Section 13

Radiofrequency Safety Guidelines and Standards

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13.1 Canada – Health Canada's Radiofrequency (RF) Exposure Guidelines: Safety Code 6

The current update of Safety Code 6 titled "Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz"[1] was released by Health Canada in 2009. It replaced the 1999 version (99-EHD-237).

Safety Code 6 applies to workers and to the general public.

In this section of the toolkit, the focus will be on the exposure of the general public.

Excerpts (*in italics*) from Safety Code 6 (SC.6) with BCCDC comments:

SC.6 Part 1 – Preface (Page 3 of the Code)

1.1 - "This code has been adopted as the scientific basis for the equipment certification specifications outlined in Industry Canada's regulatory compliance documents that govern the use of wireless devices in Canada, such as cell phones, cell towers (base stations) and broadcast antennae."

Comment: This statement is consistent with the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

1.2 – "The guidelines (exposure limits) do not apply to the deliberate exposure for treatment of patients by, or under the direction of, medical practitioners."

Comment: RF sources of different frequencies and power outputs are used in medicine (radiology, oncology, cardiology, physiotherapy) for diagnostic and therapeutic purposes. In general, there are no exposure limits pertaining to patients, but some precautions are recommended by ICNIRP.

1.3 – "The guidelines are not intended for use as a product performance specification document, as the limits in this safety code are for controlling human exposure and are independent of the source of RF energy."

Comment: Product performance specifications relate to the design and quality of the products. They fall under the responsibility of Industry Canada (IC). IC regulations apply to RF installations and devices, such as radio-communication and broadcasting antenna systems[2] and radio-communication apparatus at all frequency bands.[3]

1.4 – "The safety limits in this code are based on an ongoing review of published scientific studies on the health impacts of radiofrequency electromagnetic energy. This code is periodically revised to reflect new knowledge in the scientific literature and the exposure limits may be modified, if deemed necessary."

Comment: On the whole, Safety Code 6 guidelines are consistent with the recommendations of the International Commission on Non-ionizing Radiation Protection[4,5] and the recommendations of the World Health Organization.[6] Currently, ICNIRP is reviewing its RF guidelines, but no date has been set for the completion of this work. We would expect Health Canada to follow suit if major changes are made to ICNIRP's RF guidelines.

SC.6 Part 2 - Introduction (Pages 7- 8)

2.1- Page 7 – "The exposure limits specified in Safety Code 6 have been established based upon a thorough evaluation of the scientific literature related to the thermal and possible non-thermal effects of RF energy on biological systems.

Health Canada scientists consider all peer-reviewed scientific studies, on an ongoing basis, and employ a weight-of-evidence approach when evaluating the possible health risks of RF energy.

This approach takes into account both the quantity of studies on a particular endpoint (whether adverse or no effect), but more importantly, the quality of those studies.

Poorly conducted studies (e.g., incomplete dosimetry or inadequate control samples) receive relatively little weight, while properly conducted studies (e.g., all controls included, appropriate statistics, complete dosimetry) receive more weight."

2.2- Page 8 – "The purposes of the Code are:

(a) Specify maximum levels of human exposure to RF energy at frequencies between 3 kHz and 300 GHz, to prevent adverse human health effects;

(b) Specify maximum allowable RF contact and induced body currents to prevent the physical perception of internal currents resulting from RF energy in uncontrolled environments, and to prevent RF shock or burns to personnel in controlled environments;

(c) Provide guidance for evaluating RF exposure levels to ensure that personnel in controlled and uncontrolled environments are not exposed at levels greater than the limits specified in this code."

Comment: Safety Code 6 guidelines are based on review of both thermal and non-thermal effects.

Note: controlled environment refers to worker environment and uncontrolled environment to public spaces.

SC.6 Part 3 - Maximum exposure limits (Pages 9–21)

3.1- Page 9

- *"Despite the advent of thousands of additional research studies on RF energy and health, the predominant adverse health effects associated with RF energy exposures in the frequency range from 3 kHz to 300 GHz still relate to the occurrence of tissue heating and excitable tissue stimulation from short-term (acute) exposures."*
- *"At present, there is no scientific basis for the premise of chronic and/or cumulative health risks from RF energy at levels below the limits outlined in Safety Code 6."*
- *"For frequencies from 3 to 100 kHz, the predominant health effect to be avoided is the unintentional stimulation of excitable tissues, since the threshold for electro-stimulation in this frequency range will typically be lower than that for the onset of thermal effects.*

Experimental studies have demonstrated that exogenous electric and magnetic field exposures can induce in situ electric fields and currents within biological tissue that can lead to nerve and muscle depolarization (5, 8–9, 31–32).

