



Health  
Canada

Santé  
Canada

*Your health and  
safety... our priority.*

*Votre santé et votre  
sécurité... notre priorité.*

# LIMITS OF HUMAN EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC ENERGY IN THE FREQUENCY RANGE FROM **3 KHZ TO 300 GHZ**

---

Consumer and Clinical Radiation Protection Bureau  
Environmental and Radiation Health Sciences Directorate  
Healthy Environments and Consumer Safety Branch  
Health Canada

SAFETY CODE 6 (2015)

Canada 

**Health Canada is the federal department responsible for helping the people of Canada maintain and improve their health.**

We assess the safety of drugs and many consumer products, help improve the safety of food, and provide information to Canadians to help them make healthy decisions. We provide health services to First Nations people and to Inuit communities. We work with the provinces to ensure our health care system serves the needs of Canadians.

Également disponible en français sous le titre :

*Limites d'exposition humaine à l'énergie électromagnétique radioélectrique dans la gamme de fréquences de 3 kHz à 300 GHz*

To obtain additional information, please contact:

Health Canada  
Address Locator 0900C2  
Ottawa, ON K1A 0K9  
Tel.: 613-957-2991  
Toll free: 1-866-225-0709  
Fax: 613-941-5366  
TTY: 1-800-465-7735  
E-mail: [publications@hc-sc.gc.ca](mailto:publications@hc-sc.gc.ca)

This publication can be made available in alternative formats upon request.

© Her Majesty the Queen in Right of Canada, as represented by the Minister of Health, 2015

Publication date: June 2015

This publication may be reproduced for personal or internal use only without permission provided the source is fully acknowledged.

Cat.: H129-48/2015E-PDF  
ISBN: 978-0-660-02466-0  
Pub.: 150021

# PREFACE

This document is one of a series of safety codes prepared by the Consumer and Clinical Radiation Protection Bureau, Health Canada. These safety codes specify the requirements for the safe use of, or exposure to, radiation emitting devices. This revision replaces the previous version of Safety Code 6 (2009).

The purpose of this code is to establish safety limits for human exposure to radiofrequency (RF) fields in the frequency range from 3 kHz to 300 GHz. The safety limits in this code apply to all individuals working at, or visiting, federally regulated sites. These guidelines may also be adopted by the provinces, industry or other interested parties. The Department of National Defence shall conform to the requirements of this safety code, except in such cases where it considers such compliance to have a detrimental effect on its activities in support of training and operations of the Canadian Forces. This code has been adopted as the scientific basis for equipment certification and RF field exposure compliance specifications outlined in Industry Canada's regulatory documents (1–3), that govern the use of wireless devices in Canada, such as cell phones, cell towers (base stations) and broadcast antennas. Safety Code 6 does not apply to the deliberate exposure for treatment of patients by, or under the direction of, medical practitioners. Safety Code 6 is 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.

In a field where technology is advancing rapidly and where unexpected and unique exposure scenarios may occur, this code cannot cover all possible situations. Consequently, the specifications in this code may require interpretation under special circumstances. This interpretation should be done in consultation with scientific staff at the Consumer and Clinical Radiation Protection Bureau, Health Canada.

The safety limits in this code are based on an ongoing review of published scientific studies on the health impacts of RF energy and how it interacts with the human body. This code is periodically revised to reflect new knowledge in the scientific literature and the exposure limits may be modified, if deemed necessary.



# TABLE OF CONTENTS

PREFACE . . . . .	I
1. INTRODUCTION . . . . .	1
1.1 Purpose of the code . . . . .	2
2. MAXIMUM EXPOSURE LIMITS . . . . .	2
2.1 Basic Restrictions . . . . .	4
2.1.1 Internal Electric Field Strength Limits (3 kHz–10 MHz) . . . . .	4
2.1.2 Specific Absorption Rate Limits (100 kHz–6 GHz) . . . . .	5
2.1.3 Frequencies from 6 GHz–300 GHz . . . . .	5
2.2 Reference Levels . . . . .	6
2.2.1 Electric and Magnetic Field Strength (3 kHz–10 MHz) . . . . .	6
2.2.2 Electric Field Strength, Magnetic Field Strength and Power Density (10 MHz–300 GHz) . . . . .	8
2.2.3 Induced and Contact Current (3 kHz–110 MHz) . . . . .	10
ABBREVIATIONS . . . . .	12
DEFINITIONS . . . . .	13
REFERENCES . . . . .	15



# 1. INTRODUCTION

Electromagnetic radiation is emitted by many natural and man-made sources and is a fundamental aspect of our lives. We are warmed by electromagnetic radiation emitted from the sun and our eyes can detect the visible light portion of the electromagnetic spectrum. Radiofrequency (RF) fields fall within a portion of the electromagnetic spectrum with frequencies ranging from 3 kHz to 300 GHz, below that of visible light and above that of extremely low frequency electromagnetic fields. RF fields are produced by many man-made sources including cellular (mobile) phones and base stations, television and radio broadcasting facilities, radar, medical equipment, microwave ovens, RF induction heaters as well as a diverse assortment of other electronic devices within our living and working environments.

A number of biological effects and established adverse health effects from acute exposure to RF fields have been documented (4–9). These effects relate to localized heating or stimulation of excitable tissue. The specific biological responses to RF fields are generally related to the rate of energy absorbed or the strength of internal electric fields (voltage gradients) and currents. The rate and distribution of RF energy absorption depend strongly on the frequency, strength and orientation of the incident fields as well as the body size and its constitutive electrical properties (dielectric constant and conductivity). Absorption of RF energy is commonly described in terms of the specific absorption rate (SAR), which is a measure of the rate of energy deposition per unit mass of body tissue and is usually expressed in units of watts per kilogram (W/kg). Based on a large amount of scientific knowledge, national and international exposure limits have been established to protect the general public against all adverse effects associated with RF field exposures (10–14).

