RF Human Hazards

国家无线电监测中心

The State Radio Monitoring Center

State Radio Monitoring Center (SRMC); 9 July 2015; Beijing; China

http://mazar.atwebpages.com/

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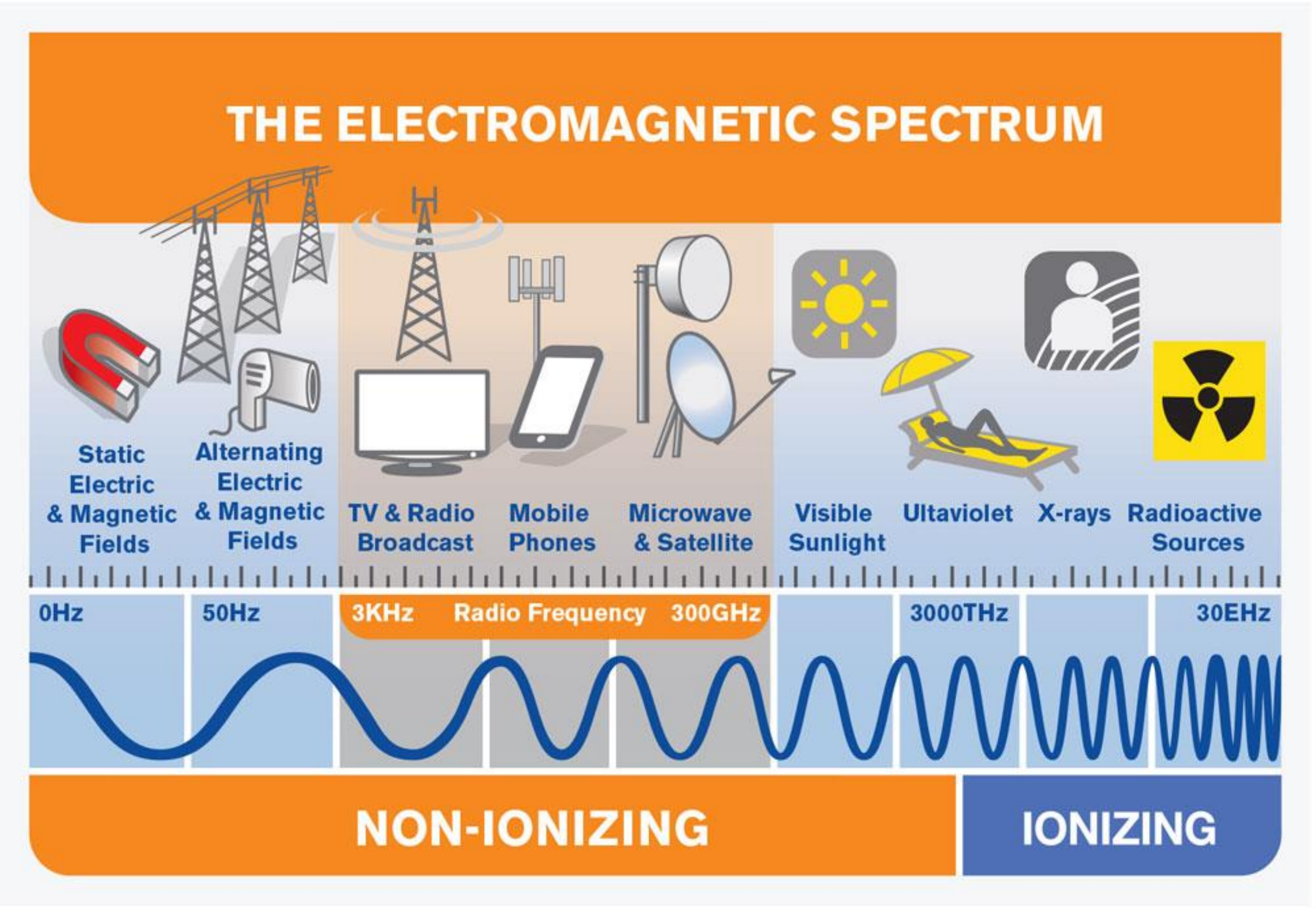
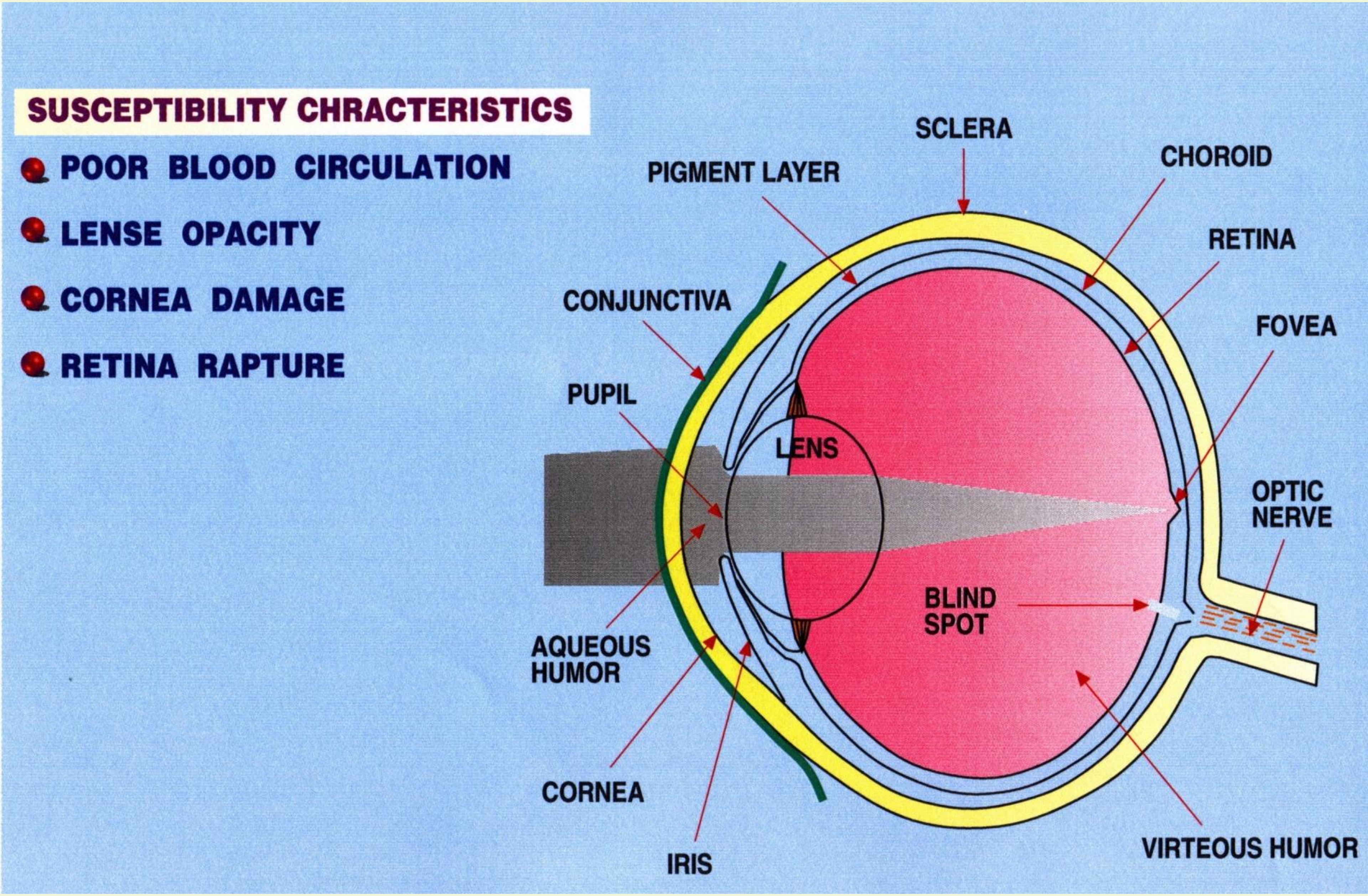
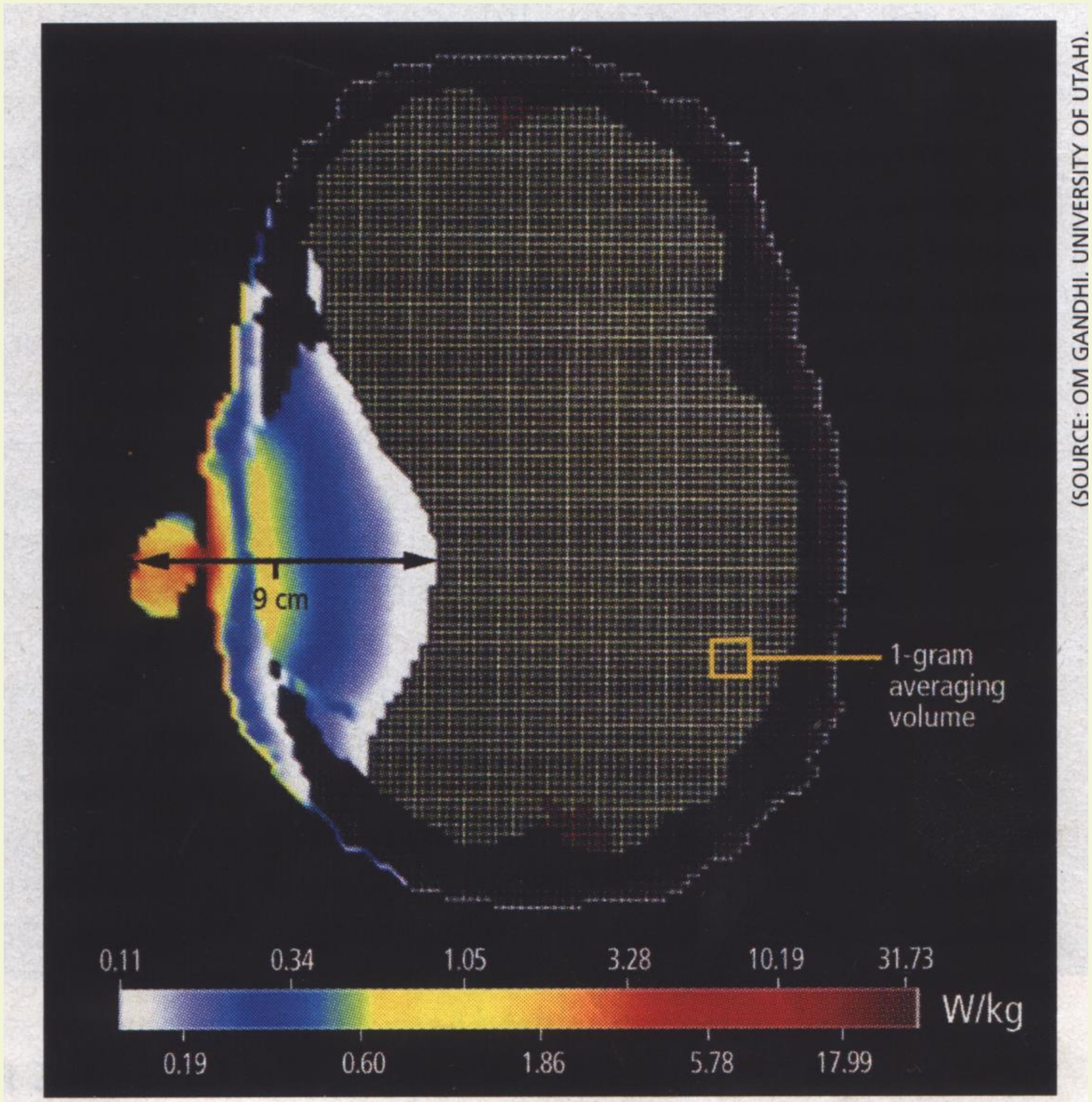


Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*

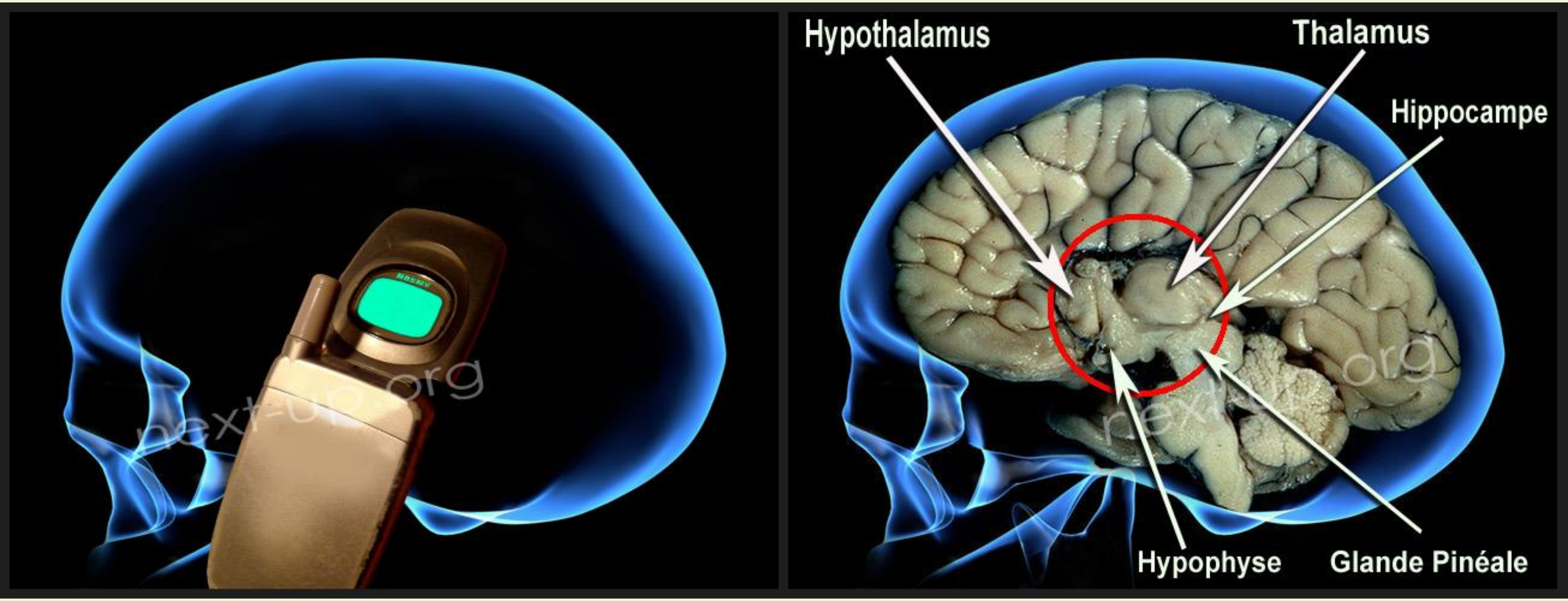
The Human Eye (Moshe Netzer)



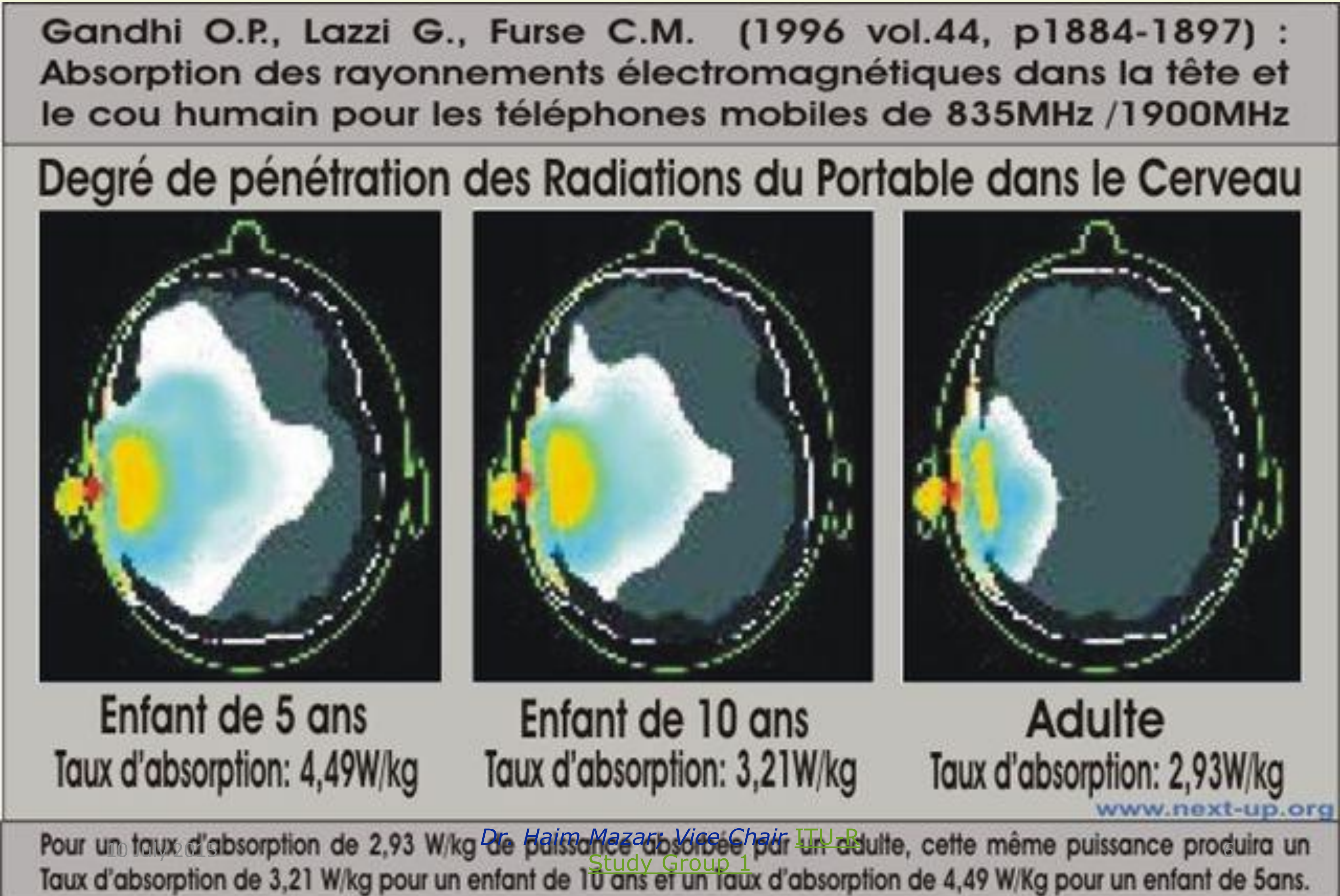
Typical SAR from a Cell Phone (Moshe Netzer)



Brain is Exposed to Cellphone Radiation (Dr. Shalita)



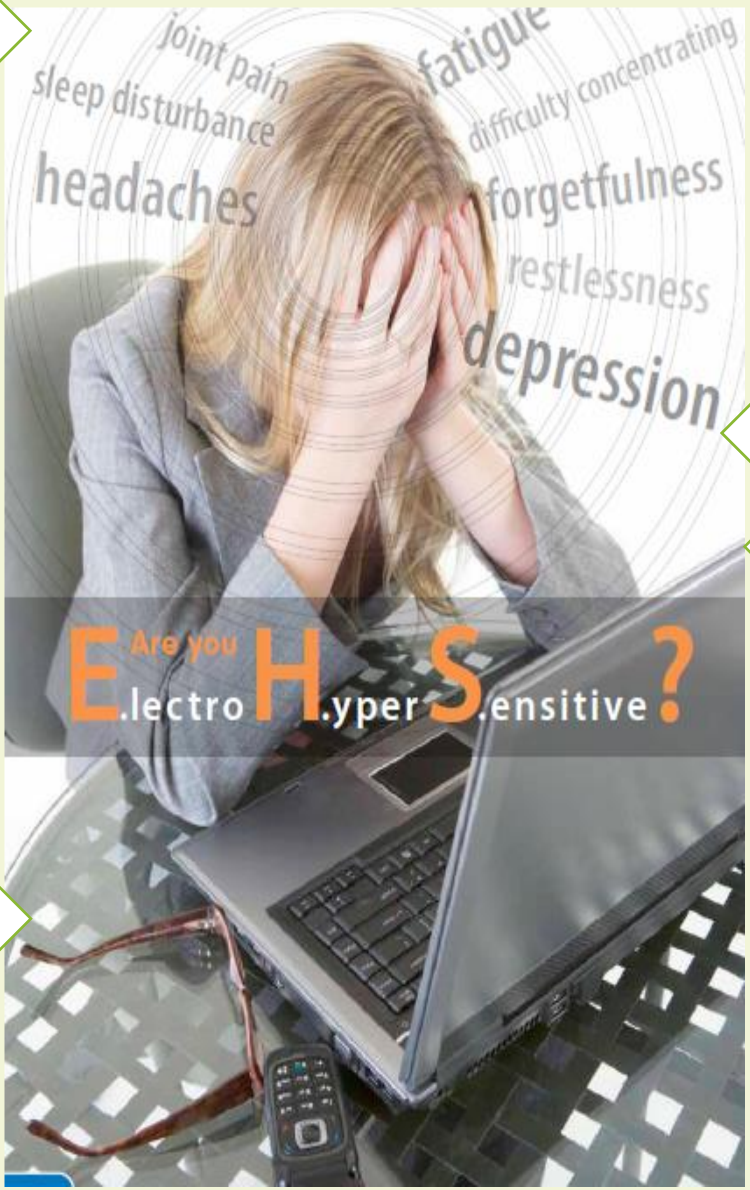
SAR overexposure in the brain



Electromagnetic Hyper-Sensitivity; electro-phobia

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

There is no evidence of causality between pains and RF exposure

Measurement of Radiation (partly Dr. Zamir Shalita, BS.1698)

Questions to be raised

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

- 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 3.5×10^{-3} (= 12.2×10^{-6} of the power density), with the 90% of the schools having a highest compliance factor below 2.9×10^{-4} (**8.4×10^{-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}**.
- 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.

So: **Why do we need to make so many measurements?**

May be ICNIRP reference levels are too high?

