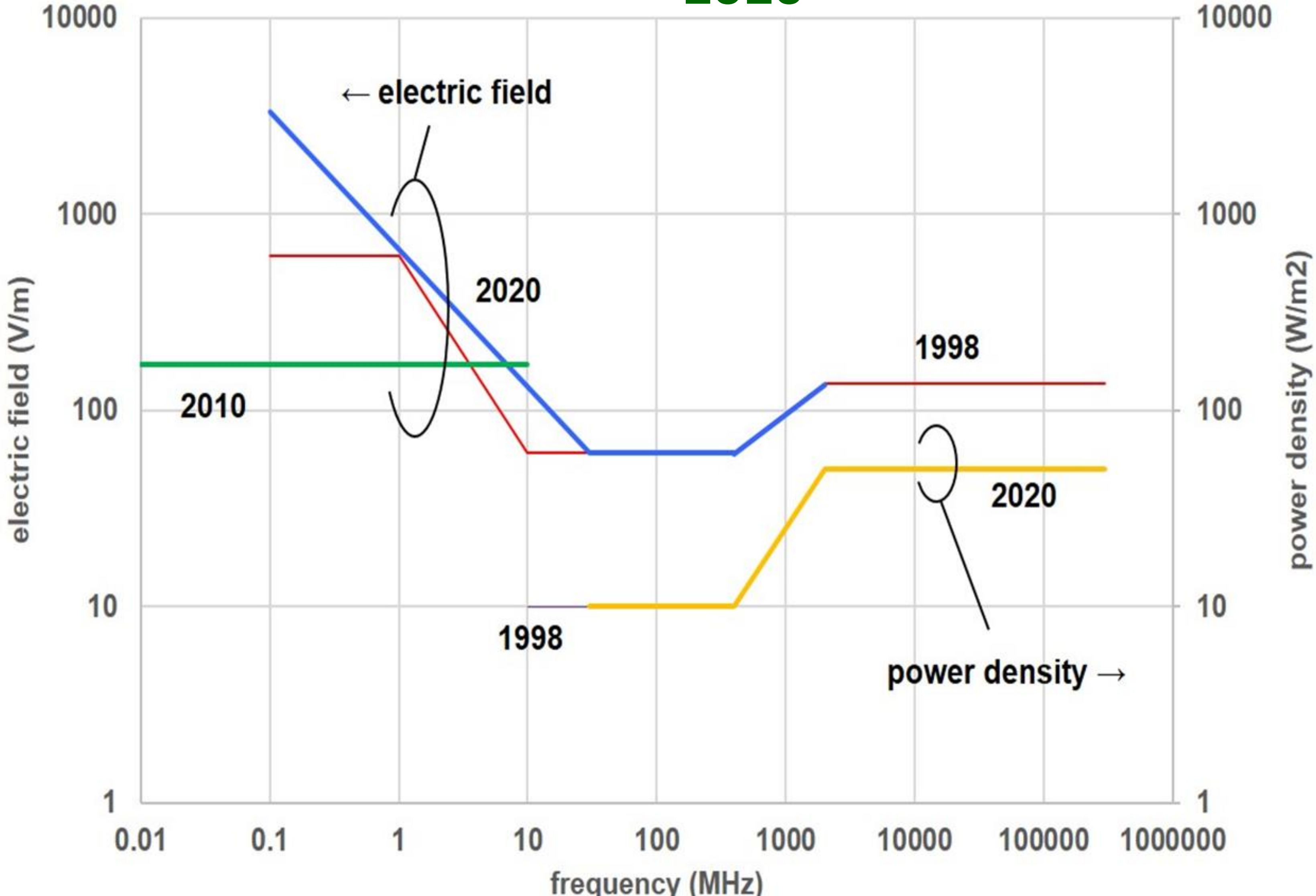
ICNIRP 2020 based on Tables 5 & 6, Figure 1 ***Occupational*** *exposures ≥ 6 min*



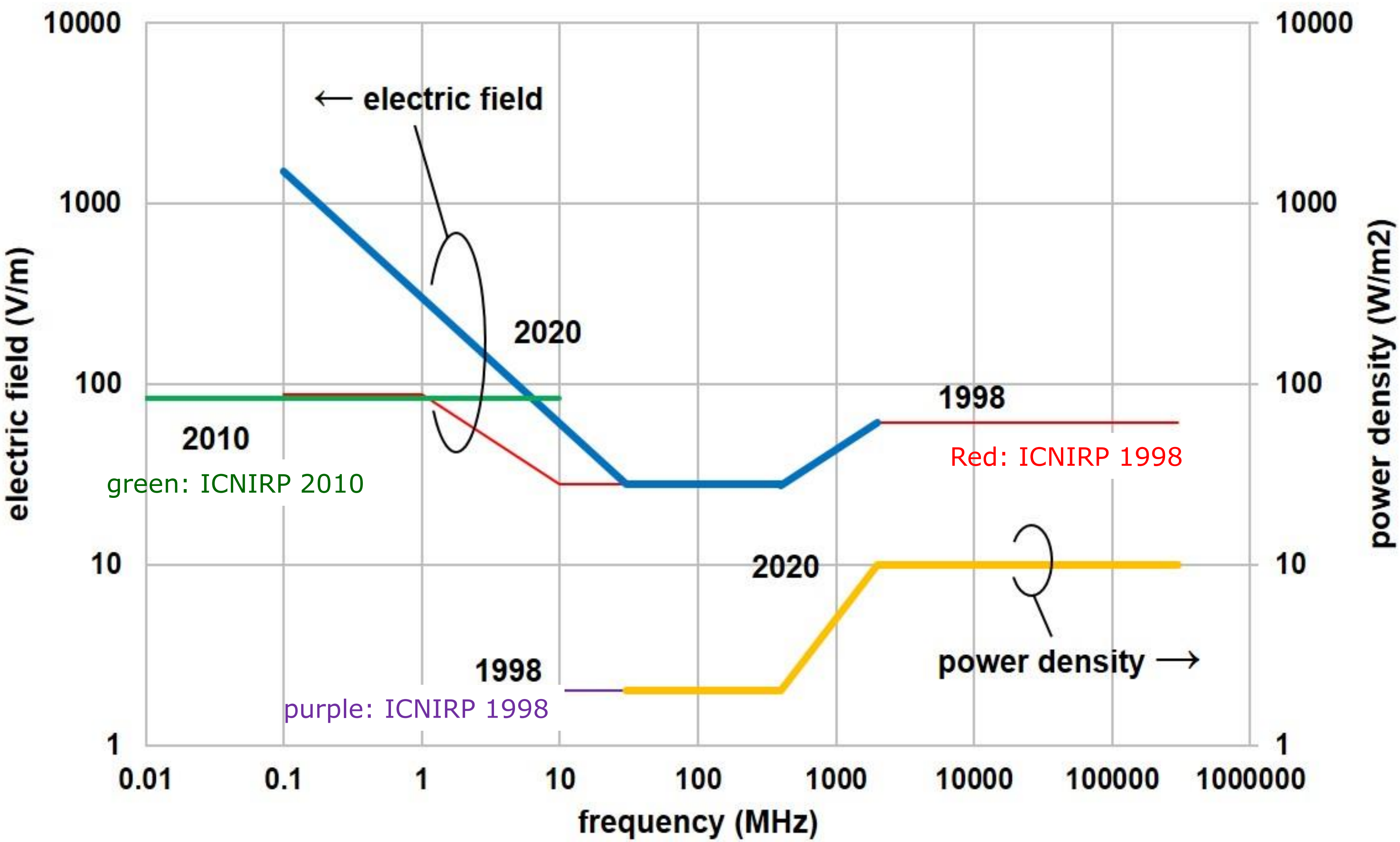
ICNIRP 2020 based on Tables 5 & 6, Figure 2, ***general public*** *exposures ≥6 min*



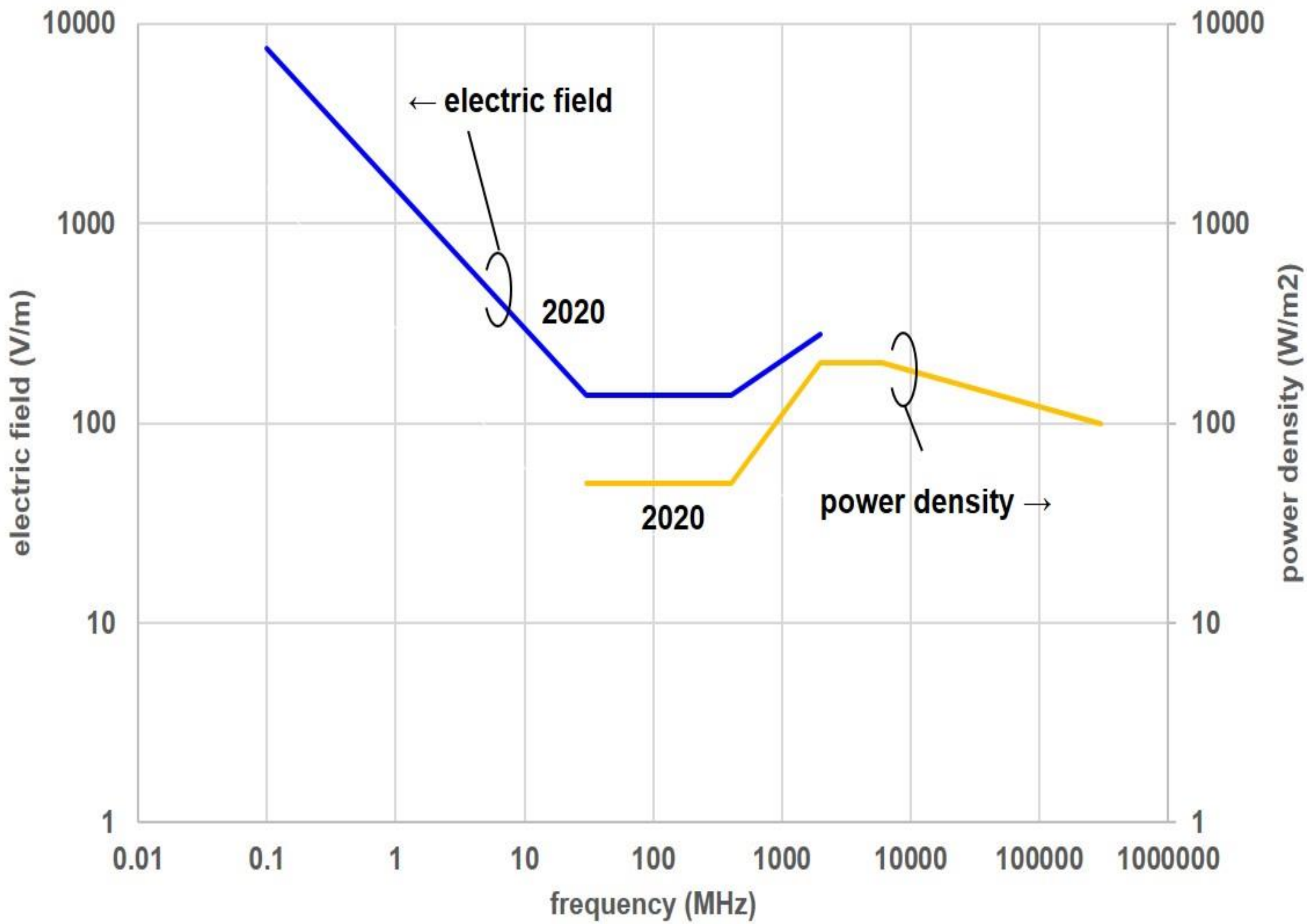
ICNIRP 2020 Web (not Guidelines) Figure 1, **Whole body** the **general public** for the **ICNIRP 1998**, **ICNIRP 2010** and **ICNIRP 2020**



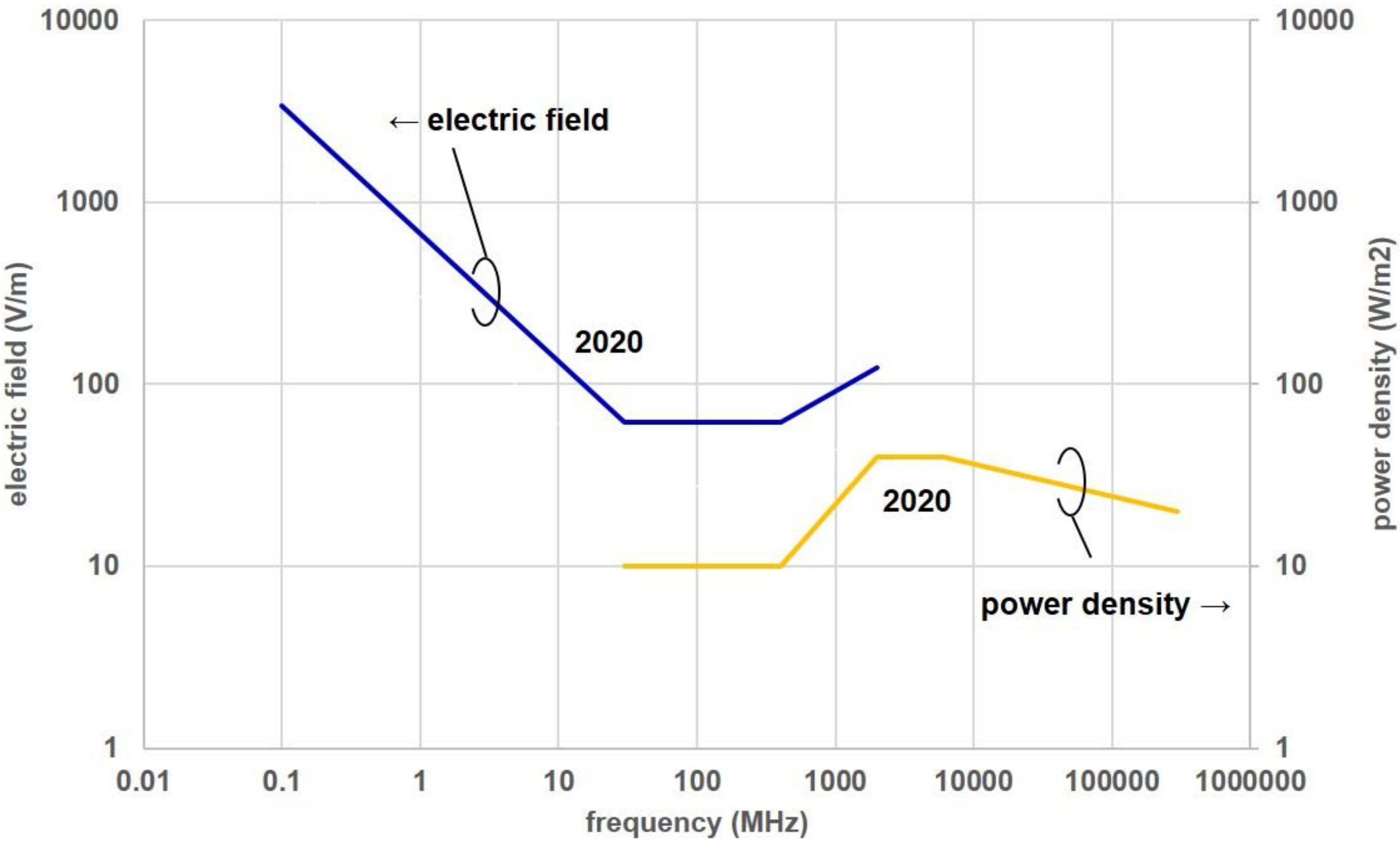
ICNIRP 2020 Web Figure 2, based on Table 6 the **general public** applying to l**ocal exposures ≥6 min** for the ICNIRP 2020 guidelines only

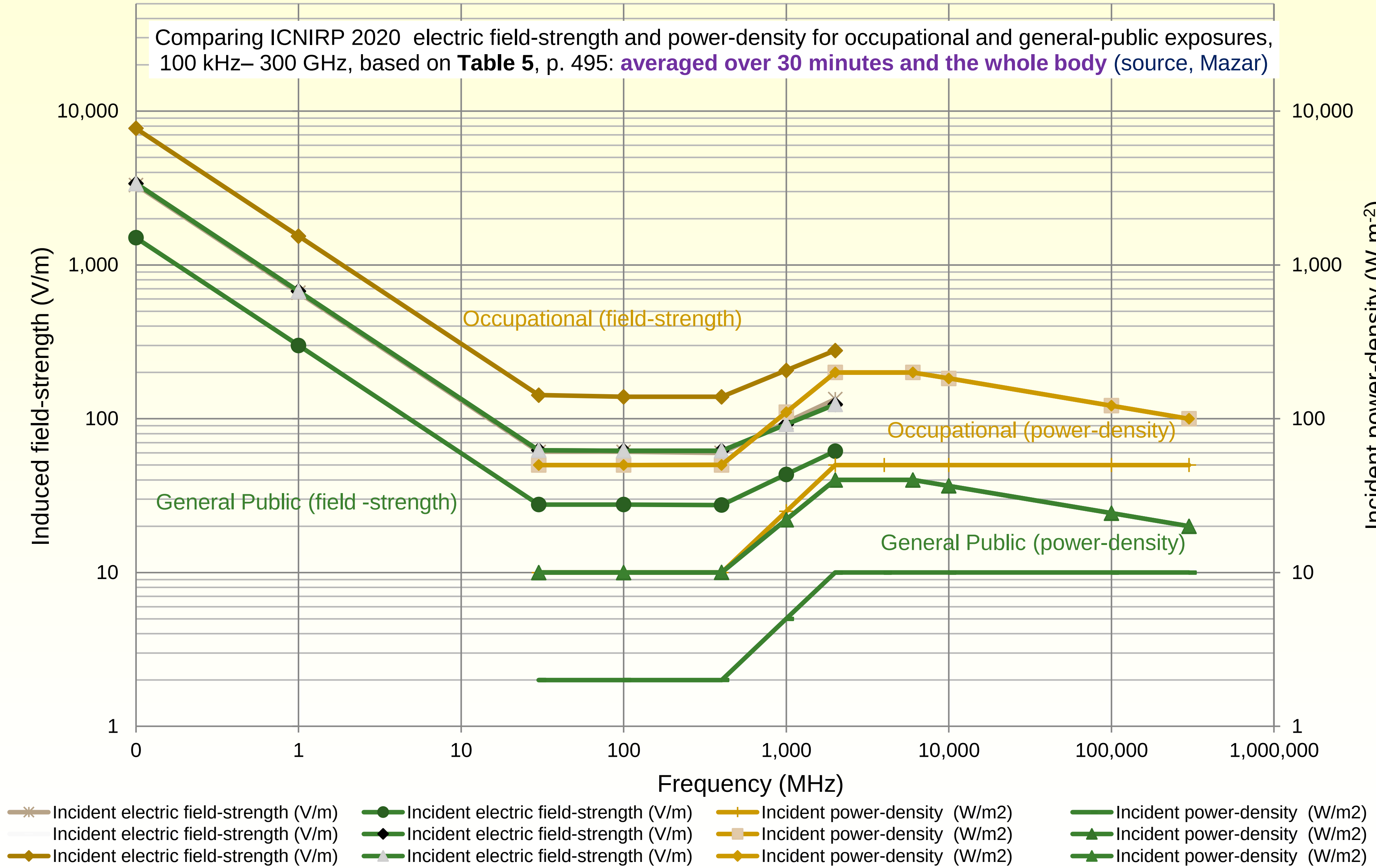


ICNIRP 2020 Web Figure 3 **occupational** (workers), **whole body** average for workers for the ICNIRP 1998, ICNIRP 2010 and ICNIRP 2020



ICNIRP 2020 Web Figure 4 workers (**occupational**)applying to **local exposures ≥6 min** for the ICNIRP (2020)




