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Scientific and Public Health Agency Perspectives on Radio Frequency Fields Related to Smart Meters

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Prepared for

Vermont Department of Health
Vermont Public Service Department
112 State Street
Montpelier, VT 05620-2601

Prepared by

Exponent
17000 Science Drive
Suite 200
Bowie, MD 20715

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Acronyms and Abbreviations

$\mu W/cm^2$	Microwatts per square centimeter
AAEM	American Academy of Environmental Medicine
AGNIR	Advisory Group on Non-Ionising Radiation
ANSES	French Agency for Food, Environmental, and Occupational Health & Safety
BED	Burlington Electric Department
BWG	BioInitiative Working Group
EEG	Electroencephalogram
EFHRAN	Environmental Health Risk Network on Electromagnetic Fields Exposure
EM	Electromagnetic
EMF	Electromagnetic fields
FCC	Federal Communications Commission
FOEN	Swiss Federal Office of the Environment
GMP	Green Mountain Power
GHz	Gigahertz
HAN	Home area network
HCN	Health Council of the Netherlands
Hz	Hertz
IARC	International Agency for Research on Cancer
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionising Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
kHz	Kilohertz
LAEC	Latin American Experts Committee
LOAEL	Lowest observable adverse health effect
MHz	Megahertz
MPE	Maximum permissible exposure

mW/cm^2	Milliwatts per square centimeter
NCCEH	National Collaborating Centre for Environmental Health
NCRP	National Council for Radiation Protection
NIPH	Norwegian Institute of Public Health
RF	Radio frequency
SAR	Specific absorption rate
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SSM	Swedish Radiation Safety Authority
W/cm^2	Watts per square centimeter
W/kg	Watts per kilogram
WHO	World Health Organization
W/m^2	Watts per square meter

Executive Summary

Electric power companies in the United States and elsewhere, as part of modernization of the electric power infrastructure, have been deploying advanced metering technologies, including smart meters. Smart meters may use radio frequency (RF) signals to send information on electricity consumption to utility companies. In 2012, in response to public concerns about potential adverse health effects of RF from smart meters, the Vermont Department of Health released a report demonstrating that measured values of RF emitted by smart meters installed in Vermont were substantially below regulatory limits set to protect against known adverse health effects of RF. In addition, it summarized the conclusions of selected reviews of research on RF exposures and health commissioned by local, state, national, and international agencies. Regulatory limits, such as the exposure limits issued by the Federal Communications Commission (FCC) in the United States, are based on thorough and systematic expert reviews of the entire relevant scientific literature on RF and health. The reviews cited by the Vermont Department of Health report concluded that the only known adverse health effects of RF are related to tissue heating at high exposure levels (i.e., “thermal” effects), and exposure limits are set to protect against these potential health effects. No authoritative agency concluded that there is any confirmed scientific evidence or demonstrated biological mechanism for adverse health effects at low exposure levels (i.e., “non-thermal” effects), that is, effects below levels where RF may cause tissue heating. In combination with the lack of evidence of non-thermal health effects of RF, the measurement results led the Vermont Department of Health to conclude that current regulatory standards for RF from smart meters are sufficient to protect public health.

This update to the 2012 Vermont Department of Health report incorporates results from a more recent and extensive set of measurements of RF signals from smart meters and associated communication devices installed in Vermont (e.g., Tell and Tell, 2013), along with a more thorough review of the relevant scientific literature and agency reports on RF and health. The measurements show that RF fields from typical smart meters in Vermont are tens of thousands of times lower than exposure levels that are known to cause any adverse health effects. Recent systematic reviews of the relevant scientific literature by authoritative national and international regulatory, scientific, and health agencies have uniformly concluded that hypothesized non-

thermal adverse health effects are not known to be caused by RF exposure. Current limits on RF exposure set by the FCC are designed with a wide margin of safety to protect all members of the general public against any potential adverse effects caused by RF exposure. Based on the substantial collective scientific evidence, the consensus of scientific and health agencies continues to conclude that current regulatory standards for RF from smart meters are sufficient to protect public health.

Introduction

Throughout the United States, Canada, and other parts of the developed world, electric power utilities, as a key part of the modern "smart grid" development, have been implementing advanced metering infrastructure that includes the deployment of advanced electrical meters, also known as "smart meters." Smart meters may use radio signals to wirelessly communicate information on consumption of electric energy for monitoring and billing purposes. The radio signals, also referred to as radio frequency (RF),[1] are part of the *non-ionizing* segment of the electromagnetic (EM) spectrum, which also includes signals used for many years for radio broadcasting, television broadcasting, and radar, as well as those used more recently by microwave ovens, Wi-Fi devices, baby monitors, and cordless and mobile (cellular) telephones. Sometimes these fields are referred to as radio frequency radiation, but this terminology may inadvertently and mistakenly imply that RF is similar to forms of *ionizing* radiation, such as X-rays and gamma rays, which have much higher frequency. RF has a significantly lower frequency and, therefore, cannot dislodge electrons from atoms to create charged ions—thus the term "non-ionizing radiation." It is worth noting that the term "radiation" just means "energy propagated through space."[2] It can be used to describe any type of energy emitted from a source, such as heat from a fire or visible light from a lamp, both of which have much higher frequency than RF, and even acoustic energy from loudspeakers.

History of Vermont Department of Health Activities

As with other new wireless technologies, public interest has arisen about RF exposure and the potential health effects associated with smart meters. Little scientific evidence specifically addresses the potential human health effects of RF from smart meters. A substantial amount of scientific literature is available, however, on the potential health effects of RF exposure from other sources (e.g., in occupational settings such as military facilities and mobile telephone manufacturing plants; residential proximity to radio, television, and cellular towers; and

[1] The terminology used by the U.S. National Council on Radiation Protection and the World Health Organization to refer to electromagnetic fields in the frequency range of 300 Hertz to 300 Gigahertz is radio frequency and radio frequency electromagnetic fields, respectively.

[2] http://er.jsc.nasa.gov/seh/e.html#electromagnetic radiation and http://er.jsc.nasa.gov/seh/r.html#radiation

personal use of mobile telephones) that can be relied upon for assessment of potential health effects of RF from smart meters.

In February 2012, the Vermont Department of Health issued a report and a fact sheet, both entitled "Radio Frequency Radiation and Health: Smart Meters." These documents succinctly summarized information evaluated by the Department regarding 1) regulatory issues pertaining to RF from smart meters, 2) results of RF measurements around smart meters of Green Mountain Power (GMP) by the Vermont Department of Health, and 3) reviews of health studies on RF exposure conducted by regulatory, public health, and scientific agencies.

Based on the RF measurements and their review of the available scientific literature and current Federal Communications Commission (FCC) limits for RF, the Vermont Department of Health concluded that the current regulatory standards for RF from smart meters are "sufficient to protect public health" (VDH, 2012). With respect to the potential health effects of RF, the Department also stated:

- The thermal health effects of RFR [radiofrequency radiation] are well understood, and are the current basis for regulatory exposure limits. These limits are sufficient to prevent thermal health effects.
- Non-thermal health effects have been widely studied, but are still theoretical and have not been recognized by experts as a basis for changing regulatory exposure limits (p. 1).

In January 2013, Tell and Tell (2013) completed a detailed measurement report, commissioned by the Vermont Department of Public Service, entitled "An Evaluation of Radio Frequency Fields Produced by Smart Meters Deployed in Vermont" (hereafter referenced as the "Tell Report"). This report provides a summary of a comprehensive series of RF measurements from smart meters deployed in the service territories of GMP and the Burlington Electric Department (BED) in Vermont. The report concludes that the RF emitted by the deployed smart meters "is small when compared to the limits set by the FCC."

Rationale for an Updated Health Report

To summarize and integrate the additional information gained from the comprehensive series of measurements described in the Tell Report, along with new scientific literature and agency reviews published since the original report, this report serves as an update to the 2012 Vermont Department of Health report. This update describes the scientific process of health risk assessment and summarizes recent reviews of RF and health conducted by national and international health and scientific agencies. It expands the discussion of the regulation of RF in the United States, including the recent activities by the FCC, and the scientific basis for regulatory standards. It also discusses internationally-applied RF standards to describe the consensus on exposure standards used by countries worldwide.

Background Information

The Electromagnetic Spectrum

The EM spectrum encompasses all forms of EM radiation and is generally characterized by the frequency of the EM signal.[3] The EM spectrum is generally classified into seven different portions ranging from the lowest frequency portion (radio) to the highest frequency portion (gamma ray). A representation of the EM spectrum including the frequency of EM energy and examples of different portions of the spectrum is shown in Figure 1. A variety of EM energy sources are encountered every day, particularly in modern society, including AM radio, microwave ovens, television remote controls, visible light, and more recently, smart meters. Each of these forms of EM energy is broadly categorized into non-ionizing radiation meaning that the EM energy is not energetic enough to strip electrons from atoms or molecules to create charged particles or ions. In contrast, EM energy in the X-ray and gamma ray portions of the spectrum are energetic enough to remove electrons and are thus broadly referred to as ionizing radiation.

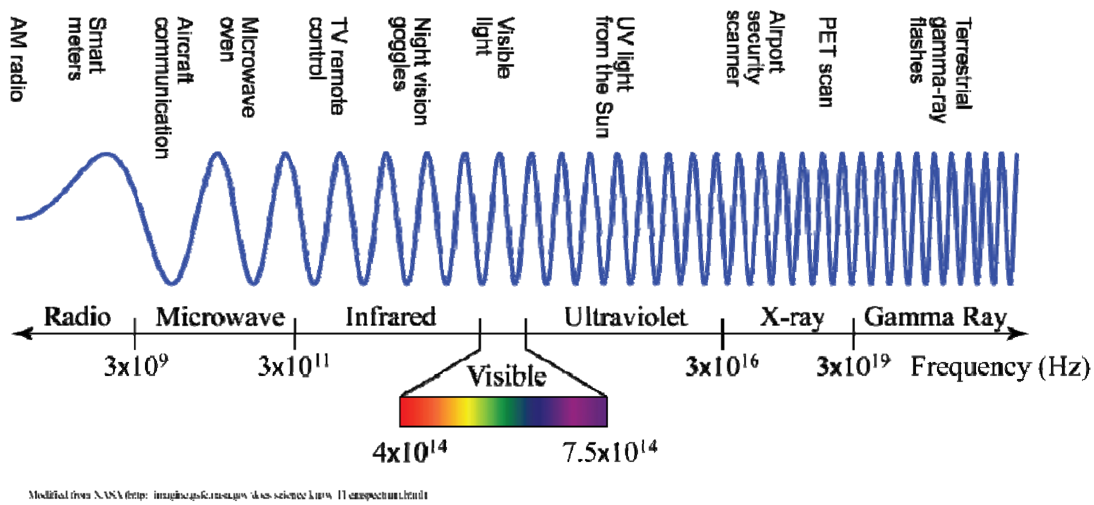

Figure 1. Electromagnetic Spectrum.

