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Summary Report on the Status of Research Related to Radiofrequency Field Exposure and Health

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July 17, 2012

1200323.000 B0T1 0712 LE03

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Acronyms and Abbreviations

AGNIR	Advisory Group on Non-Ionizing Radiation
CCST	California Council on Science and Technology
CI	Confidence interval
EMF	Electric and magnetic fields
FCC	Federal Communications Commission
HCN	Health Council of the Netherlands
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
HPA	Health Protection Agency of Great Britain
Hz	Hertz
OR	Odds ratio
RF	Radiofrequency
RR	Relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SSM	Swedish Radiation Safety Authority
UK	United Kingdom

Limitations

At the request of BC Hydro, Exponent prepared this summary report on the status of research related to radiofrequency field exposure and health. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

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Introduction

In the summer of 2011, BC Hydro implemented their Smart Metering Program as the first step in modernizing the electricity system in British Columbia by replacing old analog meters with digital meters. Since that time, 1.8 million smart meters have been installed in homes and businesses throughout the province. Since many smart meters utilize wireless technology to transmit information, they emit electromagnetic energy in the form of radiofrequency (RF) fields (also called radio waves), much like many other electronic devices that are common in everyday life (e.g., cellular and cordless telephones, WiFi routers, baby monitors, garage door openers, and Bluetooth technology).

This report was prepared at the request of BC Hydro to provide a status report on current research that relates to RF fields and health. Smart meters are a relatively new technology with deployment in the United States and Canada growing steadily over the past six years or so. As with many new technologies, questions have arisen about health effects—in this case, the possible health effects that may occur from exposure to the RF fields created when signals are emitted from smart meters installed on homes and commercial buildings. Generally, concerns center on chronic health conditions and symptoms related to well-being. The effects of long-term exposures at low levels and the adequacy of the relevant existing standards have also been questioned.

The electromagnetic spectrum includes all forms of electromagnetic energy, which are characterized by their wavelength and frequency. Wavelength is the distance covered by one full electromagnetic wave cycle and frequency is the number of electromagnetic waves that pass a fixed point in one second, measured in units of Hertz (Hz). Energy along the electromagnetic spectrum is linked to frequency levels; it ranges from the low energy associated with low frequency and long wavelength (e.g., radio waves, power-frequency electric and magnetic fields [EMF], microwaves, and infrared light) to the high energy associated with high frequency and

short wavelength (e.g., visible light, ultraviolet light, X-rays, and gamma-rays).[1] Radio waves (i.e., RF energy), are at the lower end of the electromagnetic spectrum. RF energy is typically defined as between 3,000 Hz ($3x10^3$) and 300 billion Hz (3×10^{11}).

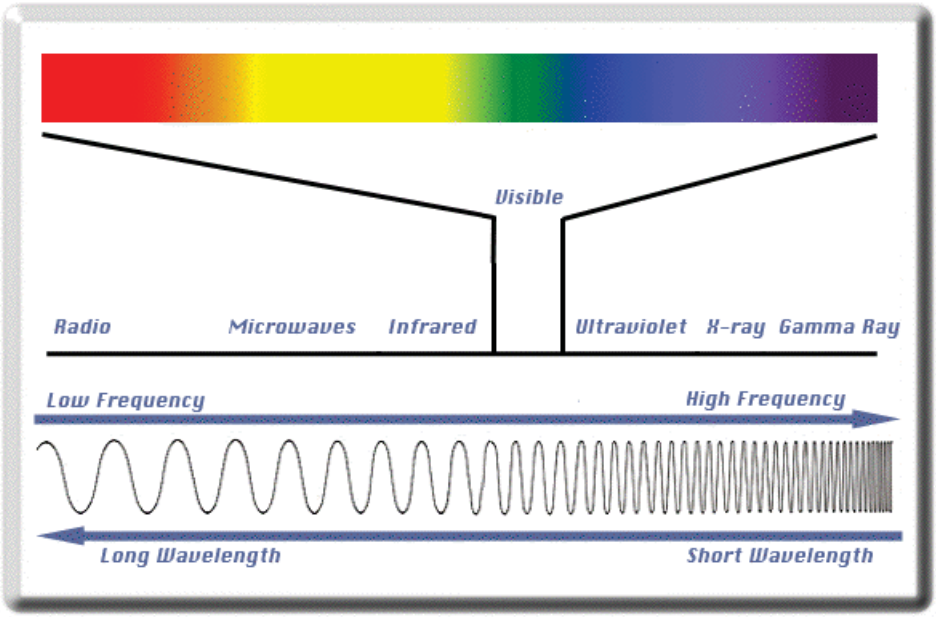

Figure 1. The electromagnetic spectrum

Over a century ago, RF energy began to be used across many disciplines—in science and medicine, in the communications and transportation industries, and by the military. One of the earliest uses was the wireless telegraph in the 1890s, followed by radio broadcasting in the early 20th century, radar during World War II, television broadcasting starting in the 1940s, and more recently, for microwave ovens. All of these technologies operate using strong RF signals.[2] Recent technological advancements have made it possible to utilize very weak RF signals for consumer products that are now common in our homes and businesses. As mentioned above,

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1 While RF and EMF are sometimes used synonymously by the public, in this report EMF will refer to the fields associated with the generation of electricity from power lines and electric devices at 50 or 60 Hz. All electromagnetic energy in the spectrum, including light, radiates outward from the source and is termed 'radiation.' The energy from very high frequency fields such as X-rays and gamma rays are known as ionizing radiation. RF and EMF are categorized as non-ionizing radiation and do not cause the biological changes that can occur from ionizing radiation.

2 The strength of the field (i.e., its intensity) is different than frequency, just as any sound, high or low depending on frequency can be loud or soft (high or low intensity).

these include cellular and cordless phones, baby monitors, garage door openers, Bluetooth devices, and WiFi routers, just to name a few.

Exposure to RF fields from these sources is considered either far-field or near-field based on physical distance from the source. Far-field exposure is defined, typically, as the location where the power density begins to decrease inversely with the square of the distance (i.e., very rapidly). Typical far-field sources include radio and TV transmitters, base stations, wireless local area network access points, and smart meters. Near-field exposure also is defined by the distance from a source, typically the region very close to antennas in which the power density does not necessarily decrease inversely with the square of the distance. As implied, near-field exposures occur when sources are close to the body, such as mobile phones and other handsets. An additional component to determine whether a source constitutes far-field or near-field exposure is the distance to the source in relation to the wavelength and the antenna geometry. The distance to a near-field source is often defined as closer than one-sixth of the wavelength and far field is typically equal to or greater than the size of the wavelength (EPRI, 2011).

Scientific research on RF energy from sources that utilize strong signals has been conducted since the 1940s; this research has consistently supported the development of health-based exposure limits and standards. The recent proliferation of technology that uses very weak RF signals has led to scientific research on exposure to RF fields from these devices and various health outcomes. This research has focused primarily on mobile phones, partly because of the close proximity of mobile phones to the human body when in use. In addition, the number of mobile phones in use (about 5 billion throughout the world in 2010) is a substantial factor in the attention given to research results related to mobile phones.

The widespread introduction of other devices that emit weak RF signals, such as smart meters, also has generated questions about exposure and health in two general areas: cancer risk from long-term exposure and symptoms related to well-being from short-term exposure. This report provides an overview of the current research on these two subjects.

The purpose of this report is to provide a summary of the significant research regarding RF exposure and health conducted by national and international health agencies and to assess the impact of recent research on the conclusions reached by these agencies. To provide a framework for our discussion of the research, the first section describes the health risk assessment and review process that scientists use to compile and evaluate research about the impact of any exposure to a chemical or physical agent on human health. The next section provides additional contextual information on the methods for evaluating the specific types of scientific studies discussed in this report. Section 3 discusses the regulatory standards and exposure guidelines in general and the standards that have been established for RF fields in particular, as well as the relevant exposure standard in Canada.

The conclusions of recent comprehensive reviews conducted by scientific and health organizations relevant to RF fields and health are discussed in Section 4. Finally, the last section summarizes recent RF research and the potential impact of this new research on the conclusions of recent comprehensive reviews, based on methods of health risk assessment described in Section 1.

1. Health Risk Assessments

Heath risk assessment approach

The standard process for evaluating a body of scientific research to understand the potential implications of an exposure is referred to as a risk assessment. Generally, risk assessments fall into two broad categories: an ecological risk assessment or a human health risk assessment.[3] A human health risk assessment is a four-step process that starts with a *hazard identification* to determine any possible risks associated with an exposure, which is performed by conducting a *weight-of-evidence review*, i.e., a systematic evaluation of the relevant scientific research. The next step is a *dose-response assessment* to determine the level of exposure at which a health risk might occur. Complementary to the dose-response assessment, an exposure assessment is performed to measure or estimate the magnitude, frequency, and duration of exposure to characterize the circumstances under analysis. Finally, a *risk characterization* is developed that provides a summary evaluation of a health risk based on the results of the hazard identification/weight-of-evidence review, dose-response assessment, and exposure assessment.[4]

Hazard identification/weight-of-evidence review

The review of scientific research is more than a collection of facts; rather, it is a method of obtaining and evaluating data to assure its accuracy and to determine whether the data correctly describes physical and biological phenomena. Since the proximity or co-occurrence of events or conditions does not guarantee a causal relationship, scientists use systematic methods to evaluate observations and assess the potential impact of a specific agent on human health.

Hazard identification involves analyzing *all* the evidence on a particular issue in a systematic and thorough manner. This analysis, a weight-of-evidence review, is conducted for three, broad research areas: epidemiology (observational studies of humans), *in vivo* research (laboratory

[3] For the risk assessment process specific to electromagnetic field exposure utilized by scientific review panels, see General Approach to Protection Against Non-Ionizing Radiation (ICNIRP, 2002, pp. 541-544); Possible Effects of Electromagnetic Fields (EMF) on Human Health (SCENIHR, 2007, pp. 12-13); Recent Research on EMF and Health Risks (SSM, 2009, pp. 5-7); and Electromagnetic Fields: Annual Update 2008 (HCN, 2009, pp. 81-91).

[4] http://epa.gov/riskassessment/basicinformation.htm#arisk

studies of animals), and *in vitro* research (laboratory studies of cells and tissues). A weight-of-evidence review is designed to ensure that scientific studies with a given result are not selected out from the available evidence to advocate or suppress a hypothesis about an adverse effect. Three basic steps define a weight-of-evidence review: a systematic review of the published literature to identify relevant studies, an evaluation of each study to determine its strengths and weaknesses, and an overall evaluation of the data, giving more weight to higher-quality studies (i.e., well-designed and properly conducted).

Dose-response assessment

The concept of dose-response is a familiar part of daily life. A common household substance, bleach (sodium hypochlorite) provides a relevant example. Household bleach contains a highly-concentrated, 6 percent solution of sodium hypochlorite and carries a warning label that it is a hazardous and corrosive substance. A similar, but highly-diluted solution of sodium hypochlorite is used to disinfect many municipal drinking water supplies; in this case, the concentration of sodium hypochlorite is extremely low, and the dose is far too low to produce a toxic effect.

Almost anything in our environment can produce adverse effects if the exposure is high enough or occurs over a long period of time, so the goal for scientists is to determine the level and period of exposure below which adverse effects do not occur. A simple principle of the dose-response relationship for chemicals or physical agents that could affect biological functions is 'more is worse.' For this reason, laboratory experiments strive to expose animals at the highest level tolerated, to ensure that potential adverse effects are not missed. Should adverse effects result, subsequent experiments are performed that utilize lower levels of exposure to identify a level that does not produce adverse effects. Studies that demonstrate increased risks with higher dose are indications of a dose-response pattern, which, if consistent across valid studies, support inferences of a causal relationship.