Comparing ICNIRP 2020 electric field-strength and power-density for occupational and general-public exposures,
100 kHz– 300 GHz, based on **Table 5**, p. 495: **averaged over 30 minutes and the whole body** (source, Mazar)
Induced field-strength (V/m)
Incident power-density (W m-2)
Frequency (MHz)
Occupational (field-strength)
Occupational (power-density)
General Public (field -strength)
General Public (power-density)
10,000
1,000
100
10
1
0
1
10
100
1,000
10,000
100,000
1,000,000
Incident electric field-strength (V/m)
Incident electric field-strength (V/m)
Incident electric field-strength (V/m)
Incident electric field-strength (V/m)
Incident electric field-strength (V/m)
Incident electric field-strength (V/m)
Incident power-density (W/m2)
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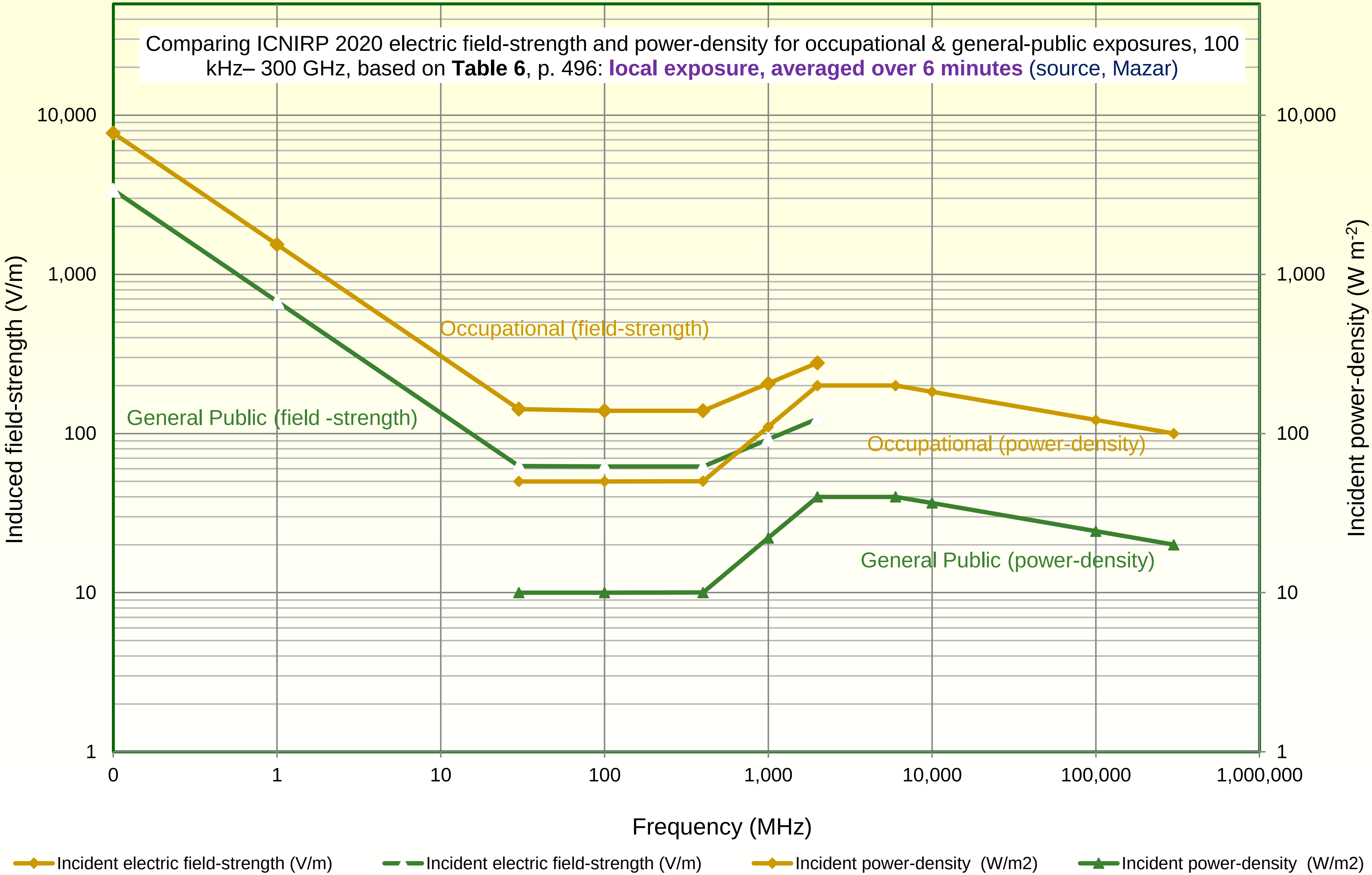
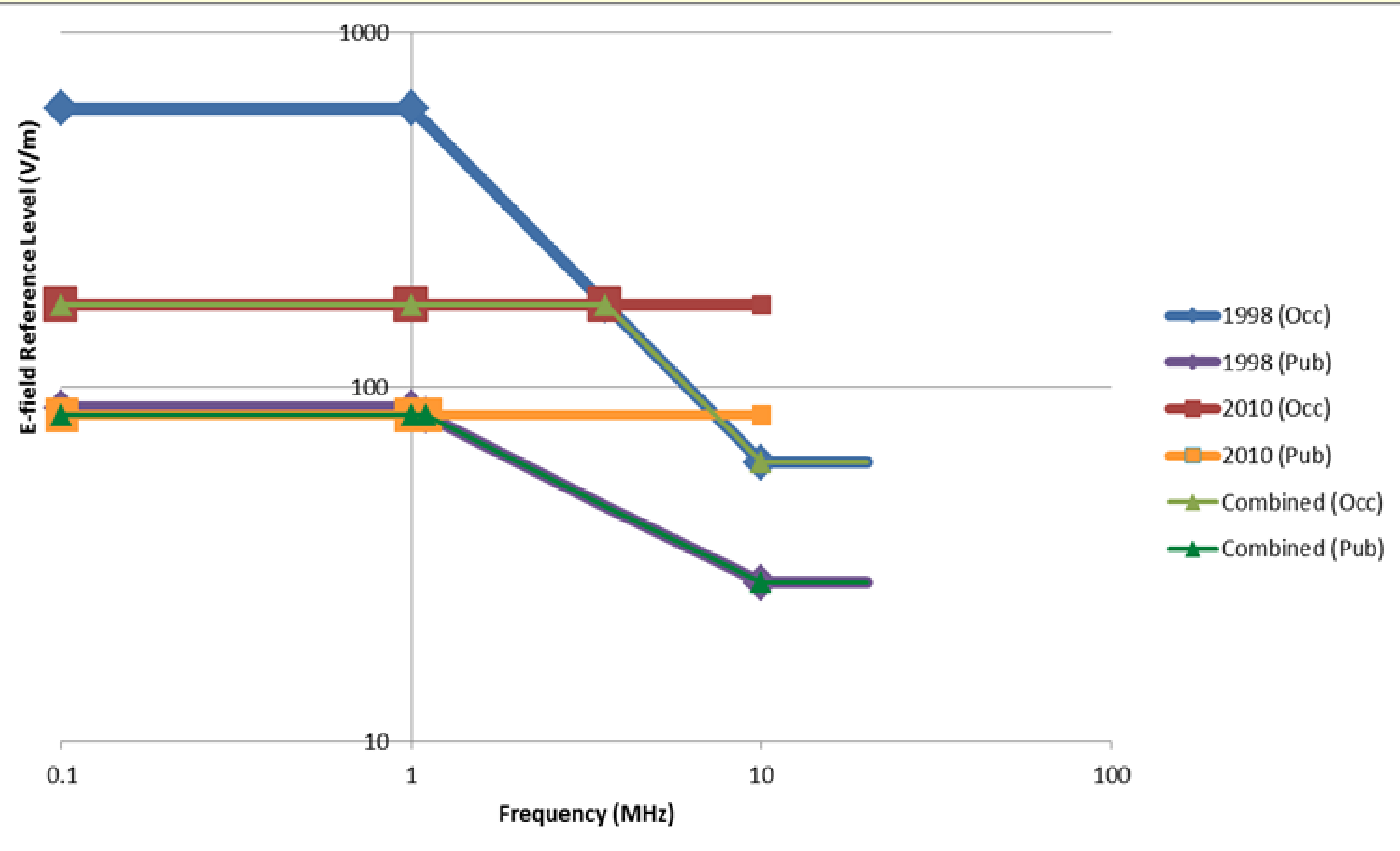
Incident power-density (W/m2)


Comparing ICNIRP 2020 electric field-strength and power-density for occupational & general-public exposures, 100 kHz– 300 GHz, based on **Table 6**, p. 496: **local exposure, averaged over 6 minutes** (source, Mazar)
Occupational (field-strength)
General Public (field -strength)
Occupational (power-density)
General Public (power-density)
Induced field-strength (V/m)
Incident power-density (W m-2)
Frequency (MHz)
10,000
1,000
100
10
1
0
1
10
100
1,000
10,000
100,000
1,000,000
Incident electric field-strength (V/m)
Incident electric field-strength (V/m)
Incident power-density (W/m2)
Incident power-density (W/m2)



April 2016 T13-SG05-C-0762R1 EBU/ Karina Beeke (Arqiva)

Updated IEEE C95.1-2019 reference levels: Safety factors applying 100 kHz- 6 GHz Thermal Effects

- Whole body averaged (WBA)
  Behavioral effects in animals over many frequencies, threshold at 4 W/kg
  10x - 0.4 W/kg for upper tier (controlled environment)
  50x - 0.08 W/kg for lower tier (general public)

- Localized exposure (averaged in 10 g)
  Cataract observed in rabbits, threshold at 100 W/kg
  10x - 10 W/kg for upper tier
  50x - 2 W/kg for lower tier

- SAR is averaged over 30 min for WBA exposure and 6 min for local exposure

- Epithelial power density through body surface is averaged over 6 min

IEEE C95.1-2019 Table 5—DRLs (100 kHz to 6 GHz)

Conditions	Persons in unrestricted environments SAR (W/kg)[a]	Persons permitted in restricted environments SAR (W/kg)[a]
Whole-body exposure	0.08	0.4
Local exposure[b] (head and torso)	2	10
Local exposure[b] (limbs and pinnae)	4	20

DRL: Dosimetric Reference Limits

[a] SAR is averaged over 30 min for whole-body exposure and 6 min for local exposure (see B.6 for averaging time).

[b] Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube). The averaging volume of 10 g of tissue would be represented as a 10 cm^3 cube (approximately 2.15 cm per side)

IEEE C95.1-2019 Table 6—DRLs (6 GHz to 300 GHz)

Conditions	Epithelial power density (W/m2)[a,b,c]	
	Persons in unrestricted Environments	Persons permitted in restricted environments
Body surface	20	100

[a] Epithelial power density through body surface is averaged over 6 min.
[b] Averaged over any 4 cm^2 of body surface at frequencies between 6 GHz and 300 GHz (defined as area in the shape of a square at surface of the body).
[c] Small exposed areas above 30 GHz: If the exposed area on the body surface is small (< 1 cm^2 as defined by −3 dB contours relative to the peak exposure), the epithelial power density is allowed to exceed the DRL values of Table 6 by a factor of 2, with an averaging area of 1 $cm2^2$ (defined as area in the shape of a square at the body surface).

IEEE C95.1-2019 Table 7—ERLs for whole-body exposure of persons in unrestricted environments (100 kHz to 300 GHz)

Frequency range (MHz)	Electric field Strength (E)[a,b,c] (V/m)	Magnetic field strength (H)[a,b,c] (A/m)	Power density (S)[a,b,c] (W/m²)		Averaging time (min)
			S_E	S_H	
0.1 to 1.34	614	$16.3/f_M$	1000	$100\,000/f_M^2$	30
1.34 to 30	$823.8/f_M$	$16.3/f_M$	$1800/f_M^2$	$100\,000/f_M^2$	
30 to 100	27.5	$158.3/f_M^{1.668}$	2	$9\,400\,000/f_M^{3.336}$	
100 to 400	27.5	0.0729	2		
400 to 2000			$f_M/200$		
2000 to 300 000			10		

Note—S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.

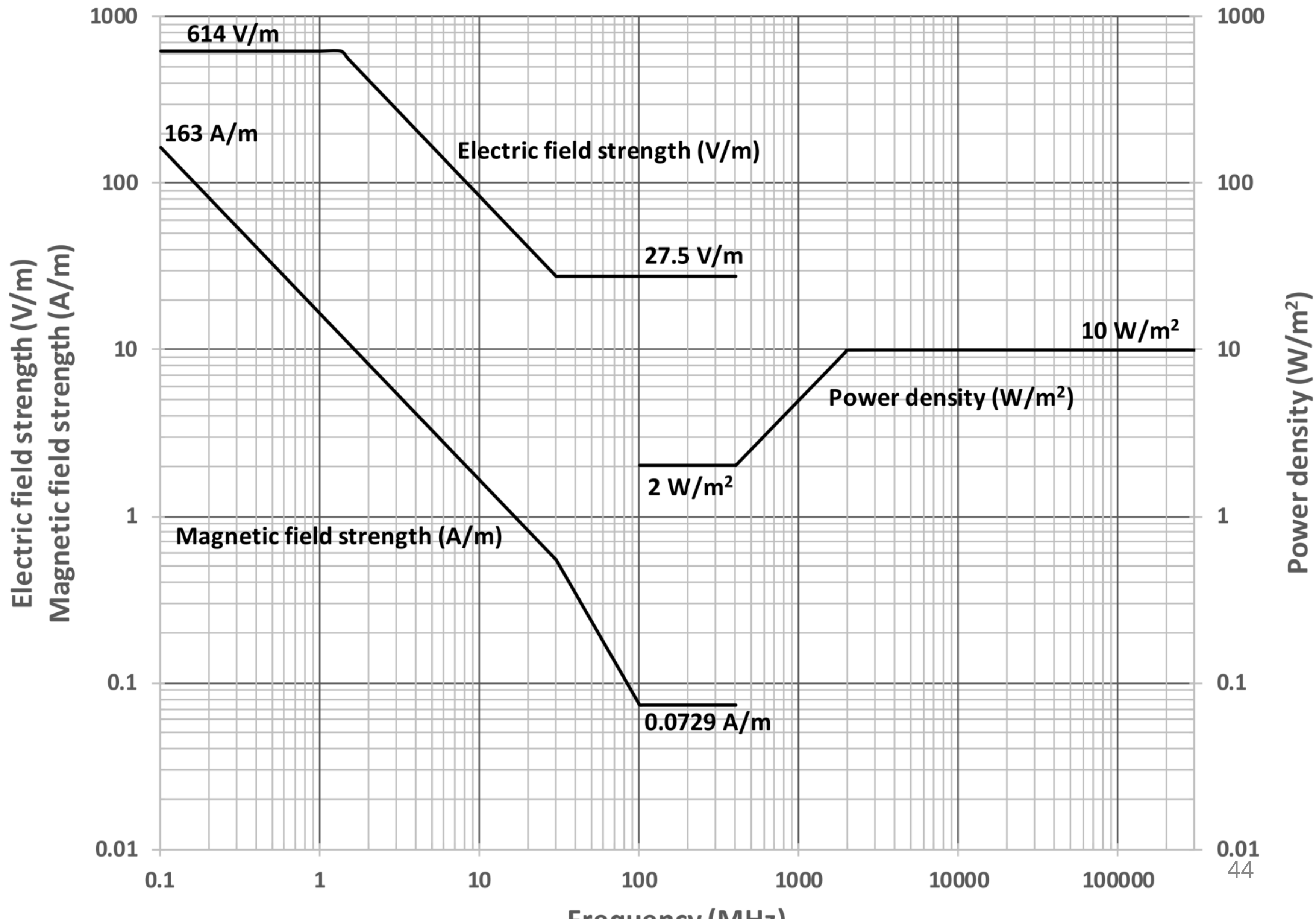
[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the ERLs in Table 7. For more typical nonuniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the plane-wave-equivalent power densities or the squares of the field strengths, are compared with the ERLs in Table 7.

[b] f_M is the frequency in MHz.

[c] The E, H, and S values are those rms values unperturbed by the presence of the body.

At frequencies below 30 MHz, the wave-length is longer than 10 m. There is no resonance with our body (shorter than 2 m.). We are not an obstacle to the signal, and low part of the RF energy enters to our body.

IEEE C95.1-2019 Fig. 3: Graphical representations of the ERLs in Table 7 for electric and magnetic fields and plane-wave-equivalent power density—Persons in unrestricted environments



IEEE C95.1-2019 Table 8—ERLs for whole-body exposure of persons permitted in restricted environments (100 kHz to 300 GHz)

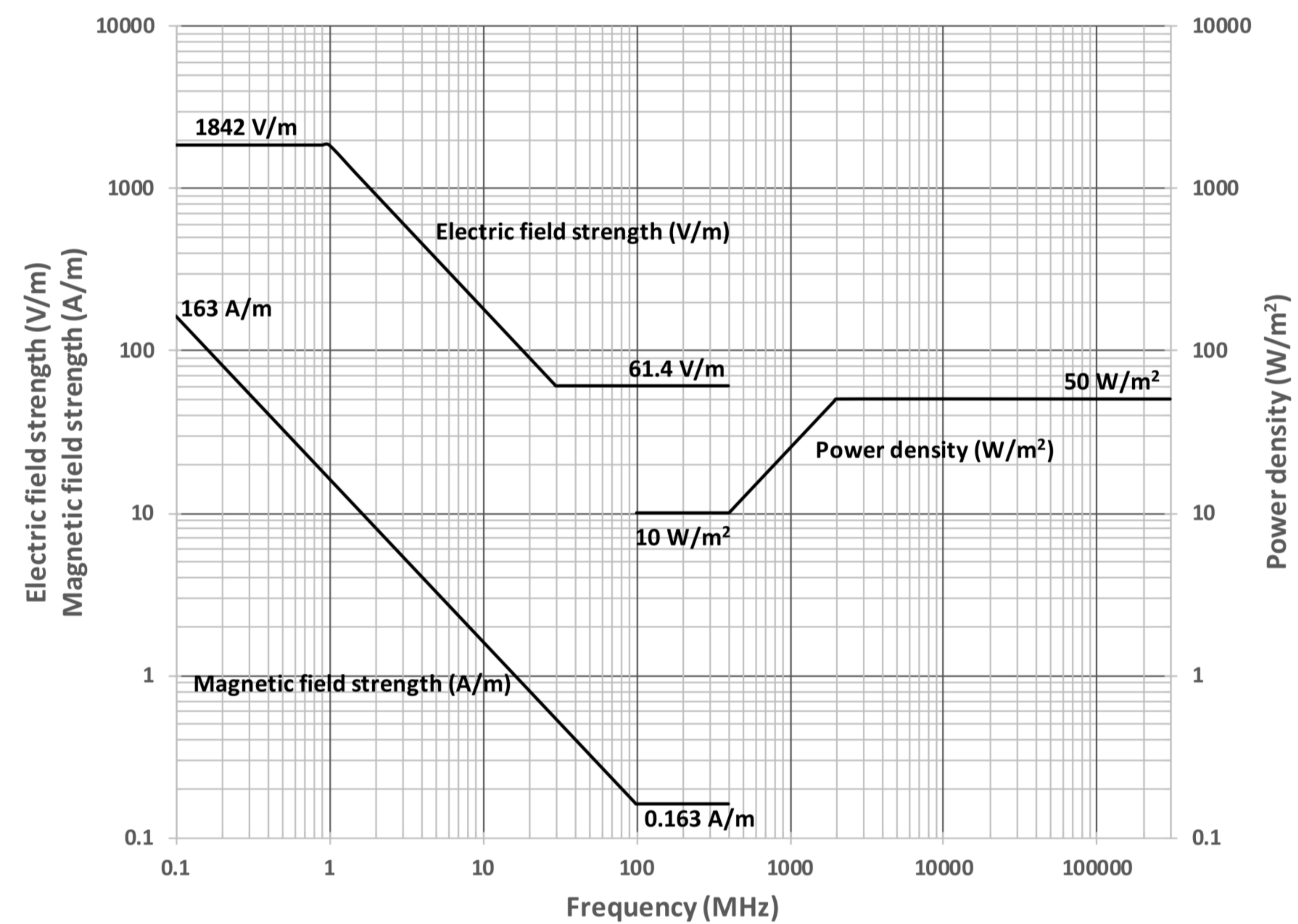
Frequency range (MHz)	Electric field Strength (E)[a,b,c] (V/m)	Magnetic field strength (H)[a,b,c] (A/m)	Power density (S)[a,b,c] (W/m²)		Averaging time (min)
			S_E	S_H	
0.1 to 1.0	1842	$16.3/f_M$	9 000	$100\,000\, f_M^2$	30
1.0 to 30	$1842/f_M$		$9000 / f_M^2$		
30 to 100	61.4		10		
100 to 400		0.163	10		
400 to 2000			$f_M/40$		
2000 to 300 000			50		

NOTE—S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.

[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the ERLs in Table 7. For more typical nonuniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the plane-wave-equivalent power densities or the squares of the field strengths, are compared with the ERLs in Table 7.
[b] f_M is the frequency in MHz.
[c] The E, H, and S values are those rms values unperturbed by the presence of the body.