Hillel (ex) Radio Antenna: Closed due to hypersensitivity

Yehuda Halevi TelAviv (8.95m)

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

ITU activities on Human Hazards

- ITU Plenipotentiary Resolution 176 (Rev. Busan, 2014) *Human exposure to and measurement of electromagnetic fields*
- ITU-D 2014 Report Question 23/1 *Strategies and Policies Concerning Human Exposure To Electromagnetic Fields*
- ITU-R 2011 Handbook *Spectrum Monitoring, Edition of 2011*, Chapter 5 - Specific monitoring systems and procedures
- ITU-R Recommendation BS.1698 *Evaluating Fields from Terrestrial Broadcasting Transmitting Systems Operating in any Frequency Band for Assessing Exposure to Non-Ionizing Radiation*
- **ITU-T Study Group (SG) 5 Recommendations:**

❖ K.52 *Guidance on complying with limits for human exposure to electromagnetic fields*

❖ K.61 *Guidance on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations*

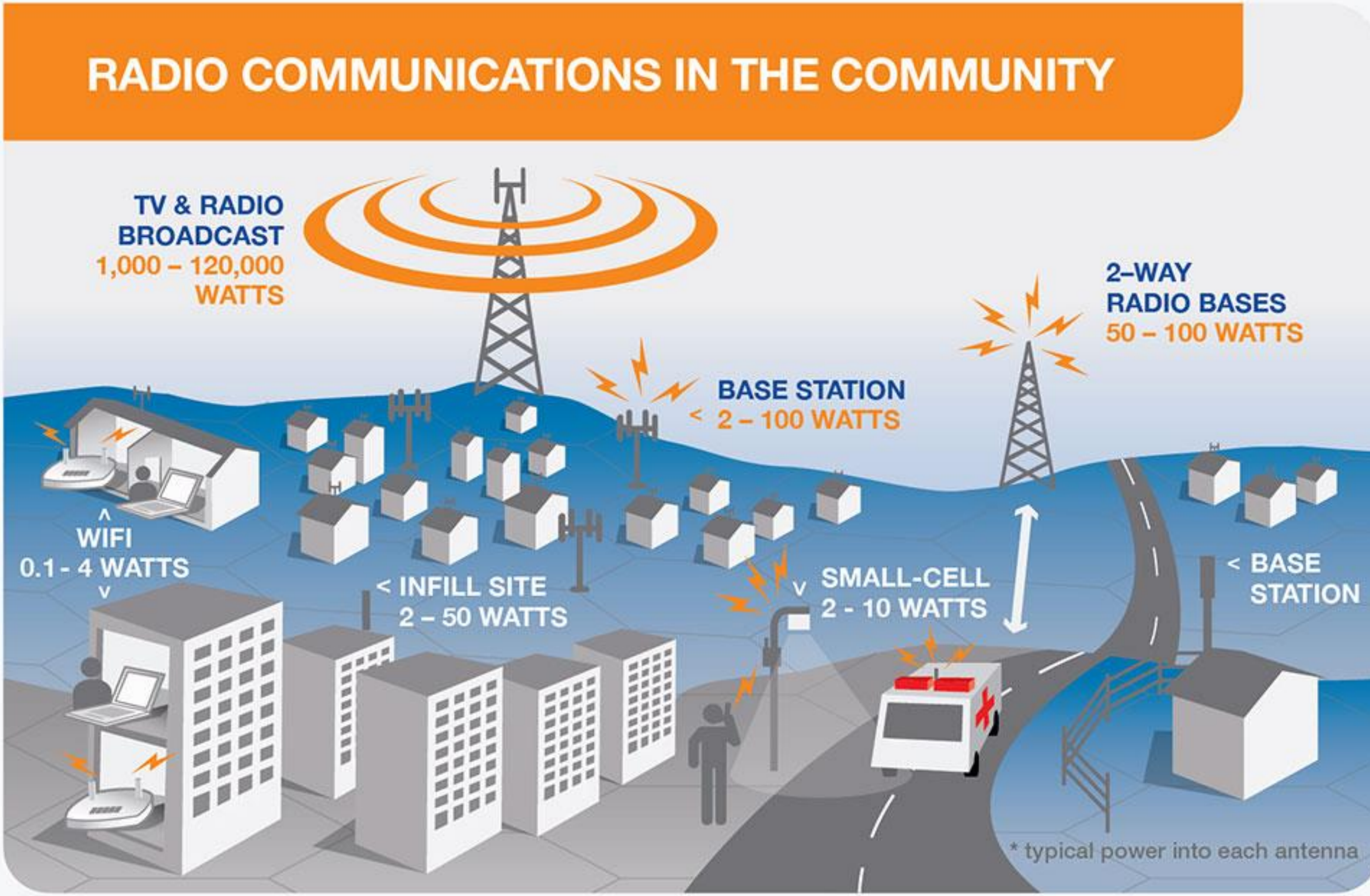
❖ K.70 *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*

❖ K.83 *Monitoring of electromagnetic field levels*

❖ K.91 *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*

- *ITU-T Technical report on "Electromagnetic field (EMF) considerations in smart sustainable cities"*
- **ITU EMF Guide**

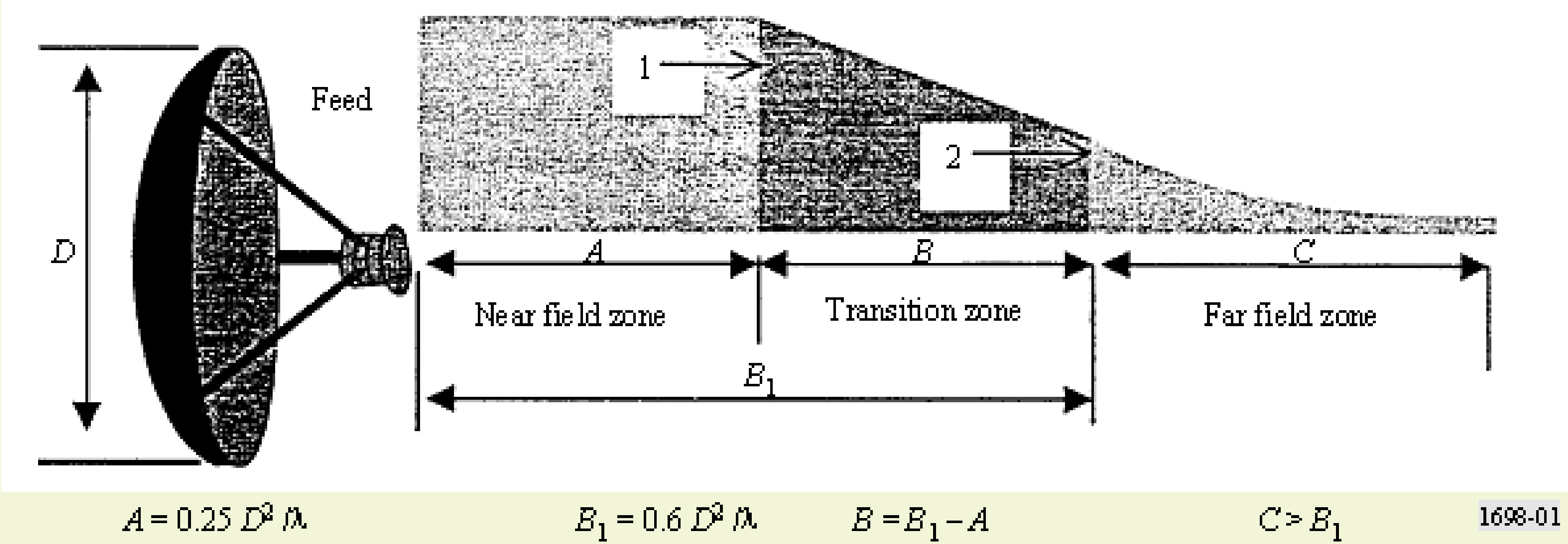
Author is nominated to represent ITU-R Study Groups 1, 5 & 6 on RF human-hazards interesectoral activities
Except BS 1698; the authot is much involved in all these publications



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



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

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

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

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

ICNIRP- Established Effects of EMF (Paolo_Vecchia)

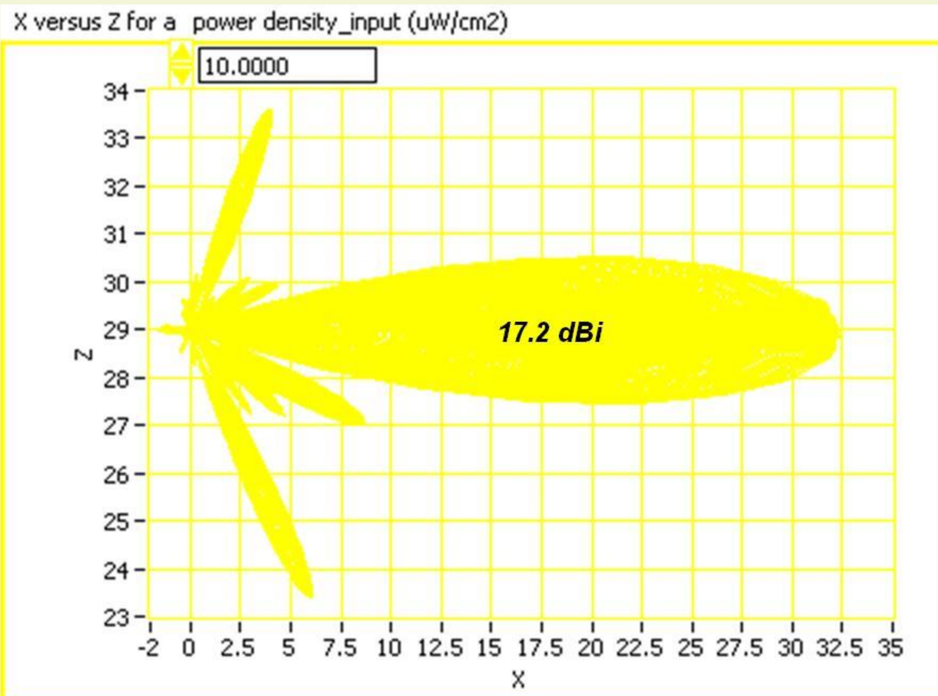
- All effects of EMF that have been established so far are acute in nature

- ELF
- Stimulation of electrically excitable tissues

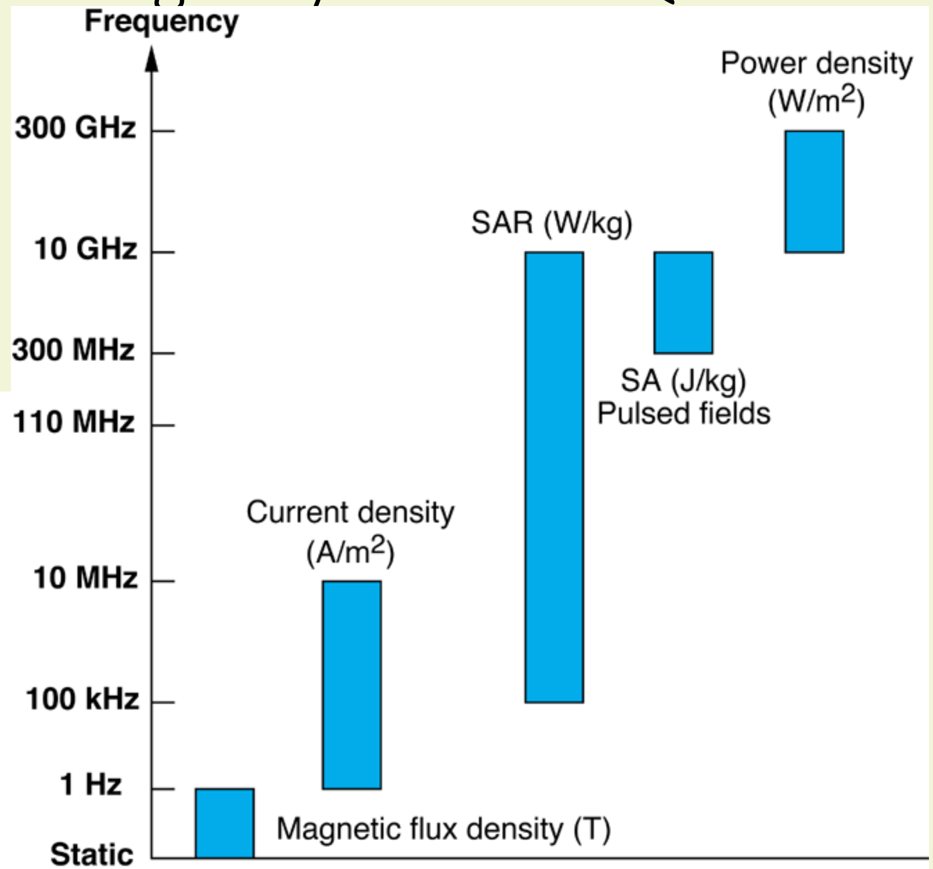
- RF
- Increase of body temperature (general or local)