Source: modified from NASA (http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html)

[3] EM energy is also characterized by wavelength or sometimes as an absorbed unit of EM energy where increasing frequency corresponds to decreasing wavelength and to increasing energy in each unit of absorbed energy (i.e., the higher the frequency, the more energetic the EM energy and the shorter its wavelength).

Smart Meter Mesh Network

As described above, many smart meters operate in the RF portion of the EM spectrum and communicate with one another in what are known as mesh networks. The purpose of installing smart meters in a network is so the smart meter can communicate electricity demand over RF signals. In a mesh network, each smart meter has the ability to communicate with other nearby meters and with end-point units.[4] The frequency of operation for the smart meters in the mesh network in Vermont is from 902-928 Megahertz (MHz). An illustrative schematic of a smart meter mesh network is shown in Figure 2.

The goal of each smart meter is to relay its relevant data back to the gatekeeper or cell router for transmission back to the utility. The path by which these data reach the gatekeeper or cell router is determined by the physical proximity of each particular meter relative to one another and the transmission path characteristics among the different meters. In Figure 2, preferred data transmission paths are shown with solid black arrows, typically routing information through the shortest individual hops back to the gatekeeper or cell router. This is one of the primary advantages of a mesh network. If meters could not communicate with one another, the transmission power of each smart meter would have to be increased so it could communicate directly with the gatekeeper or cell router. For example, meter 4 in Figure 2 would need to increase its transmission power to communicate directly with the gatekeeper. In a mesh network, meter 4 can keep transmitting at a constant lower power and instead rely on meter 2 or meter 3 to relay its data. While many meters in a mesh network will transmit only their own data, most meters will transmit the data of ‘descendant’ meters.

[4] End-point units, referred to as gatekeepers or cell routers, transmit the data for all nearby smart meters back to the utility either by a fiber optic cable or by broadband wireless communication.

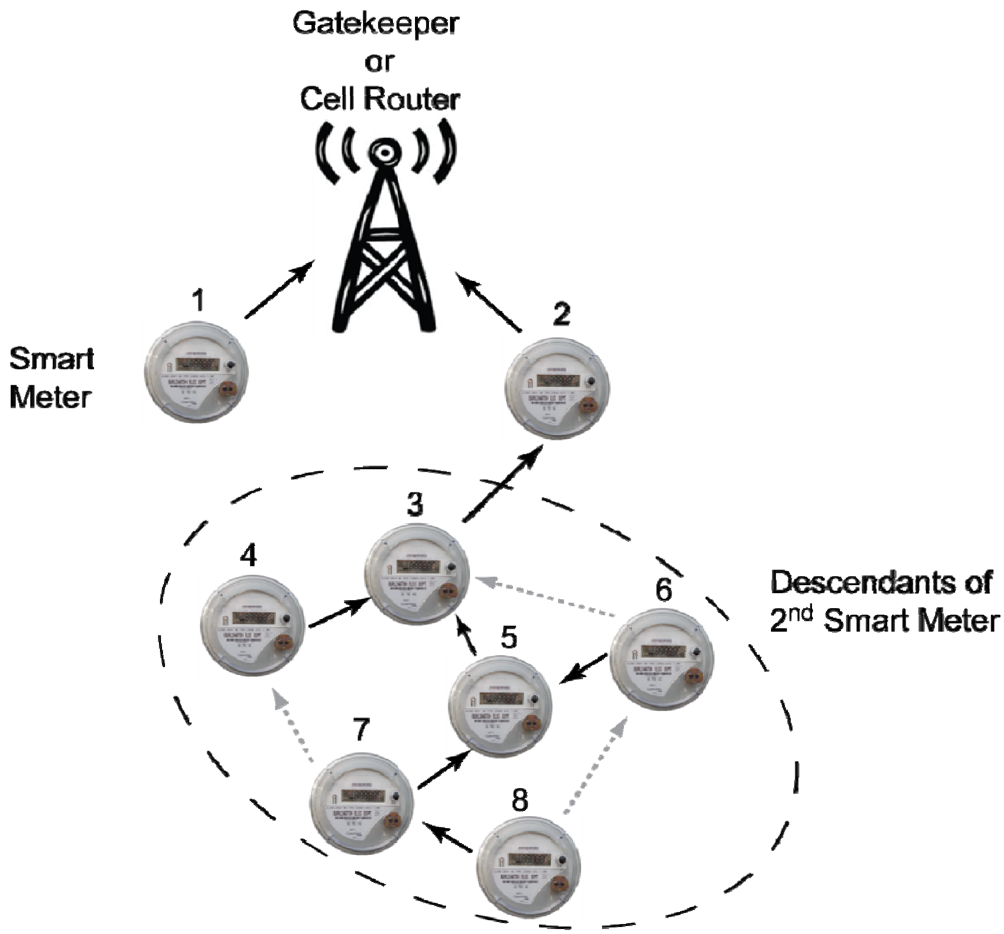

Figure 2. Schematic diagram of a smart meter network.

Data transmissions or 'hops' are shown by black arrows, alternate transmission paths are shown by gray-dashed arrows.

Smart Meter Transmissions

Most people are familiar with some common sources of RF energy such as AM/FM radio transmitters, TV transmitters, microwave ovens, Wi-Fi wireless routers, and mobile telephones. Some of these sources, such as AM/FM radio and TV transmitters, transmit continuously, while others such as microwave ovens and mobile telephones transmit intermittently when required by the user (or to maintain their presence on the mobile network), and still others, such as Wi-Fi routers, operate nearly continuously, but transmit varying amounts of data based on user demand. The variation of these transmission patterns is known as the “duty cycle,” which can be related generally to how often a particular source is transmitting.

Continuously-transmitting sources such as AM/FM radio and TV transmitters have a 100% duty cycle (since people may want to tune in to the broadcast signal at any time), while the duty cycle of a CDMA mobile telephone will vary based on the usage. A person who uses a CDMA mobile telephone for 5 minutes in a 30-minute period is operating it at a duty cycle of approximately 16.6%, while someone who uses a mobile telephone for 1 minute in a 30-minute period is operating it at a duty cycle of approximately 3.3%.[5]

A hypothetical example of a transmission pattern from a transmitter is shown in Figure 3 to illustrate the close correspondence between the peak power density, time-averaged power density, and the number of transmissions generated by a transmitter. This figure shows transmissions as a function of time. The green vertical bars represent an individual transmission, each with a constant peak power density, while the horizontal red line represents the power density obtained by averaging the total power density in a 30-minute period.[6] For the purposes of this hypothetical discussion, assume that each transmission has a peak power density of 1 milliwatt per square centimeter (mW/cm^2), well above the actual peak power density from smart meters; that it lasts for 5 seconds, much longer than the transmission period of a smart meter; and that there are 10 transmissions in each 30-minute period.

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[5] When a call is made, CDMA telephones transmit continuously. This calculated operational duty cycle example should not be confused with the actual duty cycle of the emission of a CDMA telephone.

[6] Power density is a measure of how much power is present in a particular area and is typically measured in watts per square meter or milliwatts per square centimeter.

Using this information, the duty cycle is calculated as:

$$\frac{5 \text{ seconds/transmission } \times 10 \text{ transmissions}}{30 \text{ minutes} \times 60 \text{ seconds/minute}} = \frac{5 \times 10}{30 \times 60} = 2.8\%$$

from which the average power density can be calculated as duty cycle x peak power intensity, i.e., 0.028 x 1 mW/cm^2 = 0.028 mW/cm^2.[7] Additional examples of the correspondence between peak power density, duty cycle, and average power density are shown in Figure B-1 in Appendix B.

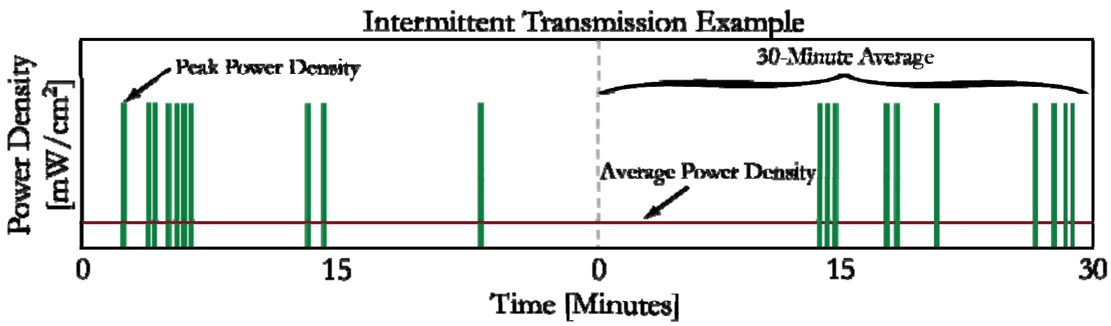

Figure 3. Hypothetical example of a transmitter illustrating the close correspondence between peak power density, duty cycle, and average power density.

The duty cycle of each smart meter varies based on its position in the mesh network as described above and in subsequent sections. The smart meters measured as part of the Tell Report all have a duty cycle less than 3.6%, and typically the duty cycles are much lower. For example, a smart meter without any descendants has a duty cycle of 0.022% and typically transmits for only approximately 0.8 seconds of each hour (broken up into many, many microscopic transmissions for approximately 19 seconds per day).

7 There are other 30-minute periods (e.g., between 10 minutes in the first block and 10 minutes in the second block) in which there are only three transmissions. In this case, the 30-minute duty cycle is 5 x 3/(30 x 60) = 0.83% and the average power density is 0.0083 mW/cm^2. In this situation, the intermediate duty cycle and average power density is lower than in other periods. The maximum duty cycle, however, would still remain 2.8%.

The Smart Meter Home Area Network

In addition to the primary function of the smart meter, interconnected through the RF mesh network, each smart meter assessed in the Tell Report also has a higher-frequency RF communication module that may provide a Home Area Network (HAN). In contrast to the RF mesh network whose purpose is to communicate with the utility (via other smart meters), the HAN provides an optional wireless connection between the smart meter and devices inside the home such as an "in home display" for real-time monitoring of electricity usage. The HAN transmission is typically accomplished in the frequency band of 2.4 to 2.5 Gigahertz (GHz), and typically uses a lower power signal with a lower data rate than the mesh network communication. RF exposure from both the mesh network and the HAN is discussed further below.