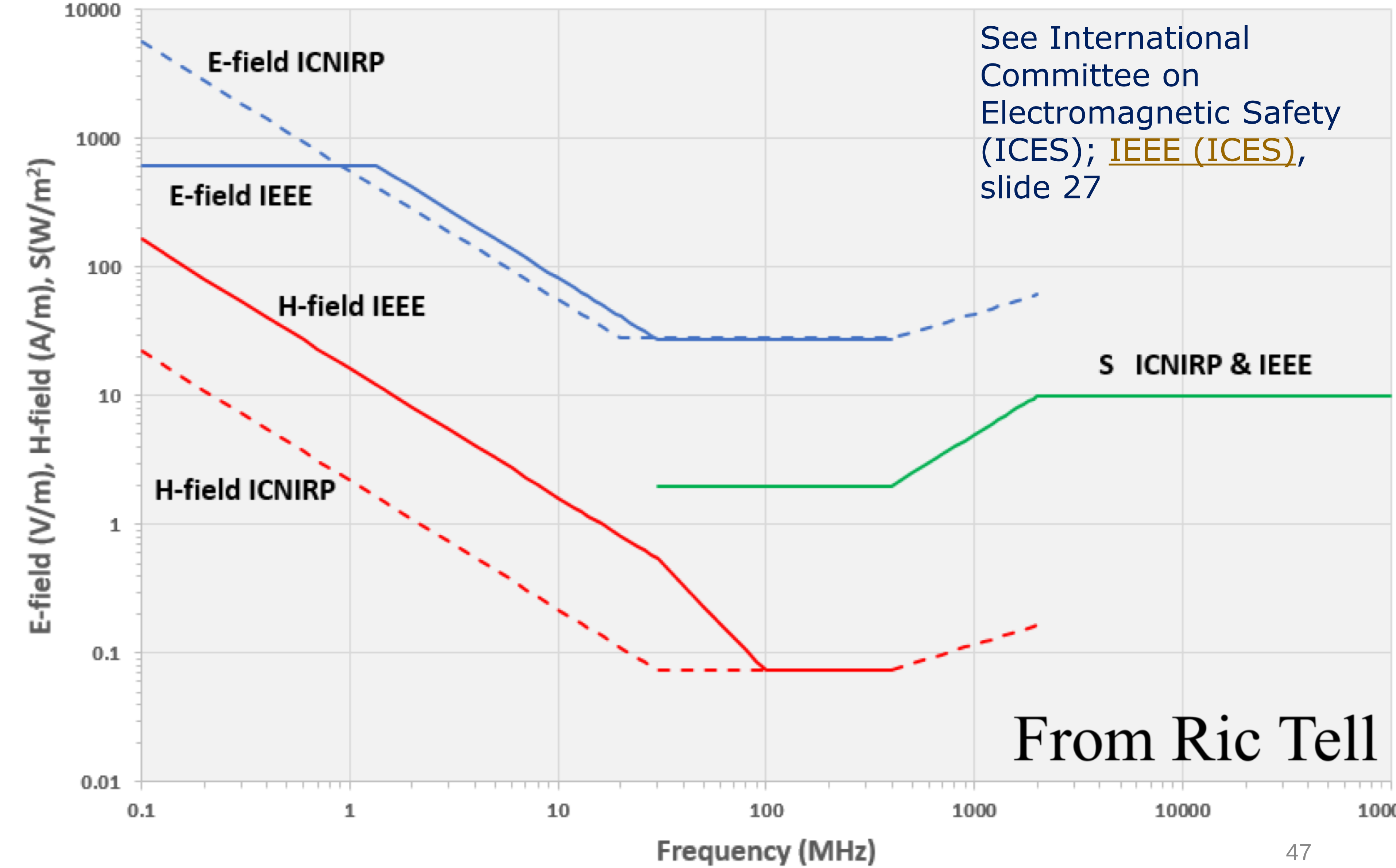
Pay attention that at 100 kHz, E=1842(V/m) here is different than in Table 7 E=614 (V/m). But H are 163 (A/m) in both Tables. Maybe mistake or levels are vey high, so no distinction .

IEEE C95.1-2019 Fig. 4: Graphical representations of ERLs in Table 8 for electric & magnetic fields and plane-wave-equivalent power density—persons permitted in restricted environments



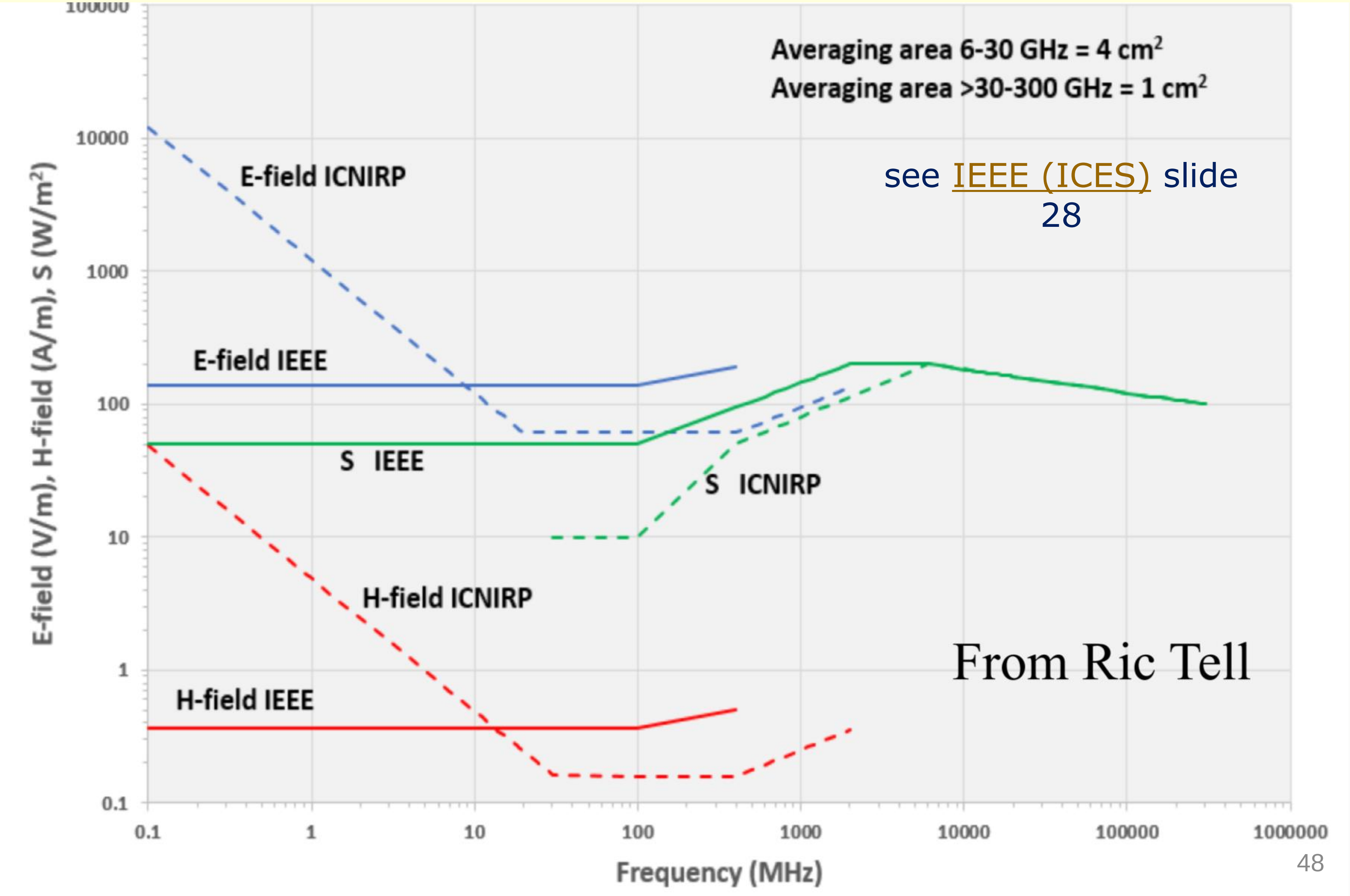
Dr.

IEEE/ICNIRP differences in limits general public/unrestricted environment; power-densities above 30 MHz are **identical**



See International Committee on Electromagnetic Safety (ICES); IEEE (ICES), slide 27

IEEE/ICNIRP differences in limits Local exposure Limits (assuming 6-minute exposure); power-densities below 6 GHz are different



see IEEE (ICES) slide 28

Similarities between IEEE Std C95.1-2005 and the revised IEEE C95.1-2019 Standard; see IEEE (ICES)

- Scientific basis of the adverse effect levels, i.e., electrostimulation for low frequencies and heating for high frequencies.
- Exposure limits for electrostimulation effects are kept the same as in IEEE Stds C95.6- 2002 and C95.1-2005.
- Exposure limits, termed dosimetric reference limits (DRLs), previously called basic restrictions, on whole body average and peak spatial average SARs **remain the same** to prevent **heating effects** from exposure over much of the RF spectrum.
- The exposure reference levels (ERLs), previously called maximum permissible exposure (MPE) levels, for the lower tier (general public) **remain the same as in IEEE C95.1-2005**.
- Continues to support the position of the earlier editions, i.e., upper tier ERLs are protective of public health and safety and that the risk of harm from exposure to fields below the lower tier ERLs has not been confirmed by scientific evidence.

Main changes in the revised IEEE C95.1-2019 Standard: Background; see IEEE (ICES)

- The evaluation of an IEEE standard is a process that is continually ongoing; that is, IEEE standards are "living" documents. The rules and procedures for comments and requests are included in the ICES Policies and Procedures and are approved by the IEEE-SASB.
- The revision process established by the IEEE/ICES is a continuing rigorous and open scientific process that is **transparent** at all levels and includes the opportunity for **scientific input** from all stakeholders.
- IEEE/ICES members are affiliated with government, industry, and academia, as well as of independent professionals and the general public. The background of the membership varies from scientific disciplines such as engineering, physics, statistics, epidemiology, life sciences, medicine, risk assessment, and risk management.
- The IEEE C95.1 standard revises and combines IEEE Std C95.1-2005 [B668] and IEEE Std C95.6-2002 [B671] into a single standard; ; changes on exposure **above 6 GHz/10 GHz**.
- IEEE Std C95.1-2005 was based primarily on research published before 2003; IEEE Std C95.6-2002 was based primarily on research published before 2001. Research has continued since these times, and a reevaluation of the extremely low-frequency (ELF) and radio-frequency (RF) biological effects databases was necessary for this revision.
- IEEE/ICES and ICNIRP organized two major workshops between 2010 and 2015. Conclusions of these workshops indicate that the two major organizations that develop RF safety standards and guidelines
agree **that thermal effects are the basis to protect against RF exposure above 100 kHz**.

Main changes in the revised IEEE C95.1-2019 Standard: upper tier / lower tier definitions

- Old: in C95.1-2005 two tiers approach was used; an upper tier for “people in controlled environments” and a lower tier “action level” for implementing an RF safety program or MPE for the general public.
- New: in C95.1-2019 standard, maximum exposure limits are established for “**persons in unrestricted environments**” and for “**persons permitted in restricted environments**”.

Main changes in IEEE C95.1-2019 Standard: SAR frequency ranges, DRL & ERL

- The upper frequency boundary for whole body average (WBA) SAR has been changed from **3 GHz to 6 GHz** because of improved measurement capabilities and to harmonize with the proposed new ICNIRP guidelines.
- **DRL** replaces basic restriction (BR), and **ERL** replaces MPE.
- The **safety program initiation level** (previously “action level”) is clarified as the ERL, marking the transition point between the lower (unrestricted) tier and the upper (restricted) tier.

Main changes in IEEE C95.1-2019 Standard: Changing Extremities to Limbs

- The term “extremities” as used in C95.1-2005 is changed to “limbs” involving the whole arms and legs, instead of portions distal to the elbows and knees. This change is to harmonize with C95.6-2002 and the ICNIRP guidelines.
- Frequency dependence instead of fixed factor: local exposure ERL is now frequency dependent, instead of being a fixed factor of 20 times the whole-body ERL regardless of frequency.
- The averaging time is 30 minutes for whole body RF exposure and 6 minutes for local exposure.

Changes in IEEE C95.1-2019 Standard: newly introduced Local Exposure DRL and ERL

- The local exposure DRL and ERL for frequencies between 6 GHz and 300 GHz have developed: the DRL is the epithelial power density inside the body surface, and ERL is the incident power density outside the body.
- Averaging power density area is defined as a 4 cm^2 square.
- Small exposed areas above 30 GHz: the epithelial power density is allowed to exceed the DRL or ERL by a factor of 2, with an averaging area of 1 cm^2.
- Peak DRL and ERL limits for local exposures to pulsed RF fields are defined, and new fluence limits for single RF-modulated pulses above 30 GHz are introduced. The averaging area for single pulse fluence is 1 cm^2 square.

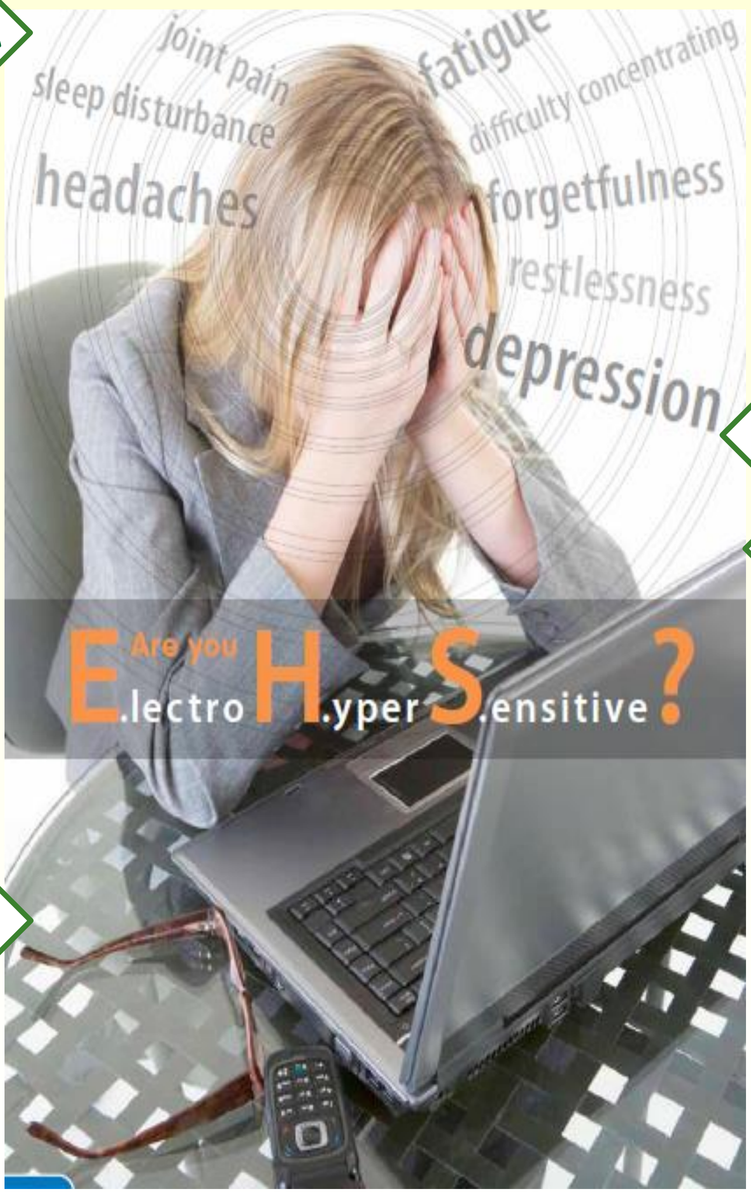
Main changes in IEEE C95.1-2019 Standard: General

- The upper tier whole-body exposure ERLs above 300 MHz are different from those in C95.1-2005 to maintain a consistent 5x factor between tiers and to harmonize with ICNIRP guidelines.
- The former induced current limit for both feet is considered an unrealistic condition and is removed. The induced current limits for a single foot are retained.
- rms induced and contact current limits for continuous sinusoidal waveforms (100 kHz to 110 MHz) are changed from those in Table 7 of C95.1-2005 to frequency dependent values

Societal Concerns

Subjective phobia, phantom risk (?!)

Precautionary Principle: billions of cellular users phones and millions of base-stations worldwide



Type I error imposes regulatory restrictions on factors that turn out to be harmless.

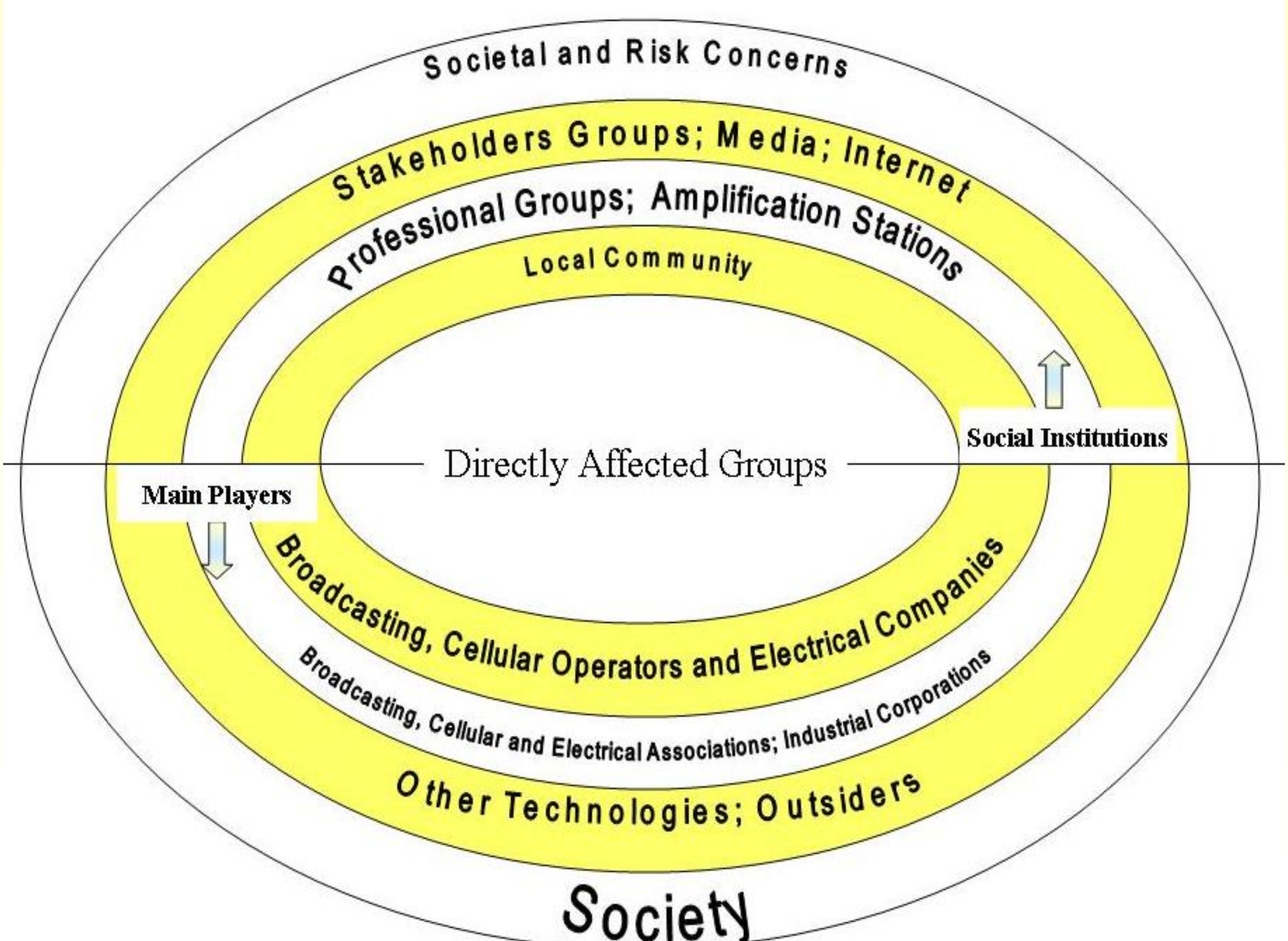
Type II error : acceptance of a null hypothesis that turns out to be false

Photo's Source:???

