

Section 1

Executive Summary

The toolkit was written by public health scientists and is intended as a background document, current to 2012, to assist medical health officers and environmental health officers in their role of communicating evidence of potential hazards of radiofrequency (RF) to the concerned public. RF-emitting devices such as mobile phones, baby monitors, WiFi and Smart Meters are used extensively for wireless communication, with applications also for medical and industrial purposes. Information on RF and RF safety is abundant but broadly scattered, technically complex, and not easily understood. RF emitting devices differ in such characteristics as frequency, power, and continuity of output, yet the public sometimes sees exposure to RF as a single issue without considering the strength and nature of the RF source and the distance between the source and the individual who might absorb its energy. The toolkit provides background on the physics of RF, its sources, measurement and exposure characteristics as well as an evaluation of the current scientific literature on potential biological and health effects associated with exposure to RF.

Section 2, *Basic Physics of Radiofrequency*, examines the nature and characteristics of RF waves as part of the electromagnetic (EMF) spectrum and provides a description of modulation of RF waves (pulsed vs. continuous beams); quantities used (including power density and effective power); units of the electrical and magnetic fields, and differences in exposure according to near, intermediate, and far-field of sources.

Section 3, *Sources of Radiofrequency Electromagnetic Fields*, describes the variety of consumer products that emit or respond to EMF. In addition to natural and biological RF sources, RF-emitting devices include mobile phones and base stations; baby monitors; cordless phones; WiFi systems: computers, security, access points; smart meter systems; AM, FM, CB radio, TV broadcast systems; and microwave ovens. Industry sources of RF include heat sealers, induction heaters, wood gluing and radar, while medical sources include magnetic resonance imaging, ablation and tumour therapy, and short-wave diathermy.

Section 4, *Detection and Measurement of Radiofrequency Waves*, describes such instruments as RF detectors, receivers, survey meters and individual RF monitors. Time averaging is compared to spatial averaging with output being peak or average power. SAR measurements can be obtained by calorimetric, E-field, and graphical techniques.

Section 5, *Assessment of Radiofrequency Exposure to the General Public*, presents data on source measurements taken in the field and in laboratories as well as personal and area measurements of multiple sources of ambient RF fields. RF emitting devices near the body are known to produce the greatest exposures (e.g., mobile phone held to the head) but once in the far-field, exposures decrease substantially. Ambient

exposures to RF are up to millions of times lower than levels from mobile phones held at the ear. Technology of the RF-emitting devices has the greatest influence on exposure levels. The original analogue mobile phone systems and the Global System for Mobile Communications (GSM) have higher energy output than newer mobile phone technologies. Environmental factors that can increase the intensity of exposure to multiple sources of RF include location (indoors vs. outdoors, urban vs. rural) and being in transit. Ongoing assessments of exposure are needed given the increasing number of sources of RF and duration of use, as well as ever-changing technology.

Section 6A, *Biological Effects of Radiofrequency Exposure – Cell Culture Studies*, reviews the literature on non-thermal exposure to RF and possible adverse biological effects on cells, and considers biological processes which suggest the potential for adverse health outcomes or mechanisms for health effects. There is no convincing evidence from cell culture studies that RF field exposure damages DNA (a cancer mechanism), induces cell transformation or affects a variety of physiologic processes such as calcium channelling in neurologic and other cells. Mixed or contradictory results have been found for cell proliferation, the presence of reactive oxygen species (which contain free radicals that are damaging to DNA), apoptosis (programmed cell death) in cell cultures, and changes in expression of heat shock or other genes or proteins indicative of cell stress. Overall, in spite of the many well-conducted cell culture experiments examining a number of putative effects, there is no convincing evidence that sub-thermal exposure to RF has adverse biological effects at the cellular level. On this basis, no biological mechanism proposed for such effects can be evaluated.

Section 6B, *Biological Effects of Radiofrequency Exposure – Animal Studies*, summarizes the recent literature on the relationship between RF exposure and biological or toxicological effects in animals. Long-term bioassays, designed to determine whether RF exposure either alone or in conjunction with known mutagens can initiate or promote development of cancer in animals, have been uniformly negative. Studies of RF fields and toxicological effects such as DNA damage, micronucleus formation, apoptosis, reactive oxygen species, and gene expression changes have been inconsistent and the results have been contradictory. Positive studies have proven difficult to replicate. There is no consistent evidence that exposure to RF produces biological effects in animal central nervous systems. Recent investigations have been unable to confirm that RF exposure alters blood-brain barrier permeability; however, other aspects of brain physiology are less well studied. Behavioural investigations of the role of RF exposure on animal learning and cognitive function are mixed. Immune function studies have been mostly negative, although most of the studies to date have been conducted in adult animals. Effects of RF exposure on endocrine function, particularly on melatonin levels, have been negative, as have been studies on reproductive function in female animals. Overall, the research studies to date have not provided convincing evidence that RF-field exposure produces adverse biologic effects in animals.