Federal Communication Commission Limits

In the United States, the regulation of RF-generating devices falls under the purview of the FCC. The regulations set forth by the FCC specify the limit on the maximum level of permissible exposure to RF of varying frequencies, from 300 kilohertz (kHz) to 100 GHz (FCC, 1996a). Since the primary role of the FCC does not generally cover human health and safety, the FCC based these standards on the work of other organizations; namely the U.S. National Council for Radiation Protection (NCRP) and the Institute of Electrical and Electronic Engineers (IEEE).

Based upon the recommendations from these organizations as well as solicited comments and input from the Environmental Protection Agency and the Food and Drug Administration, the FCC established maximum permissible exposure (MPE) limits for exposure to RF (FCC, 1997). The MPE limits promulgated by the FCC are set to protect against effects from RF exposure that can induce electric fields and currents in body tissues and cause tissue heating. As defined by the FCC, RF exposure is the root-mean-square value of the plane-wave equivalent power density averaged over a specified time period and averaged over the body dimensions. An explanation of the derivation of the MPE limits and their origin is discussed in subsequent sections of this report.

The limits for human exposure to RF are specified in terms of the specific absorption rate (SAR),[8] which measures the rate of RF-energy absorption by bodily tissues. Estimating or measuring the SAR from a particular source is quite complex and is not easily accomplished. To simplify the safety assessment, MPE limits are expressed in power density units that are easy to compute and measure for a comparison to safety limits at distances at or greater than 20 centimeters from the human body. At such distances, when the exposure is less than MPE limits, the energy absorption rate will necessarily be below the SAR limits; therefore, an

[8] A SAR-based dosage limit is utilized for RF frequencies at or above 100 kHz. As specified in FCC 47 CFR 2.1093 (2), "The SAR limits for general population/uncontrolled exposure are 0.08 W/kg, as averaged over the whole body, and a peak spatial-average SAR of 1.6 W/kg, averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). Exceptions are the parts of the human body treated as extremities, such as hands, wrists, feet, ankles, and pinnae, where the peak spatial-average SAR limit is 4 W/kg, averaged over any 10 grams of tissue (defined as a tissue volume in the shape of a cube)."

exposure-based safety assessment is more conservative than a SAR-based assessment.[9] In the frequency range at which smart meters operate, the unit used to describe exposure is power density, measured in mW/cm^2, watts per square meter (W/m^2) or microwatts per square centimeter ($\mu W/cm^2$). Unlike SAR, power density may be used to directly compare to either calculated or measured levels of RF. The MPEs for the general population vary with frequency and are replicated in Table 1 for reference.[10]

Table 1. FCC MPE Limits for Occupational and General Population Exposures

	General Population	
Frequency Range (MHz)	**Power Density (mW/cm^2)***	**Averaging Time (minutes)**
902-928†	0.6	30
2400-2500	1.0	30

*The specified power density is the plane-wave equivalent power density (*Source: Code of Federal Regulations, Title 47, Section 1.1310, (47CFR1.1310).*
†The MPE actually varies across the 902-928 MHz band.

Smart meters manufactured by Elster have been installed by GMP and smart meters manufactured by Itron have been installed by BED. The documents filed with the FCC by these manufacturers demonstrate that for distances at or greater than 20 centimeters, both these smart meters produce peak power densities well below the FCC MPE limits. Therefore, compliance of these smart meters with FCC MPE limits is assured under all operating conditions since the exposure is calculated by multiplying the peak power density by the duty cycle (whose values are mathematically defined to be less than or equal to 100%).

9 IEEE C95.1-2005, pp. 15, 16, and 24

10 A more in depth assessment of SAR from the RF signal may also be performed, but is not mandated by the FCC.

Vermont Smart Meter Measurements

Vermont Environmental and Residential Measurements

The Vermont Department of Public Service commissioned Richard Tell and Associates to conduct a measurement study to characterize the RF signals from smart meters operating in Vermont and to develop an accurate comparison of RF from smart meters in Vermont with the applicable FCC MPE limits using operational measurements. The Tell Report summarizes their measurements conducted at 37 discrete locations, including 12 detached homes and 6 apartments as well as at 6 banks of smart meters, 2 data collection points, 1 isolated meter, and 14 general environmental sites within the GMP and BED service territories.

These measurements characterized both the peak and average transmitted RF power density, which can be related to the potential exposure of an individual standing immediately next to the smart meter. Measuring both these parameters also allows the duty cycle (the percentage of time the smart meter transmits) to be computed. Power density was measured in multiple directions away from the smart meters (from the front, from the back, and from both sides), which is necessary to characterize the expected exposure behind the meter, inside the house.

Comparison of Tell Report Results with FCC Filings and FCC MPE Limits

The peak measurements from the Tell Report are consistent with those reported in the FCC Electromagnetic Conducted Emission documents. At a distance of 1 foot, the peak power density extrapolated from the FCC grant documents is approximately 9.6% of the MPE (0.059 mW/cm^2) for the GMP Elster smart meter, and approximately 7.4% of the MPE (0.045 mW/cm^2) for the BED Itron smart meter (Tell Report, p. 88). The corresponding peak measurements at a distance of 1 foot in the Tell Report are 3.9% and 2.5% for the GMP and BED smart meters, respectively, consistent with laboratory measurement values filed in FCC grant applications. It is typical for extrapolated measurement results as provided in the FCC filings to overestimate the exposure when compared to actual measurements due to the idealized assumptions made when using the inverse square law.

A comparison of extrapolated FCC grant application measurements to those reported in the Tell Report is shown Figure 4. This figure graphically places the 900 MHz measurements of the smart meters in the context of the FCC MPE limits, all shown on a logarithmic scale.[11] This figure also shows both the extrapolated FCC values and the highest peak and average measurements of smart meters in the Tell Report. Also shown for reference are the extrapolated FCC measurements and the Tell Report measurements from the HAN (2.4-2.5 GHz) portion of the smart meters. To the left of each data point, the exposure is also displayed as the fraction of the MPE limit for reference.

[11] On a logarithmic (or log) scale, numbers are displayed in powers of 10 to see very small numbers on the same figure as large numbers. A change from 10^{-3} to 10^{-4} represents a decrease by a factor of 10 and a change from 10^{-3} to 10^{-5} represents a decrease by a factor of 100.

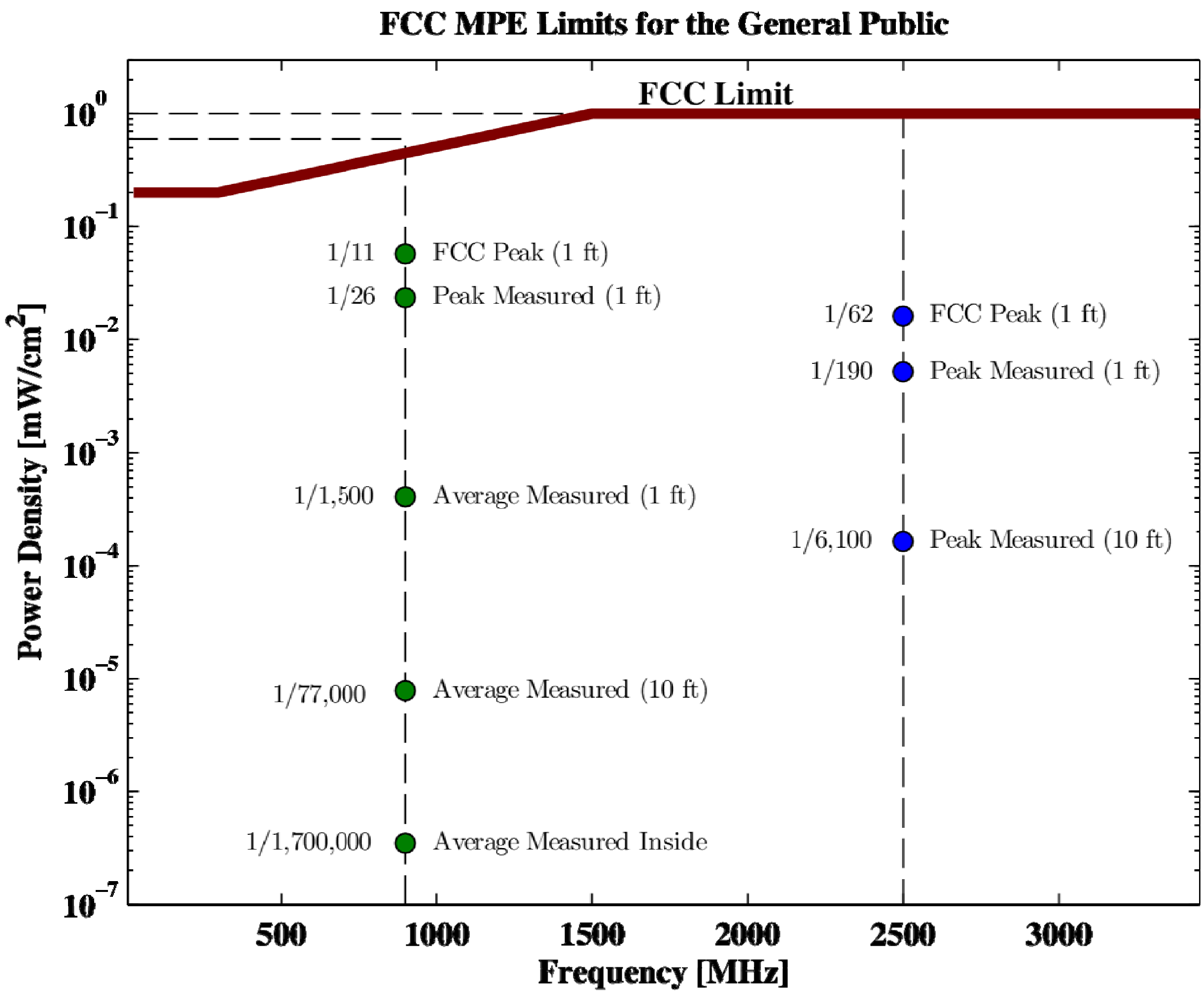

Figure 4. Comparison of measurements of smart meter exposure to FCC Limits.

Measurements from FCC Grant Application are extrapolated to a distance of 1 foot and compared to field measurements in Vermont from the Tell Report

The highest peak RF field measured at a distance of 1 foot from any smart meter evaluated in the report was 3.9% of the FCC MPE (Tell Report, p. 87). When accounting for both the time- and spatial-averaging specified by the FCC, the exposure level drops to 0.068% of the FCC MPE limit (Tell Report, p. 87). Indoors, the average exposure from a smart meter was more than 1.7 million times below the FCC MPE (Tell Report, p. 93).