There is no evidence of causality between pains and RF exposure

Electromagnetic Hyper-Sensitivity; electro-phobia

World Health Organization (1948) definition of “health”: a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

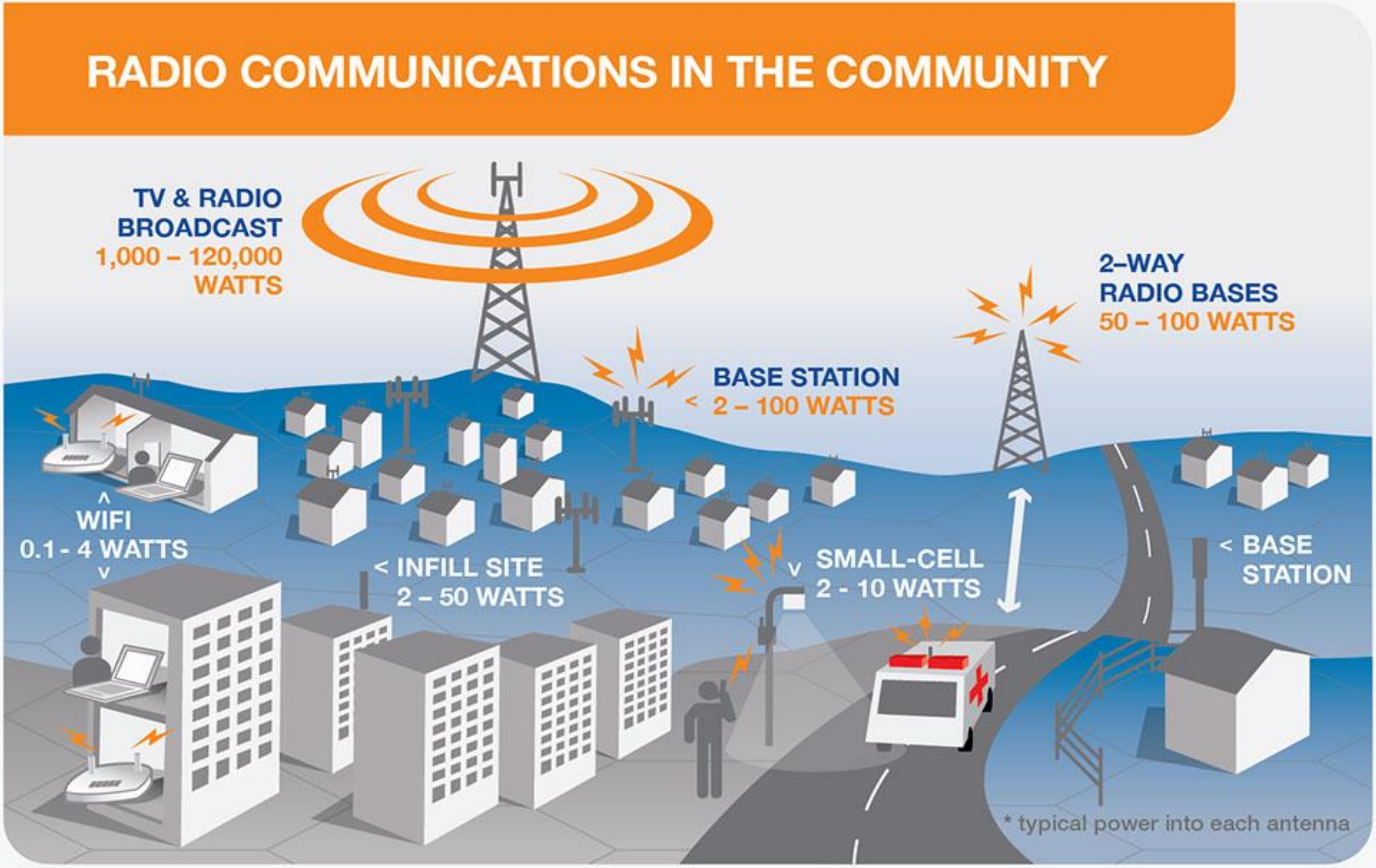


Ripple effects amplifying the Risk, Mazar 2009 http://www.moc.gov.il/new/documents/frequences/MazarThesisOct08.pdf

Hillel (ex) Radio Antenna; annulled due to fears

Yehuda Halevi TelAviv (8.95m)

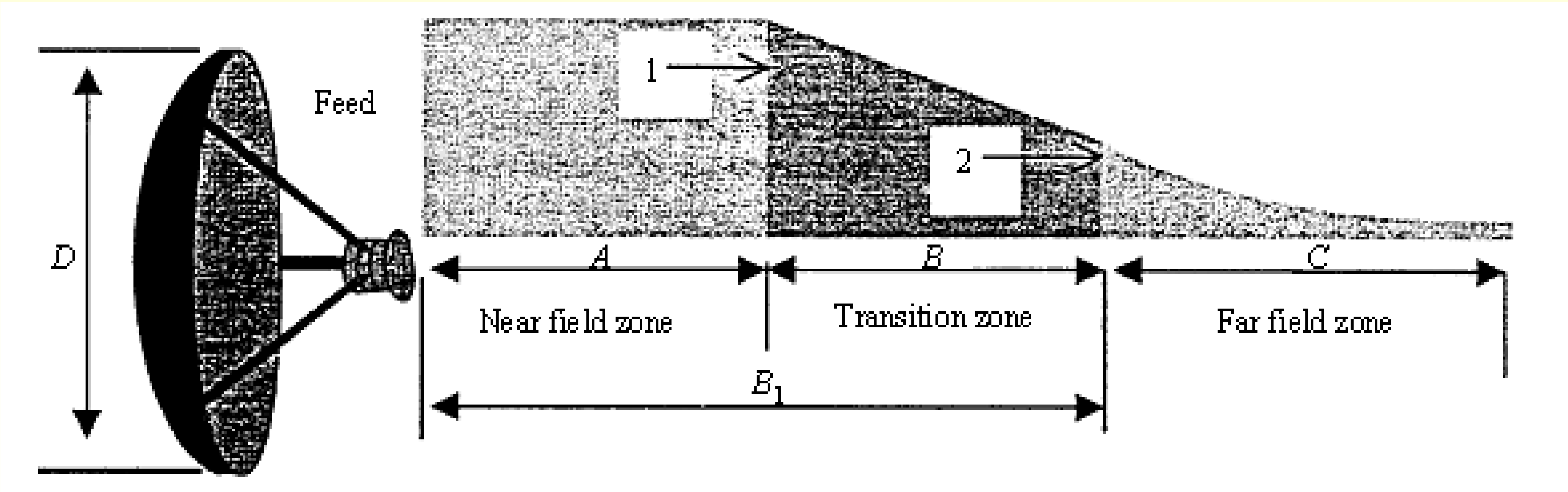
Base Station Antenna Pattern: Azimuth and Elevation (Dr. Zamir Shalita)



Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*

Various radiation zones of a parabolic antenna BS1698

a cylinder with a diameter D, along the ant main beam



$A = 0.25\ D^2/\lambda$ $B_1 = 0.6\ D^2/\lambda$ $B = B_1 - A$ $C > B_1$ 1698-01

$$s\ (\mathrm{W/m^2}) = \frac{16\eta\ p}{\pi\ r^2}$$

$$s\ (\mathrm{W/m^2}) = \frac{pg}{4\pi\ r^2}$$

η: efficiency of parabolic antenna (0.55 is used)
p: power of transmitter (W)
D: diameter of parabolic antenna (m).

g: gain of parabolic antenna with respect to an isotropic source
r: distance from the parabolic antenna (m).

If X >= 2**D**²/λ, **far-field** region

If 2**D**²/λ >X> λ/2∏ **radiating** near-field region

If λ/2∏ >X **reactive** near-field region

Specific Absorption Rate (SAR) limits for portable wireless devices.

- The SAR is determined from measurements of the E-field (e) in an anatomically-correct phantom model (liquid-filled dielectric shell) of the human head using a robotically-scanned miniature E-field probe
- The SAR (W/kg) is determined from the relationship between E and the tissue properties, i.e.,

$$SAR = \sigma|e^2|/\rho$$

where σ is the liquid conductivity and ρ is the density

ICNIRP- Established Effects of EMF (Paolo_Vecchia)

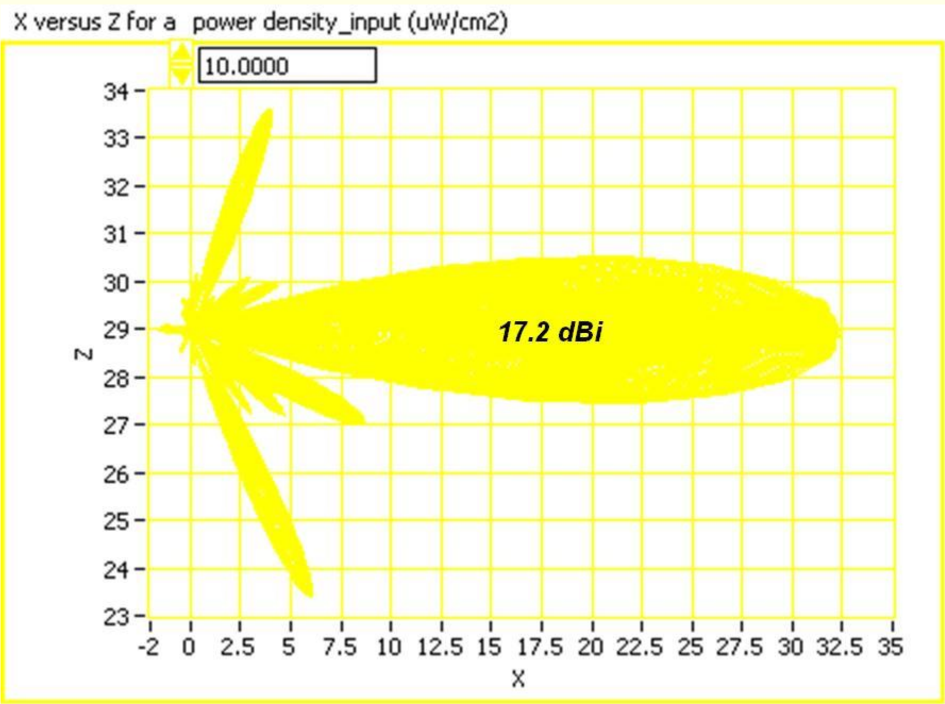
- All effects of EMF that have been established so far are acute in nature

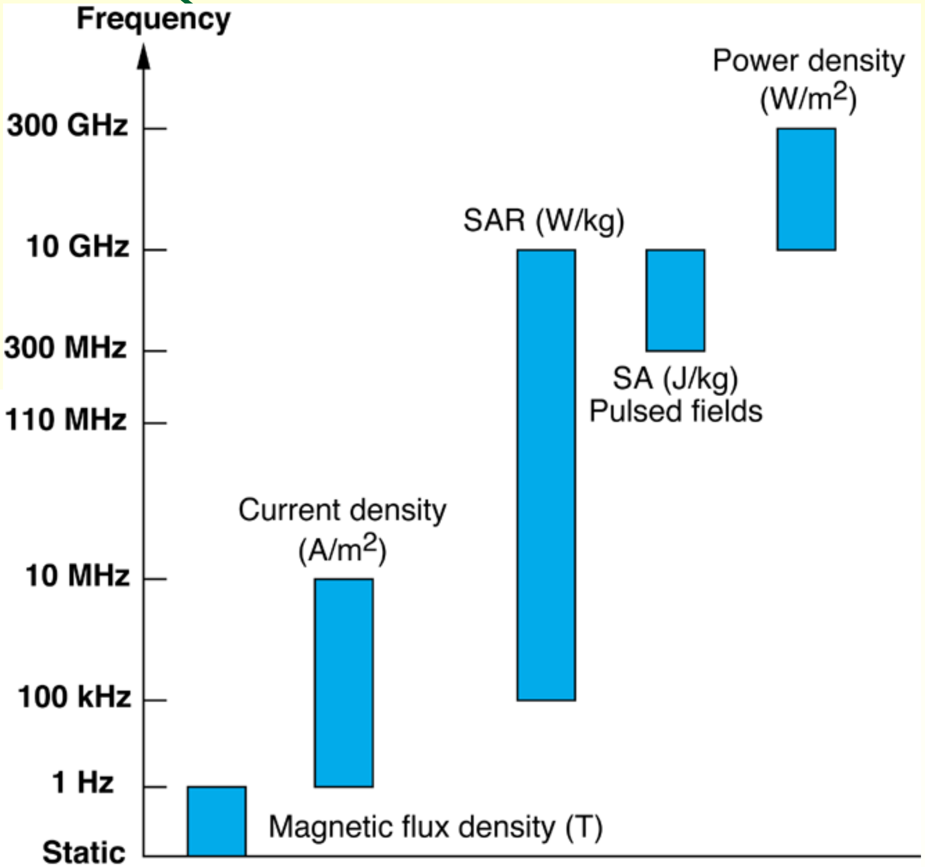
- ELF
- Stimulation of electrically excitable tissues

- RF
- Increase of body temperature (general or local)

Such acute effects occur above given exposure thresholds

Biologically Effective Quantities





SA: Specific Absorption

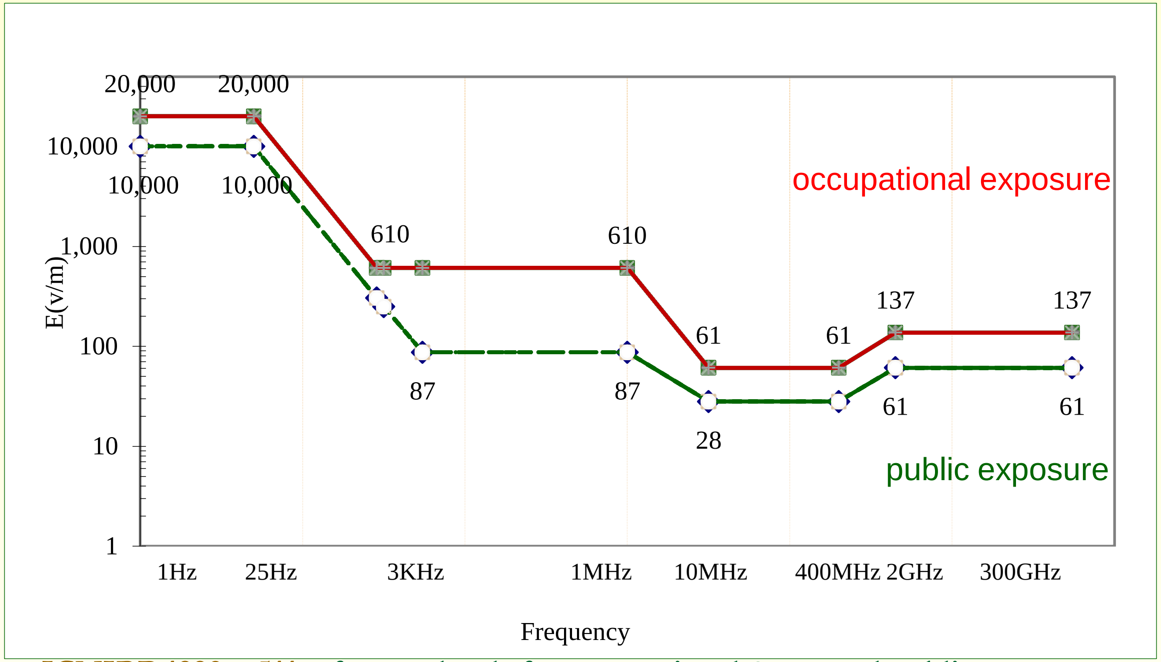
אנטנה מסוג 739686, עבור תדר 850 מגא-הרץ, בשימוש במתקנים רגילים

Physical Quantities and Units

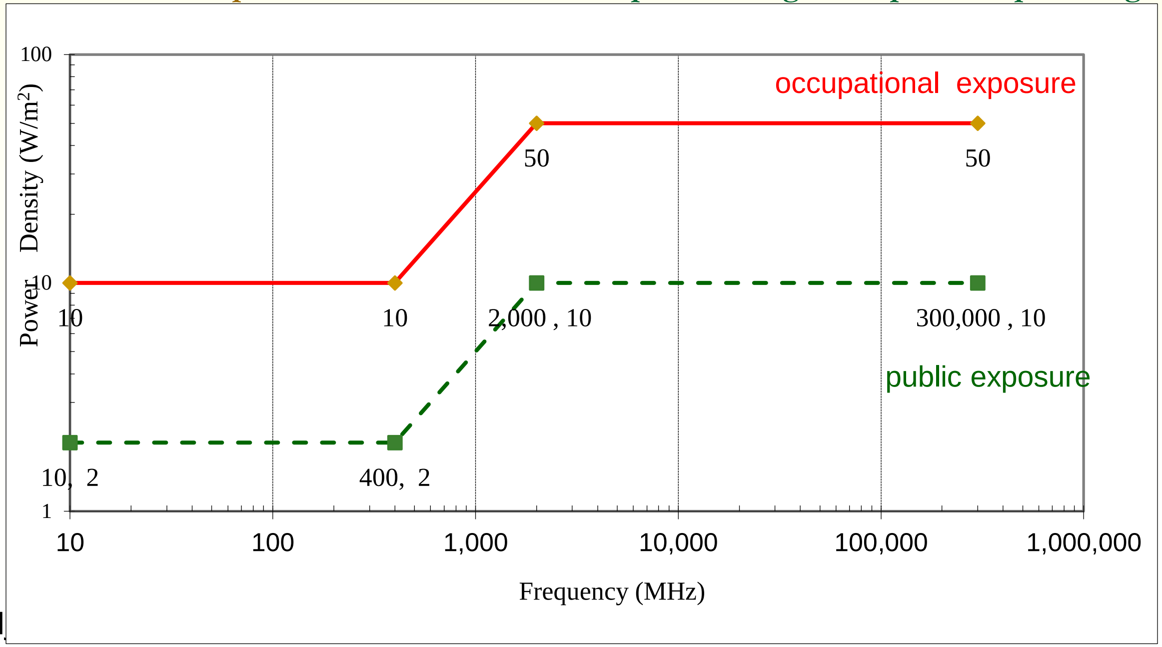
Quantity	Symbol	Unit	Symbol
Frequency	*f*	Hertz	Hz
Electric field strength	*e*	Volt per metre	V/m
Power	*p*	Watts	W
Power density or power flux density	*s*	Watt per square metre	W/m²
		mWatt per square cm	mW/cm²
Specific Absorption Rate	*SAR*	Watt per kilogram	W/kg
		mWatt per gram	mW/g

ICNIRP 1998 p.511 reference levels for occupational & general public exposure- table7

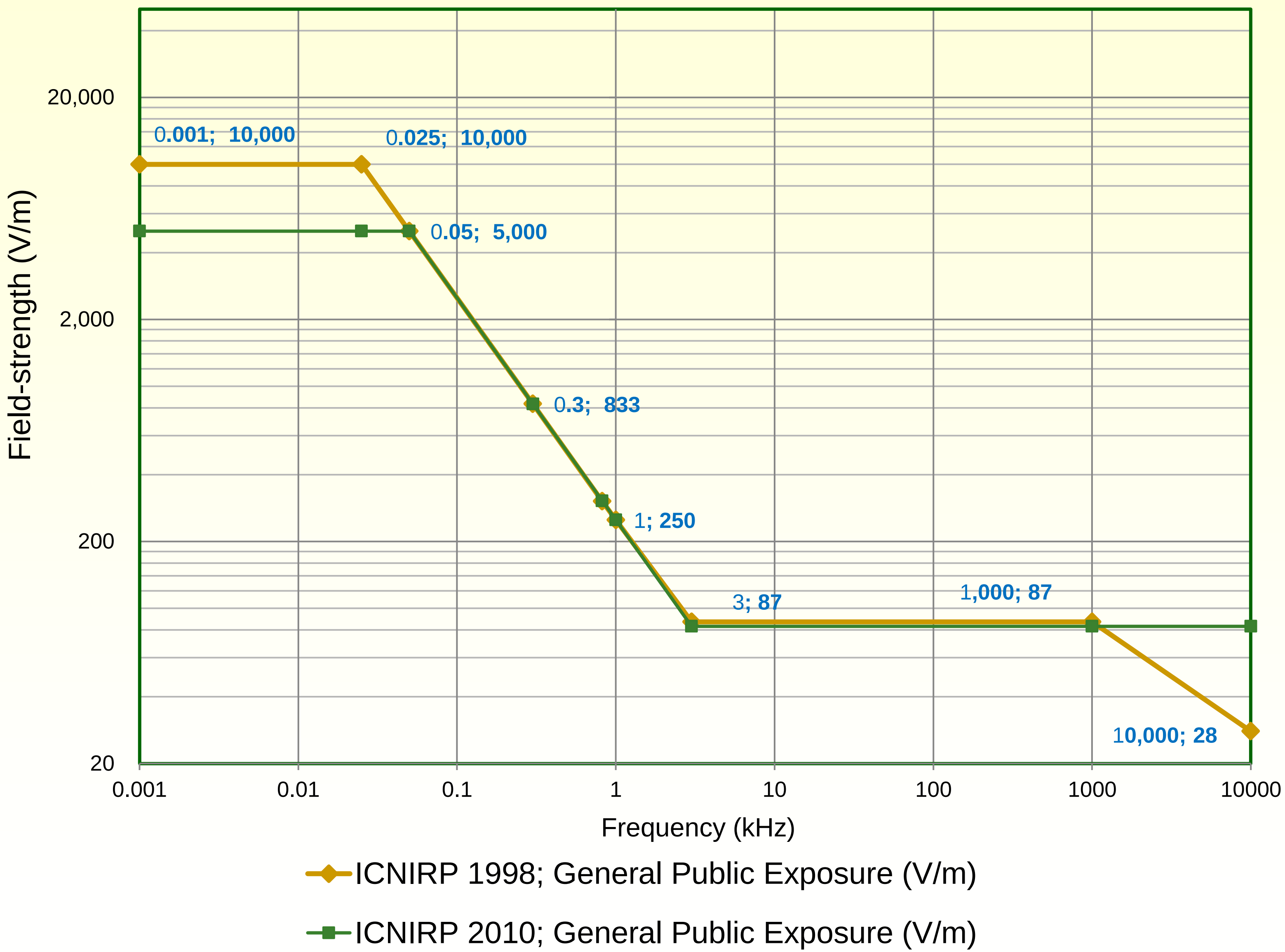
Frequency range	Electric field strength (V/m)		Equivalent plane wave power density S_{eq}(W/m^2)	
	general public	occupational	general public	Occupational
1-25 Hz	10,000	20,000	-	
0.025- 0.82 KHz	250/f(KHz)	500/f(KHz)	-	
0.82 -3 KHz	250/f(KHz)	610	-	
3-1000 KHz	87	610	-	
1-10 MHz	87/f $^{1/2}$ (MHz)	610/f (MHz)	-	
10-400 MHz	28	61	2	10
400-2000 MHz	1.375f $^{1/2}$ (MHz)	3f $^{1/2}$ (MHz)	f/200	f/40
2-300 GHz	61	137	10	50



ICNIRP 1998 p.511 reference levels for occupational & general public exposure- graphs



Reference levels: ICNIRP 2010 compared to ICNIRP 1998 till 10 MHz



SAR is "the time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of a given mass density (ϱ_m)" (ITU-T 2012 K.91:9) in W/kg

$$SAR = \frac{d}{dt}\left(\frac{dw}{dm}\right) = \frac{d}{dt}\left(\frac{dw}{\rho_m dv}\right)$$

SAR can be ascertained in three ways as indicated by the following equations:

E : value of the internal electric field strength in the body tissue (V/m)
σ : conductivity of body tissue (S/m) (siemens per meter, or mho per meter)

$$\mathrm{SAR} = \frac{\sigma e^2}{\rho} = C_i \frac{dT}{dt} = \frac{J^2}{\sigma\rho}$$

ρ : mass density of body tissue (kg/m^3)
C_i : heat capacity of body tissue (J/kg °C)
dT/dt : time derivative of temperature in body tissue (°C/s)
J : value of the induced current density in the body tissue (A/m^2).