Exposure assessment

The third step is to determine the way in which people could be exposed in a specific situation, including the amount and duration of exposure. This is important because an individual's

exposure is one of the major factors for determining the potential for an impact on health. In the case of this report, the exposure assessment involves calculations of RF levels associated with the smart meter network and a comparison of those levels to relevant scientific guidelines and standards.

Risk characterization

The fourth step, risk characterization, is the final overall health risk conclusions that result from an evaluation of the hazard identification/weight-of-evidence review, the dose-response assessment, and the exposure assessment. The risk characterization will provide a summary evaluation of the weight of evidence in support of or against a health risk for the exposure of interest.

Weight-of-evidence review process

As mentioned above, a weight-of-evidence review evaluates data from three types of studies (Figure 1), which complement one another because of the inherent limitations of each type (discussed in the following section). Similar to puzzle pieces, the results of epidemiology and experimental studies are placed together to provide a picture of the possible relationship between exposure to a particular agent and disease.

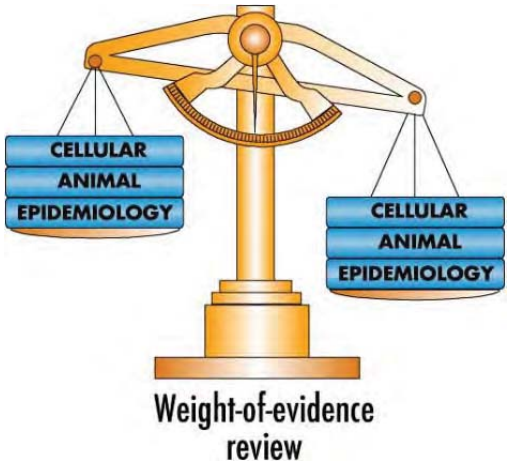

Figure 2. Weight-of-evidence reviews consider three types of research

A weight-of-evidence review is essential for arriving at a valid conclusion about a causal relationship because no individual study is capable of assessing causation with any reliability. Rather, evaluating that relationship is an inferential process that is based on a comprehensive assessment of all the relevant scientific research. The final conclusion of a weight-of-evidence review is a conservative evaluation of the strength in support of or against a causal relationship for each area of research, with primary focus on epidemiology studies and long-term *in vivo* studies. *In vitro* studies are also evaluated to determine whether they provide evidence of a mechanism for adverse effects that have been determined in the hazard identification, but provide less relevant data to the overall evaluation because the effects that occur in isolated cells and tissues may not be relevant when extrapolated to animals or humans.

2. Methods for Evaluating Scientific Research

Evaluating epidemiology studies

Epidemiology is the scientific discipline that studies the patterns and occurrence of disease in human populations and the factors that influence those patterns. Epidemiology studies examine and analyze people in their everyday setting, so by design, epidemiologists have little control over a study once it begins. Generally, epidemiologists enroll participants into studies, gather data on medical and life histories, and evaluate this data in relation to the health effect being studied. The two main types of epidemiology studies are *case-control studies* and *cohort studies* (Figure 2), and the main goal of an epidemiology study is to quantify and evaluate an *association*, i.e., the statistical measure of how exposures and health outcomes vary together in a study population.

A case-control study compares the characteristics of people with a disease (i.e., cases) to a similar group of people who do not have the disease (i.e., controls). The prevalence and extent of past exposure to a particular agent is estimated in both groups to assess whether the cases have a higher exposure level than the controls, or vice versa. A cohort study is the reverse of a case-control study in that researchers study a population without a disease and follow them over time to see if persons with a certain exposure develop disease at a higher rate than unexposed persons. Typically, a case-control study reports an association as an odds ratio (OR) and a cohort study reports an association as a relative risk (RR). An OR or RR ≤ 1.0 is generally interpreted to indicate there is no statistical association between the exposure and disease; conversely, a result > 1.0 may indicate that exposure will increase the risk of disease (Figure 3). A result of > 1.0, however, does not necessarily indicate there is a causal relationship. The interpretation of epidemiology studies requires a rigorous analysis of the influences of many other variables—such as chance, bias, or confounding—that may affect study results.

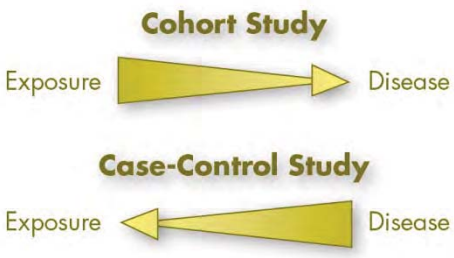

Figure 3. Basic design of cohort and case-control studies

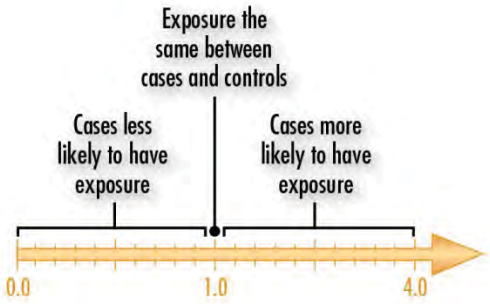

Figure 4. Interpretation of an odds ratio in a case-control study

Chance in epidemiology studies

Chance refers to a random event. In epidemiology studies, a statistical tool that is used to evaluate whether an association is due to chance is the confidence interval (CI). This can best be understood as a margin of error. Epidemiology studies typically use a 95% CI, which will indicate that if the study were conducted a large number of times, 95% of the measured estimates would be within the upper and lower limits. A resulting CI that does not include the value 1.0 is unlikely to be due to chance alone; these results are referred to as statistically significant. If an association if statistically significant, it is then necessary to determine whether other factors, such as bias or confounding, are affecting the results.

Bias in epidemiology studies

The systematic error in the design, conduct, or analysis of an epidemiology study is called bias. If bias is affecting a study's result, the estimate of an exposure's effect on the risk of disease may be distorted. The effect of bias on case-control studies is more prevalent because of their retrospective nature and the greater possibility of error in the selection process for the control group. Generally, persons selected for a control group are less likely to participate because they are healthy; if the remaining participants in the control group differ meaningfully from the case group, exposure comparisons may no longer be valid. Exposure misclassification bias, which is an erroneous classification of participants' exposure levels, is particularly relevant to studies of RF field exposure because of the difficulty in determining a valid exposure method or metric.

Confounding in epidemiology studies

Confounding is a situation in which an association is distorted because, in addition to the exposure under investigation, other risk factors may independently affect the development of disease. A hypothetical example is an association between coffee drinking in expectant mothers and low birth weight babies. Some women who drink coffee, however, also smoke cigarettes. When the smoking habits of expectant mothers are taken into account, coffee drinking may not be associated with low birth weight babies when the confounding effect of smoking has been removed.

As part of the weight-of-evidence review process, each epidemiology study is weighted and classified as providing sufficient, limited, or inadequate evidence in support of the adverse health effect being examined or suggesting the lack of an adverse health effect. In the case of sufficient evidence, the role of chance, bias, and confounding on the observed association must have been ruled out with reasonable confidence. If chance, bias, and confounding cannot be ruled out with reasonable confidence, then the data are classified as limited evidence. Inadequate evidence describes a data set that lacks quality, consistency, or power for conclusions regarding causality to be drawn.

Evaluating experimental studies

The results of experimental studies complement the findings of epidemiology studies. These two approaches are needed because humans have large variations in their genetic makeup, daily exposure levels, dietary intake, and health-related behaviors that cannot be controlled for in epidemiology studies. In laboratories, these variables can be more rigorously controlled to provide more precise information regarding the effects of an exposure.

A wide variety of approaches is available for assessing the possible adverse effects associated with exposures in experimental studies. The two general types of experimental studies are *in vivo* studies of whole animals and *in vitro* studies of isolated cells and tissues.

In vivo animal studies

Studies in which laboratory animals receive high exposures in a controlled environment provide an important basis for evaluating the safety of environmental, occupational, and drug exposures. These approaches are widely used by health agencies to assess risks to humans from medicines, chemicals, and physical agents (WHO, 1994; IARC, 2002; USEPA, 2002; USEPA, 2005). From a public health perspective, long-term (chronic) studies in which animals undergo exposure over most of their lifetime, or during their entire pregnancy, are of high importance in assessing potential risks of cancer and other adverse effects. In these long-term studies, researchers examine a large number of anatomical sites to assess changes and adverse effects in body organs, cells, and tissues.

These data are used in the hazard identification step of the risk assessment process to determine whether an environmental exposure is likely to produce cancer or damage organs and tissues. Health Canada mandates that lifetime *in vivo* studies or *in vivo* studies of exposures during critical sensitive periods are conducted to assess potential toxicity to humans (Health Canada, 1994). Furthermore, the Environmental Protection Agency's position is that, "…the absence of tumors in well-conducted, long-term animal studies in at least two species provides reasonable assurance that an agent may not be a carcinogenic concern for humans" (USEPA, 2005, pp. 2-22).

In vitro studies

In vitro studies are used to investigate the way that exposure acts on cells and tissues outside the body (mechanism of action) for effects that are observed in living organisms. The relative value of data from *in vitro* tests to a human health risk assessment is treated by the International Agency for Research on Cancer (IARC) and other agencies as supplemental to data obtained from *in vivo* and epidemiology studies. Responses of cells and tissues outside the body may not reflect the response of those same cells if maintained in a living system, so their relevance cannot be assumed (IARC, 1992). It may be difficult to extrapolate from simple cellular systems to complex, higher organisms to predict risks to health because the mechanism underlying effects observed *in vitro* may not correspond to the mechanism underlying complex

processes like *carcinogenesis*. In addition, the results of *in vitro* studies cannot be interpreted in terms of potential human health risks unless they are performed in a well-studied and validated test system.

Convincing evidence for a mechanism that explains an effect observed in experimental or epidemiology studies can add weight to the assessment of cause-and-effect, and in some cases may clarify reasons for different results among species, or between animals and humans. *In vitro* studies are not used, however, by any health agency to assess risks to human health directly.

Replication of scientific research findings is the key to determining the reliability of any scientific claim. Confirmation of claims by multiple investigators from different research groups and the use of different methods help to strengthen confidence in the claim. In addition, experimental studies that are conducted in a 'blinded' fashion are given greater weight because they minimize potential bias and of investigators in the collection and analysis of data.[5]

Experimental research methods - cancer

Cancer research in the laboratory includes studies of various stages of cancer development. Research has established that cells may take several steps to change from ordinary cells to the uncontrolled growth typical of cancer. Cancer usually begins with a mutation, that is, an irreversible change in the genetic material of the cell. This is known as *initiation*. Other steps, or stages, must occur for a cancerous cell to develop into a tumor, one of which is *promotion*. Some exposures affect both of these stages and are known as complete carcinogens. Other types of exposures affect only initiation or only promotion.

In vitro bioassays are laboratory tests that isolate specific cells or microorganisms in a test tube or culture dish to assess the likelihood that exposure to an agent can cause mutations, a step necessary in the initiation of cancer. *In vivo* initiation tests also have been developed for animals, in which scientists expose the animals for less than lifetime periods to determine

[5] Similarly, epidemiology studies that are conducted in a 'blinded' fashion minimize the potential bias of the reports of human subjects.

whether an exposure causes changes typical for the early stages of cancers in specific tissues such as liver, breast, or skin.