The Tell Report summarizes the measurement results with respect to the FCC MPE limits as follows:

> Hence, using the most conservative results from the measurements performed in this study, a potential maximum exposure of individuals to the RF fields associated with the currently deployed smart meters in the GMP and BED service territories is small when compared to the limits set by the FCC (p. 87).

The values in Figure 4, and discussed above, were measured or extrapolated to a distance of 1 foot from the front of the smart meter. At greater distances from the smart meter the exposure will decrease rapidly. The decrease with distance is governed by the inverse square law, which states that RF energy from sources such as a smart meter will decrease with the square of the distance from the source. For example, at a distance of 2 feet the exposure will be 4 times lower than at 1 foot and at 10 feet the exposure will be 100 times lower than at 1 foot. Calculations of the decrease in power level with distance for both GMP and BED smart meters are shown in Figure 5 and are generally consistent with field measurements (e.g., Tell Report, Figure 13). Calculations are included for both smart meter mesh network transmissions as well as potential HAN transmissions, with all calculations normalized to the maximum calculated value (that of the GMP mesh network transmission at a distance of 1 foot from the smart meter).

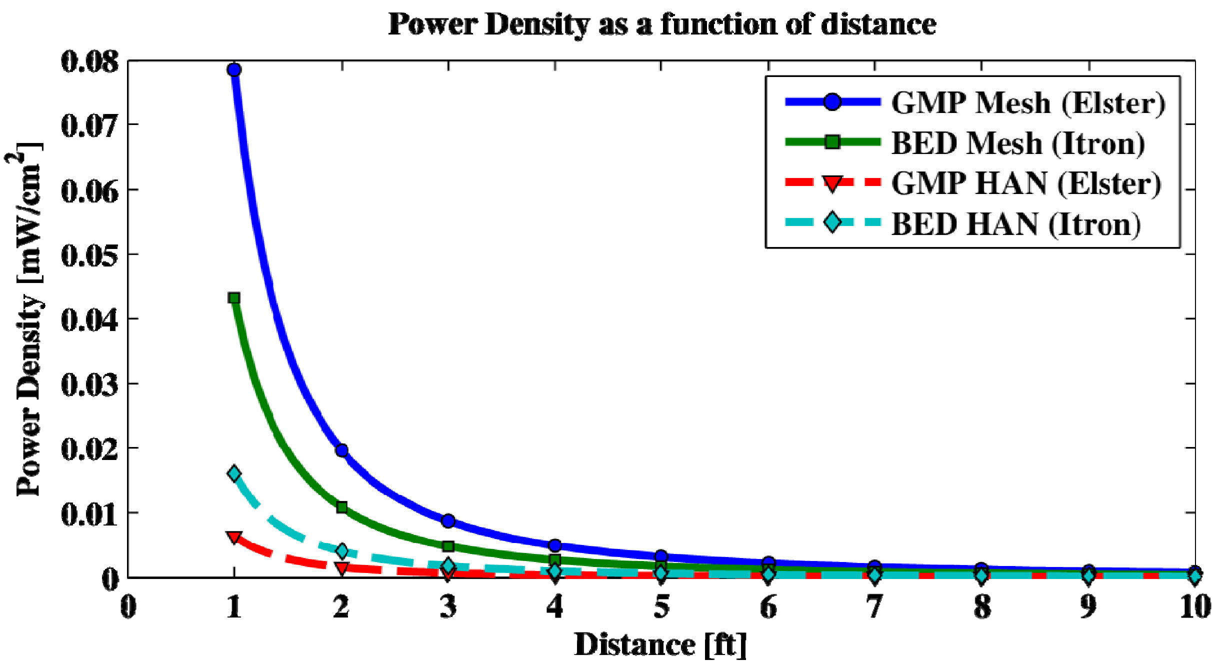

Figure 5. Calculated decrease in power density as a function of distance from the source for both smart meter wireless and potential HAN wireless transmissions.

Low Frequency Emissions

Also included in the Tell Report are evaluations of the low frequency (0 to 100 kHz) electric and magnetic fields produced by the smart meters, the primary source of which is identified as the internal switch mode power supplies, although other sources cannot be ruled out. Measurements at a distance of 1 foot from the smart meters were made covering three different frequency spans from both GMP and BED test smart meters. The results of these measurements indicate that the low frequency fields (<100 kHz) measured near smart meters is "substantially smaller in value than recommended limits" (Tell Report, p. 3).

Gatekeepers and Cell Routers

Measurements of Gatekeepers (GMP) and Cell Routers (BED) were also performed to assess for any potential increase in RF exposure from these types of units. In the GMP service area, the RF emissions from Gatekeepers were found to be much lower than those measured at a distance of 1 foot in front of the smart meters. This difference is due to both the elevated height of the Gatekeeper as well as the very high capacity for data transfer. The Cell Routers in the BED service territory operate using a fiber optic network and no additional RF is generated. The exposure from these systems is generally quite low and was found through the measurements to be "unremarkable" (Tell Report, p. 91).

Comparison of Tell Report with Previous Vermont Measurements

The Vermont Department of Health also performed measurements of the RF from smart meters in January 2012, using a Narda 8712 Survey Meter.[12] Measurements were made both in contact with the smart meter as well as at a distance of 1 foot from the smart meter. The measurement levels reported by the Vermont Department of Health at a distance of 1 foot from the smart meter ranged from approximately 0.010 mW/cm^2 to 0.050 mW/cm^2, which correspond to 1.7% to 8.3% of the FCC MPE for the general public.[13] Additional measurements were made within a residence in the room on the opposite side of the wall housing the smart meter. Measurements at this location were below the background levels insofar as the measurement setup was able to discriminate RF signals from the smart meter from other signals present. A comparison of measurements in similar locations performed in the Tell Report is shown in Table B-1 in Appendix B. The two reports are in reasonable agreement given that the measurement equipment used in 2012 by the Vermont Department of Health likely also recorded RF signals from other sources and may therefore have somewhat overestimated the exposure from the smart meter itself. The measurements performed by Tell and Associates addressed this issue by using measurement equipment that can select measurements from a precise frequency band, thus removing the contributions from other sources.

[12] The measurement probe used with the Narda 8712 meter is unspecified, but could cover one of three frequency ranges: 300 kHz to 3 GHz; 300 kHz to 50 GHz; or 300 MHz to 50 GHz. The frequency of operation of the smart meters lies within only a small portion of any of these bands (i.e., 902-928 MHz). Therefore, the measured RF level using the Narda 8712 meter may pick up signals from other sources and attribute them to the smart meter, so these measurements may overestimate the exposure from the smart meter itself in many circumstances.

[13] The variation in recorded levels at different locations is likely due to a higher or lower duty cycle on the particular smart meter being measured.

Comparison of Vermont Smart Meters to Other Common RF Exposure Sources

In addition to measurements of smart meters, the Tell Report also documented the RF exposure from other common sources in Vermont including FM radio and TV broadcast stations, microwave ovens, mobile telephones, a mobile telephone base station, and others. Comparing these measurements in relation to those from the smart meters can place the exposure from smart meters in context with other RF sources commonly encountered. Figure 6 shows the measurements of various sources, averaged over 30-minutes and expressed as a percent of the FCC MPE. This averaging includes the contribution of both the measured duty cycle and the measured peak power density. Figure 7 shows the measurements of peak power density of some of these sources, also expressed as a percent of the FCC MPE.

In both figures, the measurements are sorted by increasing power density level. Some measurements are as much as 100,000 times lower than others and therefore each figure shows the data in two separate plots, one on a linear scale (left) and one on a logarithmic scale (right). In both figures the measurements of smart meters at various locations are shown in green while measurements of other sources are in blue.

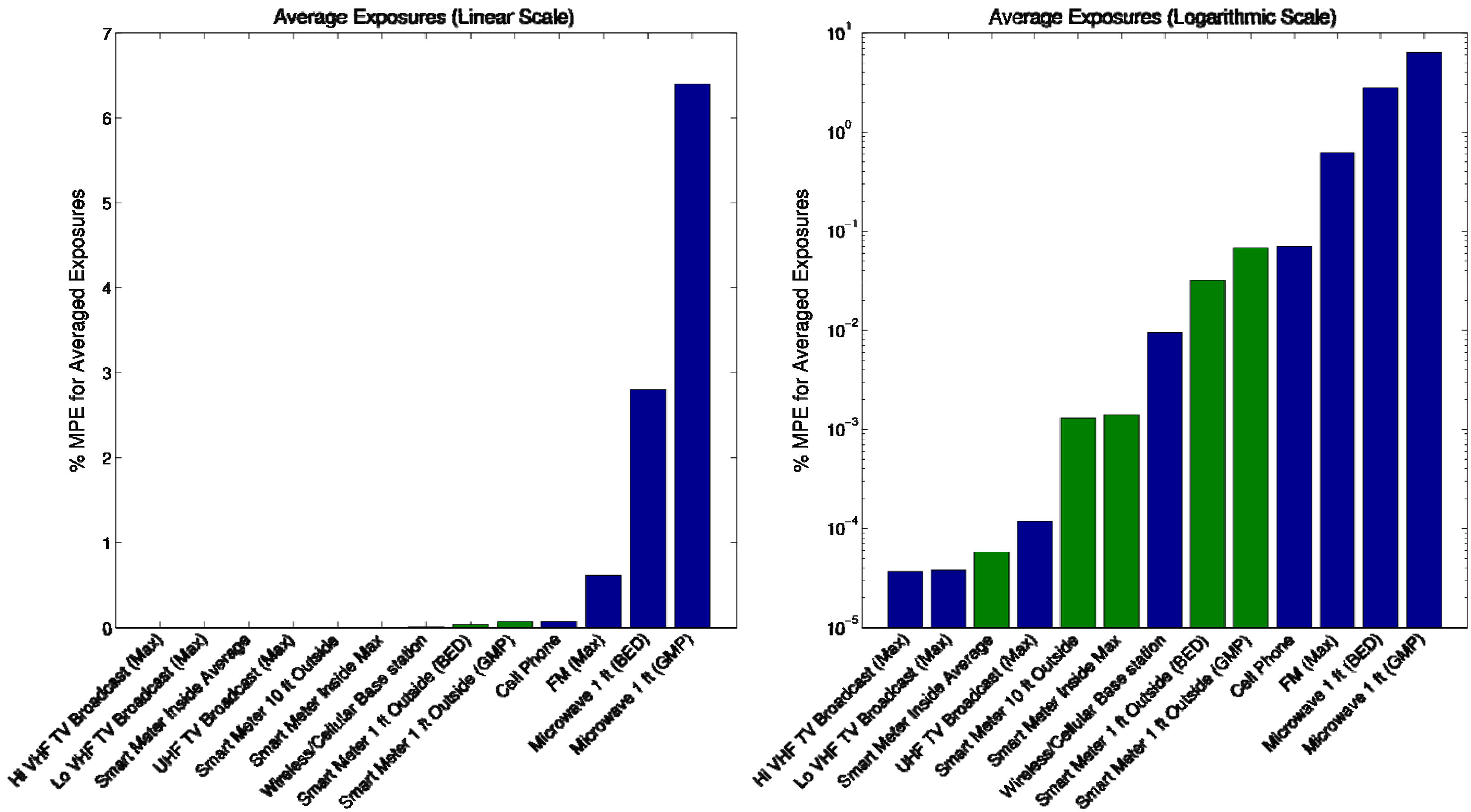

Figure 6. Time-averaged exposure of RF sources measured in the Tell Report.