Maximal power from handsets: Specific Absorption Rate, SAR (W/kg)

ICNIRP	European Community	USA and Canada
From 10 MHz to 10 GHz; Localized SAR (Head and Trunk)		Portable Devices; General Population/ Uncontrolled
2.0; averaged over 10 g tissue (also IEEE 2005 level)		1.6; averaged over 1g tissue

ICNIRP 2020 Table 3, basic restrictions for EMF Specific Absorption 100 kHz – 300 GHz, for integrating intervals >0 to <6 min

Exposure Scenario	Frequency Range	Local Head/Torso SA (kJ kg^{-1})	Local Limb SA (kJ kg^{-1})	Local U_{ab} (kJ m^{-2})
Occupational	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$3.6[0.05+0.95(t/360)^{0.5}]$	$7.2[0.025+0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$36[0.05+0.95(t/360)^{0.5}]$
General Public	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$0.72[0.05+0.95(t/360)^{0.5}]$	$1.44[0.025+0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$7.2[0.05+0.95(t/360)^{0.5}]$

Mitigation techniques to decrease the radiation level (1)

1. Maximize RF to operators in order to decrease number of sites
2. Maximize sharing, including active frequencies sharing among cellular operators
3. Close the WI-FI access point when not in use

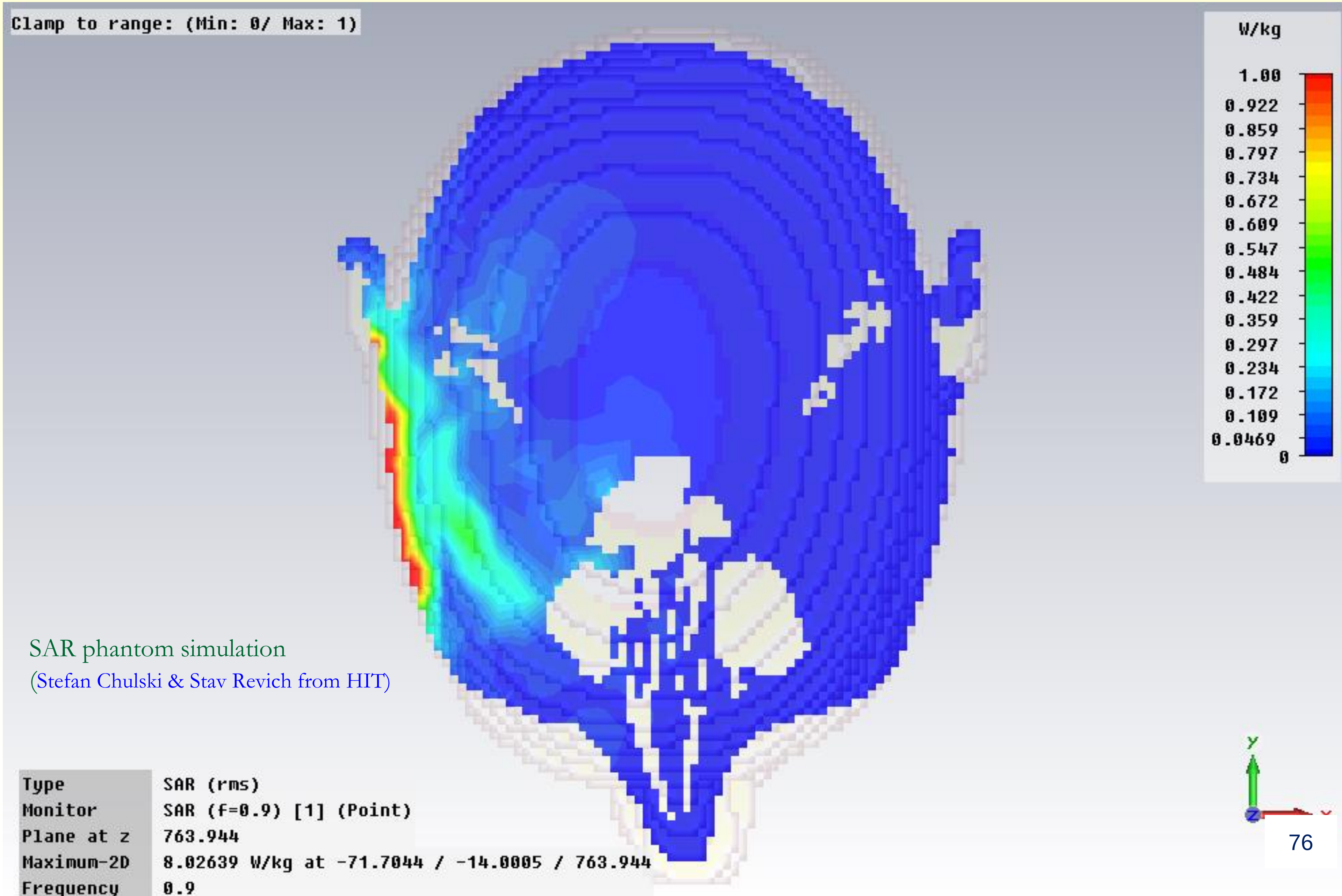
Mitigation techniques to decrease the radiation level (2)

Restrict access to areas where the exposure limits are exceeded. Physical barriers, lockout procedures and adequate signs are essential; workers can use protective clothing (ITU-T 2004 K.52 p.19)

Increase the antenna height. The distances to all points of investigation are increased and the radiation level is reduced. Moreover, additional attenuation to the radiation is achieved due to the increase of elevation angle and decrease of transmitting antenna sidelobe (ITU-T 2007 K.70 p.22)

Increase the antenna gain (mainly by reducing the elevation beam width), and consequently decrease the radiation in the direction accessible to people. The vertical beam width may be used to reduce the radiation level in close proximity to the antenna. Moreover, the same value of the EIRP can be achieved by a low power transmitter feeding high gain antenna or by high power transmitter feeding low gain antenna. As far as the protection against radiation is concerned, a much better choice is to use the low power transmitter feeding the high gain antenna. (ITU-T 2007 K.70 p.22)

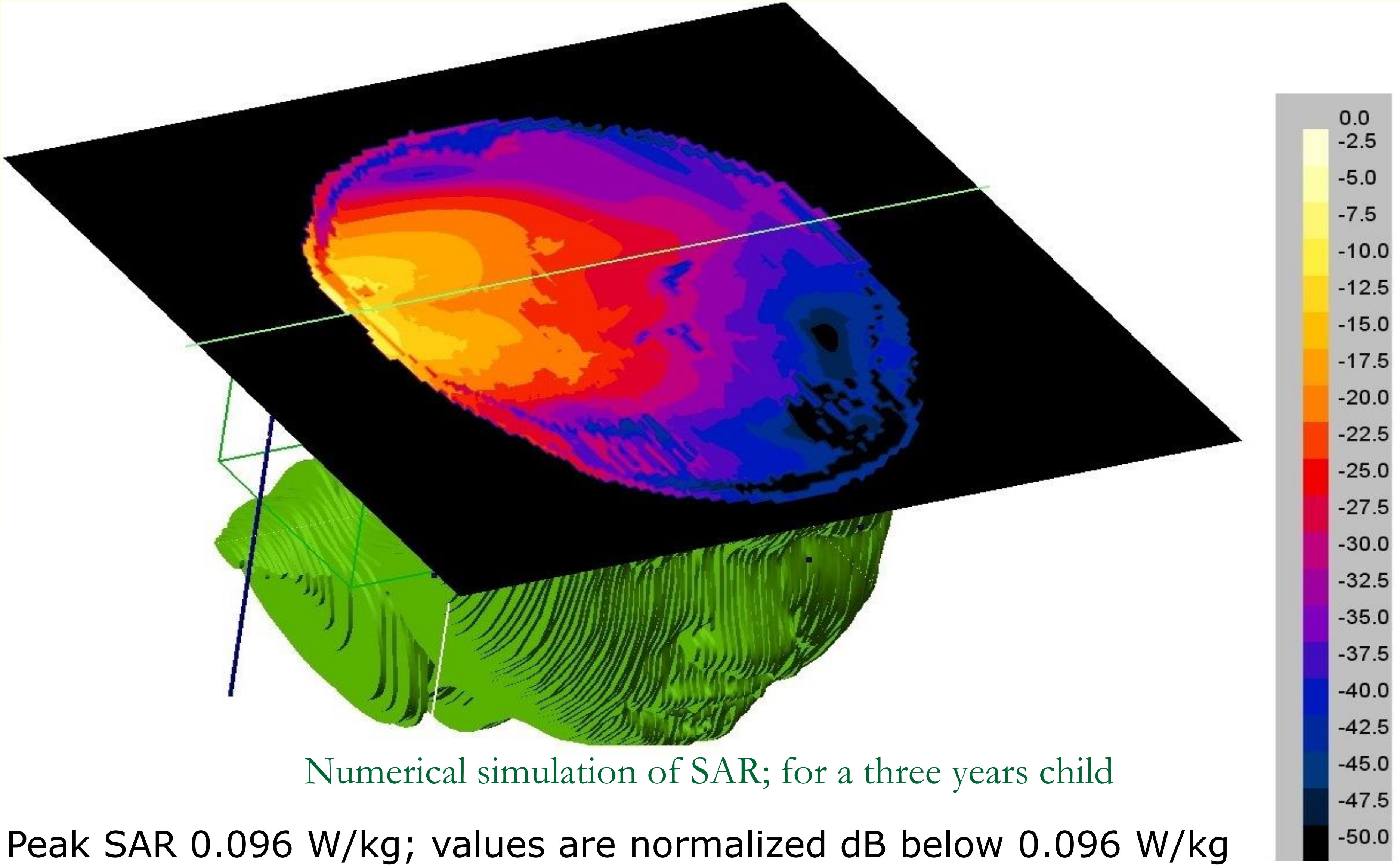
Minimize exposure to the min. needed to maintain the quality of the service, as quality criterion. Decrease the Tx power & consequently decrease linearly the power density in all the observation points. As it reduces the coverage area, it is used only if other methods cannot be applied (2007 K.70 p.22)



SAR phantom simulation

(Stefan Chulski & Stav Revich from HIT)

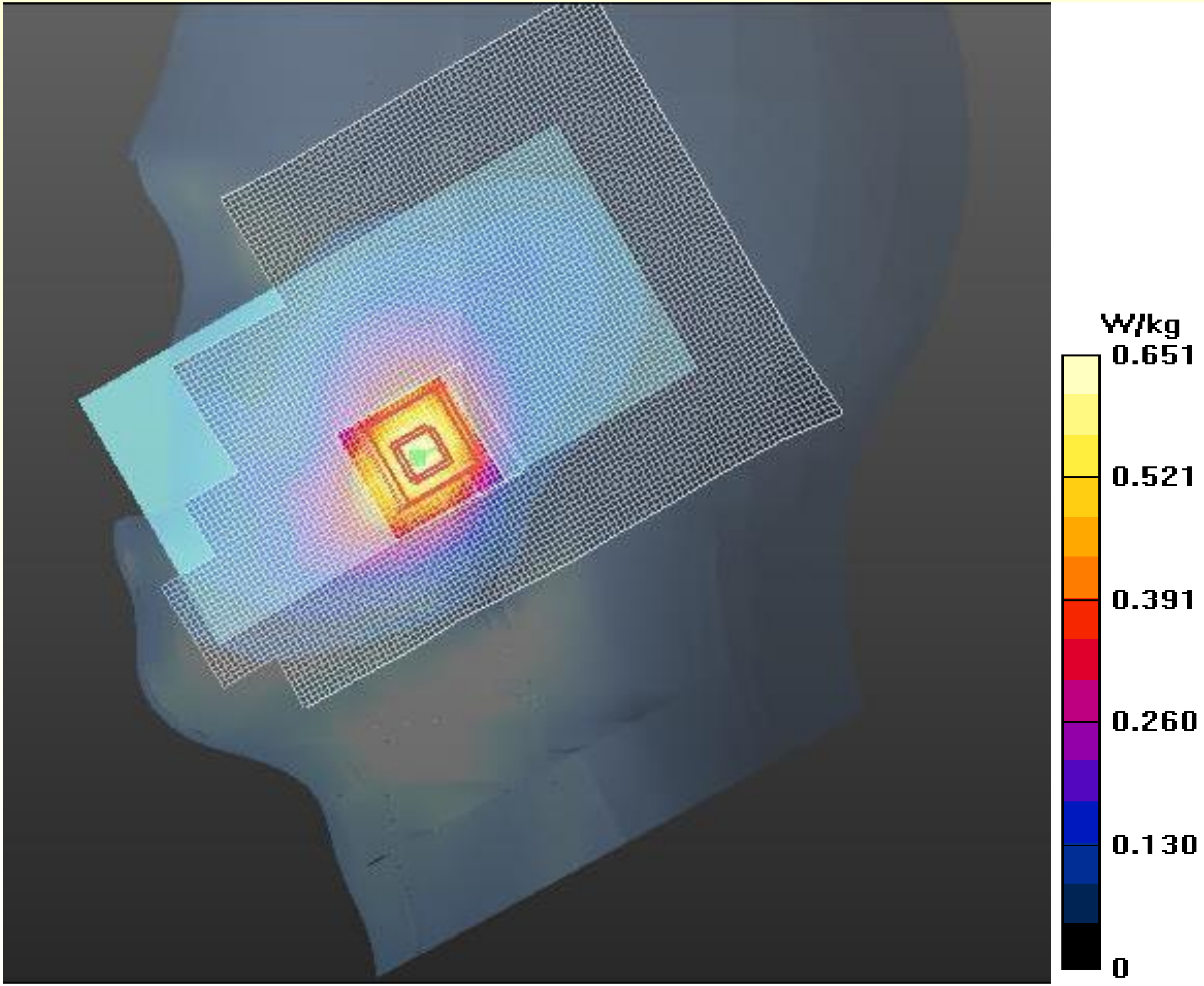
Source: Dr. Jafar Keshvari, Bio-electromagnetics
Aalto University, Helsinki-Finland



Numerical simulation of SAR; for a three years child

Peak SAR 0.096 W/kg; values are normalized dB below 0.096 W/kg

Source: Dr. Jafar Keshvari, Bio-electromagnetics Aalto University, Helsinki-Finland



SAR real measurement for a commercial mobile phone

Siemens model (Touch position, 903 MHz)

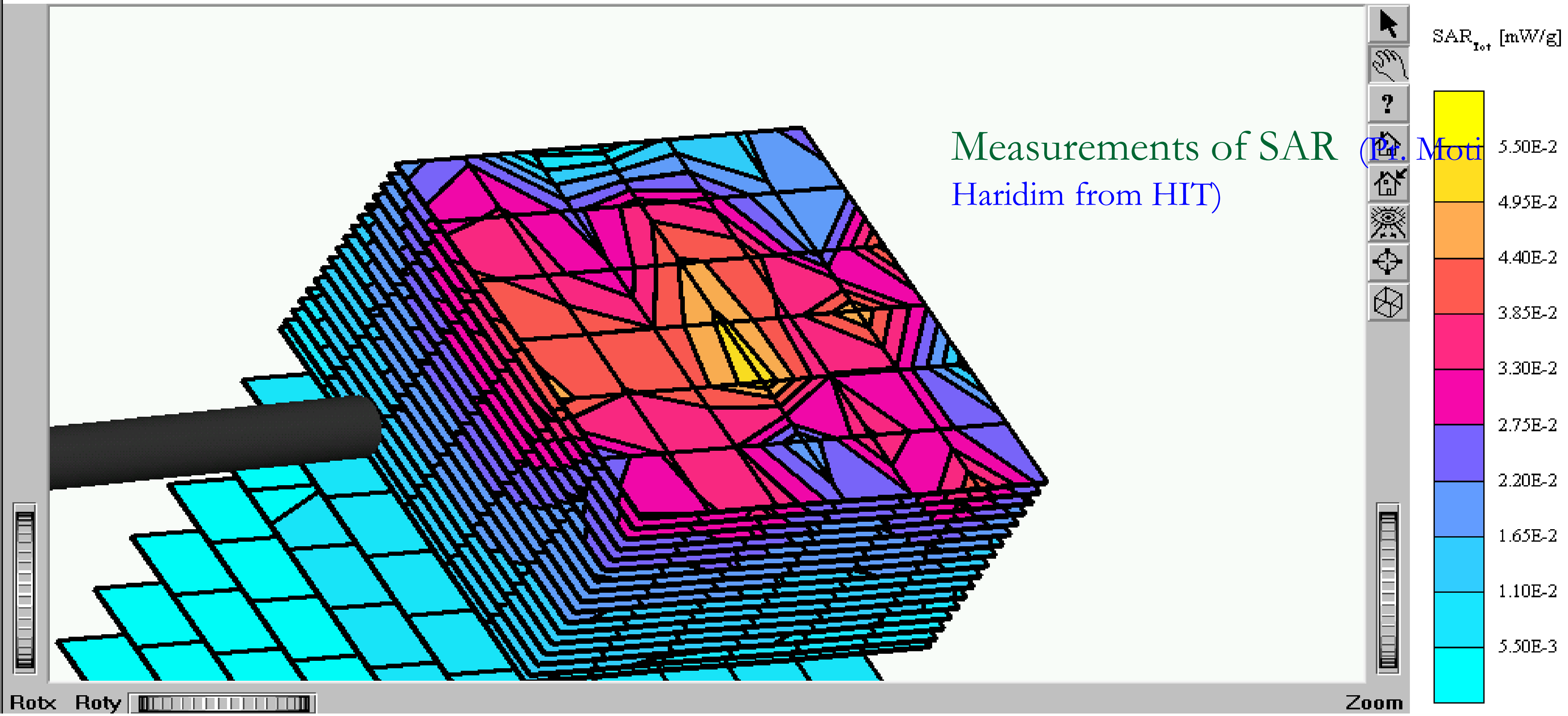
SAM; Flat

Probe: ET3DV6 - SN1662; ConvF(6.70,6.70,6.70); Crest factor: 1.0; Head 895Mhz: σ = 1.14 mho/m ε_r = 56.0 ρ = 1.00 g/cm^3

Cube 7x7x7: Peak: 0.0573 mW/g, SAR (1g): 0.0311 mW/g, SAR (10g): 0.0194 mW/g * Max outside, (Worst-case extrapolation)

Penetration depth: 11.3 (11.1, 11.8) [mm]

Measurements of SAR (Pr. Moti Haridim from HIT)



FCC (still on 5May2020) Limits for Maximum Permissible Exposure (MPE)