Such acute effects occur above given exposure thresholds

Biologically Effective Quantities



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



SA: Specific Absorption

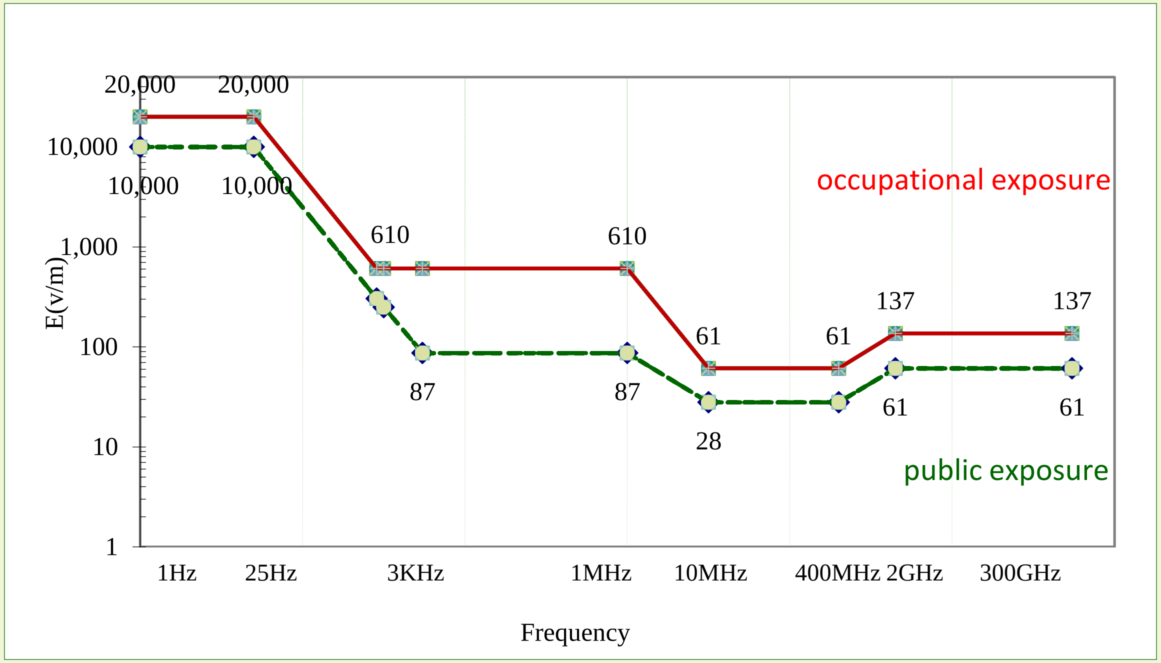
Physical Quantities and Units

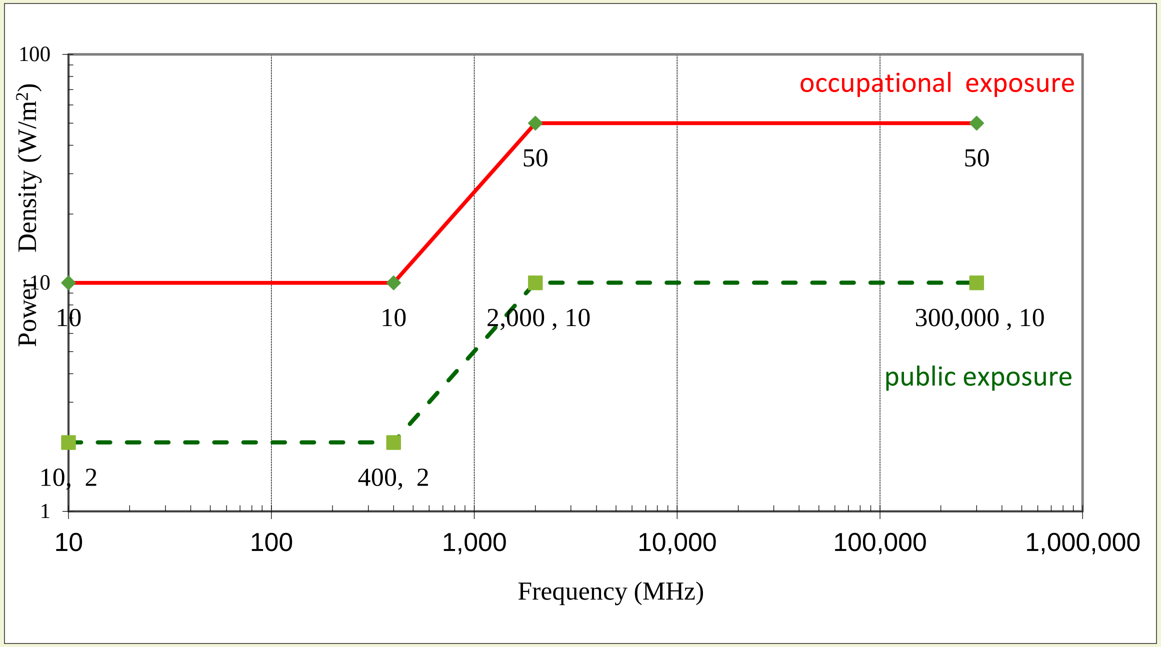
Quantity	Symbol	Unit	Symbol
Frequency	*f*	Hertz	Hz
Electric field strength	*e*	Volt per metre	V/m
Power	*p*	Watts	W
Power density or power flux density	*s*	Watt per square metre	W/m^2
		mWatt per square cm	mW/cm^2
Specific Absorption Rate	*SAR*	Watt per kilogram	W/kg
		mWatt per gram	mW/g

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

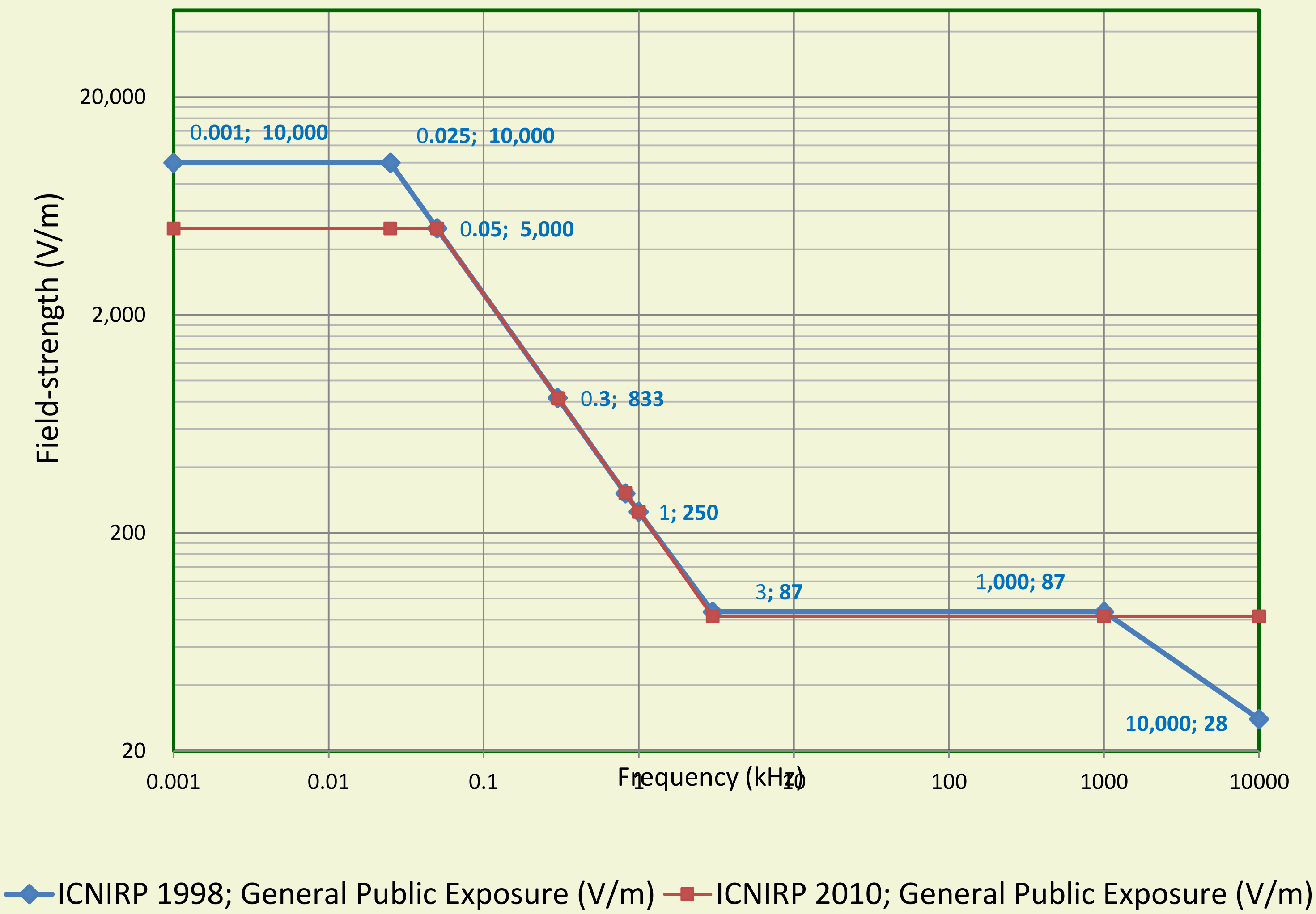
Frequency range	Electric field strength (V/m)		Equivalent plane wave power density S_{eq} (W/m^2)	
	general public	occupational	general public	occupational
1-25 Hz	10,000	20,000	-	
0.025- 0.82 KHz	250/f(KHz)	500/f(KHz)		
0.82 -3 KHz	250/f(KHz)	610	-	
3-1000 KHz	87	610	-	
1-10 MHz	87/f $^{1/2}$ (MHz)	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



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

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)

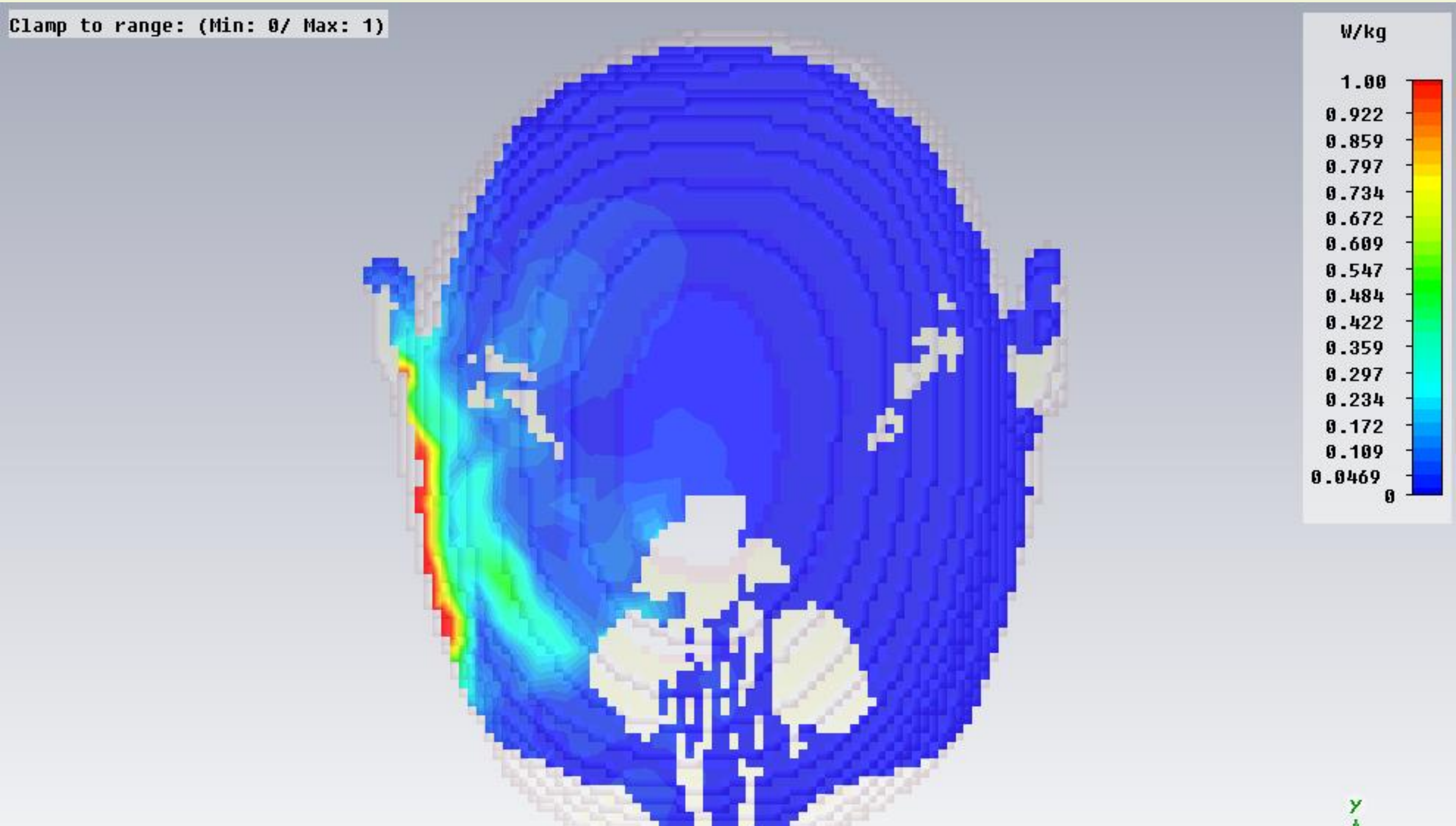
$$\mathrm{SAR} = \frac{\sigma e^2}{\rho} = C_i \frac{dT}{dt} = \frac{J^2}{\sigma\rho}$$