Other tests are designed to ascertain whether a specific exposure can stimulate tumor growth (i.e., promotion) in an animal in which cellular changes typical of initiation have already occurred. Studies of promotion include two steps: first, the animals are exposed to a chemical known to initiate cancer, and second, the animals are exposed to the agent to be tested as a promoter. The occurrence of cancer in animals exposed to an initiator and promoter is compared to the occurrence of cancer that develops in animals exposed only to the initiator.

Experimental research methods - reproductive and developmental toxicity

Studies in animals are used to assess whether an exposure can pose a risk to humans *in utero*. Experimental studies in pregnant animals provide a means for isolating the exposure in question from the myriad of other factors that can affect prenatal development. The results of these well-controlled animal studies are used by regulatory agencies to assess prenatal risk and help set human exposure limits (USEPA, 1991; USEPA, 1998; NTP, 2011).

To test the potential for an exposure to affect fetal development, pregnant mammals such as mice, rats, or rabbits are exposed from the time the embryo is implanted in the uterus to the day before delivery. Variations in study design include preconception exposure of the female in addition to exposure during gestation, and even further exposure after the animal is born. Protocols generally specify that the dose is set below the levels known to cause maternal toxicity, that unexposed controls are maintained at the same time period, and that the animals' health is monitored throughout the study. Endpoints measured include maternal body weight and weight change, the number and percent of live offspring, fetal body weight, the sex ratio, and external, soft tissue, or skeletal variations and malformations. The uterus can also be examined to assess the number of implantations and fetuses that have been lost, as an indication of miscarriage (USEPA, 1998).

Evaluating the cumulative body of experimental evidence

Key factors in evaluating individual *in vivo* studies include:

- The details of the protocol. Standard protocols usually specify at least 50 animals of each sex per dose level, in each of three different dose groups.
- The study design, including methods to minimize bias, and the analysis of the results.
- The adequacy of the dose levels selected.
- The way the study was actually conducted, including adherence to good laboratory practices in animal housing and monitoring.
- The evaluation of the effects on toxicity, tumors, or malformations, considering both biological and statistical issues (USEPA, 2005).

3. Exposure Estimation for Radiofrequency Fields

One of the most crucial aspects in the review of any epidemiology study is an evaluation of how exposure was measured. A good exposure metric should measure each individual participant's exposure to the agent under study from all sources at the appropriate time in the disease process. Measuring exposure to RF fields is difficult, however, for several reasons. In case-control studies, exposure must be estimated retrospectively, introducing the possibility of recall bias. In addition, while the use of personal exposure meters (exposimeters) can collect real-time measurements for far-field sources, the devices can be inconvenient or laborious for the participants, and it is not clear how near-field sources (such as mobile or cordless phones) affect the measurements. Also, the appropriate exposure metric and timing of exposure is unknown because of the absence of substantive knowledge about a specific mechanism by which RF energy could affect normal cells. Therefore, the focus on long-term exposure is based upon the standard assumption that exposure affecting the development of chronic disease such as cancer requires repeated exposure at elevated levels, similar to exposure to other known cancer causing agents such as tobacco smoke, alcohol, sunlight, and certain chemicals.

Different sources contribute differently to individual RF exposure, and although exposimeters have been recommended to measure RF exposure from far-field sources, their use is limited in large epidemiology studies because of their high costs and the effort required of participants to use them. Devices to measure total personal exposure have not been available or efficient to use, therefore exposure to RF has been estimated in epidemiology studies using a variety of surrogates to estimate RF exposure. Surrogates are useful in epidemiology studies when interest focuses on exposure from a specific source, but since there are many sources that can contribute to a person's RF exposure, surrogates may not provide a valid estimate of exposure for studies of RF and health. A group of investigators (Frei et al., 2010) recently evaluated the accuracy of surrogates for RF exposure by comparing them to personal measurements taken with an exposimeter (with and without the factor of mobile and cordless phone use), by correlating the results for a group of participants. The exposure surrogates they investigated included:

- Spot measurements at specific locations in the bedroom of a home, using a RF meter;[6]
- Distance from the nearest fixed transmitting source such as a television broadcasting transmitter or mobile phone base station measured by geocoding;
- A geospatial propagation model of RF levels calculated from a fixed source, using specific information on characteristics of the source transmitter;
- A full-exposure prediction model, considering multiple sources, individual information on communication devices, and behavioral characteristics such as time at home and in vehicles; and
- Self-assessment of exposure using a questionnaire.

The authors concluded that surrogates relying on distance only had limited accuracy for an exposure assessment given the variation in transmitting characteristics among sources and potential shielding and reflections of RF fields by buildings. Therefore, distance was reported to be an inappropriate surrogate for personal RF exposure. Calculations based on specifics of the technology provide more reliable estimates, but they only capture exposure from one type of source. The full exposure prediction model had the highest correlation to personal measurements, followed by spot measurements, and the geospatial propagation model. Since spot measurements record data in one location in a home, they are often used in studies of effects of short-term exposures, such as effects on sleep.

Exposure estimates of RF fields in epidemiology studies, even calculated levels, are not the same as actual RF levels encountered briefly at a single, fixed location, such as at the fence line of a radar station or next to a smart meter. The exposure estimate in epidemiology studies is intended to reflect the average person's exposure to RF fields over a specified period of time (i.e., time-averaged). It is evident then that brief instantaneous encounters with RF fields (for

[6] RF meters measure RF intensity at a specific point in a specific location, which can be used to estimate an individual's exposure at that location. Exposimeters collect cumulative RF measurements on an individual over time, which are used to estimate exposure during a time span.

example, driving by a television broadcast transmission antenna or walking by a household's smart meter) would not significantly alter a person's long-term, time-averaged RF exposure.

Research also has been conducted on occupational exposure to RF fields given that a higher range of exposure typically occurs in the occupational environment compared to the general public. These studies generally use a person's occupational title or work history by job or task (job exposure matrix) to estimate exposure. Many early studies relied on occupational title taken from a death certificate. Later studies used a job exposure matrix to estimate the overall magnitude of a person's occupational RF exposure. Both methods have limitations. Death certificate data is often inaccurate, and a job exposure matrix may not take into account variation in exposure due to different job tasks within occupational titles, the frequency and intensity of contact to relevant exposure sources, or variation by calendar time.

Basis for regulatory standards and exposure limit guidelines

Government agencies and technical organizations are likely to promulgate regulatory standards or guidelines for limiting human exposure to a substance or physical agent if a health risk assessment indicates a potential health hazard from high exposures. Standards-setting agencies that develop regulatory standards and guidelines rely on weight-of-evidence reviews such as those described in the following section, in which national and international scientific agencies typically convene a panel of scientists that have expertise in the relevant disciplines (FCC, 1997; Health Canada, 2009; ICNIRP, 2009). The approach scientists use to develop health-based standards whether for contaminants in drinking water or a myriad of other regulated substances, or to ensure air quality or food safety, is to set exposure levels many times below the level at which research suggests any potentially adverse effect could occur. This conservative approach lowers the exposure limit well below the lowest known effect level; this reduction below the minimal effect level is commonly called a "safety factor."

The safety factor compensates for any unrecognized limitations in the research and exposure assessment, and it affords additional protection to the general public, as well as protection for sensitive populations, such as the elderly, children, and those with certain chronic diseases. Although there have been a few recent epidemiology studies of children and exposure to RF

fields, most epidemiology studies of environmental exposures do not include sensitive populations, so additional measures often are taken to ensure the safety factor is relevant.

One method used by scientists is to incorporate information about the mechanism of action, i.e., how the agent affects the human body. This information helps to identify intensity levels that may or may not produce the effect, and may help to determine whether certain populations might be more sensitive or have different reactions due to their specific biological characteristics. Another method is to conduct experimental studies of animals at varying stages in their lifetimes to determine if the young or old are potentially more sensitive to exposure. These methods incorporate the basic scientific principle of dose-response, i.e., the probability that an effect occurs, or that the severity of an effect increases with the amount of exposure.

Basis for radiofrequency exposure standards

As discussed above, RF exposure standards (exposure limits) are developed based on a review of the relevant biological and health research using established scientific methods. Exposure standards address issues of both human health and safety, so exposure limits are based on research that identifies an exposure level that has not been linked to adverse effects after short-term (acute) or long-term exposure and then incorporates an adequate margin of safety. In the case of RF energy, exposure limits are set to identify the time-averaged intensity levels of RF fields at a specific frequency range that should not be exceeded.[7]

Based on the evaluation of the scientific research, the health effect known to be caused by high exposures to RF energy in the frequency range from 100 kHz to 300 GHz is a rise in body temperature through warming of tissues. This is the basis of the applicable public exposure limit set by Health Canada's Safety Code 6 and the exposure limits set by other organizations. The goal of the standard is to set limits at levels far below that which could cause this effect, since even a modest raise in body temperature can be distracting; it should particularly be limited in a work environment where such distractions can affect productivity. In addition,

[7] Standards are also used for specifications for manufacturing products to ensure safe construction, or conformity or compatibility among different companies that make the same item, but in this report we are referring to safety and health standards.

higher exposure levels can lead to more serious adverse effects, including local cell damage and hyperthermia. In order to avoid these more serious effects, exposure limits in the RF standards are set below the level at which even minor effects from tissue heating might occur (FCC, 1997; FCC, 1999; Health Canada, 2009; ICNIRP, 2009).

Relevant standard in Canada

Industry Canada is responsible for regulating Canadian industries that produce RF energy in their operations, such as radiocommunications facilities and radio and television broadcasting installations. Health Canada, as part of its mandate to protect the health of Canadians, conducts research and investigations to recommend health protection limits to a myriad of common exposures such as RF energy. The limits developed by Health Canada in its document "*Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3kHz to 300 GHZ,*" have been adopted by Industry Canada for the purpose of protecting the general public and workers in occupations with high RF exposure levels (Health Canada, 2009). These guidelines, also referred to as Safety Code 6, were first developed in 1979. They are the result of continuous evaluations of published scientific studies, reviews, as well as research conducted by Health Canada. The most current update of Safety Code 6 is based on research and reviews of the scientific literature on RF energy that were published between 1999 (the date of the last update) through August 2009. Specifically, Safety Code 6 states that the exposure limits specified were 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. The exposure limits in Safety Code 6 are based upon the lowest exposure level at which scientifically-established human health hazards occur. Safety factors have been incorporated into these limits to add an additional level of protection for

the general public and personnel working near RF sources. 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. As such, the basic restrictions in Safety Code 6 are similar to those adopted by most other nations, since all recognized standard setting bodies use the same scientific data. It must be stressed that Safety Code 6 is based upon scientifically-established health hazards and should be distinguished from some municipal and/or national guidelines that are based on socio-political considerations (Health Canada, 2009, p. 7).

4. Scientific Reviews of Radiofrequency Fields and Health

Scientific research on RF exposure and health is reviewed regularly by independent scientific and governmental organizations worldwide. These organizations assemble expert panels, whose members have the knowledge and mandate to review relevant research and provide scientifically-grounded public health recommendations. In the past five years, several of these organizations have conducted weight-of-evidence reviews of the most current epidemiology, in vivo, and in vitro studies on this subject. Health Canada, the Health Council of the Netherlands (HCN), the International Commission on Non-Ionising Radiation Protection (ICNIRP), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the Swedish Radiation Safety Authority (SSM), and the Health Protection Agency of Great Britain (HPA) all have reviewed the research and independently supported establishing exposure limits on the basis of tissue heating or they have developed exposure limits for RF energy in various frequency ranges (HCN, 2009; ICNIRP, 2009; SCENIHR, 2009; SSM, 2009, 2010; HPA, 2012). A recent review conducted by the California Council on Science and Technology (CCST), which released its final report in April, 2011, focused exclusively on smart meters. The independent Advisory Group on Non-Ionizing Radiation (AGNIR) noted that organizations conducting smart meter exposure assessments have concluded that even under maximum exposure scenarios, exposure would be well within ICNIRP's exposure limits (HPA, 2012).