Section 7, *The Use of Electromagnetic Fields in Medicine and Its Effect on Patients and Health Care Workers*, concerns the exposure and health of patients and health care workers exposed to RF from medical devices. EMF of lower frequencies up to 200 MHz are commonly used in medicine for diagnosis and therapy, which includes exposures to RF above 100 kHz (0.1 MHz). Three main EMF applications in medicine are magnetic resonance imaging (MRI), RF ablation that destroys tumours and unhealthy tissue in heart muscle, and localized dielectric heating (short-wave diathermy) used in physiotherapy to heat surfaces or deep tissue. No long-term effects of EMF exposures to MRI patients on reproductive, cardiovascular, and cognitive function outcomes have been reported, and there is no indication of chronic effects attributed to occupational exposure to the EMF fields. Complications to patients, which may arise due to non-target thermal damage during RF ablation are usually reversible; there were no studies of occupational health risks for workers administering RF ablation. There was also no literature concerning adverse effects of dielectric heating on patients. Female physiotherapists were at a slightly increased risk for spontaneous abortions and heart disease, but these may be more related to the older practice of microwave diathermy, rather than the common use of short-wave diathermy.

Section 8, *Health Effects Associated with Radiofrequency Exposure of Industrial Workers*, describes principal industrial uses of RF waves and assesses the literature concerning over-exposure and long-term chronic exposures of industrial workers to RF and associated health effects. Workers in a wide variety of industries are potentially exposed to higher levels of RF and for longer duration than the general population, although not necessarily at the same RF frequencies. Current safety guidelines are based on preventing the established acute effects of tissue heating and RF shock.

Industrial applications of RF include industrial microwave ovens (dryers), induction and dielectric heating, broadcasting applications (AM, FM, CB, and TV) and radar. Case reports on accidental over-exposures resulted in no long-term health effects. Brain tumours and hematopoietic cancers are the most extensively studied cancer outcomes in studies of chronic occupational RF exposure; no increased risk for any cancer site has been observed. The cardiovascular mortality studies of industrial workers also have been consistently negative.

Military personnel were the focus of many of the studies on the reproductive effects of occupational exposure to RF on semen parameters. Although there was some indication of adverse sperm effects, the studies were generally poorly done. The quality of exposure assessment and low statistical power are major limitations of observational studies. Further research into health effects associated with occupational exposures to RF is needed due to the potential for greater intensity and duration of exposure. Additionally, absorption in the body can be greater in occupational settings when lower frequency RF is used.

For Section 9, *Epidemiological Studies on the Risk of Head and Neck Tumours and Cancers Associated with the Use of Mobile Phones*, long-term exposure and cancer latency are important to consider as cancer develops only after an extended period of time since first exposure. As well, the highest level of personal exposure to RF is from mobile phones held to the head. Most of the original studies cited in the reviews did not find an increased risk of head and neck tumours associated with long-term use of digital phones. However, many of the literature reviews using meta-analyses (combining study results) found increased risks of specific head tumours with longer-term use of mobile phones (typically, at least 10 years since first use), along with recall of using mobile phones preferentially at the same side of the head as the tumour.

The tumours implicated were gliomas (originating from glial cells which surround neurons and often are malignant) and benign acoustic neuromas (non-cancerous) cranial nerve tumours. No relationship was found between long-term use of mobile phones and meningiomas (tumours in tissue surrounding the brain and spinal cord) or of parotid tumours (salivary gland tumours). Because of study design issues and positive findings that have not been replicated by other researchers, doubts remain about whether exposure to RF increases the risk of brain and other cancers of the head and neck. It should, however, be noted that, based on review of the same body of evidence, the IARC Working Group review in May 2011 determined that exposure to RF from wireless phones was “possibly carcinogenic to humans (Group 2B)”.

Section 10, *Mobile Phones, Radiofrequency Waves, and Male Infertility*, provides a synthesis of research into the effects of RF from mobile phones on semen parameters and on possible mechanisms for such health effects. The epidemiological studies of men assessed for infertility were consistent in demonstrating decreased sperm motility associated with use of mobile phones. Most of the in vitro (laboratory) studies, which involved exposing human semen samples to controlled mobile phone RF exposure, generally noted a decrease in sperm motility, among other adverse effects. Similar findings were noted in animal studies of a specific type of rat. Oxidative stress or decreased antioxidants are suggested as plausible mechanisms for these non-thermal effects from RF exposure. Better exposure assessment is needed in future studies, such as determining the effect of usually carrying an active mobile phone in the front pants pocket.