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 non-thermal health effects of RF fields. 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 exposure to RF fields. This approach takes into account 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. those with 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. The exposure limits in Safety Code 6 are based upon the lowest exposure level at which any scientifically established adverse health effect occurs. Safety margins have been incorporated into the exposure limits to ensure that even worst-case exposures remain far below the threshold for harm. The scientific approach used to establish the exposure limits in Safety Code 6 is comparable to that employed by other science-based international standards bodies (15–16). As such, the basic restrictions in Safety Code 6 are similar to those adopted by most other nations, since all science-based, standard-setting bodies use the same scientific data. It must be stressed that Safety Code 6 is based upon established adverse health effects and should be distinguished from some municipal and/or national guidelines that are based on socio-political considerations.

In the following sections, the maximum exposure levels for persons in both controlled and uncontrolled environments are specified. These levels shall not be exceeded.

## 1.1 PURPOSE OF THE CODE

The purpose of this code is to specify maximum levels of human exposure to RF fields at frequencies between 3 kHz and 300 GHz, to prevent adverse human health effects in both controlled and uncontrolled environments.

In this code, controlled environments are defined as those where all of the following conditions are satisfied:

- (a) the RF field intensities in the controlled area have been adequately characterized by means of measurements or calculation,
- (b) the exposure is incurred by persons who are aware of the potential for RF exposure and are cognizant of the intensity of the RF fields in their environment and,
- (c) the exposure is incurred by persons who are aware of the potential health risks associated with RF field exposures and can control their risk using mitigation strategies.

Situations that do not meet all the specifications above are considered to be uncontrolled environments. Uncontrolled environments are defined as areas where either insufficient assessment of RF fields has been conducted or where persons who are allowed access to these areas have not received proper RF field awareness/safety training and have no means to assess or, if required, to mitigate their exposure to RF fields.

## 2. MAXIMUM EXPOSURE LIMITS

The scientific literature with respect to possible biological effects of RF fields has been monitored by Health Canada scientists on an ongoing basis. Since the last version of Safety Code 6 was published (2009), a significant number of new studies have evaluated the potential for acute and chronic RF field exposures to elicit possible effects on a wide range of biological endpoints including: human cancers; rodent lifetime mortality; tumor initiation, promotion and co-promotion; mutagenicity and DNA damage; EEG activity; memory, behaviour and cognitive functions; gene and protein expression; cardiovascular function; immune response; reproductive outcomes; and perceived electromagnetic hypersensitivity among others. Numerous authoritative reviews have summarized the current literature (4–8, 17–40).

Despite the advent of numerous additional research studies on RF fields and health, the only established adverse health effects associated with RF field exposures in the frequency range from 3 kHz to 300 GHz relate to the occurrence of tissue heating and nerve stimulation (NS) from short-term (acute) exposures. At present, there is no scientific basis for the occurrence of acute, chronic and/or cumulative adverse health risks from RF field exposure at levels below the limits outlined in Safety Code 6. The hypotheses of other proposed adverse health effects occurring at levels below the exposure limits outlined in Safety Code 6 suffer from a lack of evidence of causality, biological plausibility and reproducibility and do not provide a credible foundation for making science-based recommendations for limiting human exposures to low-intensity RF fields.

This safety code provides guidance for the avoidance of adverse human health effects resulting from exposure to RF fields, in terms of basic restrictions and/or reference levels. Basic restrictions are exposure indices within the body that should not be exceeded. These exposure indices are



directly linked to established adverse health effects. The basic restrictions in this safety code are specified in terms of: a) internal electric field strength; and b) the rate of RF energy absorption (SAR). Since measurements of the SAR or internal electric field strength are often difficult to perform, reference levels for maximum human exposure to RF fields have also been specified in this safety code. The reference levels are specified in terms of unperturbed, externally applied electric- and magnetic-field strength, power density and in terms of electric currents in the body occurring from either induction or contact with energized metallic objects. They were established using dosimetric analyses that determined the levels of externally applied field strengths that would produce the basic restrictions within the body. While compliance with the basic restrictions is required, non-compliance with the reference levels does not necessarily mean that the basic restrictions are not respected. In such cases, additional measurements or calculations may be required to assess compliance.

For frequencies from 3 kHz to 10 MHz, NS from induced electric fields within the body must be avoided. Experimental studies have demonstrated that electric and magnetic field exposures can induce internal electric fields (voltage gradients) within biological tissue which, if sufficiently intense, can alter the “resting” membrane potential of excitable tissues resulting in spontaneous depolarization of the membrane and the generation of spurious action potentials (5, 10, 11, 13, 14, 35, 41). Basic restrictions for the avoidance of NS are specified in this safety code in terms of maximum internal electric field strength within the body.

For frequencies from 100 kHz to 300 GHz, tissue heating can occur and must be limited. Basic restrictions have been specified in this safety code for RF field exposures in the 100 kHz to 6 GHz frequency range, in terms of maximum whole-body SAR (averaged over the whole-body) and peak spatially-averaged SAR, (averaged over a small cubical volume). For frequencies above 6 GHz, RF energy absorption occurs predominantly in surface tissues (e.g. upper layers of skin) and the use of maximum SAR limits, either whole-body or averaged over a cubical volume, is not appropriate. In lieu of basic restrictions, reference levels are specified for maximum unperturbed, externally applied electric- and magnetic-field strengths and in terms of power density, for the avoidance of thermal effects.

Studies in animals, including non-human primates, have consistently demonstrated a threshold effect for the occurrence of behavioural changes and alterations in core body temperature of  $-1.0^{\circ}\text{C}$ , at a whole-body average SAR of  $\sim 4$  W/kg (5–8, 11, 12, 14, 36). Thermoregulatory studies in human volunteers exposed to RF fields under a variety of exposure scenarios have provided supporting information on RF field induced thermal responses in humans (42). This information forms the scientific basis for the basic restrictions on whole-body average SAR in Safety Code 6. To ensure that thermal effects are avoided, safety factors have been incorporated into the exposure limits, resulting in whole-body-averaged SAR limits of 0.08 and 0.4 W/kg in uncontrolled- and controlled-environments, respectively.