Based on their review of the research, all these agencies have concluded that RF exposure below the exposure limits developed by ICNIRP does not cause cancer or chronic diseases. In addition, their conclusions determined that adverse physiologic changes or adverse symptoms that affect well-being are not caused by exposure to RF energy within the limits for the general public determined by ICNIRP.

While some studies have reported non-thermal effects, i.e., effects that occur at RF exposure levels below that which raises body tissue temperature, the data in these studies have not been accepted as reliable because the observed biological effects were not consistent or reproducible.

In addition, the data are not supported by any plausible biological explanation as to how the effects could occur, and the biological effects reported in some of these studies are not known to be linked to adverse health effects (NRPB, 2003; NRPB, 2004; HCN, 2009; ICNIRP, 2009; SCENIHR, 2009; SSM, 2010; HPA, 2012).

Health Protection Agency

Health Effects from Radiofrequency Electromagnetic Fields

The report of the HPA was prepared by the independent Advisory Group on Non-ionizing Radiation, which reviewed research about RF and health through 2010 and part of 2011 to update its previous reports on electromagnetic fields since the agency was formed in 1999 (HPA, 2012). The review and assessment includes research on mechanisms of interaction with the human body and a variety of potential health impacts studied in cells, animals, and humans, including cancer, reproduction, immune response, symptoms and other effects on the nervous system. The report supports existing guidelines on limiting exposure such as ICNIRP's restrictions and Federal Communication Commission (FCC) limits, and commented regarding smart meters that "…given the low output power of typical devices, it is not expected that people's exposure will exceed the ICNIRP restrictions" (p. 55). The report concluded specifically as follows (pp. 318-320):

- Cellular studies have not provided robust evidence for an effect. "At present there is no known pattern of exposure conditions that has been shown consistently to cause a biological effect from exposures below guideline levels."

- Animal studies published have used a wide range of biological models, exposure levels, and signal modulations. There is no clear evidence of harmful effects from low level exposures, and large scale studies of initiation and development of cancer have been negative.

- "Studies of cognitive function and human performance measures do not suggest acute effects of RF field exposure from mobile phones and base stations."

- "The overall results of epidemiological studies to date do not demonstrate that the use of mobile phones causes brain tumours or any other type of malignancy, nor do they suggest causation is likely."

California Council on Science and Technology

Health Impacts of Radiofrequency Exposure from Smart Meters

The CCST has conducted the only review by a scientific panel that specifically addresses the health impacts of RF fields from smart meters.[8] To evaluate health questions, the CCST project team reviewed documents such as research papers and reviews, consulted with experts, and solicited written comments from experts in biology and medical sciences, physical sciences, and engineering (CCST, 2011). The report addresses topics such as RF emission levels, thermal and non-thermal effects, and the appropriateness of the relevant RF standard. The main conclusions of the CCST are:

- Smart meters emit lower levels of RF energy than many common household devices such as mobile phones and microwave ovens.

- The scientific studies conducted through 2010 "have not identified or confirmed negative health effects from potential non-thermal impacts of RF emissions such as those produced by existing common household devices and smart meters."

- The FCC guidelines[9] are acceptable and include a wide margin of safety, i.e., the recommended exposure limits are set well below levels where research indicates that effects could occur.

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[8] The CCST was established in 1988 by the California state legislature and charged to "… offer independent expert advice to the state government and to recommend solutions to science and technology-related policy issues."

[9] The FCC standard is the relevant standard in the United States for RF-emitting devices such as smart meters and mobile phones. It is based on thermal effects, includes safety factors, and is comparable to Canada's Safety Code 6.

- The smart meters proposed for use by California utility companies emit RF energy that is a very small fraction of the exposure level established as safe by FCC guidelines.

- Based on current knowledge of potential non-thermal impacts, no other standards are needed to protect health.

The International Agency for Research on Cancer

IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 102: Non-Ionizing Radiation, Part II: Radiofrequency Electromagnetic Fields (Not yet published)

In May 2011, the IARC convened a scientific panel to review the evidence on RF exposure and cancer and prepare a monograph, which is yet to be published.[10] Scientists with expertise in the various areas related to RF energy reviewed approximately 900 published studies on RF fields and cancer that considered the following sources of exposure:

- Environmental – broadcast antennas, base stations, medical devices, smart meters, and WiFi.
- Occupational – hi-frequency dielectric and induction heaters and radar installations.
- Personal Devices – cordless telephones, mobile telephone, Bluetooth devices.

These data covered several related areas, including: exposure parameters, cancer epidemiology, cancer in laboratory animals, and mechanistic data. The IARC's full report is not yet available, but a summary of the main conclusions of their review was published in July 2011 (Baan et al., 2011). The Working Group rated both epidemiologic and *in vivo* data as providing "limited evidence" for cancer. The epidemiologic data reported positive associations between use of mobile phones and a type of brain cancer. They also rated *in vivo* studies for carcinogenicity of RF exposure as providing "limited evidence" for cancer.

In the IARC's classification system, data is rated as providing "limited evidence" for cancer if a positive association between an exposure and cancer is found, although factors such as chance,

[10] The IARC is an agency of the World Health Organization. The agency's mission is to "coordinate and conduct research on the causes of human cancer, the mechanisms of carcinogenesis, and to develop scientific strategies for cancer prevention and control" (http://www.iarc.fr/).

bias, and confounding cannot be ruled out with reasonable confidence. The conclusion of "limited evidence" caused the IARC to include RF exposure in Group 2B "possibly carcinogenic to humans."

The IARC's categories err on the side of caution. Since 1971, when the IARC began to categorize agents by their current system, 946 agents have been reviewed.[11] Only one (caprolactam) has been classified as "probably not carcinogenic to humans" (Group 4). The vast majority of substances are classified as "possibly carcinogenic to humans" (Group 2B) or "not classifiable" (Group 3), leaving 107 substances classified as "carcinogenic to humans" (Group 1) and 61 "probably carcinogenic to humans" (Group 2A). Group 2B denotes exposures for which there is limited evidence of carcinogenicity in epidemiology studies and less than sufficient evidence of carcinogenicity in experimental studies of animals. Occupational exposures in textile manufacturing and firefighting, for example, are classified as 2B, as are substances such as pickled vegetables and coffee.

The IARC's classification of RF fields in Group 2B is based on the review of studies involving RF exposure from mobile phones. Although the Baan et al. (2011) summary is based on the IARC review panel's findings, they do not comment on the level of exposure. It should be noted that near-field exposure from mobile phones is far greater than the time-weighted average far-field exposure from smart meters. In addition, the degree to which exposures from mobile phones can be extrapolated to much lower exposures from devices such as smart meters is unknown. If a risk were to be confirmed for mobile phones, the risk for exposures to sources at much lower intensities, such as such as smart meters, would be expected to be lower as well based on the dose-response principle discussed previously.

[11] http://monographs.iarc.fr/ENG/Classification/index.php

The Swedish Radiation Safety Authority

Recent Research on EMF and Health Risk–7th Annual Report from SSM's Independent Expert Group on Electromagnetic Fields

The SSM published their most recent annual review on electromagnetic fields in December 2010. The agency's Independent Expert Group evaluated studies published in 2009 and 2010, including several that were available ahead of print in 2010 and published in 2011.

In particular, the SSM panel reviewed the INTERPHONE Study Group's (2010) pooled analysis of glioma and meningioma, two types of brain cancer, and identified both recall bias and participation bias as possible sources of systematic error in the study (discussed in detail in Section 5); this same conclusion was reached by the study authors as well (The INTERPHONE Study Group, 2010). The SSM also pointed out that although the Interphone Study could not provide a final resolution on the issue of mobile phones and brain cancer, they were able to exclude "with a high degree of certainty" risk from short-term mobile phone use, while "uncertainty still remains regarding very intensive and long-term use" (SSM, 2010, p. 37). The SSM's overall conclusion regarding the Interphone Study is that "the advent of these new data does not change the overall picture being that for up to about ten years of mobile phone use associations with brain tumour risk are unlikely" (SSM, 2010, p. 4).

The SSM also reviewed current scientific studies on RF exposure from mobile phone base stations and television and radio transmitters and various health outcomes. They concluded that "available data do not indicate any risks related to exposure to RF from base stations or radio or TV antennas. Taking into account also the low levels of exposure that these sources give rise to, health effects from transmitters are unlikely" (SSM, 2010, p. 4).

The Health Council of the Netherlands

Electromagnetic Fields: Annual Update 2008 and
Influence of Radiofrequency Telecommunications Signals on Children's Brains 2011

The HCN has issued two relevant reviews on the subject of radiofrequency fields and health since 2009. The Electromagnetic Fields Committee of the HCN issues annual updates on electromagnetic field research that focus each year on a topic or topics that have been at the

forefront of reporting in both scientific journals and the general media during the previous year. The committee's fifth annual update for 2008, published in March 2009, focused entirely on the effects of electromagnetic fields on the nervous system. They reviewed studies of brain electrical activity, hearing and balance, regional cerebral blood flow, and cognitive functioning (e.g., memory, attention, and concentration). Their review concluded:

> Exposure to radiofrequency electromagnetic fields produced by mobile phones may lead to subtle changes in brain activity. However, the observed effects are temporary and small and, as far as is known, have no effect on health. The picture that emerges from studies of effects on cognitive functioning is unclear: some studies found minor and reversible effects while others found no effect (HCN, 2009, p. 97).

In October 2011, the HCN's Electromagnetic Fields Committee issued an advisory report on the effects of RF fields on the developing brains of children due to the continued interest in this topic and the increase in the number of studies available for review since the committee last addressed this topic in 2005.[12] They examined short-term effects only because there is very little data available on long-term effects in children. The committee concluded the following regarding brain development and function and effects on behavior and cognition:

> **Brain Development and Function**
>
> The Committee feels that consistent effects of exposure to radiofrequency electromagnetic fields on brain function in children have not been demonstrated. Insofar as effects were observed, they are temporary and minor and there are no signs that they can influence health. Animal studies also fail to demonstrate effects on brain function (HCN, 2011, p. 25).
>
> **Effects of Behavior and Cognition**
>
> Exposure to radiofrequency electromagnetic fields appears not to have a clear effect on behaviour and cognition in children. Animal studies only

[12] The HCN reviewed research on radiofrequency fields and effects in children in an advisory report in 2002 and an advisory letter in 2005. These reviews, however, were limited by the scant amount of research that was available at the time. As the HCN points out, the call by HCN, the World Health Organization, and other scientific agencies for research to address this subject was answered. The new research justified their re-analysis of the available data, which resulted in their 2011 advisory report.

> used rats, and are therefore less relevant in the eyes of the Committee. A general problem in both studies with children and animal studies is the limited number of studies and, with one exception the small number of human subjects or animals per study (HCN, 2011, p. 26).