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

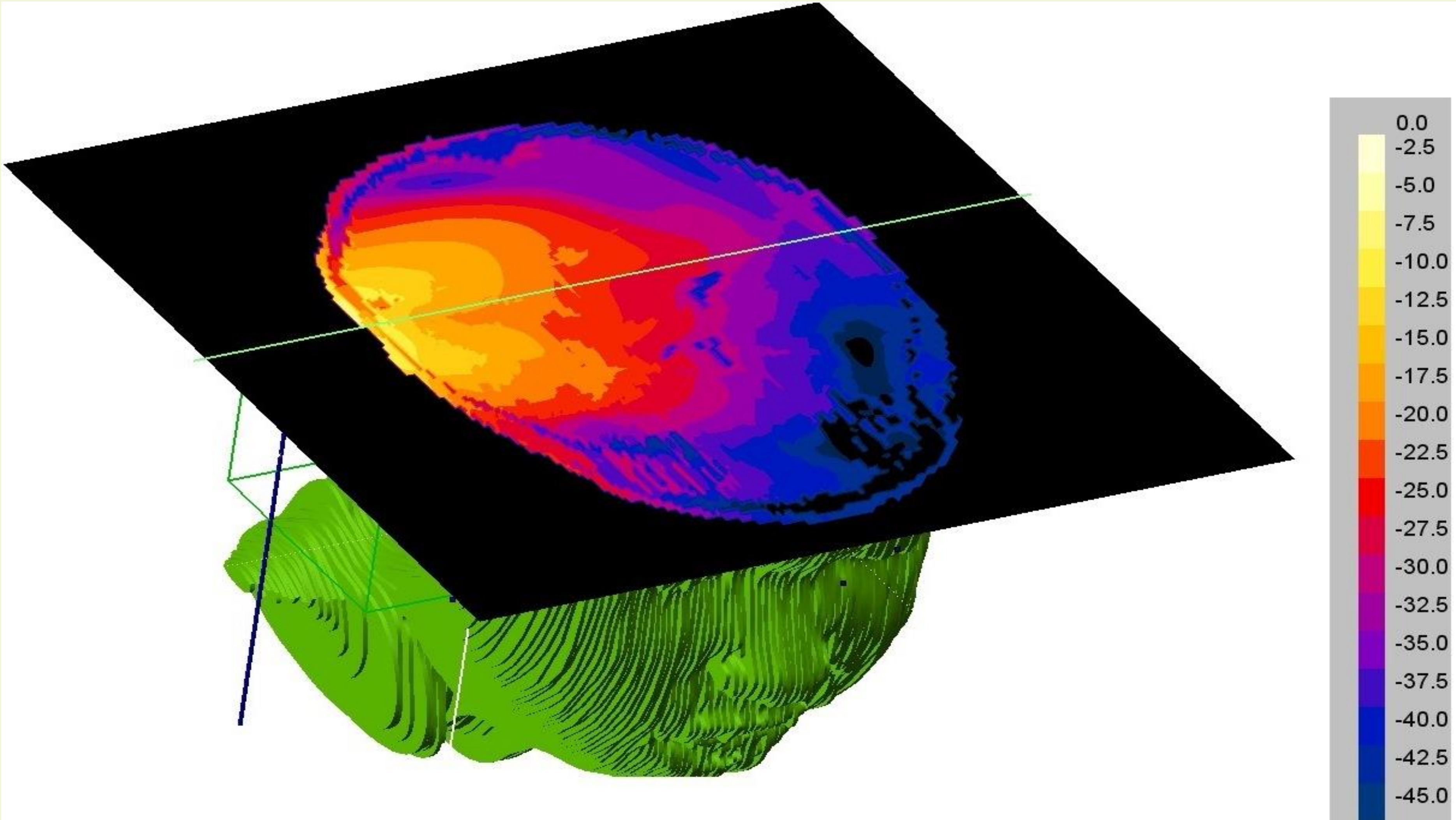
SAR phantom simulation (Stefan Chulski & Stav Revich from HIT)



Type	SAR (rms)
Monitor	SAR (f=0.9) [1] (Point)
Plane at z	763.944
Maximum-2D	8.02639 W/kg at -71.7044 / -14.0005 / 763.944
Frequency	0.9

Numerical simulation of SAR; for a three years child

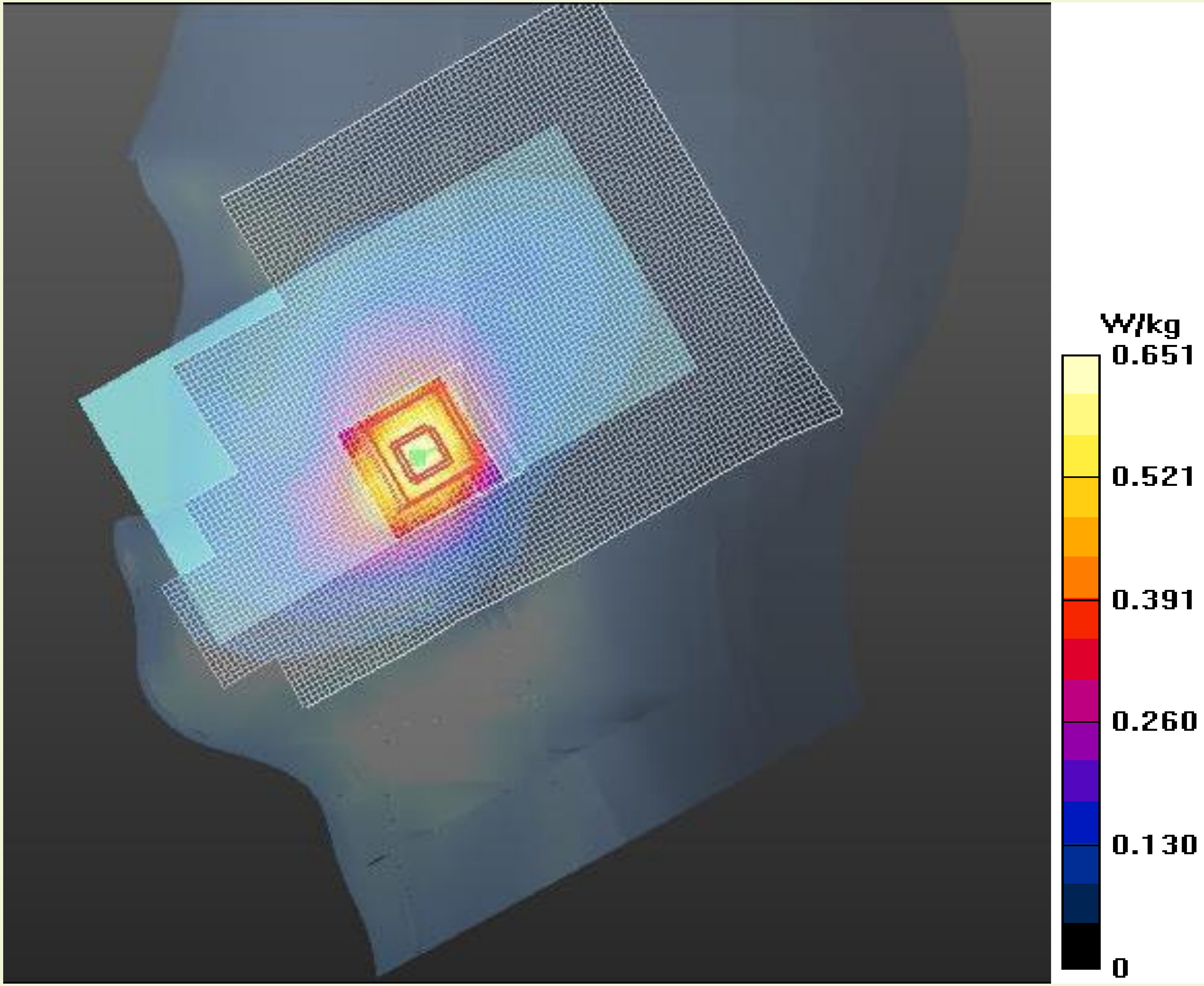
Source: Dr. Jafar Keshvari, Bio-electromagnetics Aalto University, Helsinki-Finland



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

SAR real measurement for a commercial mobile phone

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



FCC 2015 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/cm^2)*	*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 vs. N. America and Japan reference levels

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

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 population/uncontrolled

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	$0.02619x\ f^{0.6834} = 3.88$
3,000 MHz	10 W/m^2		$0.02619x\ f^{0.6834} = 6.23$
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

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

Where

$eirp_i$:	for each emitter	(watts)	
$eirp_{eq}$:	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 limit from each emitter	(W/m²)	index i
e_i :	electric field strength from each emitter	(V/m)	index i
e_{li} :	electric field strength limit 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}