Basic restrictions on peak spatially-averaged SAR have also been established in Safety Code 6 to avoid adverse thermal effects in localized human tissues (hot-spots). The peak spatially-averaged SAR limits reflect the highly heterogeneous nature of typical RF field exposures and the differing thermoregulatory properties of various body tissues. The peak spatially-averaged SAR limits pertain to discrete tissue volumes (1 or 10 g, in the shape of a cube), where thermoregulation can efficiently dissipate heat and avoid changes in body temperature that are greater than  $1^{\circ}\text{C}$ .

As such, the peak spatially-averaged SAR limits for exposures in controlled environments are 20 W/kg for the limbs and 8 W/kg for the head, neck and trunk. For exposures in uncontrolled environments, the peak spatially-averaged SAR limits are 4.0 W/kg for the limbs and 1.6 W/kg for the head, neck and trunk.

For frequencies from 100 kHz to 10 MHz, since either NS or thermal effects could occur, depending upon the exposure conditions (frequency, duty cycle, orientation), basic restrictions for both internal electric field strength and SAR (whole-body and peak spatially-averaged) must be simultaneously respected. Safety Code 6 also specifies reference levels in the 3 kHz to 110 MHz frequency range, in terms of induced- or contact-currents (mA), for the avoidance of perception (nerve stimulation), shocks or burns (4, 6).

While the biological basis for the basic restrictions specified in this safety code has not changed since the previous version (2009), the reference levels have been updated to either account for dosimetric refinements in recent years (43–64) or where feasible, to harmonize with those of ICNIRP (10–11).

To determine whether the maximum exposure levels are exceeded, full consideration shall be given to such factors as:

- (a) nature of the exposure environment (controlled or uncontrolled environment);
- (b) temporal characteristics of the RF source (including ON/OFF times, duty factors, direction and sweep time of the beam, etc.);
- (c) spatial characteristics between the exposure source and target (i.e. near-field exposures, whole body or parts thereof);
- (d) uniformity of the exposure field (i.e. spatial averaging).

Where comparison is to be made to the SAR-based basic restrictions and/or reference levels at frequencies in the 100 kHz–300 GHz range, higher exposure levels may be permitted for short durations of time under certain circumstances. For these situations, the field strengths, power densities and body currents averaged over any one tenth-hour reference period (6 minutes) shall not exceed the limits outlined in Sections 2.1 and 2.2.

SI units are used throughout this document unless specified otherwise.

## **2.1 BASIC RESTRICTIONS**

### **2.1.1 Internal Electric Field Strength Limits (3 kHz–10 MHz)**

Limits for internal electric field strength are intended to prevent the occurrence of NS. At frequencies between 3 kHz and 10 MHz, basic restrictions for internal electric field strength in excitable tissues (Table 1) shall not be exceeded. For conditions where the determination of internal electric field strength is not possible or practical (e.g. by measurement or modelling), external unperturbed field strength assessment shall be carried out and the reference levels outlined in Section 2.2 shall be respected.

**TABLE 1:** Internal Electric Field Strength Basic Restrictions (3 kHz–10 MHz)

<b>CONDITION</b>	<b>Internal Electric Field Strength (V/m) (in any excitable tissue)</b>
Controlled Environment	$2.7 \times 10^{-4}f$
Uncontrolled Environment	$1.35 \times 10^{-4}f$

Frequency,  $f$ , is in Hz. Instantaneous, root mean square (RMS) values apply. In the case of RF fields with amplitude modulation, then RMS values during the maximum of the modulation envelope shall apply.

### 2.1.2 Specific Absorption Rate Limits (100 kHz–6 GHz)

The SAR is a measure of the rate at which electromagnetic energy is absorbed in the body. Basic restrictions for SAR are intended to prevent the occurrence of thermal effects from RF energy exposure on the body. At frequencies between 100 kHz and 6 GHz, the SAR limits (Table 2) take precedence over field strength and power density reference levels (Section 2.2) and shall not be exceeded.

The SAR should be determined for situations where exposures occur at a distance of 0.2 m or less from the source. In all cases, the values in Table 2 shall not be exceeded. For conditions where SAR determination is impractical, external unperturbed field strength or power density measurements shall be carried out and the limits outlined in Section 2.2 shall be respected.

**TABLE 2:** Specific Absorption Rate Basic Restrictions (100 kHz–6 GHz)

<b>CONDITION</b>	<b>SAR Basic Restriction (W/kg)**</b>	
	<b>Uncontrolled Environment</b>	<b>Controlled Environment</b>
The SAR averaged over the whole body mass.	0.08	0.4
The peak spatially-averaged SAR for the head, neck and trunk, averaged over any 1 g of tissue*	1.6	8
The peak spatially-averaged SAR in the limbs, averaged over any 10 g of tissue*	4	20

\* Defined as a tissue volume in the shape of a cube.

\*\* Averaged over any 6 minute reference period.

### 2.1.3 Frequencies from 6 GHz–300 GHz

For frequencies above 6 GHz, energy deposition occurs predominantly in the uppermost layers of superficial tissues (e.g. skin, cornea). In this case, power density is a more appropriate exposure limit metric. Therefore, for the frequency range from 6 GHz to 300 GHz, the incident unperturbed power density and its derived electric- and magnetic-field strengths (assuming a free-space impedance of 377 ohms) form the basic restriction in this safety code (Section 2.2.2) and shall not be exceeded.

## 2.2 REFERENCE LEVELS

In practice, direct measurements of internal electric fields or SAR are often only feasible under laboratory conditions. Therefore, reference levels are specified in this safety code in terms of external unperturbed electric and magnetic field strength, power density, as well as induced and contact currents. In the far-field zone of an electromagnetic source, electric field strength, magnetic field strength and power density are interrelated by simple mathematical expressions, where any one of these parameters defines the remaining two. In the near-field zone, both the unperturbed electric- and magnetic-field strengths shall be measured, since there is no simple relationship between these two quantities. Instrumentation for the measurement of magnetic fields at certain frequencies may not be commercially available. In this case, the electric field strength shall be measured and used for assessing compliance with the reference levels in this code.