The International Commission on Non-Ionizing Radiation Protection

Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 kHz-300GHz)

In 2009, ICNIRP issued the results of their comprehensive review of the substantial body of research on RF fields and health effects (ICNIRP, 2009). Their review covered a period from 1998 through 2008 and was conducted specifically to provide a detailed analysis of the research since the publication of their 1998 exposure limits (ICNIRP, 1998). The review was conducted for three distinct research areas: dosimetry of high frequency RF fields, experimental studies of biological effects, and epidemiology studies, each of which covers a wide variety of topics and outcomes.

Based on their evaluation of the scientific evidence for biological effects at levels below those attributable to heating (i.e., non-thermal), the ICNIRP panel concluded:

> It is the opinion of ICNIRP that the scientific literature published since the 1998 guidelines has provided no evidence of any adverse effects below the basic restrictions and does not necessitate an immediate revision of its guidance on limiting exposure to high frequency electromagnetic fields. … With regard to non-thermal interactions, it is in principle impossible to disprove their possible existence but the plausibility of the various non-thermal mechanisms that have been proposed is very low. In addition, the recent in vitro and animal genotoxicity and carcinogenicity studies are rather consistent overall and indicate that such effects are unlikely at low levels of exposure. Therefore, ICNIRP reconfirms the 1998 basic restrictions in the frequency range 100 kHz–300 GHz until further notice (ICNIRP, 2009, p. 257).

More specifically, in their evaluation of studies on symptoms of well-being, they concluded:

> The evidence from double-blind provocation studies suggests that subjective symptoms, such as headaches, that have been identified by some individuals as associated with RF exposure, whilst real enough to the individuals concerned, are not causally related to EMF exposure (ICNIRP, 2009, p. 274).

5. Current Research on Radiofrequency Fields

The reviews conducted by scientific and governmental agencies are the benchmark for an overall assessment of health risk, but since there is often a time lapse between the publication dates of comprehensive reviews, other scientific data also must be evaluated to determine if any new evidence is available that may alter the conclusions of the most recent reviews.

This section evaluates studies of exposure to low levels of RF energy (both far-field and near-field exposure) and adverse effects such as cancer and non-specific symptoms that, for the most part, have been published in the past few years, and thus may not have been considered in the reviews discussed in the previous section.[13] More focus is placed on higher quality epidemiology and *in vivo* studies, regardless of the authors' conclusions. A number of weaker studies are noted as well, e.g., studies that utilize inadequate controls, proxy measurements, or a small sample size, but they provide little useful information overall to a risk assessment.

Studies of cancer

Studies of RF energy and cancer outcomes have been conducted since the 1970s. The number of studies had increased markedly in the last fifteen years, the time period in which the use of mobile phones became increasingly common. Epidemiology studies and long-term *in vivo* studies provide the most direct information about the effect of RF exposure on cancer development. Epidemiologists have examined mobile phone use and time trends in tumors with specific attention on brain cancer since the location on the body with the greatest potential exposure is the head. Laboratory studies of long-term exposure to animals, including exposures to the head, have been conducted as well. Exposure to RF fields from television and radio broadcast antennas and mobile phone base stations have been studied both by epidemiologists and in the laboratory. Since smart meters are a relatively new technology, there are few reviews or studies on exposure from this specific device; however, since frequencies used in mobile phones are similar to those used by smart meters, the emphasis in this report is on studies of

[13] There are no recent studies on RF from radar and cancer and only one recent study on RF from mobile phone base stations and cancer, so earlier studies are included in our discussion.

mobile phone use and health outcomes. It should be noted, though, that the intensity (strength) of RF fields from smart meters, under foreseeable use, is lower than that of mobile phones, and it is generally a far-field rather than a near-field exposure.

Epidemiology studies

The epidemiology studies reviewed in this section are grouped by exposure source (mobile phone base stations; AM/FM radio or TV broadcast transmitters; radar installations; and mobile phones). Currently the greatest source of individual exposure to RF fields for most people is from the use of mobile phones, for which a large set of epidemiology studies and pooled analyses were recently completed.[14] A person's overall RF exposure from mobile phone base stations and AM/FM radio or TV antennas is typically the lowest because, like all types of electromagnetic fields, RF field strength diminishes rapidly with distance from the source, and for most people, the time spent near such sources is minimal. RF exposure from sources such as base stations, transmitters, and antennas pose difficulties for individual exposure assessments in epidemiology studies. Since individuals usually spend their time in various locations during a day, or from week to week, a valid exposure metric of average exposure from environmental sources is difficult to determine. Exposure to RF fields from radar installations may be higher than exposure from mobile phones, but typically this type of exposure only occurs in occupational settings.

Exposure from mobile phone base stations

As mentioned, it is difficult to assess human exposure from a single environmental source such as a mobile phone base station because such exposure is compounded by other sources such as nearby AM/FM radio and TV broadcast transmitters and wireless appliances and devices in the home or workplace. In addition, local populations residing in the small radius around a mobile phone base station are typically too small to support an epidemiology study. Finally, these types

[14] Other household sources such as cordless phones and WiFi also contribute to an individual's household exposure, but are much weaker contributors. Only a weak signal needed to operate a WiFi network within a residence or building. In addition, since cordless phones have a base unit connected to telephone wiring in a house, they typically operate at far lower power levels than mobile phones and so produce lower RF exposures.

of studies do not take into account cancer latency—the latency period for most cancers to develop is decades rather than a few years.

There are only a few epidemiology studies that have examined RF exposure from mobile phone base stations and cancer. Eger et al. (2004) and Wolf and Wolf (2004) both assessed the rate of cancer of adults who resided near a mobile phone base station using distance as a proxy for exposure; however, epidemiology studies that estimate RF exposure for a small population group using only distance from a single base station are unreliable. These studies have additional limitations. Both used data that combined various cancer types that occurred in persons in the locality under study. Combining cancer types, however, is not a valid method to find causality because there are over 100 diseases that have been defined as cancer. These diseases affect different cells in the body, occur at various rates, and have different etiology (ACS, 2009). No valid conclusion can be drawn from these two studies because of flaws in their methodology and the small number of participants.

Better methods of estimating exposure are needed. Elliot et al. (2010) is one of the few epidemiology studies of childhood cancer and RF exposure that used methods to estimate exposure from *all* mobile phone base stations in the vicinity of the mother's residence during pregnancy (i.e., birth address). Cases were selected from the United Kingdom's (UK) National Cancer Registry 1999-2001 (n = 1,397) and four controls per case were matched by date of birth and sex from the UK's National Birth Register (n = 5,558) for children aged 0-4. The researchers assessed the mothers' exposure by using three different metrics: distance of birth address from the nearest base station; total RF output from all base stations within 700 metres; and modeled power density at the birth address. The authors found no association between a mother's exposure to RF fields from mobile phone base stations during pregnancy and risk of cancer in children.

Exposure from AM/FM radio and television broadcast transmitters

In the past few decades, peer-reviewed scientific research on exposure to RF fields from AM/FM radio or television broadcast transmitters has focused on the risk of cancer in children and adults. Until 2003, however, much of this research utilized an ecological design method

with geographic correlations around a transmitter (e.g., Hocking et al., 1996; Dolk et al., 1997a; Dolk et al., 1997b; McKenzie et al., 1998; Cooper et al., 2001). Geographic correlations rely on group data (in this case, cancer rates) in specific geographic areas rather than individual data, which is a substantial limitation. In addition, studies using geographic correlation methods suffer from poor exposure assessment because distance is used as a proxy for RF exposure. Finally, the results of ecological studies are inherently limited because they do not consider the confounding effects of other RF sources, and the use of geographic area assumes that all persons within a certain radius have the same exposure levels from the source under investigation.

After 2003, a number of case-control studies were conducted that provide more reliable epidemiologic information than studies that use ecological methods. Ha et al. (2007; 2008)[15] is a large study of RF exposure from AM radio transmitters and childhood leukemia and brain cancer (cases: n = 1,928 - leukemia, n = 956 brain cancer; controls: n = 3,082) conducted in South Korea. Merzenich et al. (2008) conducted a similarly large study (cases: n = 1,959; controls: n = 5,848) of RF exposure from AM and FM radio and TV broadcast transmitters and childhood leukemia in Germany. Both studies used calculations based on the physical characteristics of the transmitters and residential address to assess RF exposure individually for each case and control. These calculations were designed to predict each child's total RF exposure at home from all existing transmitters the year before the cancer was diagnosed.

While both Ha et al. (2007) and Merzenich et al. (2008) provide some validation of the exposure assessment model using calculations, the evidence provided by Merzenich et al. is more complete (Schmiedel et al., 2009). The German study also was stronger in several other areas. First, the study calculations used for the exposure assessment in Merzenich et al. (2008) were validated *and* published (Schmiedel et al., 2009). In addition, while Ha et al. (2007) used clinic-based controls, Merzenich et al. (2008) randomly selected population-based and three controls per case were used, which lessens the possibility of bias. Finally, RF exposure levels of participants tended to be higher. Neither study reported an elevated OR or a statistically significant association with leukemia or leukemia subtypes (lymphocytic or myelocytic

[15] Ha et al. (2008) provides a correction to the data on total RF exposure published in Ha et al., 2007.

leukemia), even in those children who had highest levels of total RF exposure (99th percentile in Merzenich et al. = 1.7-7.7 V/m). Ha et al. (2007) did not report results that suggest a link with brain cancer.

Exposure from radar

One of the most common occupational exposures to RF fields occurs at military bases where workers may be exposed from radar installations; these RF fields may be at levels greater than the safety limits set in RF exposure standards. Other settings where RF exposure is common include facilities that manufacture mobile phones and the various occupations that utilize radio communications. As discussed by Berg et al. (2006), between 1988 and 2006 seven cohort studies and two case-control studies of occupational exposure to RF fields and cancer were published. Most of these studies estimated exposure by using the proxy of occupational histories, job titles, or job descriptions rather than direct measurements.[16] One of these studies (Szmigielski, 1996) reported some statistical associations between job description and leukemia, as did an earlier study by Milham (1985), but sources of bias in the study designs and confounding from other concomitant exposures lessen the weight of these results.

Groves et al. (2002) conducted a mortality follow-up of cancers in 40,581 veterans of the Korean War who served in the United States Navy; their follow-up was a 40-year extension the original cohort study that followed these veterans through 1974 (Robinette et al., 1980). The follow-up reported no association with brain cancer or testicular cancer, but reported an association with leukemia in one of the three naval occupations (electronics technician in aviation squadrons) that were deemed *a priori* to be in the high radar exposure category.

Morgan et al. (2000) followed an occupational cohort of workers at plants that designed, manufactured, and tested wireless communications devices (e.g., two-way radios, communications devices for the military and NASA, pagers, mobile phones, and wireless communications infrastructure) for the period 1976 – 1996. The cohort included 195,775 workers (2.7 million person-years) who were classified into four exposure groups for RF: high,

[16] One of the cohort studies was non-occupational; it examined the RF exposure of amateur radio operators (Milham, 1988).

moderate, low, and background. The investigation found no association for any group with RF exposure and brain cancer or lymphoma/leukemia risk.

These earlier studies of environmental and occupational exposures including radar and broadcast transmitters (AM and FM radio and TV stations) have been among those evaluated in scientific reviews by national and international organizations, which found no consistent or convincing evidence that RF exposure is a cause of leukemia or any other cancer (ICNIRP, 1998, 2004; NRPB, 2004; IEEE, 2005).

Mobile phone exposure

One of the few studies of mobile phone use and leukemia was conducted by a group of researchers in 2010 (Cooke et al., 2010). Their case-control study conducted in South East England investigated leukemia risk in 806 adults. The researchers found no association between regular mobile phone use and leukemia when the case group was compared to the control population (OR = 1.06; 95% CI = 0.76-1.46). In addition, Cooke et al. (2010) found no risk or positive trend in relation to increased use time in years, cumulative calls, or cumulative hours.