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

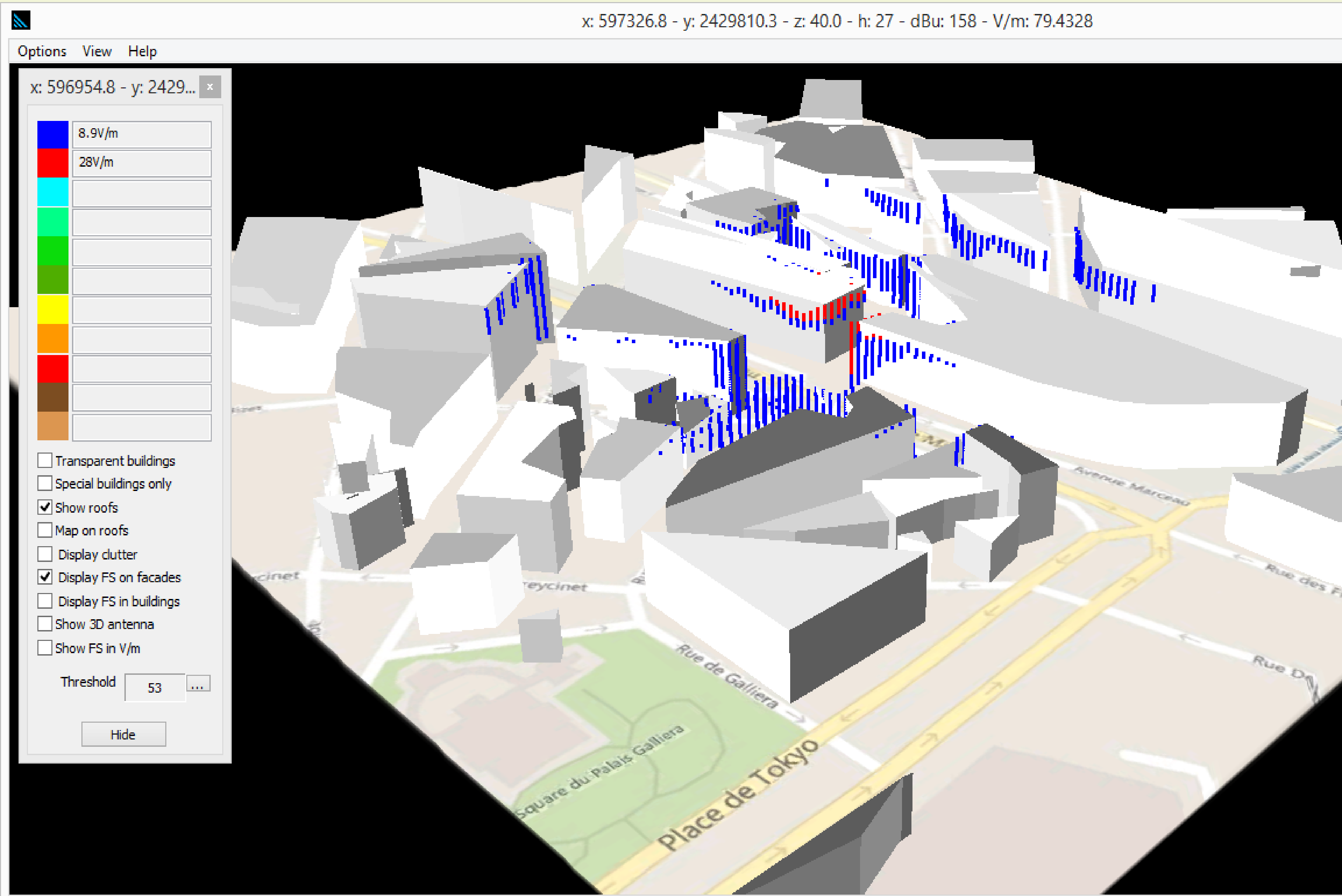
- total cumulative weighted field strength exposure ration w_{t}

See table in next slide, and

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

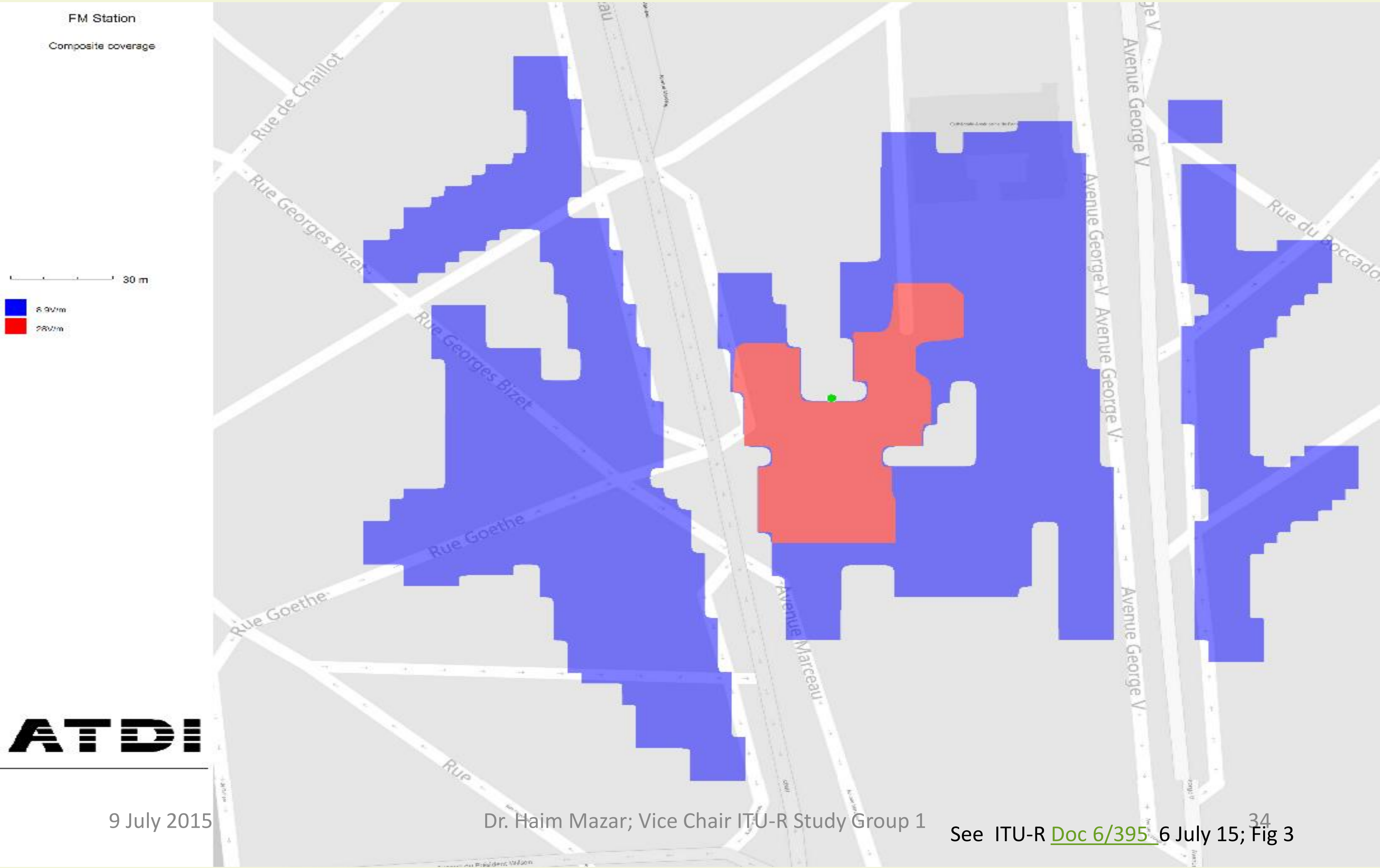
$$w_t = \sum_i \left(\frac{e_i}{e_{li}} \right)^2 \le 1$$

Three dimensions FM safety-distances: 100MHz transmitter of 60,000Watts eirp, 60m



See ITU-R Doc 6/395 6 July 15; Fig 2

2D FM safety-distances: 100MHz transmitter of 60,000Watts eirp, 60m



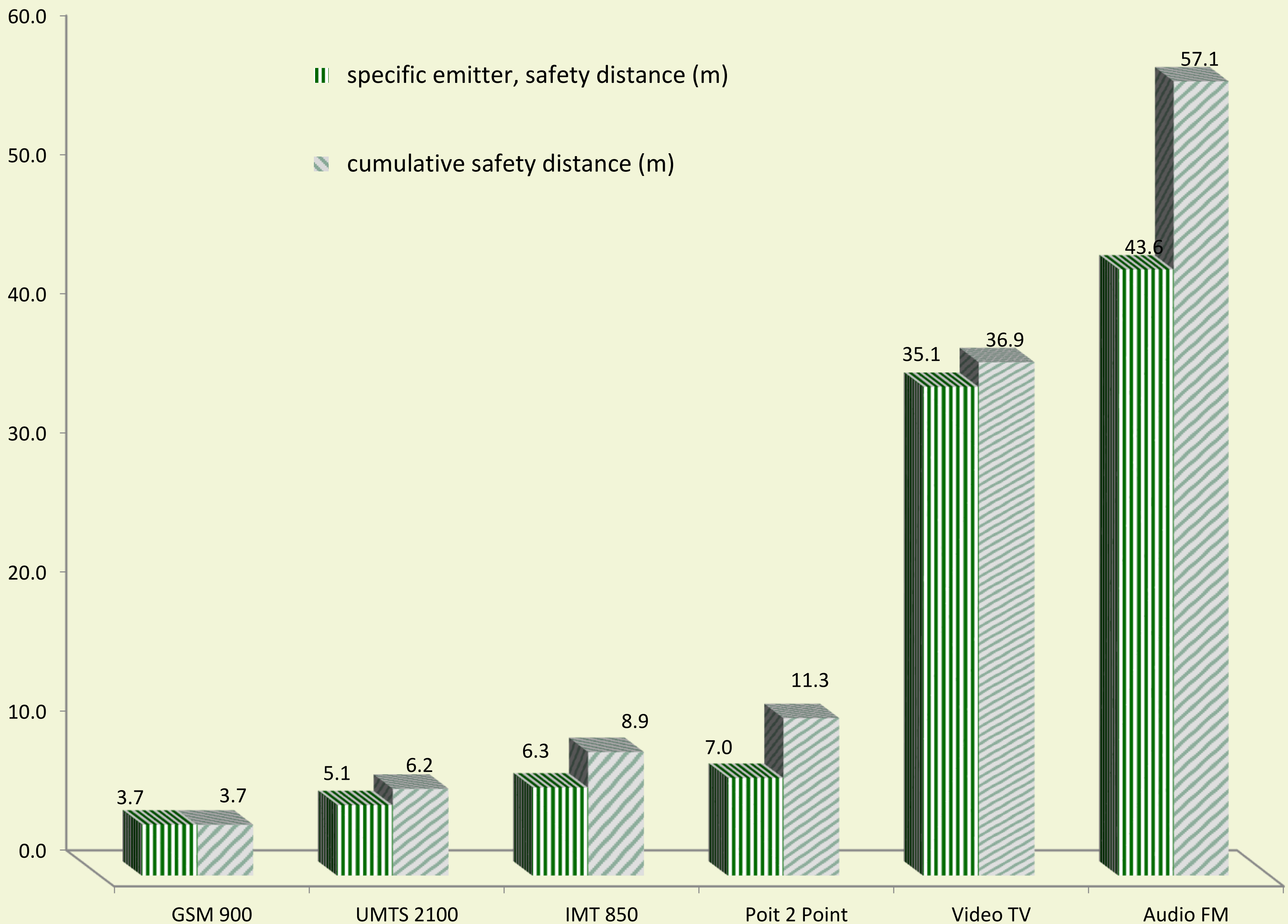
See ITU-R Doc 6/395 6 July 15; Fig 3

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_0824	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

