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Human Radio Frequency Exposure Limits: an update of reference levels in Europe, USA, Canada, China, Japan and Korea

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Abstract— Compliance with human exposure limits for electromagnetic fields (EMFs) is a significant health and safety issue to regulators, service providers and wireless equipment suppliers. The recent exposure limits are reported. The Specific Absorption Rate (SAR) and the power-density (PD) reference levels in European countries, USA, Canada, China, Japan and Korea are compared and contrasted. The allowed SAR cellular handsets' exposure limits for localized heating are more restrictive in the USA, Canada and Korea (1.6 W/kg), relative to others (2 W/kg). Even the averaging is more restrictive: averaged over 1 g in N. America and Korea, versus 10 g tissue in [ICNIRP 1998](#) and [ANSI/IEEE C95.1-2006](#). Europe in general follows the ICNIRP 1998 PD levels from base stations. Despite the (non-mandatory) EU Council Recommendation [1999/519/EC](#), some EU countries adopt more restrictive thresholds. USA and Japan are the most liberal countries, adopting in 300–1,500 MHz power-density 4/3 of the ICNIRP1998 and IEEE 2006 levels. On 13 March 2015, Health Canada revised the 2009 PD limits (that were identical to the USA), and published more restrictive reference levels. There is no scientific reason to use different exposure limits in different countries. Some explanations of the different limits are provided.

Keywords — *ANSI/IEEE C95.1-2006, Canada Safety Code 6, EMF, ICNIRP 1998, ICNIRP 2010, IEEE C95.1-1999, Specific Absorption Rate (SAR), power-density.*

I. INTRODUCTION

The proliferation of cellular base stations and wireless fixed installations around the world, the public dislike of large antenna structures and the concern in some countries against EMF exposure has led to constraining legislations and regulations to ensure protection of the public. Some countries adopt restrictive limits (lower RF thresholds), that are at odds with those of the international community. The EMF levels continue to increase due to the operation of more wireless systems. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) 1998 Guidelines provide reference levels

for general public and occupational exposure. Countries (and even cities) set different exposure levels around base stations. For example, at 1,000 MHz the allowed PD levels (W/m²) are 6.7 in USA and Japan, 5 in ICNIRP 1998, Europe and the Republic of Korea, 2.94 in Canada and 0.4 in China. The case study countries represent most countries in the world. The ICNIRP guidelines are backed by the World Health Organization ([WHO](#))¹, and constitute the current scientific 'consensuses'. Nevertheless, national regulations have a priority status in their countries. As influenced by social-economic-political factors, the values adopted in each country may vary. The [ICNIRP 1998](#) [1] reference levels are widely accepted worldwide and countries', threshold are compared to these reference levels. Additional Tables and Figures appear in the author's new Wiley book [2], Chapter 9 'Human Hazards'. Exposure limits in [various countries](#) are found at [3] Fig. 2. In addition to the [ICNIRP 1998](#) Guidelines, various institutions define the limits for international (e.g., IEEE) and specific regions (e.g., European Council). The paper starts with evaluating the SAR exposure limits from cellular handsets and wireless equipment, then details the exposure limits from base stations above 10 MHz, and summarizes the reference levels in a sample of countries around the world.

II. EXPOSURE LIMITS: CELLULAR HANDSETS

A. SAR near-field versus PD far-field

The general public receives the highest exposure from handheld devices (connected to cellular or Wi-Fi networks), which deposit most of the RF energy in the brain (phones) and surrounding tissues (notebooks). Typical environmental exposures to the brain from handsets are several orders of magnitude higher than those from mobile-phone base stations on rooftops or

¹ New WHO reference <http://www.who.int/gho/phe/emf/legislation/en/>

from terrestrial television and radio stations [4], [5] and [6]. The relevant exposure limits for handsets are those related to the localized heating, because of the proximity of the body; whereas for base stations, whole body effects are the limiting factor. The exposure limits for fixed transmitters refer to the field-strength and PD generated, whereas near-field handset exposure limits are considered mainly by the SAR value. The far-field signal (easily simulated and measured) is practical to analyse EMF human exposure, radiated from the fixed wireless base stations. The handset is used in the proximity of the user's body; the body configuration, in conjunction with the handset design, has a strong impact on the near-field EMF and energy absorption in tissues.