Studies of mobile phone use and brain cancer have been conducted more frequently than studies of other health outcomes. Recently, Aydin et al. (2011) studied mobile phone use in children and adolescents and brain cancer in a multi-center, case-control study conducted in four European countries (Denmark, Norway, Sweden, and Switzerland). Their study included 352 cases in the age range 7 to 19 years who were diagnosed between 2004 and 2008. The 646 controls were selected randomly from various population registries and matched for age, sex, and geographical region. The study's results found no association between the regular use of mobile phones and increased risk of brain tumor (OR = 1.36; 95% CI = 0.92-2.02). Risk did not increase with either duration of use or for proximity, i.e., in the area of the head closest to where a mobile phone is held.

The INTERPHONE study is the most comprehensive set of epidemiology research conducted to date on mobile phone use by adults and cancer in the head and neck region (brain and salivary gland tumors). The IARC developed and coordinated this large multi-site, multi-national project that was conducted from 16 study centers in 13 countries (Australia, Canada, Denmark,

Finland, France, Germany, Israel, Italy, Japan, New Zealand, Norway, Sweden, and the United Kingdom). The INTERPHONE researchers studied malignant brain tumors (glioma), benign brain tumors (meningioma and acoustic neuroma),[17] and salivary tumors of the parotid gland, and the study designs and methods used by the researchers were similar so that the results could be combined in a pooled analysis with reasonable confidence.[18]

At all of the study centers, the researchers first determined whether or not a participant was a regular user of a mobile phone (Cardis, 2007; The INTERPHONE Study Group, 2010). Regular use was defined as at least one call per week on average for a period of at least 6 months. For regular mobile phone users, duration of use, cumulative call time, and cumulative number of calls also was determined (Cardis et al., 2007). The analysis showed that the only positive association was in the highest category of cumulative call time, in which an association with this estimate of exposure was modestly increased. There was no evidence of a dose-response trend in any of the 10 categories of cumulative call time; results showed a weaker association in the category of cumulative call time just below the highest category, which is not what would be expected if mobile phone use caused brain cancer (The INTERPHONE Study Group, 2010).

A majority of the published epidemiologic studies to date from the INTERPHONE study centers have not reported an increased risk of brain tumors or meningioma and mobile phone use; however positive associations have been reported for parotid tumors in studies in subgroups defined by longer latency period or ipsilateral use (the side of head where the mobile phone is predominantly used), compared with the location of the tumor (Lonn et al., 2006; Sadetzki et al, 2008).

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[17] Acoustic neuromas are nerve sheath tumors that arise in the eighth cranial nerve (the acoustic nerve). The location of this nerve in relation to telephone use (near ear) is of particular interest for investigating associations with tumor development and mobile phone use.

[18] A pooled analysis combines the raw, individual-level data from a group of original studies and analyzes the data from the studies together. These methods are valuable because they increase the number of individuals in the analysis, which allows for a more robust and stable estimate of association. Meta- and pooled analyses are also important tools for qualitatively synthesizing the results of a large group of studies. Information on the design, methods, and study population at all the participating study centers is detailed in an article published in the European Journal of Epidemiology (Cardis et al., 2007).

Among the studies from individual countries, or pooled over several of the countries (Christensen et al., 2005; Lonn et al., 2005; Schoemaker et al., 2005; Hepworth et al., 2006; Schüz et al., 2006a), the statistical association between mobile phone use and brain cancer consistently tended to be less than 1.0, indicating that those diagnosed with brain cancer were less likely to have been mobile phone users. If interpreted at face value, this implies a reduced risk of brain cancer with regular phone use, compared to those who never used a mobile phone.

In 2010, The INTERPHONE Study Group published the results of brain tumor risk and mobile phone use combined from all the study center results. The overall risk estimate for glioma was below 1.0 (OR = 0.81; 95% CI: 0.70-0.94) as was the overall risk estimate for meningioma (OR = 0.79; 95% CI: 0.68 – 0.91), indicating no positive association, and that cases were less likely than controls to be non-users. The data did not indicate any increase in risk for longer duration of phone use, even in the category of over 10 years.

In a large study conducted by The INTERPHONE Study Group (2011) on mobile phone use and acoustic neuromas, the investigators compared cases with newly-diagnosed acoustic neuroma (n = 1,105) matched to two controls for each case (n = 2,145). The study authors concluded that the evidence did not support a role for mobile phone use in the development of acoustic neuroma with regular use (defined as an average of at least one call per week for 6 months), higher cumulative call time, or a higher cumulative number of calls because chance and reporting bias could not be excluded.

The pooled results of the INTERPHONE study (2010) is the largest to date on mobile phone exposure and brain cancer, and reported limited evidence of an association only for the group with the highest cumulative use of mobile phones although no evidence of dose-response pattern, which would add support for causality (The INTERPHONE Study Group, 2010). The authors concluded that recognized biases and errors in the execution of the study limit the strength of the conclusions we can draw from these analyses.

Most epidemiology studies published before the first publication of The INTERPHONE Study Group in 2004 did not report that use of mobile phone was associated with a risk of brain cancer

(e.g., Muscat et al., 2000; Inskip et al., 2001; Muscat et al., 2002). One exception to this consistency of results is a group of studies published by Hardell et al. on the risk for malignant and benign brain tumors and mobile and cordless phone use. These researchers reported positive associations in pooled results of case-control studies (Hardell et al., 2006a, 2006b, 2011) with mobile phone use in subgroups of longer term users and ipsilateral use. The positive association also tended to be stronger with increased hours of use, suggesting a dose-response pattern. If these results were consistent across valid studies, they could be interpreted as supporting an inference of causality; however, several limitations in the analyses in these studies have been raised. The first limitation in all three studies is the unclear definition of user, in which a user includes any amount of use, with no minimum duration specified. In addition, data collection methods in several of these studies are a likely cause of bias. The definition of case groups varies across the pooled study data. Finally, the exposure definitions are unclear (type of mobile phone, whether data includes or excludes cordless phone use). These limitations have been noted by reviewers (e.g., Ahlbom et al., 2009; Swerdlow et al., 2011; HPA, 2012), who raise concerns about the validity of these results.

The majority of the studies conducted on cell phone use and cancer risk have been case-control studies, which are prone to bias, particularly when individuals are contacted to obtain data (participation bias) and when past exposure is assessed by self-reporting (recall bias). Cohort studies are generally less prone to these biases because information on participants may be available from an existing source, such as an occupational database. There has been only one cohort study, to date, that has reported results of cancer risks among mobile phone users (Johansen et al., 2001), as well as several follow-ups of this cohort (Schüz et al., 2006b; Frei et al., 2011). This retrospective cohort study used subscriber lists from the two mobile phone companies in Denmark as the surrogate for person-years of mobile phone exposure. The most recent update of this cohort extended the follow-up period for 5 years, from 2002 to 2007, and modified the cohort in order to obtain additional information on various socioeconomic data, such as education and income, which are potential confounding factors (Schüz et al., 2006b; Frei et al., 2011). In the latest update, the authors compared records of 358,403 mobile phone subscribers age 30+ with the Danish Cancer Registry. In addition, subscribers on the list were

linked with another cohort study (Oksbjerg et al., 2010) that included socioeconomic data, so that the analysis could be adjusted for the effect of these factors on risk. Overall, no increased risk of brain tumors, acoustic neuromas, salivary gland tumors, eye tumors, leukemias, or overall cancer was observed in the large cohort studied. There is no evidence of increased risk even in those cases with long-term mobile phone subscriptions over 13 years (Frei et al., 2011).

By using subscriptions to mobile phone service as the surrogate for person-years of mobile phone exposure, the Frei et al. eliminated participation bias and recall bias that is of concern in many case-control studies that are based on self-reported exposure. Exposure could be misclassified, however, if there is substantial error in estimating phone use across the group labeled as subscribers. For example, users of mobile phones that were not listed as subscribers would be misclassified as unexposed in this cohort design, and corporate subscriptions were excluded. The data permitted assessment of long-term users, but heavy use in hours could not be identified.

Brain cancer rates over time

While the highest-use category in The INTERPHONE Study Group suggested a possible increased risk, as did the Hardell study data (Hardell, 2006a, 2006b; Hardell et al., 2011), there has not been an increase in incidence rates of brain cancer, which would be expected if this data were correct, particularly in the time period of 10 years after mobile phone use became widespread. This > 10 year period would allow for latency, i.e., the induction time for development of tumors. If causal, the association would lead to an increased rate of brain cancer since a longer period of exposure from mobile phone use had occurred in an increasingly larger population group.

The regular use of mobile phones in Nordic countries has increased markedly over a 28 year period, from 2% in 1980 to 79% in 2002, which Deltour et al. (2012) extrapolated to nearly 100% in 2008. In their study of time trends for incidence rates, Deltour et al. (2012) added 5 years of follow up to their previous study (Deltour et al., 2009) conducted among adults in four Nordic countries (Denmark, Finland, Norway, and Sweden) with a total adult population of 17 million people. Their follow-up study examined two questions: 1) what changes in *incidence*

rates (occurrence of new cases) for glioma have been observed over time in the high-quality national cancer registries in these countries, and 2) what is the probability of detecting an increase in rates for different assumed risks, as estimated by modeling or simulation, from 10% to a doubling, for various assumptions of induction time.

The authors found that incidence rates over time showed no clear upward trend over the period studied (1973-2008). The simulations identified the level of induction period and risk that is compatible with these data and what can be excluded. They used cancer registry incidence data to simulate the probability of detecting various levels of increases in glioma. Simulated data sets tested the probability of detecting various increased risks after first use of a mobile phone over time, in all users and in heavy users, such as a 20 % increase, or a doubling of risk. Results showed that changes in these incidence rates over time were not compatible with even the modestly increased risks that were reported in a few of the epidemiology studies. The authors note that possible interpretations consistent with these observations are either that longer induction times than the highest one studied (15 years) are needed, risks of longer term use are lower than has been detected in even the minority of the studies, or that mobile phone use does not increase the risk of glioma.

Several other studies have examined time trends and brain cancer rates. Röösli et al. (2007) examined trends in Switzerland from 1969 to 2002. Two more recent studies have extended the data another 4 to 5 years. DeVocht et al. (2011) examined time trends in England from 1998 to 2007 and Inskip et al. (2010) completed an analysis of time trend in the United States from 1992 to 2006. None of these studies has indicated that the occurrence of brain cancer increased over time since the widespread use of mobile phones began in the late 1980s and has increased exponentially since then. The lack of increase in incidence rates over time provides some evidence against a causal link between mobile phone use and brain cancer.

Laboratory studies in animals

The research conducted in laboratory animals that examined RF fields and cancer was reviewed by ICNIRP (2009), the IARC (Baan, 2011), and most recently by the HPA (HPA, 2012). The IARC group reviewed over 40 *in vivo* studies, most of which were in the frequency range

utilized by advanced meters. In addition, many of these studies were of high quality: they exposed the animals to continuous, substantial levels of RF energy, often at the level of the lowest thermal effect; exposure occurred over their entire lifespan; tissues in all organs were examined; good measures of dose were recorded; *in utero* or neonatal exposures were conducted; experiments were conducted with different species (mice as well as rats); and exposure was both whole body and localized.