Section 11, *Neurophysiologic and Cognitive Performance Effects from Exposure to Radiofrequency Waves from Mobile Phones*, poses the question, “Is there evidence of non-cancerous effects on the brain from exposure to RF waves from mobile phones?” The conclusion from five of the most recent reviews is that cumulative evidence to date does not support exposure to RF as having adverse effects on cognitive performance, as demonstrated by current neurobehavioral tests of memory and attention. Although there is some consistency of an effect on brain activity, as indicated by enhancement of the alpha waves recorded in electroencephalography (EEG) studies, it is of unknown significance on behaviour or health. Subtle effects on

brain physiology may be better characterized with new types of neurophysiologic techniques, such as measurement of brain glucose metabolism, and carefully designed replicable larger-scale studies. Whether effects on brain activity or physiology translate to adverse behavioural or health effects remains unclear.

Section 12, *Symptoms Attributed to Radiofrequency / Electromagnetic Fields*, assesses observational studies and experimental (provocation) studies to determine the association of non-specific symptoms with exposure to RF for the general public and to electrohypersensitive (EHS) individuals who attribute their health effects to exposure to electromagnetic fields, including RF. Findings from population health studies of exposures from mobile phones and mobile phone base stations are mixed and inconsistent and are prone to study design issues including poor exposure ascertainment. The prevalence of EHS is estimated to vary from 1% to 10% of the population. In general, subjects who are self-declared with “EHS” do not reliably detect RF when blinded to the source, and RF fails to trigger symptoms in self-declared EHS individuals in a reliable, reproducible, and consistent way. However, provocation studies are limited to examining acute (short-term) exposure to RF, and acute symptoms and the effects of cumulative, chronic exposure to RF on persistent human health symptoms have not been studied thoroughly.

Section 13, *Radiofrequency Safety Guidelines and Standards*, provides an overview and commentary on Safety Code 6 – Health Canada’s radiofrequency exposure guidelines, with comparison to the internationally recognized guidelines by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and to exposure limits used in other countries. The main basis for regulation is to prevent thermal effects due to the absorption of RF by soft tissue. The RF exposure limits for the general public in Canada, like the USA and Japan, are slightly higher at 6 W/m² than the ICNIRP standard (4.5 W/m²) for frequencies of 900 MHz (e.g., GSM mobile phones and base stations, and some Smart Meters). Whether and how the much lower limits of 0.10 W/m² for Eastern European countries are enforced is not known.

Section 14, *Strategies for Radiofrequency Exposure Reduction*, offers an occupational hygiene approach for the option of minimizing personal exposure to RF. This includes: 1) substitution, by replacing wireless RF devices such as phones with hard-wired alternatives; 2) engineering controls through modifications such as power-saving or non-idling functions; 3) administrative controls including limiting duration and frequency of use as well as distancing (e.g., use headsets, speaker phone, or text-messaging for mobile phones). Shielding from RF by adding mobile phone shields or wearing protective devices such as metallic clothing or headgear has limited effectiveness and may even increase exposure to RF.

Section 15, *Overview of Major Ongoing Research Projects on Electromagnetic Fields and Health*, provides a description of six international research projects on EMF and health: 1) The EMF project of the World Health Organization (WHO); 2) MOBI-KIDS

project: Study on Communication Technology, Environment and Brain Tumours in Young People; 3) EFHRAN: European Health Risk Assessment Network on Electromagnetic Fields Exposure; 4) COSMOS project: Cohort Study of Mobile Phone Use and Health; 5) Sound Exposure & Risk Assessment of Wireless Network Devices (SEAWIND); and 6) National Toxicology Program (NTP) Rodent project.

Section 16, *International Reports on Radiofrequency Exposures and Health Effects*, describes the content of recent reports reviewing biological and health effects associated with exposure to RF and EMF. These included: 1) AGNIR, the Advisory Group on Non-Ionizing Radiation (UK); 2) the BioInitiative report; 3) EFHRAN, the European Health Risk Assessment Network; 4) ICNIRP, International Commission on Non-Ionizing Radiation Protection; 5) Latin American Experts Committee on High Frequency Electromagnetic Fields and Human Health; 6) Norwegian Institute of Health Expert Committee, Report 2012; 7) SCENIHR, Scientific Committee on Emerging and Newly Identified Health Risks; and 8) the Swedish Radiation Safety Authority - SSM:s Independent Expert Group on Electromagnetic Fields.