B. Comparing SAR values

There are two diverse SAR and averaging levels: the 1.6 W/kg, averaged over 1 g, is based on dosimetric considerations related to non-uniform absorption of energy; whereas the 2 W/kg, averaged over 10 g, has a biophysical rationale related to the eye.

- [FCC, OET Bulletin 65](#) p. 40 and [OET Bulletin 65 Supplement C](#) p.75 specify the 1.6 W/kg;
- [ICNIRP 1998](#) p. 509 Table 4, [EC 1999/519/EC](#) and ANSI/IEEE [C95.1-2006](#) specify the 2 W/kg.

Like USA and Canada, the Republic of Korea ([7] and [8]) follows SAR exposure limits, based on the [IEEE Std C95.1-1999](#) [9].

Table 1 compares allowed SAR in studied countries.

Table 1: Maximal SAR (W/kg) around the world

ICNIRP 1998	European Community, Japan and China	Korea, USA and Canada ^a
From 10 MHz to 10 GHz; localized SAR (head and trunk)		portable devices
2.0; averaged over 10 g tissue (it is also ANSI/IEEE C95.1-2006 level, p.79)		1.6; averaged over 1g tissue

^a Reference [10], the U.S. CFR 47 [FCC §2.1093](#) Section 2, states 'averaged over any 1 gram of tissue'; whereas [11], [Canada Safety Code 6](#) Table 2, states 'peak spatially-averaged SAR for the head, neck & trunk'

III. EXPOSURE LIMITS: BASE STATIONS

A. ICNIRP (Europe & Korea) Reference Levels

Reference [1], [ICNIRP 1998](#) p.511, defines the reference levels as guidelines for occupational exposure (Table 6) and general public exposure (Table 7) to time-varying electric field (unperturbed rms values). The 1998 guidance includes heating effects for frequencies above 100 kHz, whereas the [ICNIRP 2010](#) [12] guidance includes consideration of nervous system effects only. In the range 100 kHz to 10 MHz, the reference level relevant for protection against nervous system effects is independent of frequency; by contrast, the reference levels relevant when heating is taken into account are frequency dependent, and reduce over the range 100 kHz to 10 MHz. In order to ensure protection against both nervous system and heating effects, at the frequency of interest, use whichever of field-strength is the lower.

Below 10 MHz (wavelength 30 meters), nervous effects on human body are mostly at near-field conditions; the reference levels are provided mainly for the electric field-strength (V/m). Between 10 MHz and 300 GHz, the reference levels are also provided in PD (W/m²), to prevent excessive heating in tissue at or near the body surface. The PD of the general public exposure is five times lower than the occupational exposure. The following Tables and Figures specify the reference ICNIRP 1998 levels at different frequencies. Table 2 specifies the [ICNIRP 1998](#) 'varying electric-field' and 'equivalent plane wave power-density' reference levels, above 10 MHz.

Table 2: ICNIRP reference levels above 10 MHz

Frequency range	field-strength (V/m)		PD (W/m ²)	
	general public	occupational	general public	occupational
10–400 MHz	28	61	2	10
400–2,000 MHz	$1.375f^{1/2}$	$3f^{1/2}$	$f/200$	$f/40$
	$f = \text{frequency in MHz}$			
2–300 GHz	61	137	10	50

Fig. 1 ([2] Fig. 9.2) depicts the [ICNIRP 1998](#) PD reference levels for occupational and general public exposure above 10 MHz.