The IARC monograph is not yet available, but the summary report (Bann et al., 2011) noted that none of the seven chronic 2-year bioassays showed an increased incidence of any tumor in tissues or organs of animals exposed to RF radiation for 2 years. Increased cancer incidence was reported in 2 of 12 studies of tumor-prone animals and in 1 of 18 studies using initiation promotion protocols. The IARC concluded that there is "limited evidence" from experimental *in vivo* studies animals for the carcinogenicity of RF energy.

The report of HPA's independent advisory group became available April 2012. Like IARC, the review considered a wide range of research approaches to assess the effect of RF exposure on cancer. Studies in whole animals are a major component of assessing human cancer risk, which includes studies of laboratory rodents exposed up to their typical lifespan, similar long term studies in strains of the animals prone to develop cancer, initiation-promotion protocols, and co-carcinogenesis studies after exposure to RF in combination with a known carcinogen. They reported that "… large scale studies investigating the initiation and development of cancer have all been robustly negative…" (HPA, 2012, p. 318).

An additional relevant long-term animal study of cancer published in 2011 was not available for the HPA's report (Lee et al., 2011). Lee et al (2011) examined the effect of chronic exposure to two types of RF signals in a mouse strain prone to developing lymphoma (AKR/J) within a year. The animals were exposed for 42 weeks to a level nearly 10 times above the ICNIRP exposure limit, and analysis showed no difference from non-exposed controls in survival time or in the development or spread of cancer.

A shorter-term study investigated the effects of RF exposure on tumor promotion. Paulraj and Behari (2011) studied the promotion of skin tumors initiated by dimethylbenz(a)anthracene (DMBA) and followed by 112 MHz, 2.45 GHz, or croton oil (a known promoter of mouse skin tumors). The RF exposure for 2 hours/day x 3 days/week for 16 weeks or continuous exposure for 2 hours/day for 14 days did not affect any indices of tumor promotion. In another experiment reported by these investigators, the growth of tumors in mice transplanted with ascites carcinoma cells and exposed to 2.45 GHz RF did not differ significantly from the control group.

Considerable interest has been focused on possible DNA-damaging effects of RF exposure because genetic changes in normal cells are one of the earliest changes in the progression to cancer. The HPA (2012) report noted some earlier studies that required replication. Since that report, two additional studies of DNA damage in animals exposed to RF have been reported. Jiang et al. (2012) compared groups of mice exposed to 900 MHz RF for 4 hours/day for 1, 3, 5, or 7 days or no exposure, which was then followed by exposure to gamma rays (a known cause of damage to DNA). Mice that were exposed to RF for one day, then gamma rays, showed the same extent of DNA damage as control mice exposed to gamma rays, but additional days of RF exposure led to a progressive reduction in DNA damage below that observed in control mice. The second study reported an increase in an indirect measure of DNA damage (levels of an oxidized DNA base in urine) in rats following 2 hours of exposure to a 1800 MHz field, but only three rats were tested in each group (Khalil et al., 2012).

The above studies published after the HPA (2012) review do not provide a basis to alter its conclusion that "there is no compelling evidence that RF fields are genotoxic or cause robust carcinogenic effects with exposures below guideline values" (HPA, 2012, p. 172).

The Federal Drug Administration in the United States has requested the National Toxicology Program[19] to conduct a laboratory study of long-term RF exposure of rats and mice. The study has begun, and will expose a large group of laboratory mice and rats to RF energy for several

[19] The National Toxicology Program is part of the United States Department of Health and Human Services.

hours a day for up to 2 years, from birth to old age. This will add to the existing research, which includes similar studies of cancer and long-term exposure to RF energy.

Summary of research on cancer

The IARC Working Group recently ranked RF energy in Group 2B, "possibly carcinogenic to humans" based on epidemiology studies of mobile phone use that provided 'limited evidence of carcinogenicity,' [20] and the 'limited evidence of carcinogenicity' in laboratory animals. Other scientific and health agencies have evaluated this same data, including IARC's animal bioassays and many, but not all, of the INTERPHONE studies, but they have not concluded that RF energy is likely to cause cancer (ICNIRP, 2009; SSM, 2010; HPA, 2012). Studies of time trends in several countries, most recently from the Denmark, Finland, Norway, and Sweden, are not consistent with an increased rate of brain cancer following the widespread use of mobile phones (Deltour et al., 2012). The first study of children and adolescents (Aydin et al., 2011), published after the IARC conducted their review, does not conclude that the scientific evidence supports an association between mobile phone use and cancer.

Studies of animals have not provided persuasive evidence that RF exposure damages DNA or otherwise affects the development of cancer.

The exposure limits developed by ICNIRP (2009) and the IEEE (2005) continue to be the reference point for exposure limits cited by The World Health Organization. Their recent fact sheet, *Electromagnetic fields and public health: mobile phones*, states:

> Currently, two international bodies (ICNIRP and IEEE) have developed exposure guidelines for workers and for the general public, except patients undergoing medical diagnosis or treatment. These guidelines are based on a detailed assessment of the available scientific evidence (WHO, 2011).

[20] This category is used when studies report an association, but when chance, bias, or confounding cannot be ruled out with confidence.

Studies of symptoms related to well-being

The scientific literature on exposure to low levels of RF energy and well-being includes studies of both near field (i.e., mobile phones) and far-field (i.e., mobile phone base stations, wireless networks, etc.) exposure. Most of these studies are concerned with short-term health effects, i.e., non-specific symptoms such as headache, sleep disturbances, and fatigue; both epidemiology studies and human experimental studies are suitable for evaluating these effects.

The literature on this subject includes a large number of relevant studies, however, many have significant limitations such as a small number of participants or, as discussed by Frei et al. (2010) their exposure assessments utilize either self-reporting methods or use distance from a single source as a surrogate. The recent studies selected for inclusion in this review incorporated factors that increased their quality: a large number of participants, improved exposure assessment methods, and field interventions.[21] They include a systematic review of studies on mobile phone base station exposure (Röösli et al., 2010), several epidemiology studies (Eger and Jahn, 2010; Heinrich et al., 2010; Mohler et al., 2010; Baliatsas et al., 2011; Heinrich et al., 2011; Frei et al., 2012), and one human laboratory study (Danker-Hopfe et al., 2010).

Röösli et al. (2010) conducted a systematic review of the literature published from August 2007 through March 2009 on the health effects of exposure to RF fields from mobile phone base stations. Their inclusion criteria required that the selected studies use objective measures of exposure and show a clear description of an acceptable method for selecting participants. In this manner, from the 134 potential results of their literature search, the study authors identified 17 that they deemed adequate based on exposure assessment and selection procedures—12 epidemiology studies and 5 human laboratory trials. The laboratory trials were randomized, double-blind studies on the perception of RF fields; these five studies were meta-analyzed by

[21] Field intervention studies are those in the ordinary environment (not a laboratory) in which the exposure sources are controlled by the research group. It shares characteristics with experimental studies because of the researchers' control of exposure and because participants do not know (i.e., are blinded to) the actual exposure.

Röösli et al (2010). [22] The 12 epidemiology studies, 10 of which were cross-sectional studies, included several outcomes of non-specific symptoms such as headache, tension, and sleep disturbances, as well as other outcomes such as cognitive function. As mentioned, Röösli et al. (2010) conducted a meta-analysis of four of the five human laboratory studies that tested the ability to detect the presence or absence of a RF field. (Although the authors had planned a meta-analysis of all the relevant studies, most of the studies did not sufficiently use similar methods or investigate similar endpoints to combine the data.)[23] When results of these studies were combined, the association did not indicate that individuals could detect whether or not the RF field was present. The same was true for individuals who reported they were sensitive to electromagnetic fields.

The results of these 17 studies, when considered together, did not provide evidence for an increase in health effects related to exposure; in addition, no one symptom or symptom pattern was consistently related to exposure. In addition, the authors noted that the cross-sectional studies "showed a noteworthy pattern: studies with crude exposure assessments based on distance showed health effects, whereas studies based on more sophisticated exposure measurements rarely indicated any association (Röösli et al., 2010, p. 890)."

Other recent human studies of far-field exposure published after the Röösli et al. (2010) systematic review described above primarily have been cross-sectional epidemiology studies. A recent cross-sectional study conducted by Eger and Jahn (2010) investigated 19 outcome categories (e.g., skin problems, toothache, weight loss, weight gain, and dizziness) for RF exposure in people who lived within 200 metres of mobile phone base stations. This study is limited by several flaws. Participants were volunteers rather than randomly selected, and the related important limitation is the low response rate to questionnaires, (23%), which can result in selection bias. The distance from two mobile phone base stations served as a surrogate for

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[22] The more reliable studies of humans are double-blind, which means that neither the participants nor the researcher is aware of the exposure status. In single-blind studies, only the participants are not aware of the exposure status. This blinding process helps to control for human error or bias to due to preconceptions about the experiment's results.

[23] Meta-analysis is an analytic technique used by epidemiologists that combines the published results from a group of studies into one summary result.

exposure, but although calculated in volts per meter, it was incomplete because it included no assessment of any other RF exposure sources, such as cordless phones, radio or television stations, or mobile phone use.

Another recent cross-sectional epidemiology study of non-specific physical symptoms was designed to assess the characteristics of individuals that may affect their response to questions of electromagnetic hypersensitivity (Baliatsas et al., 2011). The researchers conducted the study in the Netherlands in 2006, in which 3,611 participants responded to a questionnaire. The questionnaire included demographic characteristics (e.g., age, gender, and ethnicity) and social characteristics (e.g., education, occupation, home ownership). The participants also were required to answer questions that self-assessed environmental sensitivity to such factors as light, odors, and temperature and questions to evaluate the individual's ability to deal with stress. Finally, participants were asked to report on what they perceived to be their proximity to electromagnetic sources such as mobile phone base stations.[24] The study found that there was no relationship between actual distance to mobile phone base stations and report of symptoms, however, an increased report of symptoms was associated with the perception of proximity to base stations. The perception of being environmentally-sensitive, a lower rating on questions related to control, and certain demographic categories also were associated with an increased report of symptoms. The study's limitations include a low response rate (37%) and use of distance as an exposure surrogate.

As noted, one challenge of epidemiology studies of short-term effects such as headache, sleep disturbances, and fatigue when RF exposure levels are low is a valid estimate of exposure. As seen in the study by Baliatsas et al. (2011), perception of the existence of RF energy sources such as a mobile base station can be a source of reporting bias, particularly if a person holds the view that non-specific symptoms are related to that exposure. Several recent epidemiology studies have used improved exposure metrics. Heinrich et al. (2010, 2011) used personal dosimeters, which are an improved method to determine exposure; Mohler et al. (2010) used

[24] The questionnaire also asked about perceived proximity to power lines.

validated predictive mathematical models; and Danker-Hopfe et al. (2010) exposed participants to RF fields in a double-blind study.

In the study conducted by Heinrich et al (2010), the investigators studied the impact of RF exposure on the well-being of a large group of children (age 8 to 10, n=1,484) and adolescents (age 13 to 15, n=1,508) for seven different symptoms—headache, irritation, nervousness, dizziness, fear, sleep disorders, and fatigue. Their RF exposure was measured using personal dosimeters placed on the upper arm, except during night-time when it was fixed to a water bottle placed next to the bed. Since the investigators determined the dosimeter did not record valid measurements in a fixed position, only the measurements taken during the time the participants were awake were used. The dosimeters recorded RF exposure from mobile phones, cordless phones, and mobile phone base stations. The symptoms noted above were rated by the participants two times in the 24-hour period—at noon (for exposure during morning hours) and in the evening prior to bed (for exposure during afternoon hours). Although a few of the 24 associations calculated were slightly elevated, one for children (concentration) and two for adolescents (headache and irritation), they were not consistent for the two time periods. In addition, these results could not be confirmed in the top 10 percent of participants with the highest exposure. The authors concluded, therefore, that the few elevated associations reported were either chance or random events.