### 2.2.1 Electric and Magnetic Field Strength (3 kHz–10 MHz)

To ensure compliance with the basic restrictions outlined in Section 2.1, at frequencies between 0.003 MHz and 10 MHz, both the NS- and SAR-based reference levels for electric- and magnetic-field strength must be complied with simultaneously at frequencies where reference levels for both apply.

**TABLE 3:** Electric Field Strength Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level ( $E_{RL}$ ), (V/m, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–10	NS	83	170	Instantaneous*
1.0–10	SAR	$87 / f^{0.5}$	$193 / f^{0.5}$	6 minutes**

Frequency,  $f$ , is in MHz. The precise frequencies at which SAR-based electric field strength reference levels for Uncontrolled and Controlled Environments begin are 1.10 MHz and 1.29 MHz, respectively.

**TABLE 4:** Magnetic Field Strength Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level ( $H_{RL}$ ), (A/m, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–10	NS	90	180	Instantaneous*
0.1–10	SAR	$0.73 / f$	$1.6 / f$	6 minutes**

Frequency,  $f$ , is in MHz.

#### NOTES FOR TABLES 3 AND 4:

- \* At no point in time shall the RMS values for electric- and magnetic-fields exceed the reference levels with an instantaneous reference period in Tables 3 and 4. In the case of RF fields with amplitude modulation, the RMS value during the maximum of the modulation envelope shall be compared to the reference level.

2. \*\* For exposures shorter than the reference period, field strengths may exceed the reference levels, provided that the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed  $E_{RL}^2$  or  $H_{RL}^2$ , respectively. For exposures longer than the reference period, including indefinite exposures, the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed  $E_{RL}^2$  or  $H_{RL}^2$ , respectively.
3. Where external electric (at all applicable frequencies) or magnetic (at frequencies at or above 100 kHz) field strengths are spatially non-uniform, comparison to the reference levels shall be made after spatially averaging the field strengths over the vertical extent of the human body. Where comparison is to be made to the reference levels based on NS in Tables 3 and 4, spatial averaging is with respect to the sample values of the field strengths. Where comparison is to be made to the reference levels based on SAR in Tables 3 and 4, spatial averaging is with respect to the square of the sample values of the field strengths.
4. Where external magnetic field strengths are spatially non-uniform and are below 100 kHz, the spatial peak magnetic field strength over the vertical extent of the human body shall be compared to the reference levels in Table 4 (i.e. magnetic field strengths shall not be spatially-averaged at frequencies below 100 kHz).
5. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on NS, each of the field strength frequency component amplitudes shall be divided by the corresponding field strength reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as  $\sum (E_i/E_{RL}) \leq 1$  for electric field strength or  $\sum (H_i/H_{RL}) \leq 1$  for magnetic field strength.
6. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on SAR, each of the squares of the field strength frequency component amplitudes shall be divided by the square of the corresponding field strength reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as  $\sum (E_i/E_{RL})^2 \leq 1$  for electric field strength or  $\sum (H_i/H_{RL})^2 \leq 1$  for magnetic field strength.
7. For localized exposure of the limbs, the reference levels for magnetic field strength may be exceeded provided that the basic restrictions in Table 1 are respected within the limbs.

## 2.2.2 Electric Field Strength, Magnetic Field Strength and Power Density (10 MHz–300 GHz)

To ensure compliance with the basic restrictions outlined in Section 2.1, at frequencies between 10 MHz and 300 GHz, the reference levels for electric- and magnetic-field strength and power density must be complied with.

**TABLE 5:** Reference Levels for Electric Field Strength, Magnetic Field Strength and Power Density in Uncontrolled Environments

Frequency (MHz)	Electric Field Strength ( $E_{RL}$ ), (V/m, RMS)	Magnetic Field Strength ( $H_{RL}$ ), (A/m, RMS)	Power Density ( $S_{RL}$ ), (W/m <sup>2</sup> )	Reference Period (minutes)
10–20	27.46	0.0728	2	6
20–48	$58.07 / f^{0.25}$	$0.1540 / f^{0.25}$	$8.944 / f^{0.5}$	6
48–300	22.06	0.05852	1.291	6
300–6000	$3.142 f^{0.3417}$	$0.008335 f^{0.3417}$	$0.02619 f^{0.6834}$	6
6000–15000	61.4	0.163	10	6
15000–150000	61.4	0.163	10	$616000 / f^{1.2}$
150000–300000	$0.158 f^{0.5}$	$4.21 \times 10^{-4} f^{0.5}$	$6.67 \times 10^{-5} f$	$616000 / f^{1.2}$

Frequency,  $f$ , is in MHz.

**TABLE 6:** Reference Levels for Electric Field Strength, Magnetic Field Strength and Power Density in Controlled Environments

Frequency (MHz)	Electric Field Strength ( $E_{RL}$ ), (V/m, RMS)	Magnetic Field Strength ( $H_{RL}$ ), (A/m, RMS)	Power Density, ( $S_{RL}$ ), (W/m <sup>2</sup> )	Reference Period (minutes)
10–20	61.4	0.163	10	6
20–48	$129.8 / f^{0.25}$	$0.3444 / f^{0.25}$	$44.72 / f^{0.5}$	6
48–100	49.33	0.1309	6.455	6
100–6000	$15.60 f^{0.25}$	$0.04138 f^{0.25}$	$0.6455 f^{0.5}$	6
6000–15000	137	0.364	50	6
15000–150000	137	0.364	50	$616000 / f^{1.2}$
150000–300000	$0.354 f^{0.5}$	$9.40 \times 10^{-4} f^{0.5}$	$3.33 \times 10^{-4} f$	$616000 / f^{1.2}$

Frequency,  $f$ , is in MHz.

### NOTES FOR TABLES 5 AND 6:

1. For exposures shorter than the reference period, field strengths may exceed the reference levels, provided that the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed  $E_{RL}^2$  or  $H_{RL}^2$ , respectively. For exposures longer than the reference period, including indefinite exposures, the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed  $E_{RL}^2$  or  $H_{RL}^2$ , respectively.