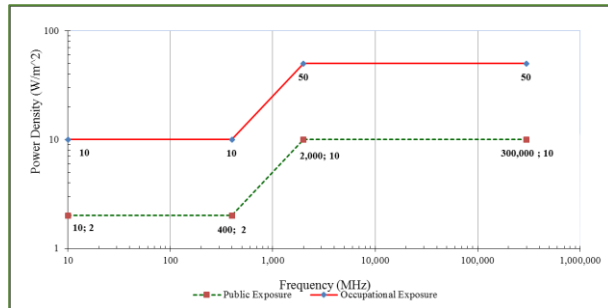


Fig. 1 ICNIRP power-density reference levels

For fixed radiating stations, the exposure limits for general public, unperturbed and uncontrolled environment (unlike the workers/ controlled/ occupational case) are the most relevant to the public. Telecommunications regulators tend to focus on public exposures, but other regulatory authorities are often interested in worker exposures. The European Union (EU) [Directive 2013/35/EU](#) ([13] Annex III Table B1) adopted ICNIRP values for exposure of workers. The ‘general public’ limits of [ICNIRP 1998](#) (Table 7) and the European Community (EC) [1999/519/EC](#) ([14] Annex III Table 2) are identical, since ICNIRP levels have been endorsed by the European Commission’s Scientific Steering Committee [15] [2015 SCENIHR Opinion](#). [ICNIRP 1998](#), [1999/519/EC](#) and ANSI/IEEE [C95.1-2006](#)² [16] for radiations from (mainly) fixed stations above 10 MHz specify closely identical exposure limits. Fig. 2 [3] depicts, that most countries adopt the [ICNIRP 1998](#) reference levels for the public.

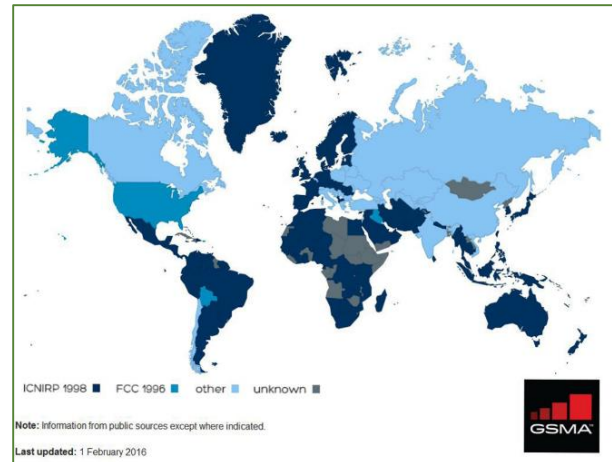


Fig. 2 Map for country specific RF limit information

C. The USA and Japan

The USA and Japan regulate similarly the PD reference levels. According to [FCC 1997 OET Bulletin 65](#) and FCC [Code of Federal Regulations CFR 47§1.1310](#) [17], the FCC is still based mainly on the [IEEE Std C95.1-1999](#) [9]. This standard was revised by in IEEE [C95.1-2006](#) [16], but not adopted by FCC. ANSI approved IEEE C95.1-2005 in 2006, and therefore it is designated as ANSI/IEEE [C95.1-2006](#). The official U.S. RF radiation exposure limits on 8 May 2016 ([17] Table 1 CFR 47 [FCC §1.1310](#)) at 400–1500 MHz are 4/3 less restrictive than the [ICNIRP 1998](#) guidelines reference levels. The international recommended PD at 400–1500 MHz is f (MHz)/200 W/m²; at the 300–1,500 MHz range, the US (and Japan³) thresholds are f (MHz)/150 W/m². Despite discussions, FCC [§ 1.1310](#) ‘radiofrequency radiation exposure limits’ keeps the limits for Maximum Permissible Exposure (MPE) (and SAR) limits un-changed; see [NOI FCC 13-39 or R&O FCC 03-137](#) 2013; FCC has received comments, but has not taken further action in this [proceeding](#).