In addition to the 24-hour exposure data described above, the researchers considered self-reported personal data on chronic symptoms (6-month retrospective period) and demographic data that could act as potential confounders, such as age, educational level, study town and personal environmental concerns that had been collected through interview forms (Heinrich et al., 2011). The results of adjusting for these additional factors still did not support an association between the symptoms and RF exposure. The study authors noted that the measured exposure was less than 0.2 % of the ICNIRP exposure limit on average and less than 1% of the limit at the maximum measured exposure.

Mohler et al. (2010) conducted a cross-sectional study of sleep quality, including disturbances to sleep and daytime sleepiness in a randomly selected population of 1,375 adult residents of

Basel, Switzerland. The study authors used a validated predictive model to estimate exposure to far-field RF energy; in their analysis, the researcher also considered estimates of exposure from mobile and cordless phones that were both self-reported by the participants and derived from 6 months of data from a mobile phone operator. The participants provided data on a questionnaire that addressed sleep quality, overall health status, possible exposures such as mobile or cordless phone use and estimated duration, and various demographic factors. The results of this study indicated no association of decreased sleep quality with exposure to RF fields, even in the top 10 percent of participants with the highest exposure.

Danker Hopfe et al. (2010) conducted a field intervention study of 397 participants in 10 locations in Germany to assess subjective and objective measures of sleep quality and RF fields. In order to control background exposure, geographic areas were selected that received no mobile phone service, i.e., there were no mobile phone base stations close by. The residents selected were randomly exposed either to sham (no RF source) or RF exposure conditions. The exposure conditions were created using a portable mobile base station; both the investigators and the participants were blinded to exposure status. Questionnaires were completed prior to the study to assess sleep quality; data gathered included self-reported sleep disorders, sleep quality, and other subjective sleep parameters, as well as opinions on mobile communicating. Objective sleep data was measured using hours asleep, time to fall asleep, and wake time, as well as EEG and EOG readings. The experiment was conducted over two different 5-day time periods, one with sham exposure and the other with RF exposure from the portable base station. The study authors concluded that neither objective measures nor subjective measures were affected by RF exposure.

Although most recent epidemiology studies of RF exposure have been cross-sectional studies, one cohort study was conducted by a group of investigators in Switzerland (Frei et al., 2012). Using the cohort design to reduce bias and confounding, the study authors evaluated exposure to ordinary sources of RF in the environment. To assess both far-field and near-field exposure, they used a combination of calculated exposures (the geospatial propagation model, total personal exposure, and network operator data on mobile phone use), as well as self-reported mobile phone use, to investigate the effects of RF fields on non-specific symptoms related to

quality of life and tinnitus. Information was collected from 1,122 individuals in a cohort at baseline and a follow up 1 year later. In the baseline questionnaire, 22% of participants identified themselves as sensitive to electromagnetic fields, and over 77% believed it is possible to develop symptoms in response to every day electromagnetic field exposure. Health status was evaluated by responses to a written questionnaire about somatic and headache complaints using standardized tests (von Zerssen and HIT-6, respectively) to score health complaints. The study's findings did not provide evidence that objective measures of near- or far-field exposures to RF fields in everyday life was associated with the development of non-specific symptoms or tinnitus, even in people who reported themselves as hypersensitive to electromagnetic fields.

Summary of studies on symptoms of well-being

None of these recent studies exposure to RF fields and non-specific symptoms (e.g., headache, sleep disturbances, and fatigue) has concluded that this exposure leads to acute symptoms or adverse effects. As a group, they do not alter the conclusions of review groups discussed in Section 4. It is important to note that the exposure levels in these studies all were below Canada's Safety Code 6 exposure limits.

Conclusion

The smart meters utilized by BC Hydro will operate in compliance with the regulations of Health Canada. Exposure to RF energy will be far below the exposure limits recommended by Health Canada, and those of ICNIRP and other scientific and regulatory agencies. In this report, recent scientific research regarding cancer and short term effects such as non-specific symptoms has been summarized to determine whether it might suggest adverse effects at levels below exposure limits recommended by these organizations. The reviews and the recently published research that includes improved exposure information in epidemiology studies and longer observation periods do not provide a reliable scientific basis to conclude that the operation of the Smart meters will cause or contribute to adverse health effects or physical symptoms in the population.

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Appendix A

RF Exposure from BC Hydro Smart Meters

BC Hydro is deploying Itron's Openway Centron Meters as part of its smart meter network. These smart meters utilize a 900 MHz RF signal to establish a meter-based network. While meters have an additional integrated ZigBee radio at a 2.45 GHz frequency, it is turned off by default. The data collected from this network is then received by special devices (i.e., collectors) to send electricity usage information back to BC Hydro.

As indicated above, BC Hydro's smart meters are equipped with the ZigBee radio transmitter that allows customers to choose to collect data from compatible home area network (HAN) devices.[1] When shipped, the ZigBee transmitter is turned off and does not result in any RF signal exposure to the customer. If the customer decides to activate the ZigBee transmitter, this transmitter will add an additional RF exposure that is 0.095% of the Safety Code 6 limit at a distance of 20 centimetres.[2] At typical, greater distances from the meter, the exposure will be much lower.

RF emitting devices (including smart meters) in Canada are required to comply with Health Canada's Safety Code 6 exposure limits.[3] These limits, established to protect the health of the general public, are based on the lowest level at which a health effect can occur. Moreover, for further protection, an additional safety factor is added, resulting in exposure limits for the general public that are well below the limit at which the harmful effects could occur.[4] These exposure limits change as a function of frequency to address the frequency-dependent consequences of RF signal exposure. At frequencies greater than 100 kHz, the exposure limit set by Safety Code 6 is based on thermal effects. Non-thermal effects, while present at higher frequencies, will only occur at signal levels that are above the threshold of thermal injury.

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1 These devices, of which there are very few on the market, come with a special matching ZigBee transmitter. Devices without such a transmitter cannot communicate the information to the smart meter.

2 Based on "Analysis of Radio Frequency Exposure Associated with Itron OpenWay® Communications Equipment," Itron, 2011. The 0.037% value in this document was multiplied by a factor of 2.56 recommended by FCC OET 65 Bulletin to allow for an increase of exposure by environmental reflections.

3 http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf05990.html

4 Ibid.; Health Canada. Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz – Safety Code 6. Ottawa: Health Canada, 2009.

As a consequence, in the frequency range that BC Hydro's smart meters operate, the exposure limit is based on the thermal effects. Specifically, at 900 MHz, this exposure limit[1] is 6 W/m^2.

RF exposure from BC Hydro's smart meters is very low, only a tiny fraction of Safety Code 6 limits. This is a consequence of two factors. First, the distance from residential areas to the smart meter is great. As the distance from the smart meter increases, the signal spreads out and less and less of signal power is available at any specific location. The signal power density drop-off with increasing distance is very rapid; for every doubling of the distance, the power density drops off by a factor of four. Second, the signal transmission by the meters is short and infrequent. BC Hydro's smart meters are configured such that they communicate for only a few seconds a day, spread out across the whole day. When averaged over 6 minutes, as prescribed by Safety Code 6, the exposure is greatly reduced compared to the peak power density from the smart meters.[2]

The combination of infrequent signal transmission and the energy spread due to distance results in a very low level of additional RF exposure produced by the smart meter. The additional exposure over background exposure, which is measured to be between 0.05% and 0.36% (depending on location) of the Safety Code 6 limit without smart meters transmitting, is 0.03% to 0.7 % of the Safety Code 6 limit,[3] even as close as 20 centimeters from the front of the meter. At the back of the meter, the exposure is at least a factor of 10 lower than in the front due to the shielding by the meter housing and panel. There will also be an additional reduction of exposure due to the shielding of the wall materials.[4] This additional exposure will drop of rapidly as a function of distance. Even when multiple smart meters are installed in a bank of meters, the RF exposure will be a tiny fraction of the Safety Code 6 limits. A smart meter signal

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1 Exposure is defined as the time-averaged power density of the RF signal that is present in the area accessible to humans. Power density is defined as the power measured in Watts (W) per unit area measured in square meters (m^2). Time average is prescribed to be over a 6-minute consecutive interval at frequencies greater than 100 kHz.

2 Note that even the peak power density is below Safety Code 6 limits due to the effect of the distance.

3 Average values. Upper range is for multiple meter banks, lower range is for single meters. Peak values may be higher, but no values above 1.7% of the Safety Code 6 limit have been observed (and these values include background exposure and may have been increased by non-smart meter transmitters).

4 See e.g., EPRI. An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter. Palo Alto: EPRI, 2010.

is one of the weakest sources of RF exposure in the residential environment. The table below compares some common sources of RF signals to that of the smart meter.

Table A-1. Comparison of RF signal exposure of smart meters to other common sources

	Source				
	Background (measured)[5]	Smart meter (20 cm in front)[6]	Smart meter bank (20 cm in front)[7]	Typical cell phone (next to head)	Typical cordless phone (next to head)
Exposure as percent of Safety Code 6	0.36	0.02	0.07-0.09	0.45-0.95	0.025-0.60

Two recent report that evaluated exposures to RF signals from Wi-Fi devices and smart meters are summarized below.

Wi-Fi devices

To address the recent public concerns related to the proliferation of Wi-Fi technology, Industry Canada (the Department of the Government of Canada with responsibility for regional economic development, investment, and innovation/research and development) performed measurements of RF fields in an Industry Canada boardroom located in Aurora, Ontario. The boardroom contained two Wi-Fi access points and 24 Wi-Fi-enabled devices (laptops). The aim of this study was to obtain measurements of the levels of aggregated RF exposure from multiple Wi-Fi access points and Wi-Fi-enabled devices in an indoor environment. It was found that the aggregated RF exposure levels at this indoor location are well below the maximum exposure limits for RF fields in Health Canada's Safety Code 6. In addition, the Wi-Fi access points selected for this study were operating at higher power compared with most of the Wi-Fi devices currently available on the Canadian market. Therefore, the measured values in this study are likely higher than would typically be observed in equivalent setups in public and private environments.[8]

5 Planetworks, "BC Hydro – Single Smart Meter Safety Code 6 Report," 2011
6 Ibid.
7 Planetworks, "BC Hydro – Bank of 10 Smart Meters," Safety Code 6 Report," 2011
8 Executive summary and download of the full 38-page test report at: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10383.html

Evaluation of radio frequency signals from smart meters in New Zealand

This study of RF signals from smart meters was commissioned by Arc Innovations Limited, a New Zealand company involved in the development, deployment, and management of advanced meter infrastructure (AMI) technology and services. The research was carried out by the Electric Power Engineering Centre, College of Engineering, University of Canterbury, Christchurch. The body of work was mainly related to the RF signals from the communications transmitters in the meters themselves and, where applicable, in other equipment forming part of the relevant network. Researchers assessed the RF signals from smart meters operating at 900 MHz, 1.8 GHz, and 2.4 GHz and reported that the wireless signals from smart meters fall well within the New Zealand safety standard (based on ICNIRP guidelines) for general public exposure levels and far below the levels often encountered from cell phone use.[9]

[9] http://www.research.canterbury.ac.nz/rss/news/index.php?feed=news&articleId=390. Download of a brief study summary and the full report at: http://www.epecentre.ac.nz/media/smartmeter.shtml