2. Where exposure is estimated in terms of power density and for exposures shorter than the reference period, power density levels may exceed the reference levels provided that the time average of the power density over any time period equal to the reference period shall not exceed  $S_{RL}$ . For exposures longer than the reference period, including indefinite exposures, the time average of the power density over any time period equal to the reference period shall not exceed  $S_{RL}$ .
3. Spatially non-uniform external field strengths or power density can be spatially averaged, provided the sampling scheme applied ensures that none of the basic restrictions are exceeded at spatially-averaged exposures equal to the reference level. If spatial averaging is not applied, the spatial peak field strength shall be compared to the reference levels. In the case of field strengths, spatial averaging is with respect to the squared values of the field strength samples while for power density, spatial averaging is with respect to the power density samples.
4. For simultaneous exposure to multiple frequencies and where exposure is estimated in terms of power density, each of the power density frequency component amplitudes shall be divided by the corresponding reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as:  $\sum (S_i/S_{RL}) \leq 1$ .
5. For simultaneous exposure to multiple frequencies and where exposure is estimated in terms of field strength, each of the squares of the field strength frequency component amplitudes shall be divided by the square of the corresponding field strength reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as  $\sum (E_i/E_{RL})^2 \leq 1$  for electric field strength or  $\sum (H_i/H_{RL})^2 \leq 1$  for magnetic field strength.
6. For pulsed RF field exposures estimated in terms of power density, the time-averaged power density, averaged over any time period equal to the reference period, shall not exceed  $S_{RL}$  and the power density, as averaged over the pulse width, shall not exceed 1000 times the reference level,  $S_{RL}$ .
7. For pulsed RF field exposures estimated in terms of field strength, the time average of the squared value of the electric or magnetic field strength over any time period equal to the reference period shall not exceed  $E_{RL}^2$  or  $H_{RL}^2$ . In addition, the time average of the squared value of the electric or magnetic field strength, as averaged over the pulse width, shall not exceed 1000 times  $E_{RL}^2$  or  $H_{RL}^2$ , respectively. Therefore, the RMS electric or magnetic field strength, determined over the pulse, shall not exceed 32 times  $E_{RL}$  or  $H_{RL}$ , respectively.

### 2.2.3 Induced and Contact Current (3 kHz–110 MHz)

Induced current is defined as the current flowing through a single foot to ground in a free-standing body (no contact with conductive objects) exposed to an electric field. Where assessment is made of the current flowing through both feet, the result shall be compared to twice the reference level for a single foot.

Contact current is defined as the total current flowing through the body to ground resulting from finger-touch contact with a conductive object insulated from the ground that has been energized in an electric field. Conversely, it can be defined as the total current flowing in an insulated body that has been energized in an electric field and is in finger-touch contact with a grounded conductive object. The current path in the body is from point of touch to ground through the feet. The total current can be assessed anywhere along the path of flow.

**TABLE 7:** Induced Current Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level ( $I_{RL}$ ) through a single foot, (mA, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–0.4	NS	100 $f$	225 $f$	Instantaneous*
0.4–110	SAR	40	90	6 minutes**

Frequency,  $f$ , is in MHz.

**TABLE 8:** Contact Current Reference Levels

Frequency (MHz)	Reference Level Basis	Reference Level ( $I_{RL}$ ), (MA, RMS)		Reference Period
		Uncontrolled Environment	Controlled Environment	
0.003–0.10	NS	200 $f$	400 $f$	Instantaneous*
0.1–10	SAR	20	40	Instantaneous*
10–110	SAR	20	40	6 minutes**

Frequency,  $f$ , is in MHz.

**NOTES FOR TABLES 7 AND 8:**

- \* At no point in time shall the RMS values for induced and contact currents exceed the reference levels with an instantaneous reference period in Tables 7 and 8. In the case of currents with amplitude modulation, the RMS value during the maximum of the modulation envelope shall be compared to the reference level.
- \*\* For exposures shorter than the reference period, currents may exceed the reference levels, provided that the time average of the squared value of the current over any time period equal to the reference period shall not exceed  $I_{RL}^2$ . For exposures longer than the reference period, including indefinite exposures, the time average of the squared value of the current over any time period equal to the reference period shall not exceed  $I_{RL}^2$ .



3. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on NS, each of the induced- or contact-current frequency component amplitudes shall be divided by the corresponding reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as  $\sum (I_i/I_{RL}) \leq 1$ .
4. For simultaneous exposure to multiple frequencies and where comparison is to be made to the reference level based on SAR, each of the squares of the induced- or contact-current frequency component amplitudes shall be divided by the square of the corresponding reference level for that frequency, and the sum of all these ratios shall not exceed unity. This may be expressed as  $\sum (I_i/I_{RL})^2 \leq 1$ .
5. For pulsed induced- or contact-currents where a 6 minute reference period applies, the time average of the squared value of the induced- or contact-currents over any time period equal to the reference period shall not exceed  $I_{RL}^2$ . In addition, the time average of the squared value of the induced- or contact-current, as averaged over the pulse width, shall not exceed 1000 times the reference level  $I_{RL}^2$ . Therefore the RMS value of the induced- or contact-current, determined over the pulse, shall not exceed 32 times the reference level  $I_{RL}$ .