Limits for maximum external electric and magnetic field strengths have been established in Safety Code 6 to avoid in situ electric field strengths greater than that of the minimum excitation threshold for excitable tissues."

- *"For frequencies from 100 kHz to 300 GHz, tissue heating is the predominant health effect to be avoided. Other proposed non-thermal effects have not been conclusively documented to occur at levels below the threshold where thermal effects arise. Studies in animals, including non-human primates, have consistently demonstrated a threshold effect for the occurrence of behavioral changes and alterations in core-body temperature of ~1.0˚C, at a whole-body average SAR of ~4 W/kg. This forms the scientific basis for the whole-body average SAR limits in Safety Code 6. To ensure that thermal effects are avoided, a safety factor of 10 has been incorporated for exposures in controlled environments, resulting in a whole-body-averaged SAR limit of 0.4 W/kg.*

  A safety margin of 50 has been incorporated for exposures in uncontrolled environments to protect the general public, resulting in a whole-body average SAR limit of 0.08 W/kg."

Comment: RF devices used by the general public operate at frequencies ranging from 300 kHz to 2.45 GHz. Thus, the main interest is on frequencies above 300 kHz. As stated in Safety Code 6, the thermal effects due to absorption of radiofrequency energy by soft tissue are the main basis for regulation. The exposure limits have been set to prevent excessive tissue heating. The rate at which RF energy is absorbed by the body is described in terms of the Specific Absorption Rate (SAR) in units of Watt/Kilogram (W/Kg). For reference, a list of SAR values for Cellular Telephones has been made available by the US Federal Communication Commission.[7]

3.2- Exposure limits for public areas – Safety Code 6 Exposure Limits[1] *(Table 6, p. 18)*

Table 6. Exposure Limits for Uncontrolled Environments.

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m^2)	5 Averaging Time (min)
0.003 - 1	280	2.19		6
1 - 10	$280/f$	$2.19/f$		6
10 - 30	28	$2.19/f$		6
30 - 300	28	0.073	2*	6
300 - 1 500	$1.585f^{0.5}$	$0.0042f^{0.5}$	$f/150$	6
1 500 - 15 000	61.4	0.163	10	6
15 000 - 150 000	61.4	0.163	10	$616\,000/f^{1.2}$
150 000 - 300 000	$0.158f^{0.5}$	$4.21 \times 10^{-4}f^{0.5}$	$6.67 \times 10^{-5}f$	$616\,000/f^{1.2}$

* Power density limit is applicable at frequencies greater than 100 MHz.

Notes: 1. Frequency, f, is in MHz.
2. A power density of 10 W/m^2 is equivalent to 1 mW/cm^2.
3. A magnetic field strength of 1 A/m corresponds to 1.257 microtesla (μT) or 12.57 milligauss (mG).

- ICNIRP's Exposure Limits[4] *(Table 7, p. 511)*

Table 7. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).[a]

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

Comment: There are differences between Safety Code 6 and ICNIRP power density limits in the frequency range 300 MHz–1500 MHz. Canada and the United States apply a limit of f/150 for frequencies between 300 MHz and 1.5 GHz while ICNIRP recommends a limit of f/200, f being the frequency in MHz.

For example, at a frequency of 900 MHz, the Canadian limit is 900/150 = 6 Watt/m^2 (600 μW/cm^2) while ICNIRP's limit is 900/200 = 4.5 Watt/ m^2 (450 μW/cm^2).

However, this has little practical impact on the protection of the public since the time-averaged power densities from existing domestic devices are much lower even at close distances. For example, the power densities from RF devices such as baby monitors, microwave ovens, mobile phones, Wi-Fi, and smart meters are less that 0.01 Watt/m^2 at 1 meter from the source.

13.2 Guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP)

"Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)"[4]

ICNIRP's limits of exposure to electromagnetic fields (EMF) are based on established health effects and are termed reference levels. Depending on the frequency and the exposure conditions, the physical quantities used to specify the exposure limits are: current density, SAR, and power density.