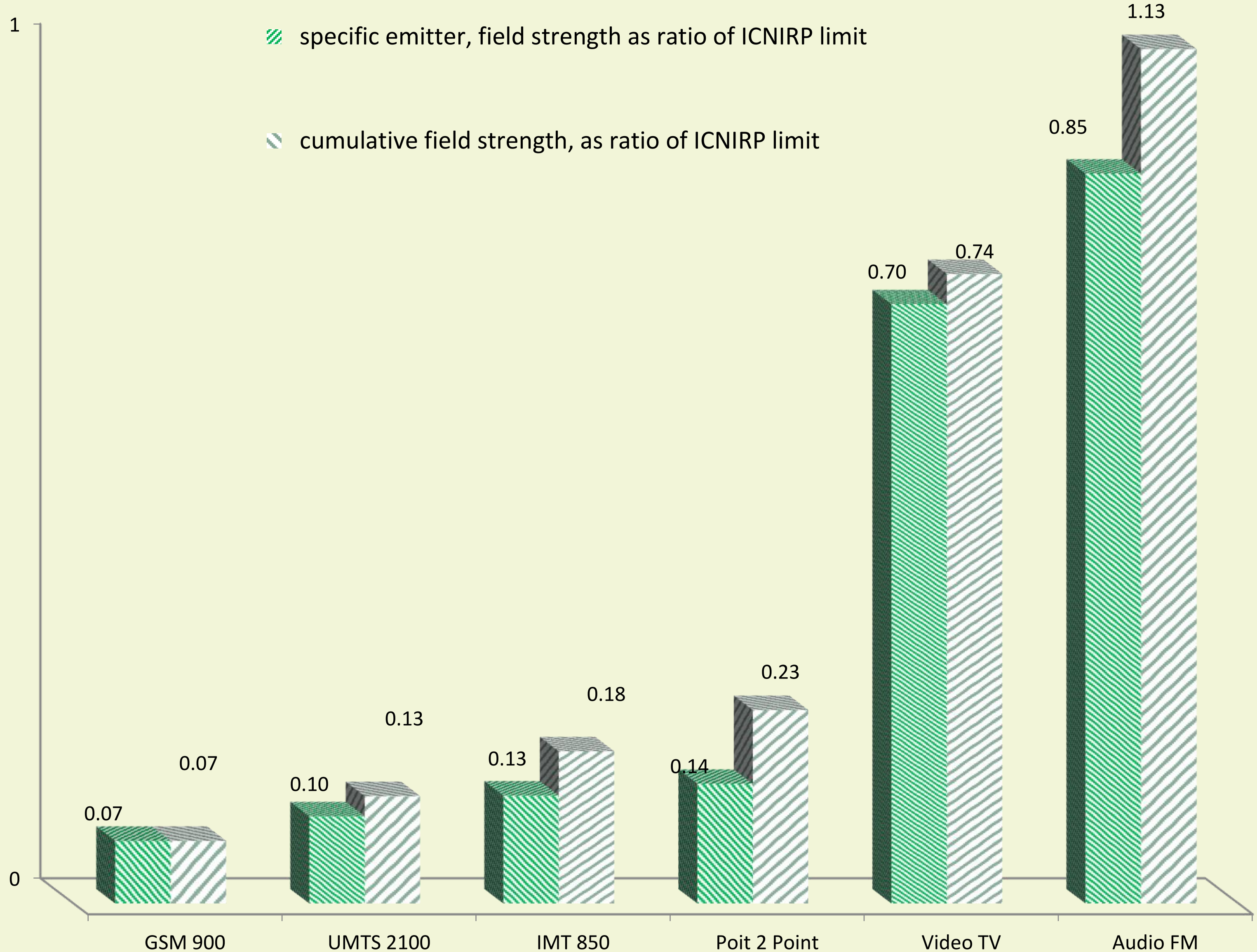
calculated by author

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



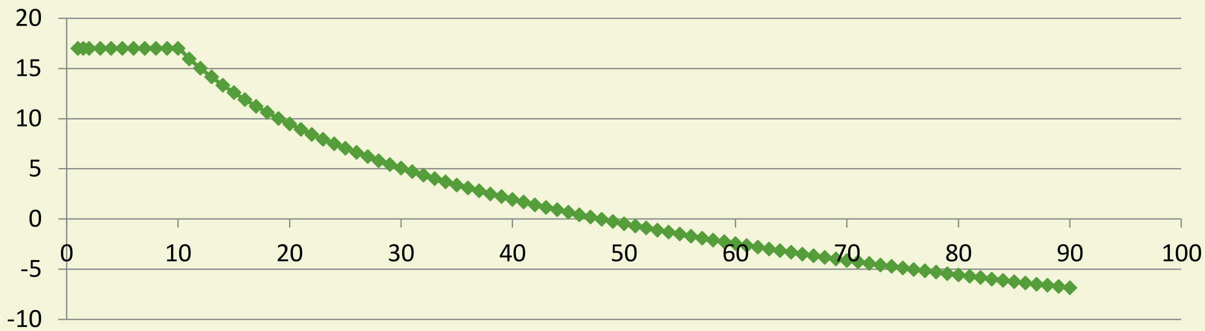
calculated by author

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

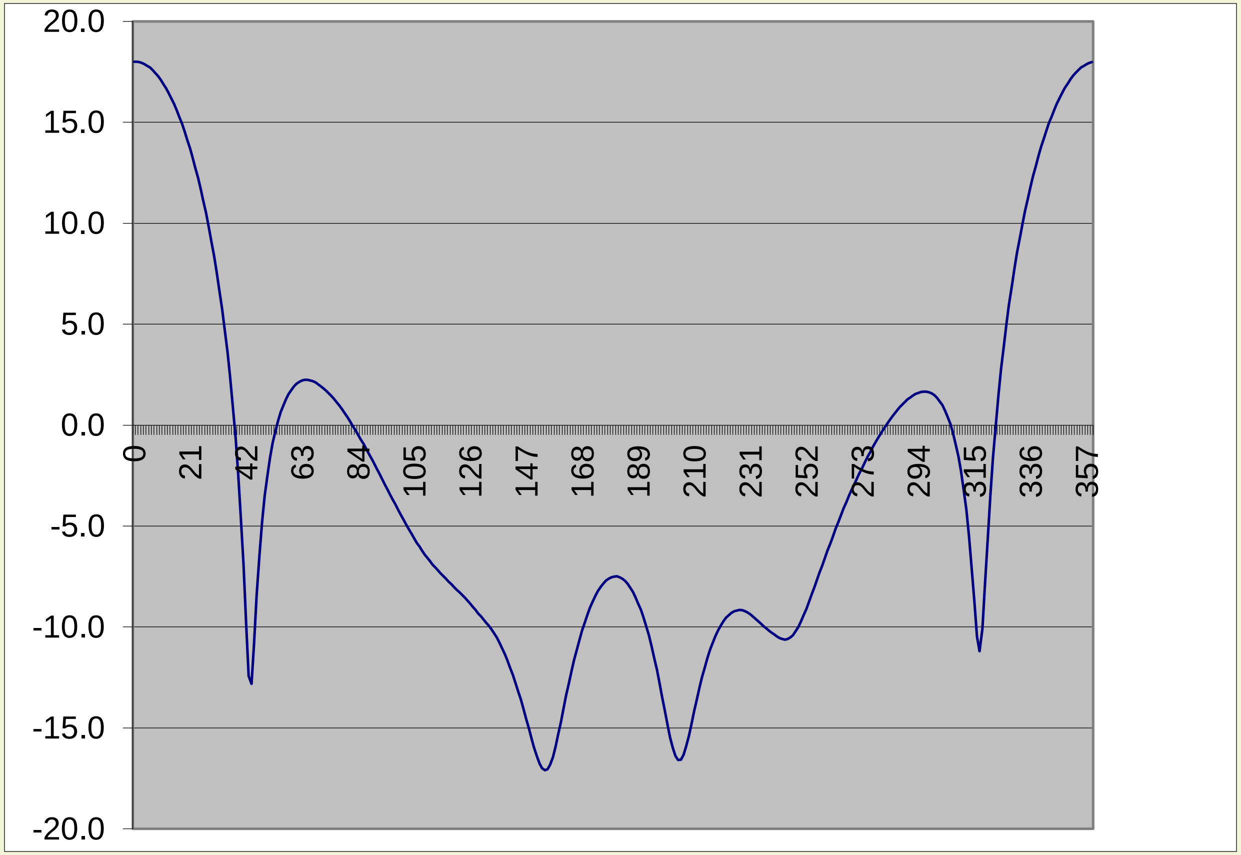


calculated by author

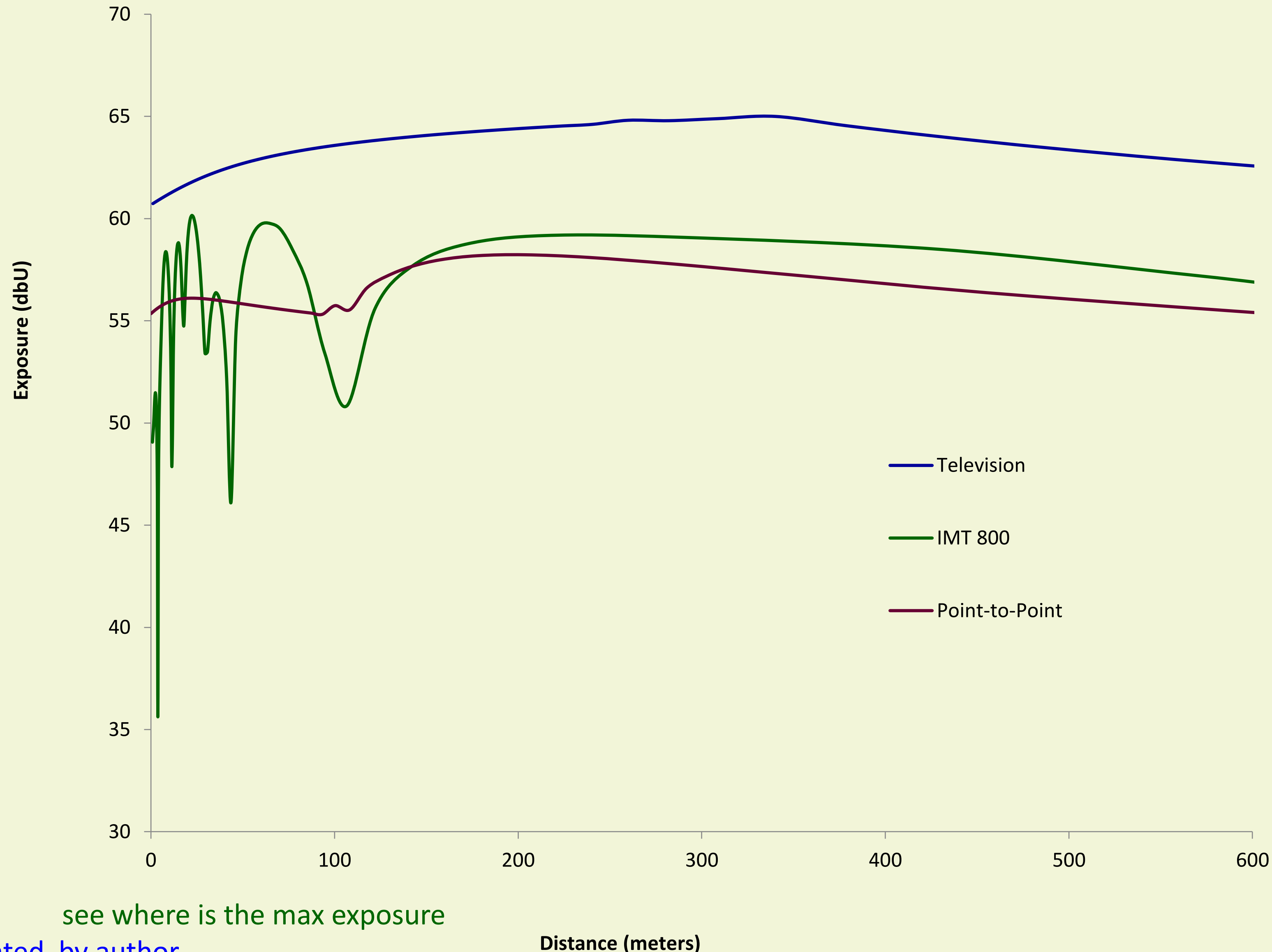
Vertical pattern of TV antenna 17 dBi calculated by ITU-R Rec. F.699