Measurements of smart meters at various distances and locations are shown in green. Measurements of other sources of RF exposure are shown in blue. Plots are presented both on a linear scale (left) to show the relative magnitude of measurements and on a logarithmic scale (right) to show dynamic range. On the logarithmic plot, each marking on the vertical axis represents a 10-fold change in exposure. On the linear plot, exposure inside residences from the smart meter is so low as to be indistinguishable from the horizontal axis of the figure.

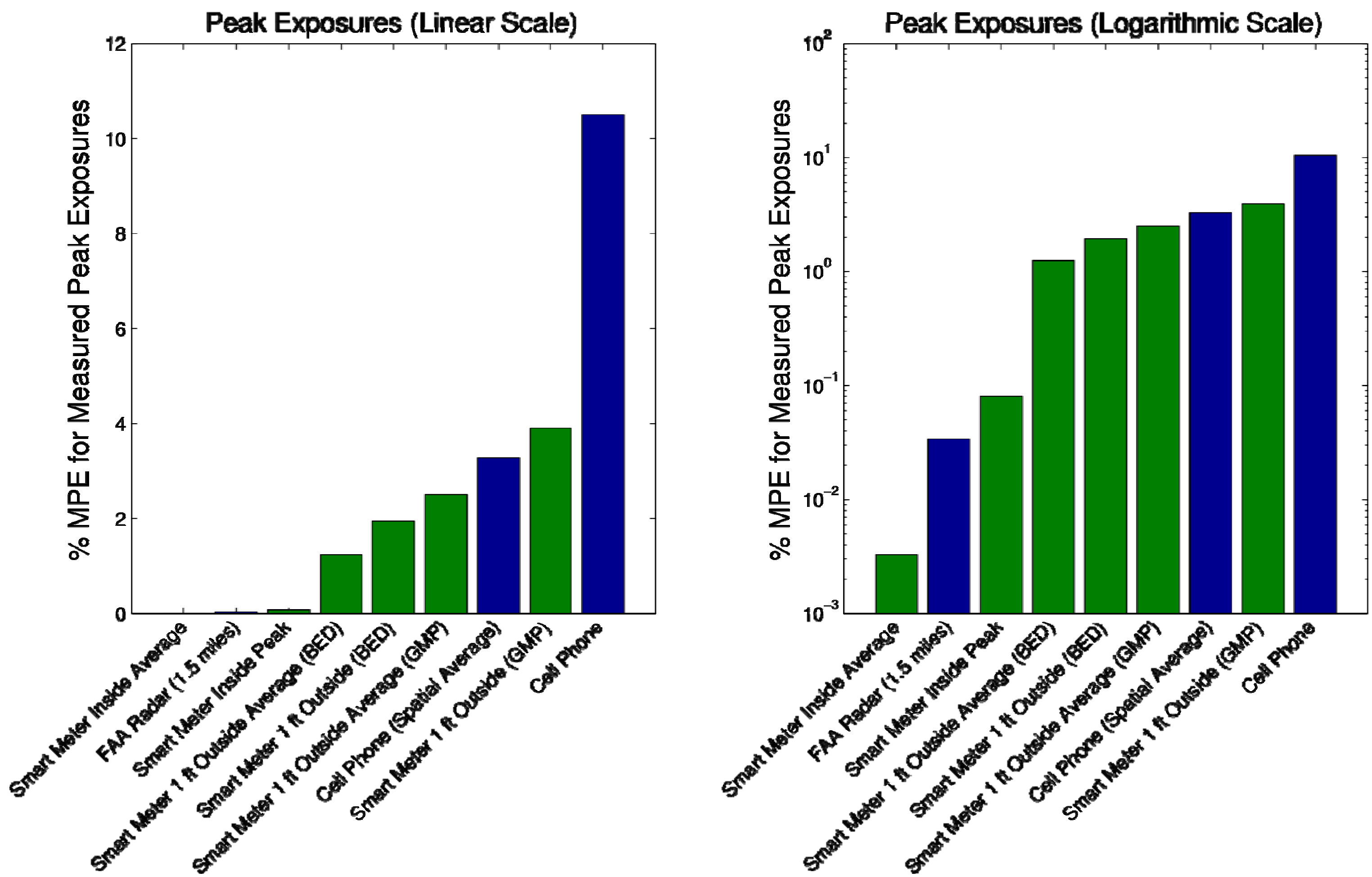

Figure 7. Peak exposure of RF sources measured in the Tell Report.

Measurements of smart meters at various distances and locations are shown in green. Measurements of other sources of RF exposure are shown in blue. Plots are presented both on a linear scale (left) to show the relative magnitude of measurements and on a logarithmic scale (right) to show dynamic range. On the logarithmic plot, each marking on the vertical axis represents a 10-fold change in exposure. On the linear plot, exposure inside residences from the smart meter is so low as to be indistinguishable from the horizontal axis of the figure.

As shown in Figure 6, the highest measured average level of RF, by far, was taken at a distance of 1 foot in front of a microwave oven in both the GMP and BED service areas. In contrast, the average potential exposure from a smart meter at a distance of 1 foot outdoors is between approximately 0.032% and 0.068% of the FCC MPE (or between approximately 1,500 and 3,000 times lower than the specified FCC MPE limit). This result is consistent with measurements of RF from smart meters taken in other areas, all of which show that the level of RF is a small fraction of the specified MPE limits (e.g., ARPANSA, 2013; EMC, 2011; NSGI, 2011; Tell et al., 2012). Also illustrated in Figure 6 is the rapid decrease in RF with distance from the smart meter, which diminishes to 0.0013% of the MPE limit (approximately 1/77,000th of the MPE limit) at a distance of 10 feet from the smart meter outdoors. **Inside buildings, the level of RF decreases even more rapidly (due to shielding from the meter's back-plate), with the highest RF inside a residence measured directly behind the smart meter at approximately 0.0014% of the MPE limit (1/71,000 of the MPE limit), while the average RF inside a residence was 0.000058% of the MPE limit (more than 1.7 million times lower than the MPE limit).**

The instantaneous peak power density measured near various sources is shown in Figure 7, including typical (average) and maximum peak power density from a smart meter inside a residence, as well as peak power density at a distance of 1 foot from a smart meter outside with and without spatial averaging. Also shown for comparison is the RF from a Federal Aviation Administration radar facility (approximately 1.5 miles distant), as well as the peak power density from a mobile telephone with and without spatial averaging. Consistent with calculations shown above, Figure 7 demonstrates that even the peak power density from a smart meter is a small fraction of the FCC MPE limit. **At a distance of 1 foot (outside) from a smart meter, the peak potential exposure is approximately 3.9% of the MPE limit and is approximately 50 to 1,200 times lower inside a residence as compared to outside (1,250 to 30,000 times lower than the MPE limit).**

Measurements demonstrate that even when using the highest measurements recorded as a part of this study, the potential RF exposure associated with the smart meters is a small fraction of the MPE limit set by the FCC.

Since questions have been raised as to different descriptors of exposure to RF fields, it should be recognized that for a given duration of exposure, there is a close correspondence between the peak exposure duration, time-averaged exposure, and the number of transmissions generated by a smart meter as illustrated in Figure 3 and further in Appendix B, Figure B-1.

Health Risk Assessment Approach

A health risk assessment is the scientific method used by scientists worldwide for determining whether or how an exposure in the environment, such as chemicals in the air, water, or food, or devices such as mobile telephones or smart meters, can affect human health. Health risk assessments include four general steps: hazard identification, dose-response assessment, exposure assessment, and specific risk characterization (U.S. EPA, 1989). In the first step, **hazard identification**, scientists identify and review all of the relevant scientific research studies of effects in humans and laboratory animals to determine the types of health problems that might result from exposure. The next step, **dose-response assessment**, is an evaluation of the data from the hazard identification to determine what intensity and duration of exposure causes adverse effects that have been identified. The dose-response assessment is the basis for developing exposure limits and regulatory standards. Next, the **exposure assessment** evaluates the amount and nature of human exposure from the agent being studied. The final step, **specific risk characterization**, compares the dose-response pattern to the amount of the specific exposure being investigated to determine a level of risk for the exposed population. For some exposures, limits already have been developed from the data as a regulatory standard. In such cases, as for exposure to RF from smart meters, the final step is to compare the specific exposure to the relevant standard.

Hazard Identification

A hazard identification includes a weight-of-evidence review of the scientific literature; this is a standard scientific process used by regulatory, scientific, and health agencies worldwide (European Chemicals Agency, 2010; Guyatt et al., 2008; IARC, 2006; ICNIRP, 2002; U.S. EPA, 2005) to evaluate potential health hazards. This process entails a comprehensive consideration of the evidence on a particular scientific issue in a systematic and thorough manner to determine whether the overall data present a logically coherent and consistent picture of a causal relationship between an exposure and a health outcome. A hazard identification consists of three broad steps, as follows.

1. **A systematic search of the scientific literature, typically using computerized biomedical research databases of published reports, to identify relevant research studies**. A thorough search of the scientific literature should retrieve epidemiologic studies of humans observed in their natural environment, experimental laboratory studies of humans or laboratory animals (*in vivo* studies), and laboratory studies of cells and tissues (*in vitro*) that may provide evidence regarding a mechanism (i.e., the way in which the exposure interacts with biological tissue).

   These types of studies provide different but complementary information to determine how an exposure may affect biological organisms. Epidemiologic studies are non-experimental, meaning that researchers do not have control over the exposures under study. By contrast, scientists tightly control the exposure conditions in experimental studies of humans and animals and, therefore, have greater certainty that an observed outcome is due to the exposure being studied and not some other factor. On the other hand, epidemiologic studies evaluate humans in their natural environment and may therefore yield generalizable results, whereas experimental studies in animals are limited by the uncertainty of extrapolating findings from animals to humans, and experimental studies of humans are typically limited by artificial, short-term exposures and acute, relatively minor health outcomes. Both types of studies must be considered together, in addition to *in vitro* studies, to develop a better picture of the potential relationship between the exposure and the biological or health outcome.