Reassessment of RF Exposure Limits & Policies, and Proposed Changes in the Rules Regarding Human Exposure to RF Fields

Frequency range (MHz)	*electric field strength (V/m)*	*magnetic field strength (A/m)*	*power density (mW/cm²)*	*averaging time (minutes)*
(A) limits for occupational/controlled exposure				
0.3 – 3.0	614	1.63	100 *	6
3.0 – 30	1,842/*f*	4.89/*f*	900/*f*² *	6
30 – 300	61.4	0.163	1.0	6
300 – 1,500	–	–	*f*/300	6
1,500 – 100,000	–	–	5	6
(B) limits for general population/uncontrolled exposure				
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 – 1,500	–	–	*f*/1,500	30
1,500 – 100,000	–	–	1.0	30

[1] FCC uses different units than ICNIRP 1998 for power density: mW/cm^2 and not W/m^2; $W/m^2 = 0.1\ mW/cm^2$

ICNIRP 1998 vs. N. America and Japan reference levels

ICNIRP 1998, EC (1999/519) and IEEE reference levels for public

Frequency range	electric field strength (V/m)	equivalent plane wave power density S_{eq}(W/m^2)
10–400 MHz	28	2
400-2000 MHz	$1.375f^{1/2}$	$f/200$
2-300 GHz	61	10

USA and Japan Maximum Permissible Exposure for general

RF (MHz)	electric Field (E) (V/m)	power Density (S) (mW/cm^2)
30-300	27.5	0.2
300-1500	--	$f/1{,}500$
1,500-100,000	--	1

[1] FCC uses different units than ICNIRP for power density: mW/cm^2 and not W/m^2; W/m^2 = 0.1 mW/cm^2

ICNIRP 1998, FCC §1.1310 and Canada Safety Code SC6 (W/m^2)

Frequency	ICNIRP 1998	FCC §1.1310	SC6
300 MHz	2	2	1.291
1,500 MHz	f/200=1500/200=7.5	10	$0.02619 \times f^{0.6834} = 3.88$
3,000 MHz	10 W/m^2		$0.02619 \times f^{0.6834} = 6.23$
6,000 MHz	10 W/m^2		

Far-field free-space propagation loss

$$s = \frac{p_t g_t}{4\pi d^2} = \frac{eirp}{4\pi d^2}; d = \sqrt{\frac{eirp}{4\pi s}}$$

$$\vec{s} = \vec{e} \times \vec{h} = \frac{eirp}{4\pi d^2} \qquad \vec{h} = \frac{\vec{e}}{z_o} \qquad z_0 \equiv \mu_0 \times c_0 = \mu_0 \times \sqrt{\frac{1}{\varepsilon_0 \times \mu_0}} = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{1}{\varepsilon_0 \times c_0} = 120\pi$$

$$\vec{s} = \vec{e} \times \vec{h} = \frac{eirp}{4\pi d^2} = \frac{\vec{e} \times \vec{e}}{120\pi} \qquad |\vec{s}| = \frac{e^2}{z_o} = \frac{e^2}{120\pi} \qquad e = \frac{\sqrt{30\, eirp}}{d}; d = \frac{\sqrt{30\, eirp}}{e}$$

where:

p_t:	transmitter power (watts)
g_t :	transmitter antenna gain (numeric)
eirp:	equivalent isotropically radiated power (watts)
s:	power density (watts/m^2) (limit)
d:	distance (m)
e :	electric field strength (V/m) (limit)
z_0 :	impedance of free-space, 120π (Ohms)
μ_0:	vacuum permeability (or magnetic constant)
ε_0 :	vacuum permittivity (or electric constant)
c_0 :	speed of light in vacuum

Multiple-antenna emissions from the same site and same frequency

at a frequency range whose limits are frequency independent (like 10–400 MHz and 2–300 GHz), the power density limits are equal for all transmitters emitting at the same frequency range, i.e. $s_{l1}=s_{l2}=\ldots=s_l$. The equivalent cumulative *eirp* is the power scalar sum of all the emitters; this equivalent *eirp* is used to calculate the safety-distance in ICNIRP 1998 tables 6 and 7

$$eirp_{eq}=\sum eirp_i \qquad d_{eq}=\sqrt{\frac{eirp_{\mathrm{eq}}}{4\pi s_l}}=\sqrt{\frac{\sum eirp_{\mathrm{i}}}{4\pi s_l}}$$

the total field strength exposure ration w_{t}

$$w_t=\sum_i\left(\frac{e_i}{e_l}\right)^2=\frac{\sum_i (e_i)^2}{(e_l)^2}\leq 1$$

Where

$eirp_{\mathrm{i}}$:	for each emitter	(watts)	
$eirp_{\mathrm{eq}}$:	equivalent cumulative *eirp*	(watts)	
d_{i}:	safety-distance from each emitter	(m)	
d_{eq}:	equivalent cumulative safety-distance	(m)	
s_{i} :	power density from each emitter	(W/m²)	index i
s_{li} :	power density **l**imit from each emitter	(W/m²)	index i
e_{i} :	electric field strength from each emitter	(V/m)	index i
e_{li} :	electric field strength **l**imit from each emitter	(V/m)	index i

Emissions transmitted from the same site: multiple-antenna installation

- ICNIRP 1998 limits are **RF dependent**; the equivalent cumulative safety-distance d_{eq}

$$d_{eq} = \sqrt{\sum_i d_i^{\,2}} \qquad d_i = \sqrt{\frac{eirp_{\mathrm{i}}}{4\pi s_i}}$$

- *eirp* is weighted by the inverse of its power density limit s_{li}

$$d_{eq} = \sqrt{\sum_i d_i^{\,2}} = \sqrt{\sum_i \frac{eirp_i}{4\pi s_{li}}} = \sqrt{\frac{eirp_1}{4\pi s_{l1}} + \frac{eirp_2}{4\pi s_{l2}} + \ldots + \frac{eirp_{\mathrm{n}}}{4\pi s_{\mathrm{ln}}}}$$

- check the limit compliance at each frequency band relative to the threshold s_{l} (or e_{l}); total exposure quotient (or cumulative exposure ratio) based on total cumulative weighted PD s_{t}

$$s_t = \sum_{i=1}^{n} \frac{s_i}{s_{li}} = \frac{s_1}{s_{l1}} + \frac{s_2}{s_{l2}} + \ldots + \frac{s_n}{s_{\mathrm{ln}}} \le 1$$

- total cumulative weighted field strength exposure ration w_{t}

$$w_t = \sum_i \left(\frac{e_i}{e_{li}} \right)^2 \le 1$$

See table in next slide, and

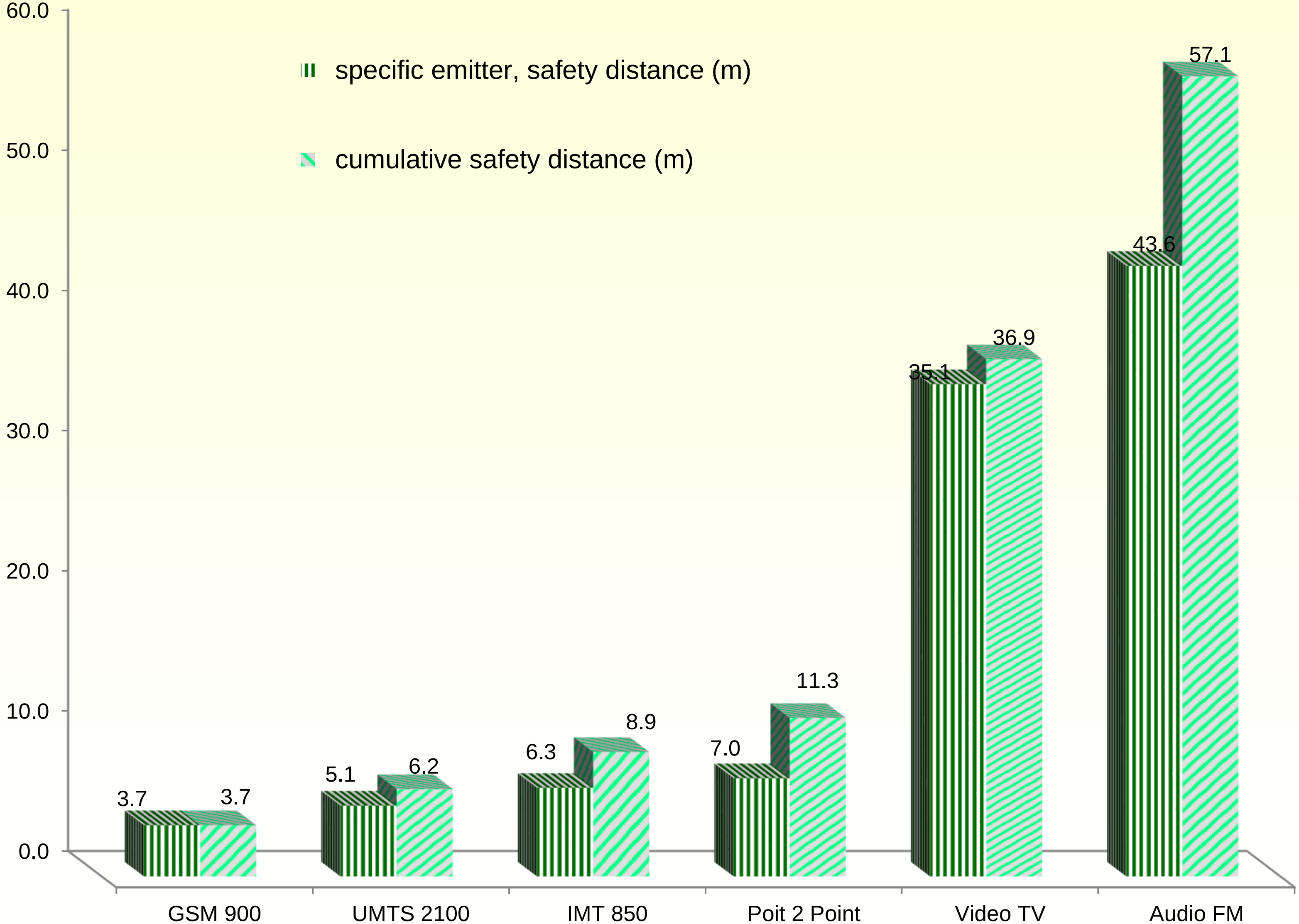
Coefficient Wt vs. distance for co-located site with FM

Worst-case horizontal safety-distances & cumulative exposure; co-located site

Transmission System	GSM 900	UMTS 2100	IMT 850	point-to-point	Video TV	Audio FM
Frequency (MHz)	891	2100	800	514	514	100
ICNIRP limit, power density (W/m^2)	4.75	10.00	4.00	2.57	2.57	2.00
Antenna Gain (dBi)	16	18	18	23	17	10
Antenna elevation model or real pattern	742 265	TBXLHA	80010302_0 824	ITU-R F.1336	ITU-R F.699	ITU-R F.699
Ant. Altitude above ground level (m)	32	45	15	25	60	60
Cable Loss (dB)	0	1	1	1	1	1
Power (Watt)	20	64	40	10	1,000	6,000
EIRP (Watt)	800	3,210	2,000	1,580	39,810	47,660
Specific safety distance (m)	3.7	5.1	6.3	7.0	35.1	43.6
Cumulative safety distance (m)	3.7	6.3	8.9	11.3	36.9	57.1
ICNIRP limit, field strength (V/m)	41.30	61.00	38.89	31.17	31.17	28.00
Specific field strength at 50m, ICNIRP ratio	0.08	0.10	0.13	0.14	0.70	0.85
Cumulative field strength ratio	0.08	0.13	0.18	0.23	0.74	1.13

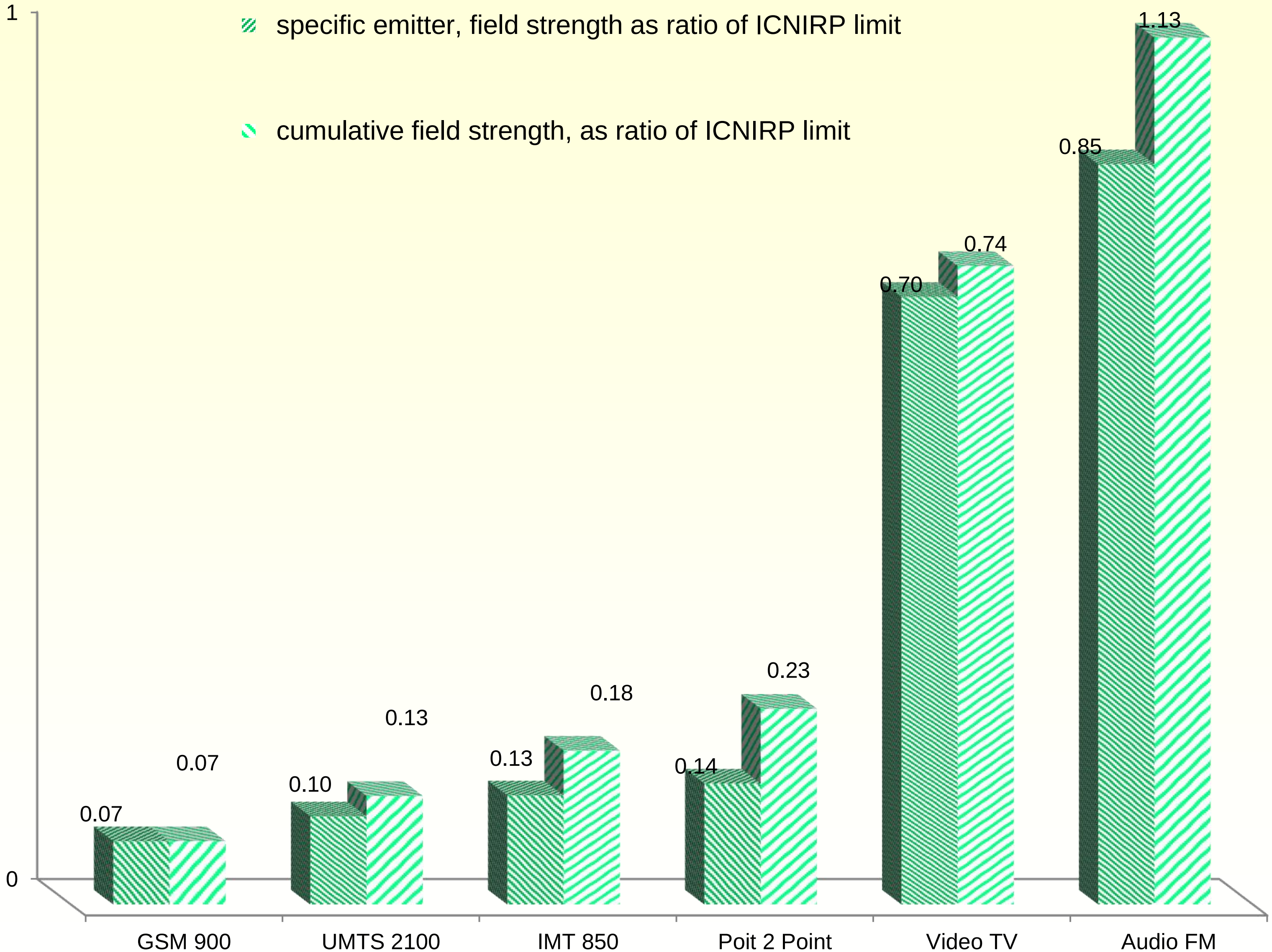
calculated by author

Cumulative horizontal safety-distance, co-located site; y axis (m)



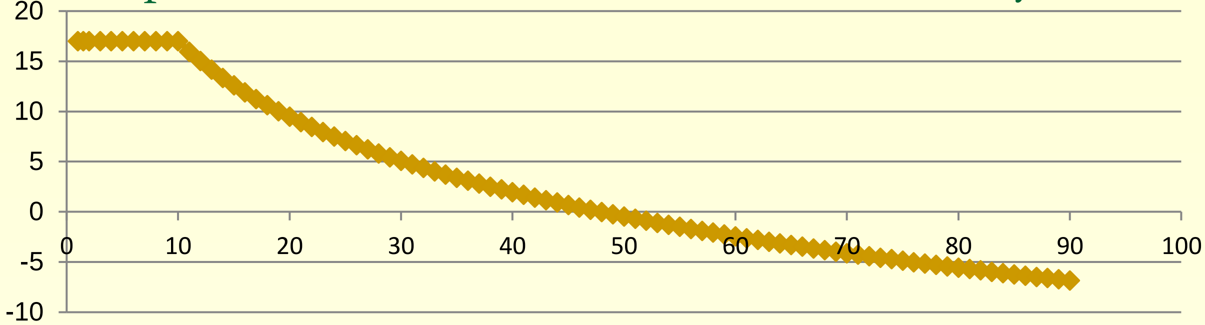
calculated by author

Cumulative field strength exposure ratio , co-located site; point of investigation at 50 meter