Vertical pattern of 80010302_0824_X_CO_M45_00T; Anatel



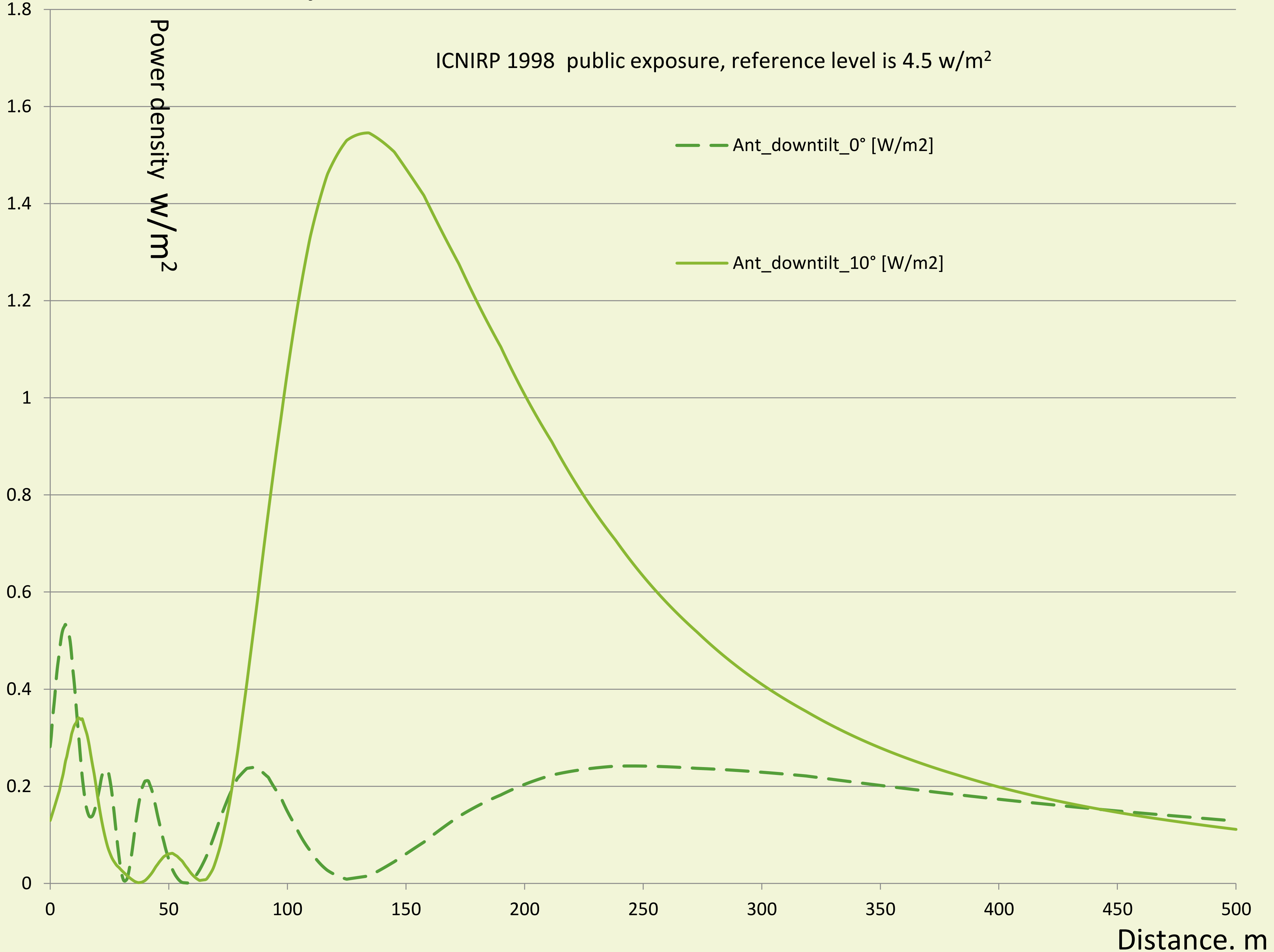
Field Strength (dBµV/m) vs. distance (m), co-located site TV, IMT 850 & Point 2 Point



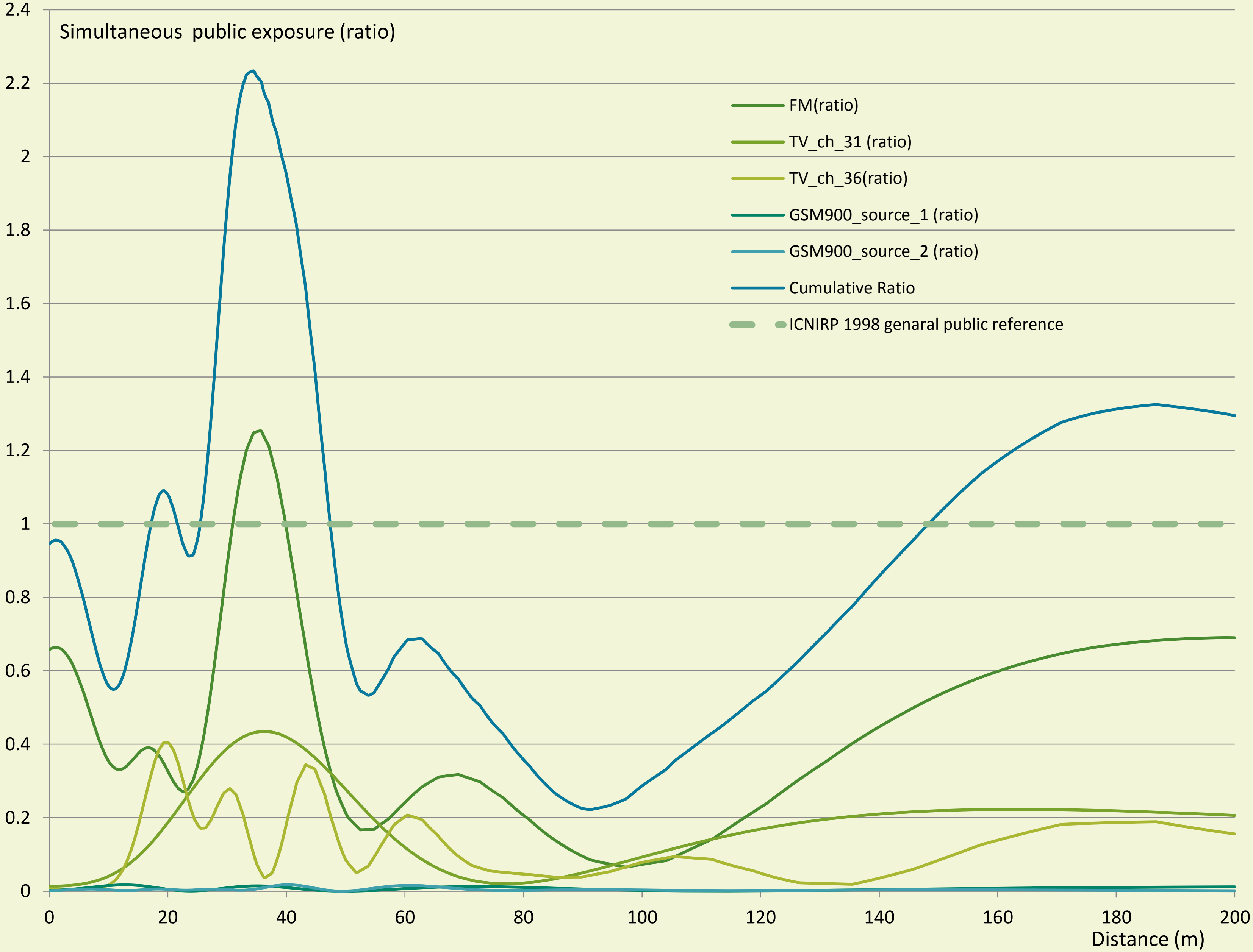
see where is the max exposure

calculated by author

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

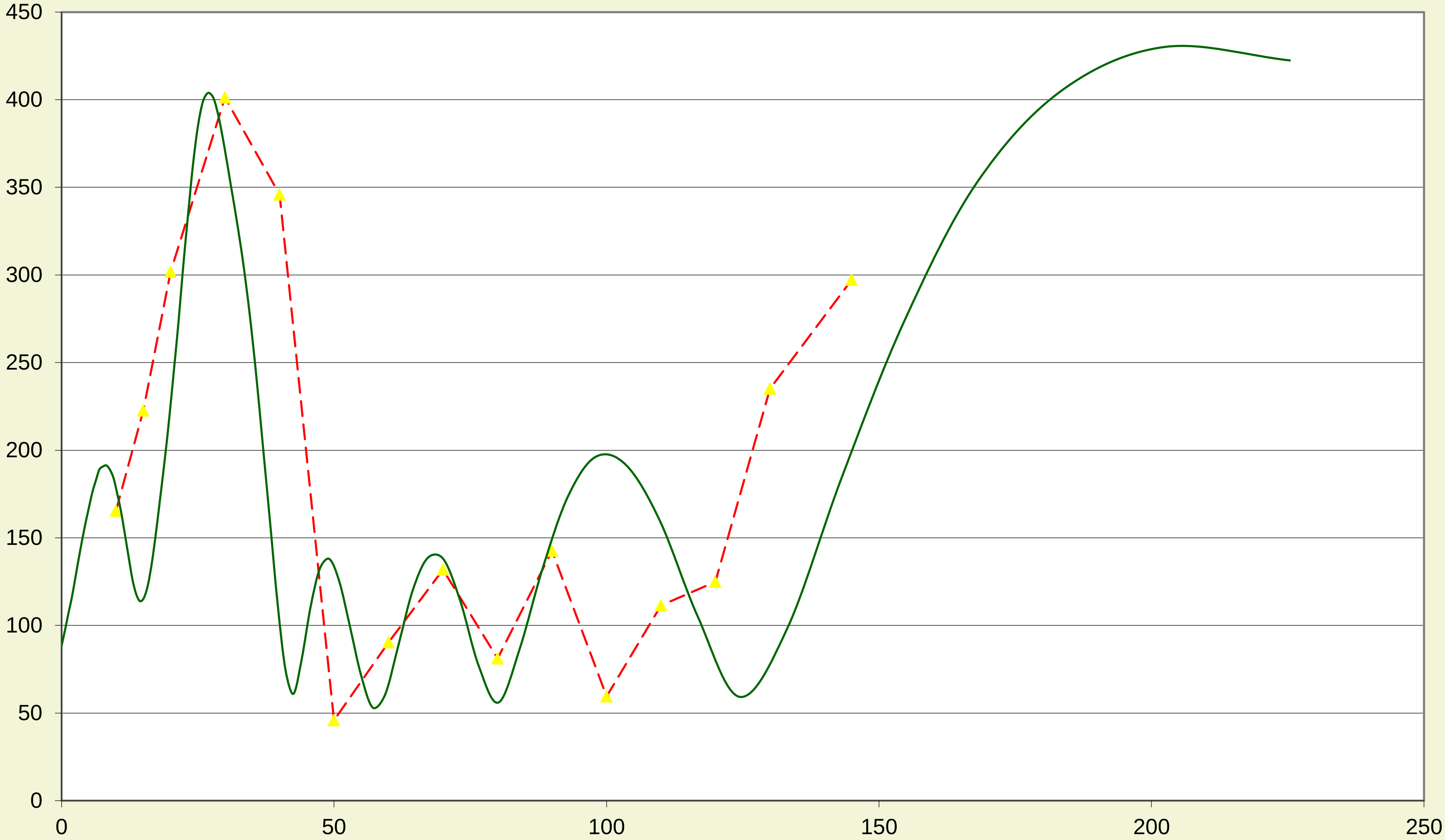


Coefficient W_t vs. distance for co-located site with FM, TV & GSM 900



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

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
  - 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 to be published Oct 2015

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

Related author's presentations

- A Global Survey and Comparison of Different Regulatory Approaches to Non-Ionizing RADHAZ and Spurious Emissions, IEEE TelAviv, COMCAS, November 2009. Hyperlink to the slides presentation; 9 November 2009
- A Comparison Between European and North American Wireless Regulations, presentation at the 'Technical Symposium at ITU Telecom World 2011' www.itu.int/worl2011 on 27 October 2011; hyperlink to the slides presentation, 27 October 2011
- Technical limits of Human Exposure to RF from Cellular Base Stations and Handsets, Jerusalem, 11 April 2013. Professional presentation of the Ministry of Communications to the experts of Ministry of Environmental Protection, human-exposure monitoring laboratories and cellular operators
- Technical limits of Human Exposure to RF from Broadcasting Emitters, Cellular Base Stations and Handsets, at 'Holon institute of technology', 30 January 2014
- Smart_Cities_RF_Human_Exposure_Ministries_of_Comms_Energy.pdf; presentation at intra-ministerial commission, on 21 January 2015

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Any Questions ?