   In vitro studies are widely used to investigate the mechanisms for effects that are observed in living organisms. The relative value of *in vitro* studies to a human health risk assessment, however, is much less than that of *in vivo* and epidemiologic 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 to animals and humans cannot be assumed (IARC, 2013a). It may, therefore, be difficult to extrapolate from simple cellular systems to complex, higher organisms to predict health risks. In addition, the results of *in vitro* studies cannot be interpreted in terms of potential human health risks unless they are performed in well-studied and validated test systems. For these reasons, data from *in vitro* studies are treated as supplementary to data obtained from *in vivo* and epidemiologic studies.

2. **Evaluation of individual studies to determine their strengths and weaknesses, so that more weight can be given to studies of higher quality.** The validity of a study depends upon the quality of the data, which in turn depends upon the methods used to collect and analyze the information gathered. To evaluate the results of any type of investigation, whether an epidemiologic study or an experimental laboratory study, it is crucial to assess the way the study was designed and conducted, the number of participants, the accuracy of the exposure and outcome assessment, and the statistical methods of analysis. This is particularly necessary in epidemiologic studies to determine whether an association is a result of systematic error (bias) in the selection of participants or classification of exposures and outcomes; failure to account for an extraneous variable that is associated with the exposure and outcome of interest (confounding); or random variation (chance) as opposed to a valid association. In scientific experiments, specific methods that are used to maximize validity and minimize bias include the random assignment of subjects to exposure vs. comparison conditions, blinded collection of information (i.e., without knowledge of exposure assignment), and inclusion of a sufficient sample size to overcome random variation. The greater the validity of a study, the more weight is assigned to its findings in a weight-of-evidence evaluation. Even if a statistical association from a single study is deemed valid, further scrutiny is warranted to determine whether the statistical association indicates a cause-and-effect relationship.

3. **Evaluation, using standard guidance, of the weight of scientific evidence for and against a cause-and-effect relationship between a particular exposure and outcome.** This guidance is often patterned after the Bradford Hill guidelines, a framework used to facilitate the weight-of-evidence review process for epidemiologic studies (Hill, 1965). These guidelines include consideration of the strength of the association, the consistency of the association within and across studies, the specificity of the exposure for the outcome, the temporal relationship between the exposure and the outcome, evidence for an exposure-response gradient, the biological plausibility of the hypothesized causal link, coherence with

known facts about the natural history and biology of the health outcome, support from experimental or semi-experimental studies, and the existence of established analogous associations. Similar guidance, taking into account consideration of whether a health effect has been demonstrated in two or more species of animals or in two or more independent studies of one species carried out at different times, in different laboratories, or under different protocols, can also be applied toward the evaluation of experimental studies for risk assessment (e.g., Repacholi and Cardis, 1997). Independent replication of results by different laboratories under different conditions is a cornerstone of scientific research and is necessary for reaching consensus within the scientific community about a potential cause-and-effect relationship. Concerted efforts to increase the transparency, consistency, and quality of scientific reporting have recently come to the forefront due to a growing emphasis on scientific reproducibility (e.g., Landis et al., 2012; McNutt, 2014; Nature, 2013).

Although, as expressed by Sir Austin Bradford Hill himself, "[n]one of my nine viewpoints can bring indisputable evidence for or against the cause-and-effect hypothesis and none can be required as a *sine qua non*" (Hill, 1965), in general, the more firmly the epidemiologic evidence is judged to meet these guidelines, the more convincing the evidence for a causal relationship. A hazard assessment should be transparent and reproducible, with all types of studies considered in a standardized manner.

Dose-Response Assessment

The second step in the risk assessment process is to determine how responses to the exposure relate to the level of exposure. Almost anything in our environment can produce adverse effects if the exposure is high enough, including water and oxygen, so the goal of a dose-response assessment is to find the level below which adverse effects do not occur.

In a dose-response assessment, scientists evaluate the scientific research to estimate the amount of exposure (dose) that is likely to result in a particular health effect in humans. This is important because many things that might impact human health only do so after a certain amount of exposure has occurred. A simple summary of the dose-response principle is that for chemicals or physical agents that could affect biological function, more is generally worse. For this reason, laboratory experiments strive to expose animals at the highest level tolerated, to ensure that potential adverse effects are not missed. Then, exposures at lower levels are used to identify exposure levels that do not produce adverse effects.

The concept of a dose-response relationship is a familiar part of our daily life. We know, for example, that the application of sunscreen lowers an individual's exposure to sunlight, thereby reducing the risk of sunburn. Another example is that a 6 percent solution of sodium hypochlorite, commonly known as bleach, carries a warning label that this substance is hazardous, dangerous, and corrosive. A highly-diluted solution of the same agent, however, 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.

Exposure Assessment

The third step of the process is to determine the way in which people could be exposed in a specific situation, including the magnitude, frequency, duration, and pathways of exposure. This assessment is important because an individual's exposure is one of the major factors for determining the potential for an impact on health.

Specific Health Risk Characterization

In the final step of a risk assessment, the information developed in the hazard identification, dose-response assessment, exposure assessment steps is used to reach a conclusion and characterize the specific health risk, if one exists.

Key Lines of Scientific Evidence

As mentioned above, four key lines of scientific evidence contribute to hazard identification as part of a health risk assessment: epidemiologic studies of humans, experimental studies of humans, experimental studies of whole animals, and experimental studies of cells and tissues. This section broadly depicts the landscape of available scientific evidence on the potential health effects of RF, and highlights the best evidence upon which to draw conclusions. Since several recent detailed, comprehensive reviews of the relevant literature are publicly available (as discussed later in this report), the results of individual studies are not described in detail here; rather, this section is intended to provide an overview of the breadth and depth of the current scientific information on RF and health, with a focus on cancer. Studies of other chronic health outcomes have generally been of similar design but fewer in number, with especially fewer high-quality studies, in part because no other chronic diseases are routinely monitored on a population-wide basis. Studies of acute health symptoms, including symptoms attributed to electromagnetic hypersensitivity, are discussed separately at the end of this section.

Epidemiologic Studies

Epidemiologic studies of the potential effects of RF exposure on human health outcomes include studies of occupational exposure to RF in settings such as military facilities and mobile telephone manufacturing plants; environmental exposure to RF from radio and television transmitters and mobile telephone base stations; and personal exposure to RF from mobile and cordless telephones. At present, the major source of individual exposure to RF for most people is mobile telephones, whereas other sources such as cordless telephones, wireless local area networks, mobile telephone base stations, and radio and television transmitters are minor contributors to individual exposure.

Occupational Exposure to Radio Frequency

Workers in environments such as military facilities, where exposure to radar is likely, may incur RF exposure above levels that are permitted for the general public. In most occupational epidemiologic studies, exposure to RF has been estimated mainly by using occupation or job as a proxy for exposure. Although earlier studies reported some statistically significant positive associations between proxy measures of exposure and leukemia risk (e.g., Szmigielski, 1996), the interpretation of the results was limited by inaccurate exposure classification, potential bias in the study design and conduct, and uncontrolled confounding by other exposures that may have explained the observed associations. More recent studies have not consistently detected an excess risk of any type of cancer in association with occupational RF exposure (e.g., Groves et al., 2002; Morgan et al., 2000).

Environmental Exposure to Radio Frequency from Radio and Television Transmitters and Mobile Telephone Base Stations

Exposure to RF from radio and television transmitters and mobile telephone base stations is relatively low because exposure declines rapidly with increasing distance from the source. Most early studies of these exposure sources were ecologic in design, meaning that they compared aggregated cancer incidence or mortality rates across geographic areas at specified distances from a transmitter or base station, under the almost certainly false assumption that all residents of a given area had the same level of exposure. Information on exposures and outcomes of individual study subjects is not available in ecologic studies. Ecologic studies are generally considered one of the weakest epidemiologic study designs because associations observed at the group level may not hold at the individual level.

Such studies are also limited by the use of residential proximity as a surrogate for RF exposure from a single source, and by the inability to account for residential mobility and any latency period—that is, the interval between exposure to a causal agent and the onset of disease—which for cancer and other chronic diseases may be decades. Another limitation is the difficulty of accurately assessing exposure from a single RF source, such as a nearby radio transmitter, while also accounting for other sources of low-level RF in the environment, including other transmitters, mobile telephone base stations, household wireless devices, and mobile telephones carried by the public.

A few more recent studies have improved the estimation of RF exposure by using calculations based on physical characteristics of radio and television transmitters and the residential location of each study subject (e.g., Ha et al., 2008; Ha et al., 2007; Li et al., 2012; Merzenich et al., 2008). These studies did not find consistent, statistically significant positive associations between total RF exposure and risk of childhood leukemia or brain cancer. Likewise, a study of estimated maternal exposure to RF from mobile telephone base stations and risk of early childhood cancer found no association with leukemia/lymphoma or brain cancer (Elliott et al., 2010).

Exposure to Radio Frequency from Mobile Telephones

Numerous epidemiologic studies have been conducted to investigate the risk of brain tumors associated with mobile telephone use. The vast majority of such studies have used the case-control design, in which self-reported history of mobile telephone use is compared between subjects with and without brain tumors. Substantially fewer studies have used the cohort design, in which a large group of subjects with varying levels of mobile telephone use are followed over time for the subsequent occurrence of brain tumors. Since cohort studies are not susceptible to recall bias (i.e., systematic error caused by differences in the accuracy or completeness of reporting past exposures between cases and non-cases) and are less prone to selection bias (i.e., systematic error caused by differences in study participation or drop-out related to exposure and disease status) than case-control studies, they are generally considered to provide more valid results than case-control studies. Cohort studies, however, tend to be substantially more resource-intensive than case-control studies, since they require the inclusion of large populations and long follow-up periods.

While early case-control studies showed no increased risk of brain tumors with increasing use of mobile telephones, these early studies were restricted to the assessment of relatively short-term telephone use and short periods at risk after exposure (Inskip et al., 2001; Muscat et al., 2000). More recently, two sets of case-control studies (described below), with combined data from multiple sites or recruitment periods, have become available and have formed the primary basis of health risk evaluations regarding the epidemiologic evidence on mobile telephones and brain tumor risk. Arguably the most comprehensive research effort to date in this area comes from the multi-national INTERPHONE Study Group, a consortium of 16 research groups in 13 countries in Europe, Asia, North America, and Australia/New Zealand (Cardis et al., 2011;

Cardis et al., 2007; Interphone Study Group, 2010, 2011). The majority of results from the INTERPHONE Study Group, including analyses from individual countries and those pooled over several countries, have shown no significant positive association between self-reported mobile telephone use and risk of three main types of brain tumors—glioma, meningioma, and acoustic neuroma. In fact, having ever been a regular mobile telephone user was associated with a significantly *lower* risk of glioma and meningioma in the pooled data (Cardis et al., 2011; Interphone Study Group, 2010), possibly due to selection bias (i.e., greater participation among controls who had ever used mobile telephones than those who had not). When all data were combined in one analysis, a significant risk increase was observed in the highest of 10 categories of cumulative call time; however, the authors noted that there were implausible values of reported use in that highest category, and that they could not rule out chance or reporting bias as an explanation for these findings (Interphone Study Group, 2010, 2011).