The Japanese [pamphlet](#)⁴ (March 2015) ([18] p. 5) specifies the same PD limits as FCC. The upper RF limit in Japan is 300 GHz and not 100 GHz as in USA. Table 3 specifies the FCC [§1.1310](#) and Japan above 30 MHz. It details MPE limits for radiating emitters in uncontrolled environment: general public exposure.

² ANSI/IEEE [C95.1-2006](#) (p. 25 Table 9) exposure values are similar (not to FCC) to the [ICNIRP 1998](#) level ($f_{\text{MHz}}/200$ W/m²); at 10–400 MHz the IEEE electric field (E) and FCC are 27.5 (V/m), compared to 28 (V/m) the [ICNIRP 1998](#). IEEE provides an additional equation above 100 GHz: $[(90 \times f_{\text{GHz}} - 7,000)]/200$ W/m²

³ Japan and USA use different units than ICNIRP for PD, mW/cm² and not W/m²; to convert: W/m² = 0.1 mW/cm²

⁴ Levels endorsed by K. Yoshida, Japan’s telecoms bureau, electromagnetic environment division radio; Ministry of Internal Affairs and Communications

Table 3: USA & Japan general population/uncontrolled exp.

Frequency Range (MHz)	electric-field (E) (V/m)	power-density (mW/cm ²)
30–300	27.5	0.2
300 ^a –1,500	1.585f ^(1/2)	f/1,500
1,500–100,000	61.4	1

^a Only in Japan, V/m is detailed above 300 MHz

Important to note that FCC, ICNIRP and IEEE all have the same fundamental whole-body SAR limits; the FCC and Japanese limits rely on reference levels from a different model, to convert from internal SAR to external field-strength.

D. Canada

[Health Canada](#) (HC) is the federal department responsible for protecting the health and safety of Canadians; HC has set limits for human exposure, which are published in a document commonly known as Canada Safety Code 6. On 13 March 2015 [Health Canada](#) revised the 2009 limits (that were identical to the USA), and published new reference levels: Canada Safety Code [SC6 \(2015\)](#) [11]. The updated rigorous SC6 science-based limits include more restrictive reference levels in some frequency ranges, to take account of improved modelling of the interaction of RF fields with the human body, and to ensure larger safety margins to protect all population, including newborn infants and children; see HC [media release](#). For its part, Innovation, Science and Economic Development Canada ([ISED](#), formerly Industry Canada) is responsible for radio-communication, and has adopted HC's SC6 limits, in ISED's standards and regulations. Table 5 ([11] Table 5) details the HC's reference levels for PD at 10MHz–300GHz in uncontrolled environments.

Table 4: Canada Safety Code 6, reference levels

Frequency (MHz)	Power Density (W/m ²)
10 - 20	2
20 - 48	8.944 / f ^{0.5}
48 - 300	1.291
300 - 6000	0.02619 f ^{0.6834}
6000 -15000	10
15,000 – 150,000	10
150,000 – 300,000	6.67×10 ⁻⁵ f

⁵ The values in GB 9175 are expressed in μ W/cm², where 1 W/m² =100 μW/cm², and 0.1 W/m² = 10 μW/cm²

Table 5 compares the exposure limits in [ICNIRP 1998](#), [FCC §1.1310](#) (as in Japan) and the Canada Safety Code [SC6](#); it details the PD S_{eq}(W/m²) thresholds in uncontrolled environment at some relevant frequencies 20 MHz–6 GHz. It demonstrates that Canada is the most restrictive above 20 MHz and below 6,000 MHz.