Excerpts (*in italics*) from ICNIRP guidelines with BCCDC comments:

ICNIRP-Page 510: Guidelines for limiting EMF exposure –

The basic restrictions for time varying electric and magnetic fields are for frequencies up to 10 GHz. The health effects considered in the development of basic exposure restrictions for various frequency ranges are:

- *"Between 1 Hz and 100 KHz, basic restrictions are provided on current density to prevent effects on nervous system functions."*

Comment: In the frequency range 1 Hz–100 kHz, the thermal effects are negligible and the induced currents generated by magnetic fields are the main concern. The limits are intended to prevent peripheral nerve and/or cardiac stimulation.

Example of sources in the frequency range 1 Hz–100 kHz: electrical power lines (50–60 Hz), MRI magnetic fields, electrical appliances, radio navigation, industrial induction heaters, etc.

- *"Between 100 kHz and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating; in the 100 kHz–10 MHz range, restrictions are provided on both current density and SAR."*

Comment: At frequencies between 100 kHz and 10 GHz, the thermal effects are predominant. Therefore, the limits apply to the specific absorption rate (SAR).

Example of sources in the frequency range 100 kHz–10 GHz: AM/FM radio, shortwave radio, CB radio, TV, mobile phones and base stations, microwave ovens, radar, etc.

- *"Between 10 GHz and 300 GHz, basic restrictions are provided on power density to prevent excessive heating near the body surface (skin)."*

Comment: Above 10 GHz and up to 300 GHz, the penetration of RF energy into tissue is weak, and most of the incident energy is absorbed at the surface of the skin. As a result, SAR is negligible in this frequency range and power density is the appropriate quantity to measure.

Example of sources in the frequency range 10 GHz–300 GHz: Transmission video devices (remote sensing, security screening, telecommunications by satellite, etc.).

- *"In the low-frequency range up to 100 kHz, the general public reference levels for magnetic fields are set at a factor of 5 below the values set for occupational exposure."*

- *"In the frequency range 100 kHz–10 MHz, the general public reference levels for magnetic fields have been increased compared with the limits given in the 1988 IRPA guideline. In that guideline, the magnetic field strength reference levels were calculated from the electric field strength reference levels by using the far-field formula relating E and H."*

- *"In the high-frequency range 10 MHz–10 GHz, the general public reference levels for electric and magnetic fields are lower by a factor of 2.2 than those set for occupational exposure. The factor of 2.2 corresponds to the square root of 5, which is the safety factor between the basic restrictions for occupational exposure and those for general public exposure."*

Comment: In the far field, the electrical field E is proportional to the square root of the power density: E= $\sqrt{S}$

The occupational power density limit $\mathbf{S(W)_{limit}}$ is equal to five times the public power density limit $\mathbf{5\ x}\ \boldsymbol{S(P)_{limit}(public)}$:

$$\boldsymbol{S(W)_{limit}(workers)} = \mathbf{5\ x}\ \boldsymbol{S(P)_{limit}(public)},$$

Then:

$$\boldsymbol{E_{limit}(workers)} = \sqrt{\mathbf{5}}\ \boldsymbol{E_{limit}(public)} = \mathbf{2.2}\ \boldsymbol{E_{limit}(public)}$$

- *"In the high-frequency range 10–300 GHz, the general public reference levels are defined by the power density, as in the basic restrictions, and are lower by a factor of 5 than the occupational exposure restrictions."*

Comment: At high frequencies above 10 GHz, RF waves are much less penetrating and rapidly absorbed by the skin. As a result, the internal thermal effects are insignificant and the assessment of SAR is inappropriate. Therefore, only power density measurements are necessary above 10 GHz.

13.3 Other RF Guidelines

USA

In the United States, the **Federal Communications Commission** (FCC) regulates interstate and international communications by radio, television, wire, satellite and cable in all 50 states, the District of Columbia, and US territories.

On August 1, 1996 the FCC adopted the RF guidelines developed by the National Council on Radiation Protection and Measurements (NCRP): "Maximum Permissible Exposure limits for field strength and power density for the transmitters operating at frequencies of 300 kHz–100 GHz."[8]

The Commission adopted also the RF standards developed by the **Institute of Electrical and Electronics Engineers** IEEE-C95.1–2005 Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.[9]

Comment: At 900 MHz, the FCC RF power density limits are 33% higher than ICNIRP reference levels. For other frequencies, the FCC limits are similar to ICNIRP's.