Another series of case-control studies of malignant and benign brain tumors was conducted by a research group in Sweden (e.g., Hardell et al., 2006a; Hardell et al., 2006b, 2011; Hardell et al., 2013; Hardell et al., 2002a; Hardell et al., 2002b; Hardell et al., 1999). These studies have repeatedly reported a significant positive association, with evidence of a positive exposure-response trend, between use of mobile telephones and risk of brain tumors, especially with a longer latency. Concerns about selection bias, recall bias, interviewer bias, and multiple hypothesis testing, along with unclear exposure definitions and study inclusion criteria, however, limit the strength of conclusions based on the results of these studies. The higher relative risks reported in these studies are not consistent with results from other epidemiologic studies, including those from the Swedish INTERPHONE group (Lonn et al., 2005).

Recently, a multi-center European case-control study of brain tumors in children and adolescents (aged 7–19 years) found no exposure-response relationship between the amount of mobile telephone use and risk of brain tumors, nor did it detect an increased risk of brain tumors in brain areas calculated as having received the highest amount of exposure (Aydin et al., 2011). In general, however, little epidemiologic evidence is available regarding any association between mobile telephone use and risk of brain tumors in children. Likewise, few case-control studies have been conducted of mobile telephone use in relation to risk of cancers other than brain tumors, including parotid and salivary gland tumors, leukemia, non-Hodgkin lymphoma, uveal melanoma, testicular cancer, and intratemporal facial nerve tumors. The available studies have not revealed any consistent or convincing positive associations, but have the same general limitations as other case-control studies.

To date, two cohort studies have reported on the risk of cancers associated with mobile telephone use. In Denmark, based on the records of 358,403 mobile telephone subscription holders followed from 1990 through 2007, no association was found between increasing duration of mobile telephone use or time since first use and risk of glioma, meningioma, or other brain tumors (Frei et al., 2011). In an earlier analysis of the same cohort with follow-up from 1982–1995 through 2002, no significant positive association was detected with any other type of cancer (i.e., leukemia) or cancer site, including salivary glands, eye, breast, prostate, testis, and others (Schüz et al., 2006).

In a prospective cohort study of 791,710 women in the United Kingdom followed from 1999–2005 through 2009 or 2011, no association was detected between ever use of mobile telephones and risk of all brain tumors, glioma, meningioma, pituitary tumors, acoustic neuroma, or any other cancer, including cancers of the eye, thyroid, other head and neck sites, skin (melanoma), breast, leukemia, lymphoma, and others (Benson et al., 2013a; Benson et al., 2013b).

Since exposure assessment in these cohort studies was based on mobile telephone subscription records (Frei et al., 2011; Schüz et al., 2006) or self-reported mobile telephone use ascertained prior to disease diagnosis (Benson et al., 2013a; Benson et al., 2013b), the results were not susceptible to recall bias, which threatens the validity of case-control studies. Mobile telephone subscription records, however, may not be a good proxy for actual use if the subscriber is not the primary user of the mobile telephone or if cumulative use varies substantially among subscribers; moreover, the exclusion of corporate subscriptions probably led to further exposure misclassification. The cohort study in the United Kingdom that used self-reported information of mobile telephone use was not affected by these limitations. Exposure assessment in the study was limited, however, by the lack of information to quantify the amount of mobile telephone use and to assess potential changes in mobile telephone use over time; moreover, the study had a relatively short follow-up time. Nevertheless, with minimal loss to follow-up from both cohorts, these studies are substantially strengthened by their avoidance of recall and selection biases.

Cancer Incidence Trends

If prolonged use of mobile telephones increased the risk of brain cancer, then we might expect to see an increase in annual rates of brain cancer incidence, especially more than 10 years after mobile telephone use became widespread. On the contrary, however, no observable increase in the occurrence of brain cancer over time has been observed in the United States (Inskip et al., 2010; McKean-Cowdin et al., 2013), Scandinavia (Aydin et al., 2012; Deltour et al., 2009), Japan (Shibui, 2012), England (de Vocht et al., 2011), Switzerland (Röösli et al., 2007), or New Zealand (Cook et al., 2003) during a period of substantially increased mobile telephone use. Although effects of small magnitude, effects restricted to the small proportion of heaviest users, and effects with a long latency period of decades cannot be ruled out with certainty, these trend analyses provided reassurance and evidence against a potentially major adverse public health impact of mobile telephone use. Trends in the incidence of brain tumors will continue to be monitored as the time since widespread public adoption of mobile telephones increases, thereby allowing for a longer potential latency period before brain cancer onset, but thus far they do not support a causal effect of mobile telephone use on brain cancer.

In Vivo Animal Studies

Typically, experimental studies of laboratory animals involve higher RF exposures than human studies, although some laboratory studies have tested lower RF exposure levels. *In vivo* studies evaluating the carcinogenicity of RF have employed several different animal models including classical bioassays, in which laboratory animals are exposed to controlled doses of RF and examined at fixed time intervals for pathological changes; studies using animal models bred to be genetically predisposed to develop cancer; initiation-promotion studies, which test the effect of RF exposure on tumors induced by a DNA-damaging carcinogen; and co-carcinogenicity studies, which involve combined exposure to RF and known carcinogens. Many experimental animal studies of RF are of relatively high quality, with well-controlled, well-recorded continuous exposures to RF, and include tests of *in utero* and neonatal exposures, tests of whole-body and localized exposures, examination of tissues in all organs for evidence of an effect, and replication in different rodent species and strains.

Of seven chronic bioassay studies of RF, two in mice and five in rats, none showed a significant increase in the incidence of any tumor type in animals with lifetime (2-year) exposure to RF (reviewed in IARC, 2013a). Of 12 studies using 4 different tumor-prone animal models, only 2 demonstrated an increased incidence of tumors after RF exposure, but later studies using the same models did not confirm the positive results. Of 16 initiation-promotion studies, 15 showed no association with RF, including 5 studies in animal models of skin cancer, 6 studies of brain cancer models, 1 study using lymphoma model, and 3 studies of mammary gland tumors. Only one study of mammary-gland tumor models showed an increase, but this was not replicated in the other three studies, which used the same experimental model and exposure conditions. Of six co-carcinogenesis studies in five animal models, four positive results were reported, but their relevance to cancer in humans is unknown. Overall, these results in laboratory animals provide little evidence to support a carcinogenic effect of RF exposure.

In Vitro Studies

In vitro studies of carcinogenicity generally aim to test whether an agent has genotoxic effects (i.e., whether it is capable of damaging DNA) potentially resulting in mutations that may lead to cancer; or whether an agent has promoting or co-carcinogenic effects (i.e., whether it is capable of inducing proliferation of mutated cells or enhancing the effects of other established carcinogens, respectively). Although high-intensity RF exposure far above allowable human exposure limits can cause DNA damage, this effect is attributed to tissue heating (as in a microwave oven). At RF levels below those that cause tissue heating, studies of genotoxicity have yielded inconsistent results, with positive results often not replicated, and no evidence of mutagenicity (i.e., retained DNA damage that is not repaired, thereby leading to mutations) (reviewed in EFHRAN, 2010b; IARC, 2013a). Results of *in vitro* studies of non-genotoxic carcinogenic effects have also been inconsistent and of unclear relevance to carcinogenesis in humans.

Given the lack of consistent and convincing evidence from epidemiologic and *in vivo* studies to demonstrate an increase in cancer risk among humans or animals exposed to relatively high non-thermal RF levels, the available science does not support a carcinogenic effect of RF on cancer.

Epidemiologic and Human Experimental Studies of Symptoms

Whether RF affects symptoms related to well-being has been investigated in a large number of epidemiologic and human experimental studies. Many of these studies have been limited by small study sizes, which produce statistically unstable results. Many of the epidemiologic studies have used self-reported rather than objectively measured or controlled exposures, and some have used exposure surrogates such as residential proximity to a single source. Electromagnetic hypersensitivity, also called idiopathic environmental intolerance attributable to exposure to electromagnetic fields (extremely low frequency or RF), has been the subject of over 40 experimental studies. Electromagnetic hypersensitivity is characterized by nonspecific symptoms (such as dizziness, palpitations, skin itching, dry mouth, sleep disorders, and digestive problems) that are attributed by the individual to exposure to electromagnetic fields. Some experimental studies have been undermined by the absence of double-blinding, that is, awareness of exposure status by study participants or investigators, or both, thereby allowing for human error or bias in data reporting or collection due to conscious or subconscious preconceived ideas. Higher-quality human experimental trials and epidemiologic and field intervention studies of a range of symptoms (e.g., headache, dizziness, concentration problems, sleep disturbances, and fatigue) have not provided consistent evidence of an increase in any symptom or symptom pattern in relation to RF exposure (e.g., Danker-Hopfe et al., 2010; Frei et al., 2012; Heinrich et al., 2010, 2011; Mohler et al., 2010; Mohler et al., 2012; Röösli et al., 2010). While symptoms may be real, and in some cases could be severe, well-conducted provocation studies have consistently demonstrated that individuals who reported a sensitivity to RF are unable to differentiate between exposure and no exposure, and that the reported symptoms are not causally related to exposure (Röösli et al., 2010; Rubin et al., 2011).

Recent Reviews of Radio Frequency and Health

Given the existence of several recent and ongoing systematic reviews of the epidemiologic literature on RF and human health outcomes, the assessment expressed in this report relies on such recent reviews rather than a *de novo* review of the literature. The evaluation of reviews rather than single studies provides perspective on the overall weight of the relevant scientific evidence, including consideration of whether individual findings have been consistently replicated across multiple studies. Publicly available English-language reviews published in the last five years were identified from online searches for keywords such as "electromagnetic," "non-ionizing," "radio frequency," "health," "cancer," "review," "agency," "committee," and "national," as well as from checking reference lists of identified publications.

In this report we primarily aimed to include reviews that documented their methods for systematically assembling and evaluating the weight of evidence in accordance with established methods, as described in the earlier section of this report on hazard identification. For completeness and for comparative purposes, we also included some reviews that did not document objective methods for systematically identifying, reviewing, and evaluating the scientific literature (e.g., AAEM, 2012; BWG, 2012). Summaries of each review are included in Appendix A.