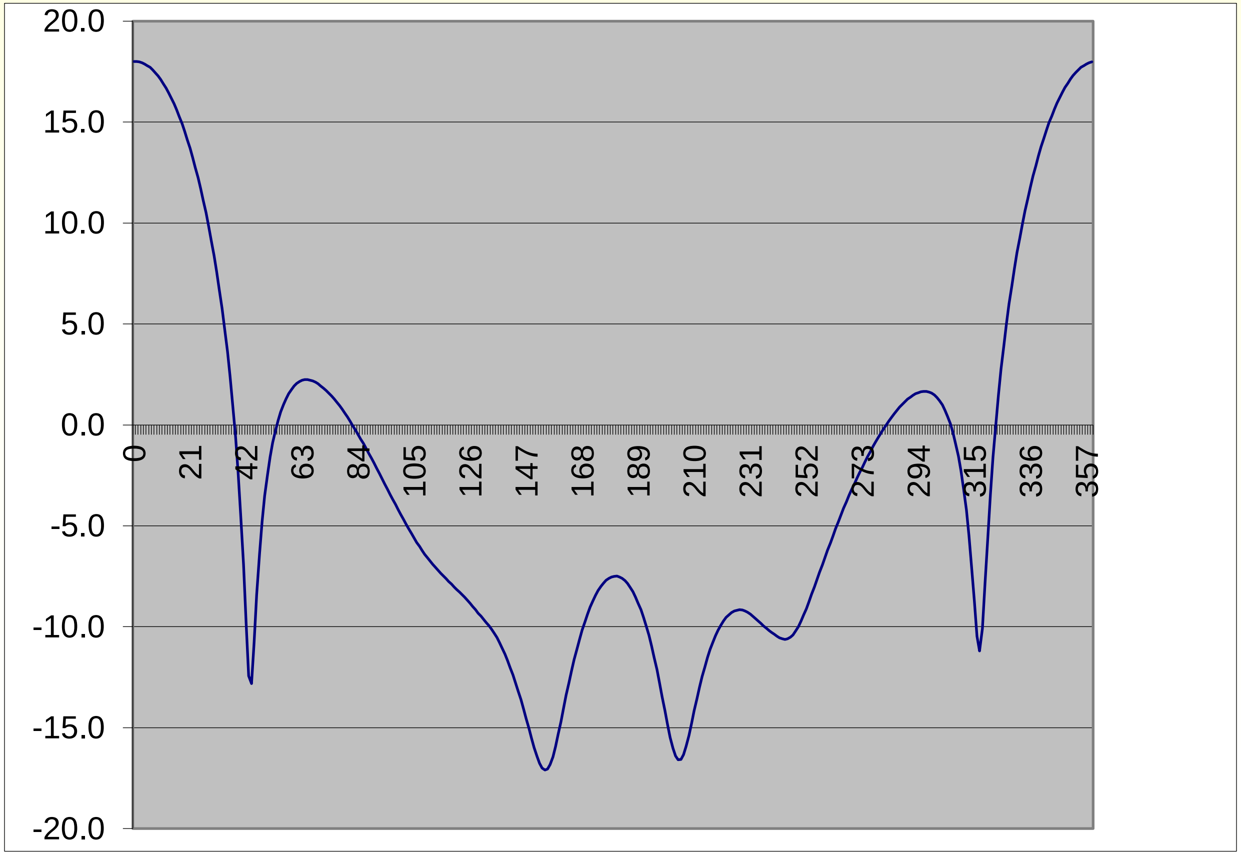


calculated by author

Vertical pattern of TV antenna 17 dBi calculated by ITU-R Rec. F.699



Vertical pattern of 80010302_0824_X_CO_M45_00T; Anatel



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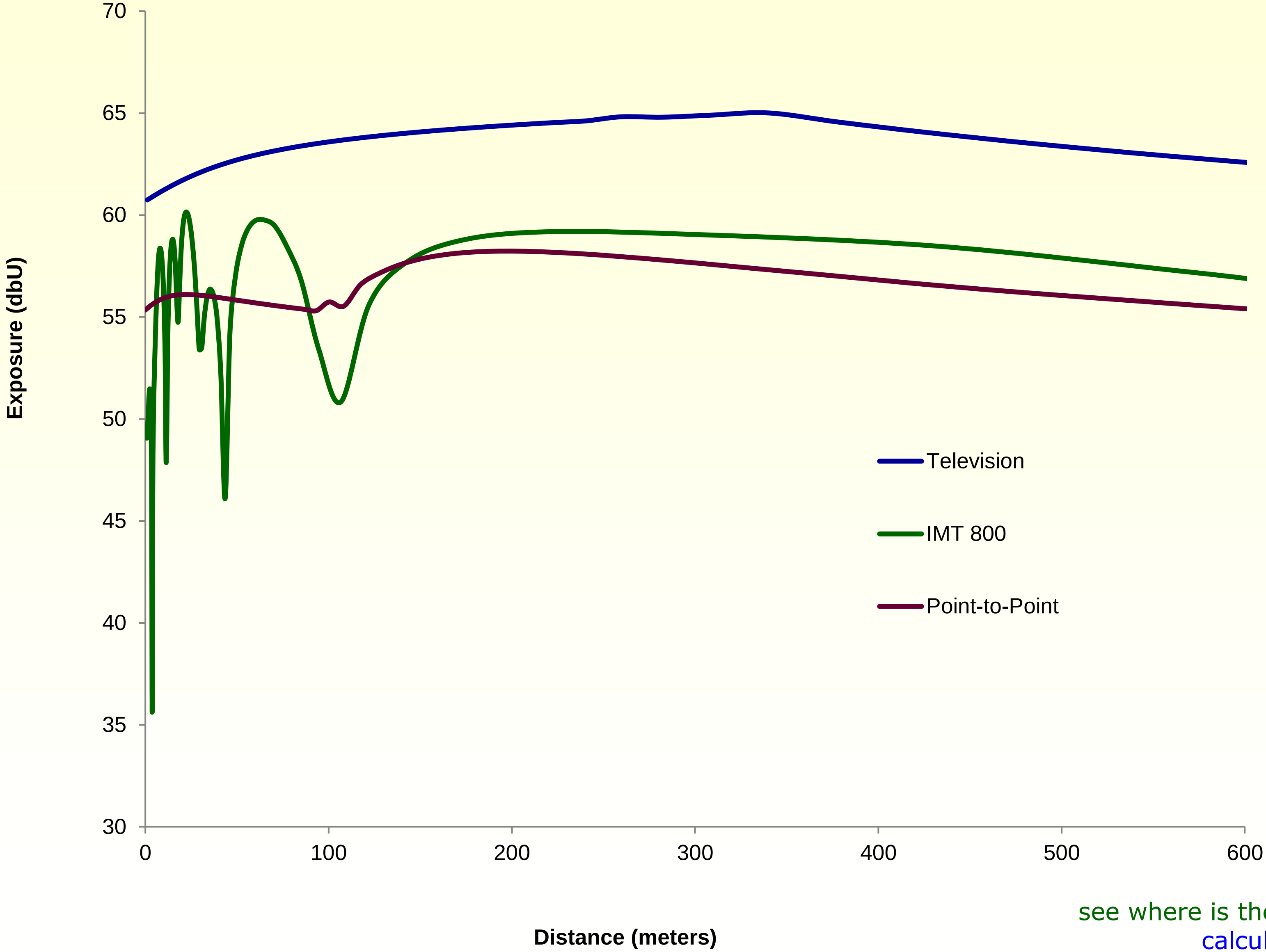
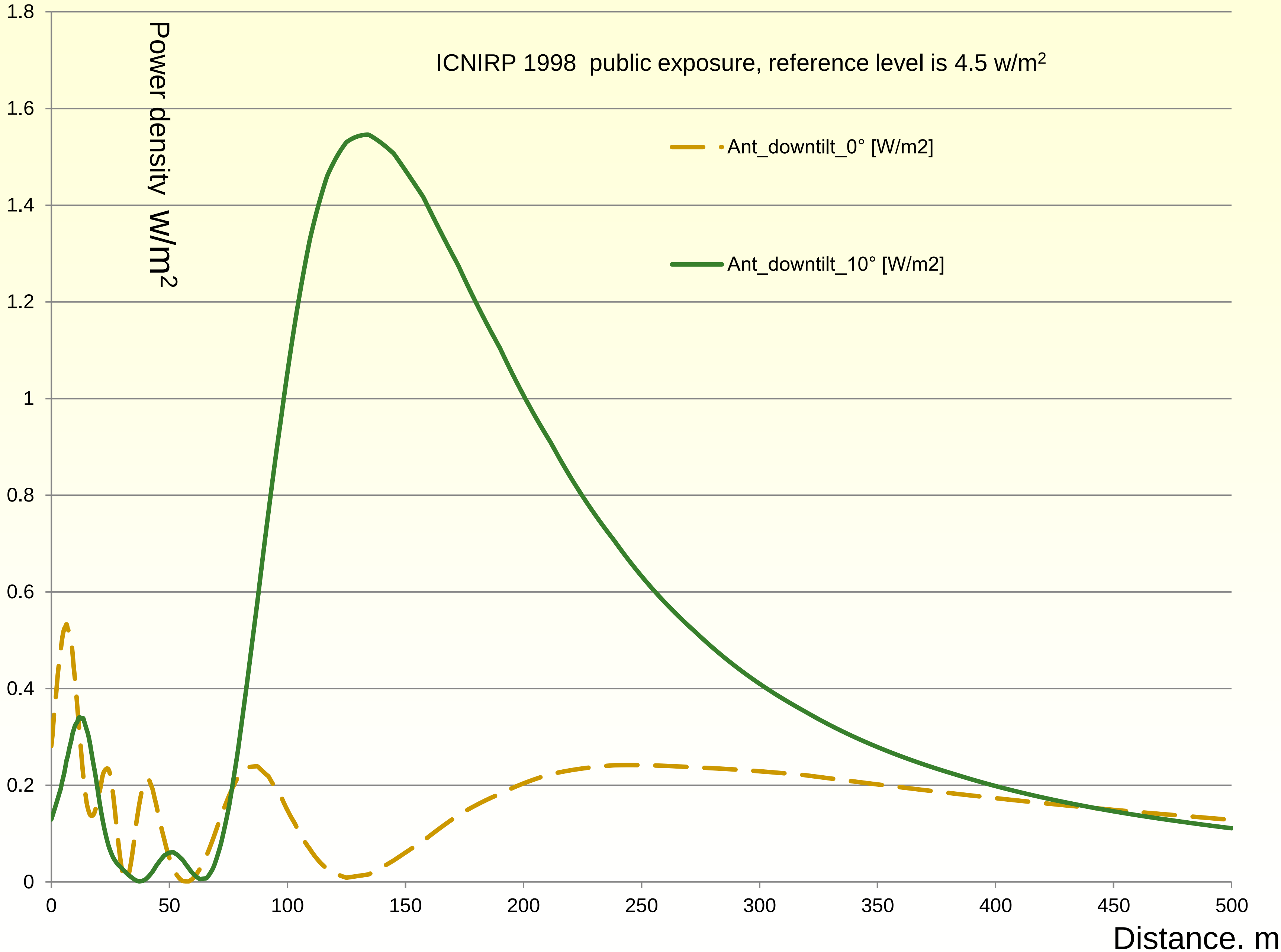
Field Strength (dBµV/m) vs. distance (m), co-located site TV, IMT 850 & Point 2 Point

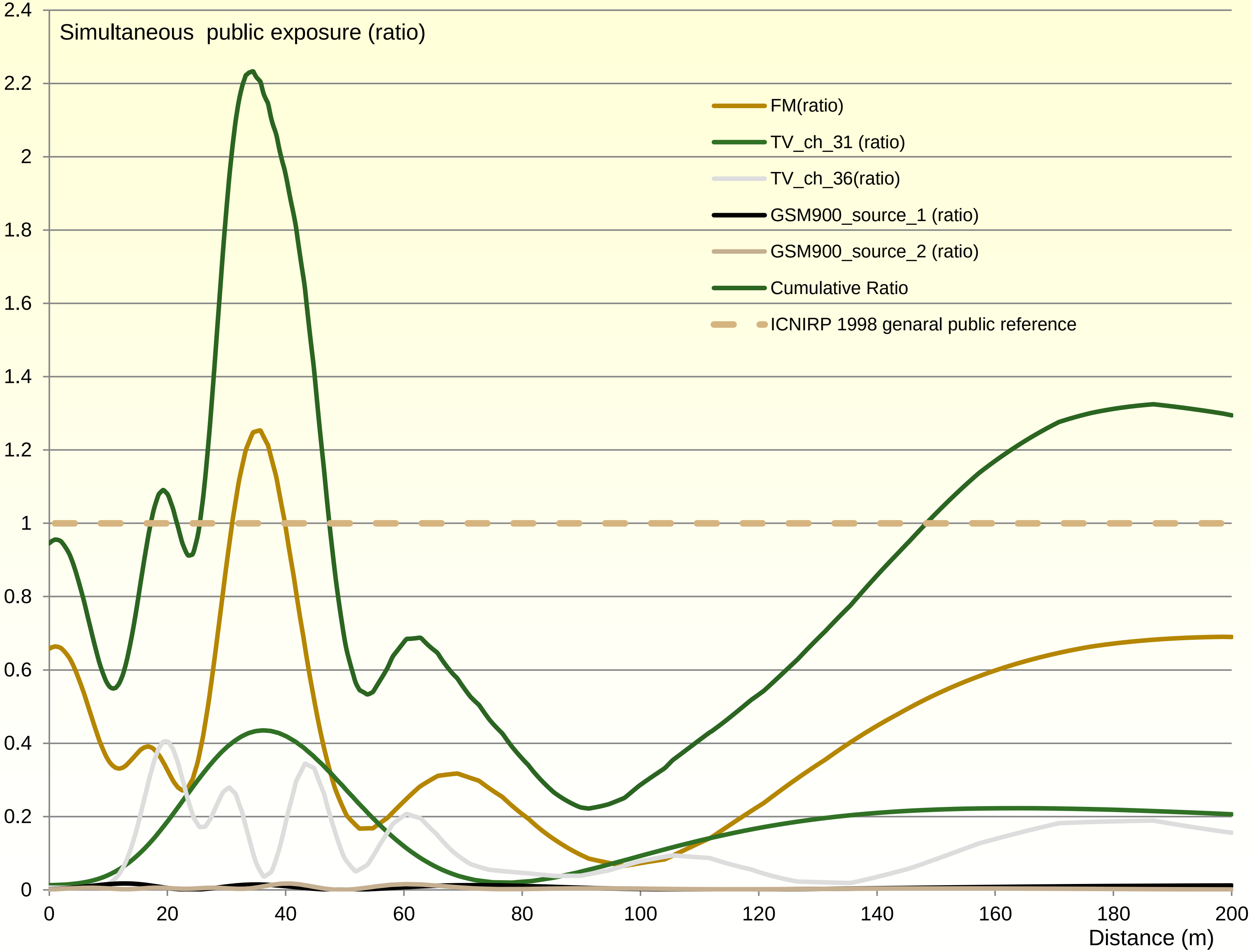


see where is the max exposure
calculated by author

Power density vs. horizontal distance, for 2 down-tilts

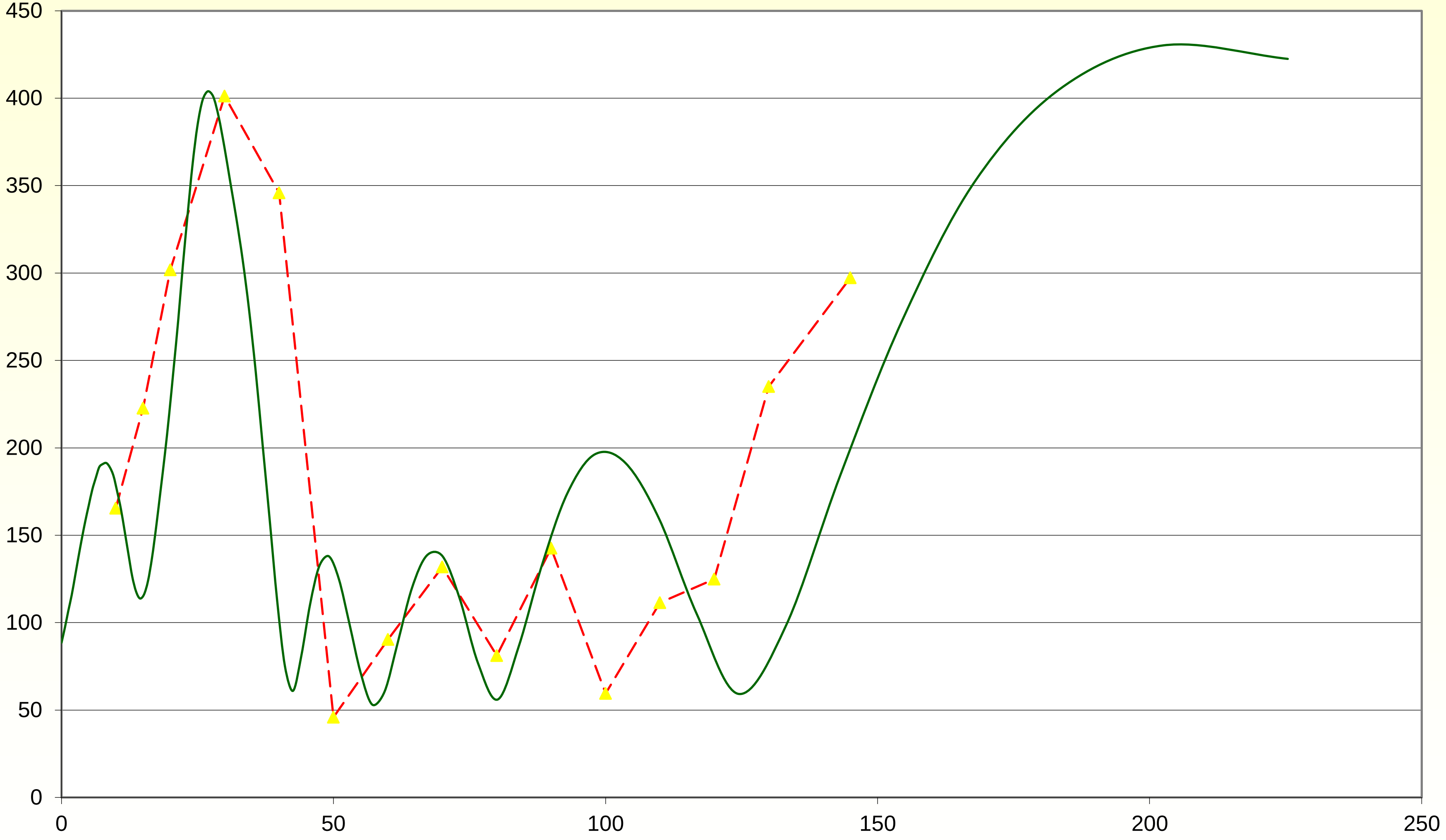


Coefficient W_t vs. distance for co-located site with FM, TV & GSM 900

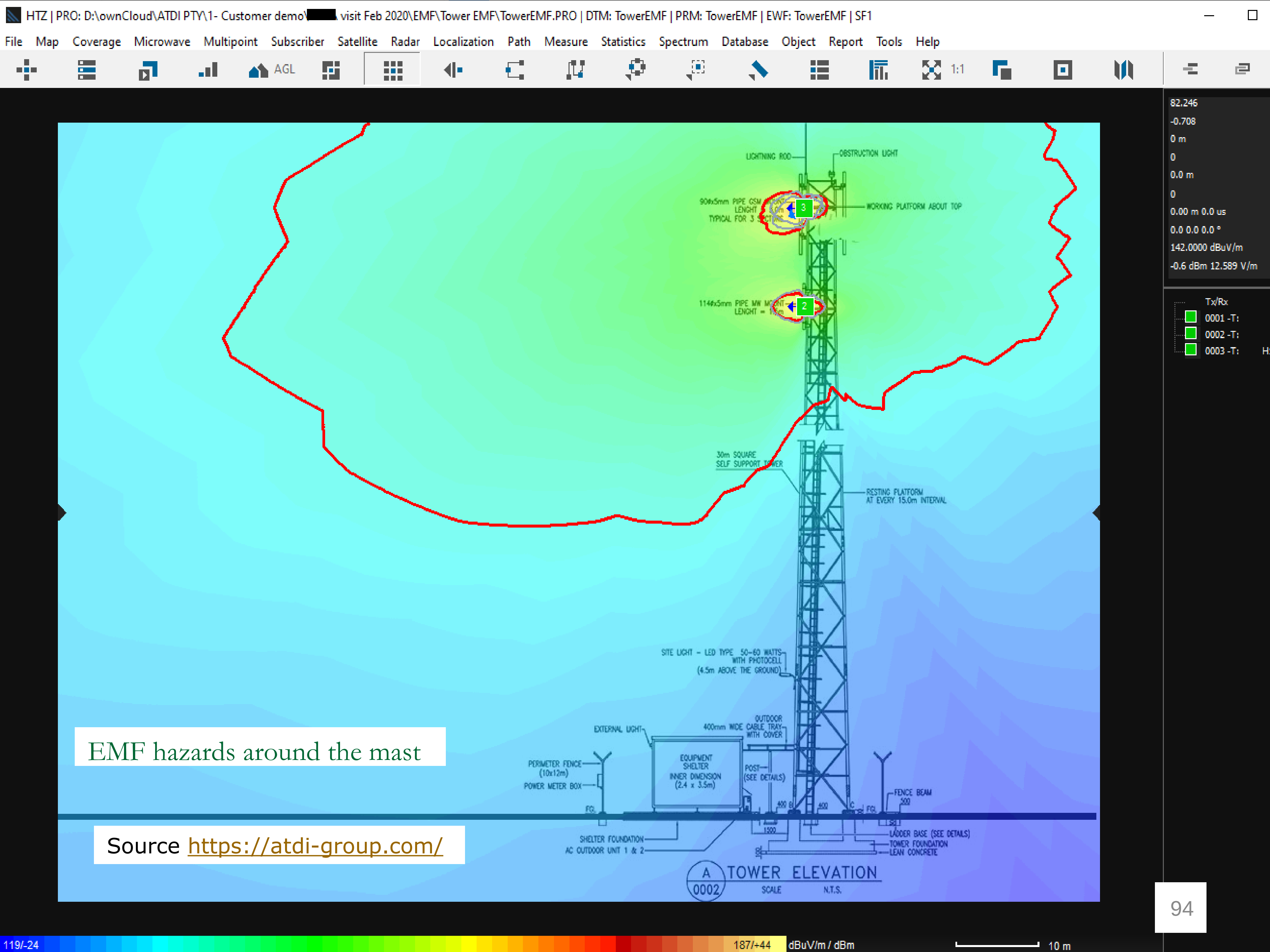


Field Strength (mV/m) vs. distance (m)