# ABBREVIATIONS

<b>A</b>	ampere
<b>EEG</b>	electroencephalogram
<b>E<sub>i</sub></b>	electric field strength frequency component amplitude (RMS)
<b>E<sub>RL</sub></b>	electric field strength reference level
<b>g</b>	gram
<b>GHz</b>	gigahertz
<b>H<sub>i</sub></b>	magnetic field strength frequency component amplitude (RMS)
<b>H<sub>RL</sub></b>	magnetic field strength reference level
<b>ICNIRP</b>	International Commission on Non-Ionizing Radiation Protection
<b>I<sub>i</sub></b>	current frequency component amplitude (RMS)
<b>I<sub>RL</sub></b>	current reference level
<b>kg</b>	kilogram
<b>kHz</b>	kilohertz
<b>m</b>	meter
<b>mA</b>	milliampere
<b>MHz</b>	megahertz
<b>mm</b>	millimeter
<b>NS</b>	nerve stimulation
<b>RMS</b>	root mean square
<b>RF</b>	radiofrequency
<b>SAR</b>	specific absorption rate
<b>SI</b>	International System of Units
<b>S<sub>i</sub></b>	power density frequency component amplitude
<b>S<sub>RL</sub></b>	power density reference level
<b>V</b>	volt
<b>W</b>	watt

## DEFINITIONS

**basic restrictions**—Maximum allowable internal electrical quantities in the body, arising from exposure to incident external fields, that prevent the occurrence of all established adverse health effects.

**contact current**—The total current flowing through the body to ground resulting from finger-touch contact with an insulated conductive object that has been energized in an electric field, or from an insulated body that has been energized in an electric field and is in finger-touch contact with a grounded conductive object.

**controlled environment**—An area where the RF field intensities have been adequately characterized by means of measurement or calculation and exposure is incurred by persons who are: aware of the potential for RF field exposure, cognizant of the intensity of the RF fields in their environment, aware of the potential health risks associated with RF field exposure and able to control their risk using mitigation strategies.

**electric field**—A vector quantity assigned to any point in space where the magnitude and direction of the force that would be experienced by a hypothetical test charge, is defined.

**electromagnetic radiation**—A form of energy emitted by accelerating electric charges, that exhibits wave-like behavior as it travels through space.

**far-field zone**—The space beyond an imaginary boundary around an antenna, where the angular field distribution begins to be essentially independent of the distance from the antenna. In this zone, the field has a predominantly plane-wave character.

**field strength**—The magnitude of the electric or magnetic field, normally a root-mean-square (RMS) value.

**frequency**—The number of cycles in the variation of the amplitude of an electromagnetic wave within one second, expressed in units of hertz (Hz).

**general public**—Individuals of all ages, body sizes and varying health status, some of whom may qualify for the conditions defined for the controlled environment in certain situations.

**induced current**—The current flowing through one foot to ground in a free-standing human body (no contact with a conductive object) exposed to an electric field.

**limbs**—Extremities distal from the shoulder and hip joints, which do not include the gonads.

**magnetic field**—A vector quantity assigned to any point in space where the magnitude and direction of the force that would be experienced by a hypothetical test charge-in-motion, is defined. A magnetic field exerts a force on charges only if they are in motion, and charges produce magnetic fields only when they are in motion.

**near-field zone**—A volume of space close to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point at the same distance from the source.

**non-thermal effects**—Biological effects resulting from exposure to RF fields, that are not due to tissue heating.

**power density**—The rate of flow of electromagnetic energy per unit area usually expressed in  $W/m^2$  or  $mW/cm^2$  or  $\mu W/cm^2$ .

**radiofrequency (RF)**—A rate of oscillation in the range of about 3 kHz to 300 GHz, which corresponds to the frequency of radio waves typically used in radio communications.

**reference level**—An easily measured or calculated quantity (i.e. externally applied electric field strength, magnetic field strength and power density or resulting body current), that when respected, ensures compliance with the underlying basic restrictions in Safety Code 6.

**reference period**—A time period used for averaging temporally non-uniform RF field exposures, for comparison with the exposure limits in Safety Code 6. The reference periods specified in Safety Code 6 are based upon the established adverse health effects to be avoided and the time required for those responses to occur. The reference period is not a maximum exposure time.

**RMS (root mean square)**—As applied to a set of data, it is the square root of the average of the square of the data values.

**safety**—The absence of established adverse health effects caused by RF field exposure.

**specific absorption rate (SAR)**—A measure of the rate at which energy is absorbed by the body (or a discrete tissue volume) when exposed to a radiofrequency (RF) field. SAR is expressed in units of watts per kilogram ( $W/kg$ ), and can be calculated from the product of the tissue conductivity ( $S/m$ ) and the square of the RMS electric field strength induced in the tissue ( $V/m$ ), divided by the mass density ( $kg/m^3$ ) of the tissue.

**thermal effects**—Biological effects resulting from heating of the whole body or of a localized region due to exposure to RF fields, where a sufficient temperature increase has occurred that results in a physiologically significant effect.

**uncontrolled environment**—An area where any of the criteria defining the controlled environment are not met.

# REFERENCES

- <sup>1</sup> Industry Canada. General Requirements and Information for the Certification of Radio Apparatus, Radio Standards Specifications (RSS-Gen), Spectrum Management and Telecommunications.
- <sup>2</sup> Industry Canada. Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands), Radio Standards Specifications (RSS-102), Spectrum Management and Telecommunications. 2010.
- <sup>3</sup> Industry Canada. Radiocommunication and Broadcasting Antenna Systems, Client Procedures Circular (CPC-2-0-03), Spectrum Management and Telecommunications.
- <sup>4</sup> World Health Organization (WHO). Extremely Low Frequency Fields, Environmental Health Criteria 238. Geneva, Switzerland, 2007. ISBN 9789241572385.
- <sup>5</sup> World Health Organization (WHO). Electromagnetic Fields (300 Hz to 300 GHz), Environmental Health Criteria 137. Geneva, Switzerland, 1993. ISBN 9241571373.
- <sup>6</sup> International Commission on Non-Ionizing Radiation Protection (ICNIRP). Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz–300 GHz). Munich, Germany, 2009. ISBN 9783934994102.
- <sup>7</sup> Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Possible Effects of Electromagnetic Fields (EMF) on Human Health. European Commission, Health & Consumer Protection DG, Directorate C: Public Health and Risk Assessment. Brussels, Belgium, 2007.
- <sup>8</sup> Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Health Effects of Exposure to EMF. European Commission, Health & Consumer Protection DG, Directorate C: Public Health and Risk Assessment. Brussels, Belgium, 2009.
- <sup>9</sup> Advisory Group on Non-ionising Radiation (AGNIR). Health Effects from Radiofrequency Electromagnetic Fields (RCE 20). Chilton, United Kingdom, 2012. ISBN 9780859517140.
- <sup>10</sup> International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys. 99:818–836, 2010.
- <sup>11</sup> International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys. 74:494–522, 1998.
- <sup>12</sup> International Commission on Non-Ionizing Radiation Protection (ICNIRP). Statement on the “Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)”. Health Phys. 97:257–258, 2009.
- <sup>13</sup> Institute of Electrical and Electronic Engineers (IEEE). IEEE C95.6-2002 Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz. New York, USA, 2002.
- <sup>14</sup> Institute of Electrical and Electronic Engineers (IEEE). IEEE C95.1-2005 Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. New York, USA, 2005.
- <sup>15</sup> World Health Organization (WHO). Framework for developing health-based EMF standards. Geneva, Switzerland, 2006. ISBN 9241594330.
- <sup>16</sup> International Commission on Non-Ionizing Radiation Protection (ICNIRP). Statement: General approach to protection against non-ionizing radiation. Health Phys. 82:540–548, 2002.
- <sup>17</sup> International Agency for Research on Cancer (IARC). Non-Ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields, IARC Monograph, volume 102. Lyon, France, 2013. ISBN 9789283213253.