Table 5: [ICNIRP](#), [FCC §1.1310](#) (& Japan) & [SC6](#) (W/m²)

RF	ICNIRP	USA	Canada
20 (MHz)	2	1800/f ² =4.5	2
30 (MHz)	2		8.944 / f ^{0.5} =1.63
48 (MHz)			1.291
300 (MHz)	2		
500 (MHz)	f/200 =2.5	f/150 =3.3	0.02619 f ^{0.6834} =1.83
570 (MHz)	f/200 =2.8	f/150 =3.8	0.02619x f ^{0.6834} =2
1,000 (MHz)	f/200 =5	f/150 =6.7	0.02619x f ^{0.6834} =2.9
1,500 (MHz)	f/200 =7.5	10	0.02619x f ^{0.6834} =3.9
3,000 (MHz)	10 W/m ²		0.02619x f ^{0.6834} =6.2
6,000 (MHz)	10 W/m ²		

E. China

China is unique. There are two RF exposure standards in force in China with differing limit values: a national standard for electromagnetic radiation [GB 8702-88](#) ([19] Table 2) formulated by the national environmental protection agency and a second national standard [GB 9175](#) [20], formulated by the Ministry of Health. In respect of base stations, the national standard [GB 8702-88](#) is the legal requirement; however, in practice operators often design for compliance with the most restrictive Ministry of Health value from GB 9175⁵, in order to minimise confusion by the public. The Chinese general public exposure PD limit at all RF 30–3,000 MHz is 0.4

W/m², according to [GB 8702-88](#). To exemplify: the Chinese official level at 900 MHz is 0.4 W/m², relative to 4.5 W/m² [ICNIRP 1998 Guidelines](#) level; 9% of ICNIRP 1998 PD, and 0.8% of ICNIRP 1998 field-strength. [GB 9175](#) standard does not include SAR values, only field-strength limits. In standard [GB 8702-88](#) the worker (occupational) SAR limit is 0.1 W/kg and for the public 0.02 W/kg; thus ¼ SAR limit, compared to the whole body limits in ICNIRP, IEEE, EU. [GB 8702-88](#) does not contain a part body SAR limit; that limit is covered by [GB 21288-2007](#) [21].

F. Republic of Korea, France, the UK and Europe
The Republic of Korea [7] and [8] adopts the ICNIRP 1998 reference levels, whereas Korea follows USA and Canada in SAR levels (IEEE C95.1-1999). France and the UK follow officially the non-mandatory EU Council Recommendation 1999/519/EC [13], the same exposures of human-hazards as the [ICNIRP 1998](#) levels. In France, the RF human exposure levels around cellular sites are measured by accredited laboratories and [published](#). According ruling *décret n° 2013-1162* of 14 December 2013, every person can ask for specific measurement. In 2004, the UK government agreed that exposures from cellular base stations should meet the [ICNIRP 1998](#) guidelines.

Europe addresses RF hazards at [Directive 2013/35/EU](#) [13]; [22] details [implementation report](#) for 1999/519/EC Council Recommendation limiting the public exposure to electromagnetic fields (0 Hz to 300 GHz). There is a difference⁶ in the exposure limits among European countries, as there is no legal basis for the European Commission, to establish public exposure limits for base stations. In general, Northern Europe is more aligned with 1999/519/EC, than Southern Europe; there are no clear distinctions between Western and Eastern European countries.

Switzerland (in the base of technical feasibility) and Italy apply up to 0.01 [ICNIRP 1998](#) reference level for PD below 2 GHz. Switzerland uses ICNIRP as the fundamental limit on total exposures, and then adds the Installation Limit Values (ILV) layer; Switzerland also implements precautionary exposure limitations, at places of sensitive use, such as apartment buildings, schools, hospitals, permanent workplaces and children's playgrounds.

Polish exposure limit for the general public, for the RF 300 MHz–300 GHz is 0,1 W/m². As ICNIRP reference levels above 10 MHz are 2 to 10 W/m², the Polish levels are 20 to 100 times more restrictive. Polish limits are long standing and influenced by the former Soviet status. In the past, Poland used even more restrictive limits; two zones for exposure limits: temporary presence and permanent presence (such as, including houses); the first zone limit was 0,1 W/m² and the second was 0,025 W/m². Since about 1998, this separation disappeared and there is only one limit 0,1 W/m². Hungary moved from the Soviet to the ICNIRP limits in 2004. Luxembourg reduces ICNIRP level by 20 times; Luxembourg limits are newer.