United Kingdom (UK)

Advice on limiting exposure to electromagnetic fields between 0 and 300 GHz – NRPB-Volume 12, No. 2, **2004**.[10]

Comment: The UK guidelines are based on ICNIRP recommendations, with the same exposure limits.

Australia: Australian Radiation Protection and Nuclear Agency (ARPANSA)

Regulations: Maximum exposure levels to RF fields – 3 kHz to 300 GHz (adopted on 20 March 2002).[11]

Comment: Australian guidelines are based on ICNIRP recommendations, with the same exposure limits.

Switzerland

In Switzerland,[12,13] an ordinance on the protection against non-ionizing radiation was adopted in 1999. RF exposure limits similar to ICNIRP's reference levels apply in all public areas.

However, lower precautionary limits are added as follows:

- A limit for the electric field E of **10% of ICNIRP reference level** (equivalent to **1% of ICNIRP power density** reference level) applies to mobile base stations.

- Frequency-dependent exposure limits for electrical field strength E of **11% to 3% of ICNIRP reference level**s apply to other RF transmitters and radar.

Russia

In Russia, the protection of the population is governed by the Law 2.2.4/2.1.8.055-96 on "Sanitary norms and regulations."[14] Exposure limits are based on "Hygienic-epidemiological requirements" and equal to 2% of ICNIRP reference levels for RF fields in the frequency range 300 MHz–300 GHz. The basis of the Russian limits is to "prevent biological effects that are not generally seen as health risk in Western countries."[13]

European Union (EU)

The EU issued a Directive on RF in 2004: Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) - Frequencies Covered: > 1 Hz – 300 GHz[15]

Comment: The European Union Directive is based on ICNIRP recommendations, with the same exposure limits. However, EU countries adopted three different approaches, as shown in Table 1.[13]

Table 1. Different regulatory approaches by EU countries

Group	Countries	Regulations	National RF limits	Basis
G1	Cyprus, Czech republic, Estonia, Finland, France, Hungary, Ireland, Malta, Portugal, Romania, and Spain	Yes, mandatory. Identical to EU Directive 2004/40/EC	Based on ICNIRP reference levels	As ICNIRP, science-based
G2	Austria, Denmark, Latvia, Netherlands, Sweden, UK	No binding regulations	Recommended limits based on ICNIRP reference levels but not mandatory.	As ICNIRP, science-based
G3	Belgium, Bulgaria, Greece, Italy, Lithuania, Luxembourg, Poland, Slovenia	Yes, mandatory. More stringent rules than EU Directive	1% of ICNIRP reference levels	Precautionary principle, public pressure

13.4 Comparison of exposure limits in different countries

Most countries follow the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for limiting exposure to RF fields. However, some differences exist between North America, Eastern Europe and Western Europe.

Table 2 below[13] shows the RF exposure limits for the general public in different countries at RF frequencies of **900 MHz** (e.g., GSM mobile phones and base stations, baby monitors, cordless phones, headphones, smart meters), **1.8 GHz** (e.g., GSM, cordless phones), **2.1 GHz** (UMTS mobile phones and base stations), and **2.45 GHz** (e.g., microwave oven, baby monitors, Bluetooth, home area network).

Table 2. RF exposure limits for the general public in different countries
Equivalent plane wave power density, **W/m²**

FREQUENCY / COUNTRY	900 MHz	1.8 GHz	2.1 GHz	2.45 GHz
ICNIRP	4.5	9	10	10
Canada	6	10	10	10
USA	6	10	10	10
Japan	6	10	10	10
Australia	4.5	9	10	10
Austria	4.5	9	10	10
Belgium	4.5	9	10	10
Finland	4.5	9	10	10
France	4.5	9	10	10
Germany	4.5	9	10	10
UK	4.5	9	10	10
Spain	4.5	9	10	10
Ireland	4.5	9	10	10
Bulgaria	0.10	0.10	0.10	0.10
Poland	0.10	0.10	0.10	0.10
Russia	0.10	0.10	0.10	0.10
Switzerland	0.045	0.095	0.095	0.095

Most Western European countries apply ICNIRP's RF limits. Some Eastern Europe countries like Russia, Poland, and Bulgaria have adopted more stringent limits of the order of 2% of ICNIRP reference levels, but it is unclear how they are enforced.

The RF exposure limits adopted in Canada and the USA are similar to ICNIRP reference levels, except at 900 MHz.

13.5 References

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