- 18 Krewski D, Glickman BW, Habash RW, Habbick B, Lotz WG, Mandeville R, Prato FS, Salem T, Weaver DF. Recent advances in research on radiofrequency fields and health: 2001–2003. *J. Toxicol. Environ. Health B Crit. Rev.* 10:287–318, 2007.
- 19 Habash RW, Elwood JM, Krewski D, Lotz WG, McNamee JP, Prato FS. Recent advances in research on radiofrequency fields and health: 2004–2007. *J. Toxicol. Environ. Health B Crit. Rev.* 12:250–288, 2009.
- 20 Valberg PA, van Deventer TE, Repacholi MH. Workgroup report: base stations and wireless networks-radiofrequency (RF) exposures and health consequences. *Environ. Health Perspect.* 115:416–424, 2007.
- 21 Moulder JE, Foster KR, Erdreich LS, McNamee JP. Mobile phones, mobile phone base stations and cancer: a review. *Int. J. Radiat. Biol.* 81:189–203, 2005.
- 22 Verschaeve L. Genetic damage in subjects exposed to radiofrequency radiation. *Mutat. Res.* 681:259–270, 2009.
- 23 Vanderstraeten J and Verschaeve L. Gene and protein expression following exposure to radiofrequency fields from mobile phones. *Environ. Health Perspect.* 116:1131–1135, 2008.
- 24 McNamee JP, Chauhan V. Radiofrequency radiation and gene/protein expression: A review. *Radiat. Res.* 172:265–287, 2009.
- 25 Cook CM, Saucier DM, Thomas AW, Prato FS. Exposure to ELF magnetic and ELF-modulated radiofrequency fields: the time course of physiological and cognitive effects observed in recent studies (2001–2005). *Bioelectromagnetics* 27:613–627, 2006.
- 26 D’Andrea JA, Chou CK, Johnston SA, Adair ER. Microwave effects on the nervous system. *Bioelectromagnetics Suppl.* 6:S107–147, 2003.
- 27 D’Andrea JA, Adair ER, de Lorge JO. Behavioural and cognitive effects of microwave exposure. *Bioelectromagnetics Suppl.* 6:S39–62, 2003.
- 28 McNamee JP and Bellier PV, “Cytogenetic and Carcinogenetic Effects of Exposure to Radiofrequency Radiation” In: “Chromosomal Alterations: Methods, Results and Importance in Human Health”. Obe, Günter; Vijayalaxmi (Eds.) Springer, New York, USA, 2007. ISBN 9783540714132.
- 29 Jauchem JR. Effects of low-level radio-frequency (3kHz to 300GHz) energy on human cardiovascular, reproductive, immune, and other systems: a review of the recent literature. *Int. J. Hyg. Environ. Health.* 211:1–29, 2008.
- 30 Rubin GJ, Das Munshi J, Wessely S. Electromagnetic hypersensitivity: a systematic review of provocation studies. *Psychosom. Med.* 67:224–232, 2005.
- 31 Rubin GJ, Nieto-Hernandez R, Wessely S. Idiopathic environmental intolerance attributed to electromagnetic fields (formerly ‘electromagnetic hypersensitivity’): An updated systematic review of provocation studies. *Bioelectromagnetics* 31:1–11, 2010.
- 32 Rösli M. Radiofrequency electromagnetic field exposure and non-specific symptoms of ill health: a systematic review. *Environ. Res.* 107:277–287, 2008.
- 33 Rösli M, Hug K. Wireless communication fields and non-specific symptoms of ill health: a literature review. *Wien. Med. Wochenschr.* 161: 240–250, 2011.
- 34 Rösli M, Frei P, Mohler E, Hug K. Systematic review on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations. *Bull. World Health Organ.* 88:887–896F, 2010.
- 35 Reilly JP. *Applied Bioelectricity: From Electrical Stimulation to Electropathology.* Springer, New York, USA, 1998. ISBN 0387984070.