Some European cities set more restrictive limits. Salzburg assessment value of 1 mW/m² (0.001 W/m²; equivalent to 0.61 V/m); the Salzburg PD threshold is 4,500 more stringent than [ICNIRP 1998](#) level at 900 MHz and 9,000(!) more at 1,800 MHz. The ‘Salzburg model’ seems not to have been effective under any point of view; it has prevented the development of networks, with no evident health benefit for public health; at the same time, it has not settled down the controversies and probably has not reduced public concern [23] p. 148. In addition to Salzburg in Austria, Perugia and Novara in Italy limit the field-strength to 3 V/m (7.3 % ICNIRP field-strength and 0.5 % PD) and 1 V/m (2.4 % ICNIRP 1998 field-strength and 0.06 % PD), respectively. These city policies often have no regulatory basis.

IV. COMPARISONS AND SUMMARY

The technical rationale for the human exposure limits differ substantially. The national thresholds reveal the regulator’s risk tolerability and leniency [24] [Mazar 2009](#) p.12. It may also reflect the vulnerability to political intervention and activist pressure, or the age of the regulations and unwillingness to update.

Europe, Japan and China all use 2 W/kg in 10 g SAR, for the partial body limit for mobile devices; however, in the Republic of Korea, the USA and Canada the limit is 1.6 W/kg in 1g. In the far-field, at 400–1,500 MHz (which includes cellular transmission and UHF TV bands), the maximum allowed PD level of ICNIRP, Europe and the Republic of Korea for the general public exposure is $f(\text{MHz})/200$ W/m². At the 300–1500 MHz range, the US and Japanese threshold

⁶ The difference in implementing RF standards is smaller

is f (MHz)/150 W/m², which is higher by 4/3 (200/150), compared to the [ICNIRP 1998](#) threshold. Like Japan, the USA seems lenient and tolerant by allowing higher thresholds to RF exposure from the base stations.

It is important to underline that Korean and N. American regulations are more restrictive than [1999/519/EC](#) and ANSI/IEEE [C95.1-2006](#) in the allowed SAR from the cellular terminal. The [ICNIRP 1998](#) threshold, adopted by the European Community and ANSI/IEEE is **2.0** W/kg, while the limit in Korea, the FCC [§ 2.1093](#) and Canada Safety Code [SC6](#) is **1.6** W/kg for the partial body; see Table 1. This position seems more rational (at least compared to Switzerland and Italy, dividing [ICNIRP 1998](#) power levels up to 100), as the RF energy absorbed from the handset and notebook is much stronger, being much nearer to the user's body, compared to the received signal from the base stations ([25] [Mazar 2011](#) section F). The USA and Japan are the most tolerant in regulating uncertain risks around fixed transmitters.

Table 6 provides overall comparison: France, UK, USA, China, Japan and Korea limits relative to the general public [ICNIRP 1998](#) reference levels (adopted by EC, IEEE and ANSI): PD 5 W/m² at 1,000 MHz, and SAR 2 W/kg. Reference levels are calculated at f 1,000 MHz, and indicate the partial body limit for mobile devices average SAR. Table 6 assort the rows by power-density (PD), descending percentage of ICNIRP level; indicating that China (0,08 ICNIRP level) is the most restrictive.

Table 6: Overall comparison

	PD 1,000 MHz (W/m²)	SAR (W/kg)
USA	$f/150$ = <u>6.67</u> ; 133/%	<u>1.6</u> , averaged over 1g tissue
Japan		
France ^a & UK	$f/200$ = <u>5</u> ; 100%	<u>2.0</u> , over 10 g
Korea		
Canada	$0.02619f^{0.6834}$ = <u>2.94</u> ; 59%	<u>1.6</u> , averaged over 1g tissue
China	<u>0.4</u> ; 8%	<u>2.0</u> , over 10 g

^a it is also ICNIRP and IEEE 2006 reference levels

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