RF = 1875.8 MHz; red- measured, green- calculated



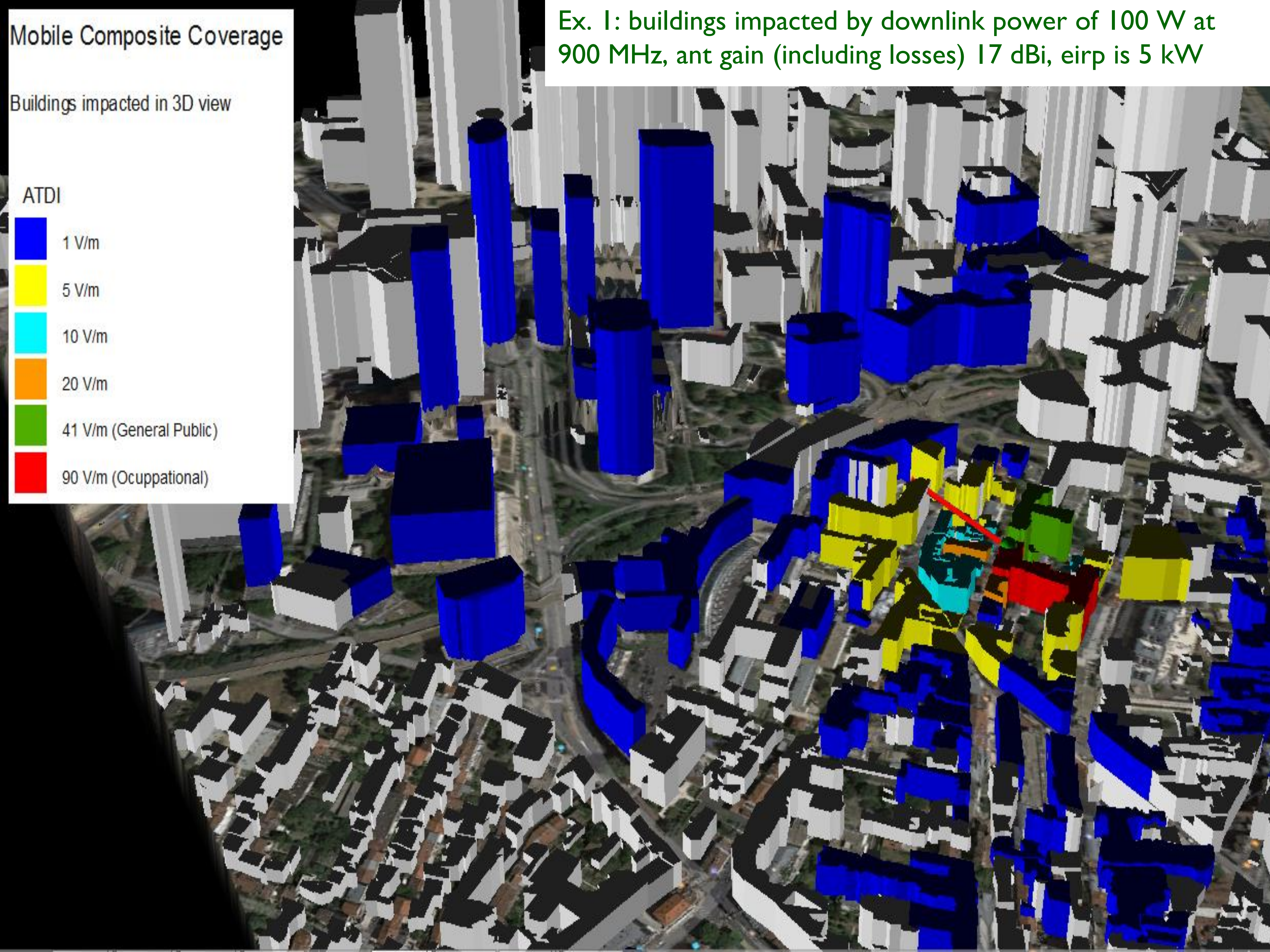
Measured and calculated by ANATEL 2012, Eng . Agostinho Linhares de Souza Filho



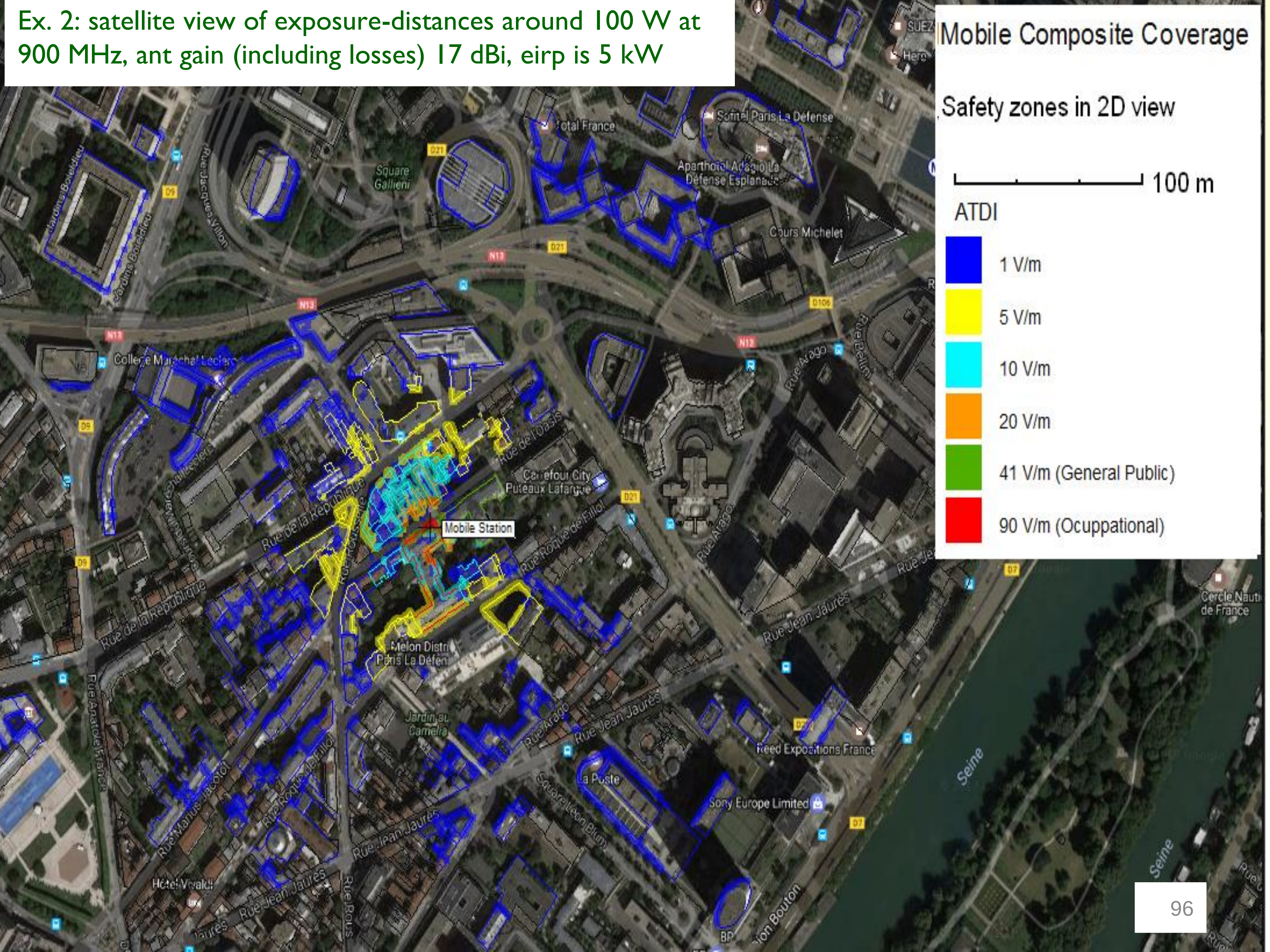
EMF hazards around the mast

Source https://atdi-group.com/

Ex. 1: buildings impacted by downlink power of 100 W at 900 MHz, ant gain (including losses) 17 dBi, eirp is 5 kW

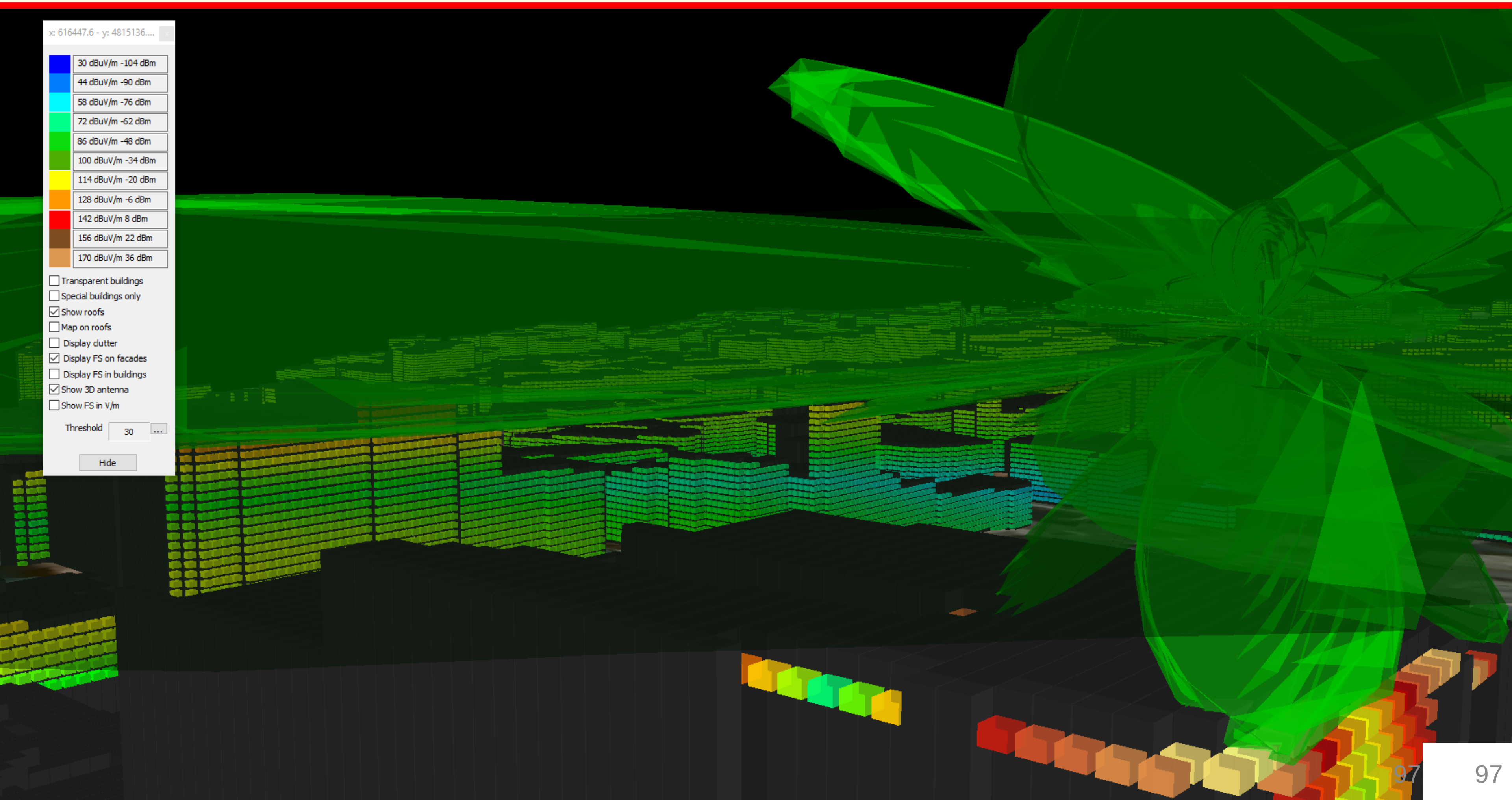


Ex. 2: satellite view of exposure-distances around 100 W at 900 MHz, ant gain (including losses) 17 dBi, eirp is 5 kW



Calculating far-field safety-distances around base stations using elevation ant. pattern

Ant. tilt 0 degrees; also in azimuth antenna pattern is analysed; typically in 3 sectors 5G, there is azimuth overlap: 6dB attenuation in $\pm 60^0$ & 3dB $\pm 45^0$, around mainbeam



RF Hazards limits & their impact on network planning

Excessive exposure limits affect network planning

- Co-location and MIMO increase the safety distance and restrict mast construction near buildings
- Countries (e.g. Switzerland) reduce by 100 (and Salzburg by 9,000) the power density level and restrict the cellular BTS planning and location
- Lower RF exposure limits enforce to decrease the EIRP (in order to reduce the power density and field strength near the station) or to extend the distance of the mast from the public
- Handling low exposure thresholds by additional cellular antennas or RF Spectrum

Mitigation techniques to decrease the radiation level (1)

- Avoid wireless communications if the transmitter & receiver stations are fixed; e.g. terrestrial TV
  - Close the WI-FI access point when not in use
  - U may avoid WiFi routers based on cellular infrastructure
  - Use Satellite and Cable TV
- Maximize sharing, including active frequencies sharing among cellular operators
- Maximize the RF to operators in order to decrease sites

Mitigation techniques to decrease the radiation level (2)

Restrict access to areas where the exposure limits are exceeded. Physical barriers, lockout procedures and adequate signs are essential; workers can use protective clothing (ITU-T 2004 K.52 p.19)

Increase the antenna height. The distances to all points of investigation are increased and the radiation level is reduced. Moreover, additional attenuation to the radiation is achieved due to the increase of elevation angle and decrease of transmitting antenna sidelobe (ITU-T 2007 K.70 p.22)

Increase the antenna gain (mainly by reducing the elevation beam width), and consequently decrease the radiation in the direction accessible to people. The vertical beam width may be used to reduce the radiation level in close proximity to the antenna. Moreover, the same value of the EIRP can be achieved by a low power transmitter feeding high gain antenna or by high power transmitter feeding low gain antenna. As far as the protection against radiation is concerned, a much better choice is to use the low power transmitter feeding the high gain antenna. (ITU-T 2007 K.70 p.22)

Minimize exposure to the min. needed to maintain the quality of the service, as quality criterion. Decrease the Tx power & consequently decrease linearly the power density in all the observation points. As it reduces the coverage area, it is used only if other methods cannot be applied (2007 K.70 p.22)

Low exposure thresholds by additional cellular antennas or RF Spectrum

Simplistic equations; see Mazar Wiley book 2016 Chapter 9 section 9.6.3

For a given network (technology, number of sites, RF spectrum, quality of service), better coverage is achieved by transmitting at higher effective power (for both downlink and uplink channels), installing base stations at higher altitude above ground level (less signal attenuation) and using lower radio frequency.

Max. channel capacity for each communications link in a given network is derived from Shannon Hartley monumental paper (**Shannon 1948 p.43, theorem 17**), relating capacity (bit/s), RF bandwidth (Hz) and the signal to noise (dimensionless) ratio

$$c = b \times log_2 \left(1 + s/n\right)$$

Moreover, in urban scenario *s/n* is small. LTE RSRQ (Reference Signal Received Quality) quantifies the capacity; UE measures this parameter as reference signal. Values higher than −9dB guarantee the best subscriber experience; the range between −9 and −12dB can be seen as neutral with a slight degradation of Quality of Service. So for *s/n* very small relative to 1, 5.1 aims to:

$$c = b \times log_2 \left(1 + s/n\right) \approx b \times \frac{s/n}{\ln 2} \approx 1.44 \times b \times s/n$$

Therefore, staying with the same *capacity* c- less sites (reduced s) can be compensated by more frequency *band* (b).

The capacity is limited by power s and noise density n_o.

Summary: cellular capacity is limited by power and noise; adding RF to base stations may decrease the number of base stations and the total EMF

Recent EMF material from Author

- ITU Conferences on EMF
  1) A Comparison Between European and North American Wireless Regulations, presentation at the 'Technical Symposium at ITU Telecom World 2011' www.itu.int/worl2011; the slides presentation, 27 October 2011
  2) 2016 ITU R-D-T 'Intersectoral activities on human exposure to EMF'; Bangkok, 26 April 2016
  3) 2017 ITU Workshop '5G, EMF & Health'; Warsaw, Poland, 5 December 017
  4) 2018 ITU workshop 'modern policies, guidelines, regulations and assessments of human exposure to RF-EMF'; Geneva, Switzerland, 10 October 2018 ; see slide
- Papers and Presentations
  1) Updated Chapter 9 on EMF exposure of my Wiley book on Spectrum Management
  2) Human RF Exposure Limits: Reference Levels in Europe, USA, Canada, China, Japan and Korea EMC Europe 2016; Wroclaw, Poland, 9 Sept. 2016
  3) Regulation of RF Human Hazards Lusaka, Zambia; 13 January 2017
  4) EMF Concerns and Perceptions Modiin, Israel; 25 March 2019
  5) EMF, New ICNIRP Guidelines and IEEE C95.1-2019 Standard: Differences and Similarities; Warsaw, Poland; 3 Dec 2019
  6) Module on EMF to the ITU Spectrum Training; April 2020
  7) PRIDA Track 1 (T1) Online training in English and in French; April and May 2020

ITU workshop on modern policies, guidelines, regulations and assessments of human exposure to RF-EMF

ITU, Geneva 10 Oct. 18

See workshop presentations at
https://www.itu.int/en/ITU-D/Study-Groups/2018-2021/Pages/meetings/session-Q7-2-oct18.aspx

ITU-T Recommendations on EMF assessment

ITU-T SG5 (Environment, climate change and circular economy) has been particularly active in developing recommendations for the protection from and measurement/computation of RF fields. Enclosed the EMF ITU-T Recommendations (Standards). All of them include “related supplements”:

1. K.52: Guidance on complying with limits for human exposure to electromagnetic fields
2. K.61: Guidance on measurement and numerical prediction of EMF for compliance with human exposure limits for telecommunication installations
3. K.70: Mitigation techniques to limit human exposure to EMFs in the vicinity of radio stations
4. K.83: Monitoring of electromagnetic field levels
5. K.90: Evaluation techniques and working procedures for compliance with exposure limits of network operator personnel to power-frequency EMF
6. K.91: Guidance for assessment, evaluation and monitoring of human exposure to RF-EMF
7. K.100: Measurement of RF-EMF to determine compliance with human exposure limits when a base station is put into service
8. K.113: Generation of RF-EMF level maps
9. K.121: Guidance on the environmental management for compliance with RF-EMF limits for radiocommunication base stations
10. K.122: Exposure levels in close proximity of radiocommunication antennas

New Supplements ITU-T K on EMF

1. Suppl. 9: 5G technology and human exposure to RF EMF
2. Suppl.10: Analysis of EMF compatibility aspects and definition of requirements for 5G mobile systems
3. K.Suppl.13: RF-EMF exposure levels from mobile and portable devices during different conditions of use
4. K.Suppl.14: Impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment
5. K. Suppl. 16: EMF compliance assessments for 5G wireless networks
6. K. Suppl. 19: EMF strength inside underground railway trains
7. K.70 Appendix I – Software: EMF-estimator

Additional Bibliography

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2. Gati et al., 2009 'Exposure induced by WCDMA mobiles phones in operating networks'
3. Glatte et al., 2019 'Architecture of the Cutaneous Autonomic Nervous System'
4. ICNIRP 1998 ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHZ)
5. ICNIRP 2010 ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1HZ – 100 kHz)
6. ICNIRP 2020 ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 KHz to 300 GHz)
7. IEC 62232 2017 'Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure'
8. IEC 62669 Case studies supporting IEC 62232 - Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure …
9. IEEE Std C95.6- 2002 IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz
10. IEEE Std C95.1-2005 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
11. IEEE C95.1-2019 Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
12. Inskip et al., 2010 Brain cancer incidence trends in relation to cellular telephone use in the United States; Neuro-Oncology, Oxford University Press, ITU-R HB 2011 ITU Handbook on Spectrum Monitoring, Chapter 5.6
13. ITU-T FGTR, 2014 EMF considerations in smart sustainable cities; Focus Group Technical Report
14. ITU-R SM.2452, 2019 Report SM.2452 'Electromagnetic field measurements to assess human exposure
15. Mazar H. 2009 An analysis of regulatory frameworks for wireless communications, societal concerns and risk: the case of radio frequency (RF) allocation and licensing
16. Mazar H. 2016 Radio Spectrum Management: Policies, Regulations and Techniques; Chapter 9, 2019 on EMF is public-domain
17. Rowley & Joyner 2012 Comparative international analysis of radiofrequency exposure surveys of mobile communication radio base stations; *Journal of Exposure Science & Environmental Epidemiology* **volume 22**, pages304–315(2012)
18. Rowley J. 2019 RF-EMF presentation at WRC-19, 8 Nov. 2019
19. Sagar et al. 2017 Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: A systematic literature review Journal of Exposure Science and Environmental Epidemiology

Abbreviations and Acronyms

3D	Three Dimensional
3G	3rd Generation mobile technology
4G	4th Generation mobile technology
5G	5th Generation mobile
BR	Basic Restriction
BS	Base Station
CENELEC	European Committee for Electrotechnical Standardization
DRL	Dosimetry Reference Limit
DVB-T	Digital Video Broadcasting - Terrestrial
EHS	Electromagnetic HyperSensitivity
EIRP	Equivalent Isotropic Radiated Power
EMC	ElectroMagnetic Compatibility
EMF	ElectroMagnetic Field
EMR	ElectroMagnetic Radiation
ERL	Exposure Reference Level
ERP	Effective Radiated Power
FCC	Federal Communications Commission
Gbit/s	Giga bits per second
GPS	Global Positioning System
HF	High Frequency
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communication Technology
ICES	International Committee on Electromagnetic Safety (IEEE/ICES)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
ITU	International Telecommunication Union
LAN	Local Area Network
LTE	Long-Term Evolution
M2M	Machine-to-Machine
Mbit/s	Megabits per second
MPE	Maximum Permissible Exposure
NCD	Non-Communicable Diseases
NIR	Non-ionizing Radiation (NIR)
PFD	Power Flux Density
RAN	Radio Access Network
RF	Radio Frequency
SASB	Standards Association Standards Board (IEEE-SASB)
SAR	Specific Absorption Rate
SI	International System of Units
SRD	Short Range Devices
TTT	Transport and Traffic Telematics
UHF	Ultra High Frequency
VHF	Very High Frequency
WAN	Wide Area Network
WHO	World Health Organization
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
xDSL	x-type Digital Subscriber Line