- <sup>36</sup> D'Andrea JA, Ziriak JM, Adair ER. Radio frequency electromagnetic fields: mild hyperthermia and safety standards. *Prog. Brain Res.* 162:107–135, 2007.
- <sup>37</sup> Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (Anses). *Radiofréquences et santé : Mise à jour de l'expertise.* Maisons-Alfort, France, 2013.
- <sup>38</sup> Norwegian Institute of Public Health. *Low-level radiofrequency electromagnetic fields—an assessment of health risks and evaluation of regulatory practice (English summary).* Oslo, Norway, 2012. ISBN 9788280825100.
- <sup>39</sup> Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). *Preliminary opinion on Potential health effects of exposure to electromagnetic fields (EMF).* European Commission, Health & Consumers Directorate C: Public Health. Luxembourg, 2013. ISBN 9789279301346.
- <sup>40</sup> Swedish Radiation Health Authority (SSM). *Eighth report from SSM:s Scientific Council on Electromagnetic Fields.* Stockholm, Sweden, 2013. Report number: 2013:19, ISSN: 2000-0456.
- <sup>41</sup> So PP, Stuchly MA, Nyenhuis JA. Peripheral nerve stimulation by gradient switching fields in magnetic resonance imaging. *IEEE Trans. Biomed. Eng.* 51:1907–1914, 2004.
- <sup>42</sup> Adair ER, Black DR. Thermoregulatory responses to RF energy absorption. *Bioelectromagnetics Suppl.* 6:S17–S38, 2003.
- <sup>43</sup> Conil E, Hadjem A, Lacroux F, Wong MF, Wiart J. Variability analysis of SAR from 20 MHz to 2.4 GHz for different adult and child models using finite-difference time-domain. *Phys. Med. Biol.* 53:1511–1525, 2008.
- <sup>44</sup> Kühn S, Jennings W, Christ A, Kuster N. Assessment of induced radio-frequency electromagnetic fields in various anatomical human body models. *Phys. Med. Biol.* 54:875–890, 2009.
- <sup>45</sup> Nagaoka T, Kunieda E, Watanabe S. Proportion-corrected scaled voxel models for Japanese children and their application to the numerical dosimetry of specific absorption rate for frequencies from 30 MHz to 3 GHz. *Phys. Med. Biol.* 53:6695–6711, 2008.
- <sup>46</sup> Gandhi OP, Chen JY, Riaz A. Currents induced in a human being for plane-wave exposure conditions 0–50 MHz and for RF sealers. *IEEE Trans. Biomed. Eng.* 33:757–767, 1986.
- <sup>47</sup> Tofani S, d'Amore G, Fiandino G, Benedetto A, Gandhi OP, Chen JY. Induced foot-currents in humans exposed to VHF radio-frequency EM fields. *IEEE Trans. Electromagn. Compat.* 37:96–99, 1995.
- <sup>48</sup> Kaune WT, Guttman JL, Kavet R. Comparison of coupling of humans to electric and magnetic fields with frequencies between 100 Hz and 100 kHz. *Bioelectromagnetics* 18:67–76, 1997.
- <sup>49</sup> Bakker JF, Paulides MM, Neufeld E, Christ A, Chen XL, Kuster N, van Rhoon GC. Children and adults exposed to low-frequency magnetic fields at the ICNIRP reference levels: theoretical assessment of the induced electric fields. *Phys. Med. Biol.* 57:1815–1829, 2012.
- <sup>50</sup> Gandhi OP, Chatterjee I, Wu D, Gu YG. Likelihood of high rates of energy deposition in the human legs at the ANSI recommended 3–30 MHz RF safety levels. *Proc. IEEE* 73:1145–1147, 1985.
- <sup>51</sup> Gandhi OP, Chatterjee I. Radio-frequency hazards in the VLF to MF band. *Proc. IEEE* 70:1462–1464, 1982.
- <sup>52</sup> Bernhardt JH. The establishment of frequency dependent limits for electric and magnetic fields and evaluation of indirect effects. *Radiat. Environ. Biophys.* 27:1–27, 1988.
- <sup>53</sup> Dimbylow PJ. The calculation of induced currents and absorbed power in a realistic, heterogeneous model of the lower leg for applied electric fields from 60 Hz to 30 MHz. *Phys. Med. Biol.* 33:1453–1468, 1988.
- <sup>54</sup> Dimbylow PJ. The calculation of localised SAR in a 2 mm resolution anatomically realistic model of the lower leg. *Radiat. Prot. Dosimetry* 72:321–326, 1997.

- <sup>55</sup> Dimbylow PJ. The relationship between localised SAR in the arm and wrist current. *Radiat. Prot. Dosimetry* 95:177–179, 2001.
- <sup>56</sup> Dimbylow PJ. Fine resolution calculations of SAR in the human body for frequencies up to 3 GHz. *Phys. Med. Biol.* 47:2835–2846, 2002.
- <sup>57</sup> Dimbylow PJ. The calculation of SAR from limb current in the female voxel phantom, NAOMI. *Radiat. Prot. Dosimetry* 121:236–239, 2006.
- <sup>58</sup> Dimbylow P. Development of the female voxel phantom, NAOMI, and its application to calculations of induced current densities and electric fields from applied low frequency magnetic and electric fields. *Phys. Med. Biol.* 50:1047–1070, 2005.
- <sup>59</sup> Dimbylow P, Bolch W. Whole-body-averaged SAR from 50 MHz to 4 GHz in the University of Florida child voxel phantoms. *Phys. Med. Biol.* 52:6639–6649, 2007.
- <sup>60</sup> Chatterjee I, Wu D, Gandhi OP. Human body impedance and threshold currents for perception and pain for contact hazard analysis in the VLF-MF band. *IEEE Trans. Biomed. Eng.* 33:486–494, 1986.
- <sup>61</sup> Findlay RP, Lee AK, Dimbylow PJ. FDTD calculations of SAR for child voxel models in different postures between 10 MHz and 3 GHz. *Radiat. Prot. Dosimetry* 135:226–231, 2009.
- <sup>62</sup> Lee AK, Choi HD. Determining the influence of Korean population variation on whole-body average SAR. *Phys. Med. Biol.* 57:2709–2725, 2012.
- <sup>63</sup> Dimbylow P, Bolch W, Lee C. SAR calculations from 20 MHz to 6 GHz in the University of Florida newborn voxel phantom and their implications for dosimetry. *Phys. Med. Biol.* 55:1519–1530, 2010.
- <sup>64</sup> Hirata A, Yanase K, Laakso I, Chan KH, Fujiwara O, Nagaoka T, Watanabe S, Conil E, Wiart J. Estimation of the whole-body averaged SAR of grounded human models for plane wave exposure at respective resonance frequencies. *Phys. Med. Biol.* 57:8427–8442, 2012.