Table 2. Scientific Panels Convened by Scientific and Regulatory Agencies to Review RF Health Research

Sponsoring Organization (Date)	Report Title
Canadian National Collaborating Centre for Environmental Health (2013)	Radiofrequency Toolkit for Environmental Health Practitioners
EMF-NET: European Commission 6th Framework Programme Coordination Action (2009)	EMF-NET: Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace. Deliverable D17: Report on Health Effects of RF with Recommendations for Non-Ionising Radiation Protection and Research Needs Deliverable D15_c: Report on New Epidemiological Studies on Static Fields, ELF, Intermediate Frequencies, and RF

Sponsoring Organization (Date)	Report Title
European Health Risk Assessment Network on Electromagnetic Fields Exposure (2010)	Risk Analysis of Human Exposure to Electromagnetic Fields – Deliverable Report D2 of EFHRAN Project EFHRAN Work package 5 D-3 - Report on the Analysis of Risks Associated to Exposure to EMF: *In Vitro* and *In Vivo* (Animals) Studies
French Agency for Food, Environmental and Occupational Health & Safety (2013)	OPINION of the French Agency for Food, Environmental and Occupational Health & Safety Concerning the Update of the "Radiofrequency Electromagnetic Fields and Health" Expert Appraisal
Health Council of the Netherlands (2013)	Mobile Phones and Cancer. Part 1: Epidemiology of Tumours in the Head
International Agency for Research on Cancer (2013)	IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 102. Non-Ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields
International Commission on Non-Ionizing Radiation Protection (2009)	Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 kHz-300 GHz)
Latin American Experts Committee on High Frequency Electromagnetic Fields and Human Health (2010)	Non-Ionizing Electromagnetic Radiation in the Radiofrequency Spectrum and its Effects on Human Health, with a Review on the Standards and Policies of Radiofrequency Radiation Protection in Latin America
Norwegian Institute of Public Health (2012)	Low-Level Radiofrequency Electromagnetic Fields - An Assessment of Health Risks and Evaluation of Regulatory Practice
Scientific Committee on Emerging and Newly Identified Health Risks (2014)	Preliminary Opinion on Potential Health Effects of Exposure to Electromagnetic Fields (EMF)
Swedish Radiation Safety Authority (2013)	Research 2013:19. Eighth Report from SSM:s Scientific Council on Electromagnetic Fields
Swiss Federal Office for the Environment (2013)	Radiation from Transmission Installations and Effects on Health
U.K. Advisory Group on Non-Ionising Radiation (2012)	Health Effects from Radiofrequency Electromagnetic Fields. Report of the Independent Advisory Group on Non-ionising Radiation (AGNIR)
Alternative Views	
American Academy of Environmental Medicine (2012)	Community Resource: AAEM Position Papers
BioInitiative Working Group (2012)	BioInitiative 2012. A Rationale for Biologically-based Exposure Standards for Low-Intensity Electromagnetic Radiation

In the past five years more than a dozen prominent regulatory, scientific, and health organizations have systematically reviewed the available research on RF and health, and all have independently reached the same conclusion. While the organizations differed somewhat in their overall characterizations of the available scientific evidence for any potential effect—"limited evidence," "insufficient," "inadequate," "inconsistent," "inconclusive," or "unlikely"—they all concluded that RF exposure below the current scientifically-based exposure limits has not consistently or convincingly been established as causing any type of cancer, other chronic diseases, or symptoms that adversely affect well-being in humans. Among the 13 weight-of-evidence reviews listed in Table 2, the most informative are those that provided detailed descriptions and critiques of the methods, results, and interpretations of *in vitro*, *in vivo* animal, and human studies, and offered scientific justifications for their conclusions (AGNIR, 2012; IARC, 2013a; ICNIRP, 2009a; LAEC, 2010; NCCEH, 2013; SCENIHR, 2013; SSM, 2013). Alternative opinions were expressed only by groups who did not follow the established methods for a systematic weight of evidence evaluation of the entire scientific literature (AAEM, 2012; BWG, 2012).

Ultimately, based on systematic, weight-of-evidence reviews of epidemiologic, *in vivo*, and *in vitro* studies of health and biological endpoints in association with RF exposures below the level that raises body temperature, all of the organizations described above uniformly concluded that the results do not provide sufficient evidence to demonstrate a causal effect on any adverse health outcome. In the absence of sufficient evidence of a causal effect of RF exposure below levels that may result in tissue heating resulting in adverse health outcomes, the additional steps of a health risk assessment—i.e., dose-response assessment, exposure assessment, and health risk characterization—are not necessary.

What Other States Have Concluded about Smart Meters and Health

To date, no scientific research studies have directly evaluated the human health effects of smart meters. A search of PubMed (http://www.ncbi.nlm.nih.gov/pubmed), the U.S. National Library of Medicine database that contains more than 23 million citations for biomedical literature from the Medical Literature Analysis and Retrieval System Online (MEDLINE), life science journals, and online books from before 1946 to the present, yielded no health studies of RF from smart meters as of January 2014.

In the peer-reviewed scientific literature, a few exposure assessment studies (Foster and Tell, 2013; Tell et al., 2013; Tell et al., 2012) and one study examining potential interference with implanted medical devices (Ostiguy et al., 2013) were identified in relation to smart meters. The exposure assessment studies reported RF values well below current exposure limits. The study by Ostiguy et al. (2013) reported no interference between smart meters and implanted medical devices, such as pacemakers and cardiac defibrillators even when the device was as close as 2.25 inches from the front of the meter.

In response to public concern about potential health effects related to RF from smart meters, state agencies in Maine, Colorado, Michigan, Oregon, and Texas, in addition to the Vermont Department of Health and the California State Assembly have sought to assess the current scientific evidence on the potential human health effects of smart meters. In the absence of research directly evaluating smart meters, such agencies have typically based their conclusions on health studies of RF from other sources and health risk evaluations conducted by national and international regulatory, scientific, and health agencies on the potential health effects of RF.

The state agencies that evaluated the potential health effects of RF from smart meters have published documents with varying forms and levels of detail. These documents range from a simple summary letter to fact sheets to more in-depth reports. All of the published documents by these agencies agree that smart meters emit low-level RF, typically intermittently, in a small fraction of time (i.e., with a low duty cycle), well below current exposure limits, and that these exposure characteristics are sufficient to protect against potential health effects of RF.

A summary statement issued by the Maine Center for Disease Control in November 2010 declared that "our review of these agency assessments and studies do not indicate any consistent or convincing evidence to support a concern for health effects related to the use of radio frequency in the range of frequencies and power used by smart meters. They also do not indicate an association of EMF exposure and symptoms that have been described as electromagnetic sensitivity" (MCDC, 2010).

The California Council on Science and Technology was commissioned by the California State Assembly to perform an "independent, science-based study . . . [that] would help policy makers and the general public resolve the debate over whether smart meters present a significant risk of adverse health effects." The April 2011 report entitled "Health Impacts of Radiofrequency Exposure from Smart Meters" concluded that "[t]he current FCC standard provides an adequate factor of safety against *known thermally* induced health impacts of existing common household electronic devices and smart meters. To date, scientific studies have not identified or confirmed negative health effects from *potential non-thermal* impact of RF emissions such as those produced by existing common household electronic devices and smart meters" [emphasis in the original] (CCST, 2011).

A fact sheet issued by the Colorado Department of Public Health and Environment in February 2012 concluded that "Smart Meters are unlikely to cause health effects because … [t]o date, research does not suggest any consistent evidence of adverse health effects of RF emissions produced by Smart Meters or other common household electronic devices" (CDPHE, 2012).

A report issued by the Michigan Public Service Commission in June 2012 stated that "[a]fter careful review of the available literature and studies, the Staff has determined that the health risk from the installation and operation of metering systems using radio transmitters is insignificant" (MPSC, 2012).

In a transmittal issued July 2012, the Oregon Health Authority concluded that "[b]ased on our review of these reports, evidence from the scientific literature and consultations with radiation experts, we conclude at this time that the implementation of smart meters will not adversely impact public health" (Oregon Health Authority, 2012).

The Public Utility Commission of Texas, in its December 2012 report, concluded that "the large body of scientific research reveals no definite or proven biological effects from exposure to low-level RF signals. Further, Staff found no credible evidence to suggest that advanced meters emit harmful amounts of EMF" (Public Utility Commission of Texas, 2012).

Like the Vermont Department of Health, these other state agencies have consistently concluded, on the basis of scientific studies and reviews of the potential health effects of RF exposure, that the current scientific evidence does not consistently or convincingly demonstrate that RF in the range of frequencies and power used by smart meters can cause adverse human health effects.

Regulatory Standards

Development of Regulatory Standards

If, based on a properly conducted health risk assessment, exposure to a substance or physical agent is adjudged to pose potential health risks to the general public or occupationally exposed workers, then specific safety standards may be promulgated to protect against those risks. As described earlier in this report, a health standard is developed based on findings from scientific research, including epidemiologic studies of humans, *in vivo* laboratory studies of animals, and *in vitro* laboratory studies of cells and tissues. These three approaches provide different but complementary information for the general risk assessment process. Typically, expert panels, assembled by health agencies or scientific organizations to include scientists with expertise in the relevant scientific disciplines, systematically identify all relevant studies representing all three main scientific approaches. Then they evaluate the individual studies and weigh the evidence, giving more weight to studies of better design.

The objective of any standard, whether it is designed to regulate drinking water, air quality, or food safety, is to keep exposure below the level at which any established potentially adverse effect is known to occur. A health standard is developed from the hazard identification and dose-response assessment steps of the health risk assessment process. The approach that scientists use to develop health based standards is to set the exposure many times below the level at which research suggests that an effect could occur, that is, below the "lowest observable adverse effect level" (LOAEL). This conservative approach helps to compensate for unrecognized limitations in the research and exposure assessment, and to afford additional protection to all members of the population. The number used to lower the exposure limit below the lowest known effect level is referred to as a "safety factor." To arrive at an exposure limit for all members of the general public, for example, the FCC RF standard uses a 50-fold safety factor below the LOAEL reported in research studies.

Figure 8 below illustrates the relationship between RF power densities identified by the FCC as an adverse effect level, i.e., the LOAEL, the lower exposure limits for occupational and general public environments, and the far lower average power densities measured in the Tell Report from a mobile phone or inside the home when a smart meter is signaling. It also calls to attention the much greater RF power densities of mobile phones compared to smart meters partially because the distances of common use are so much greater for smart meters than for mobile phones.

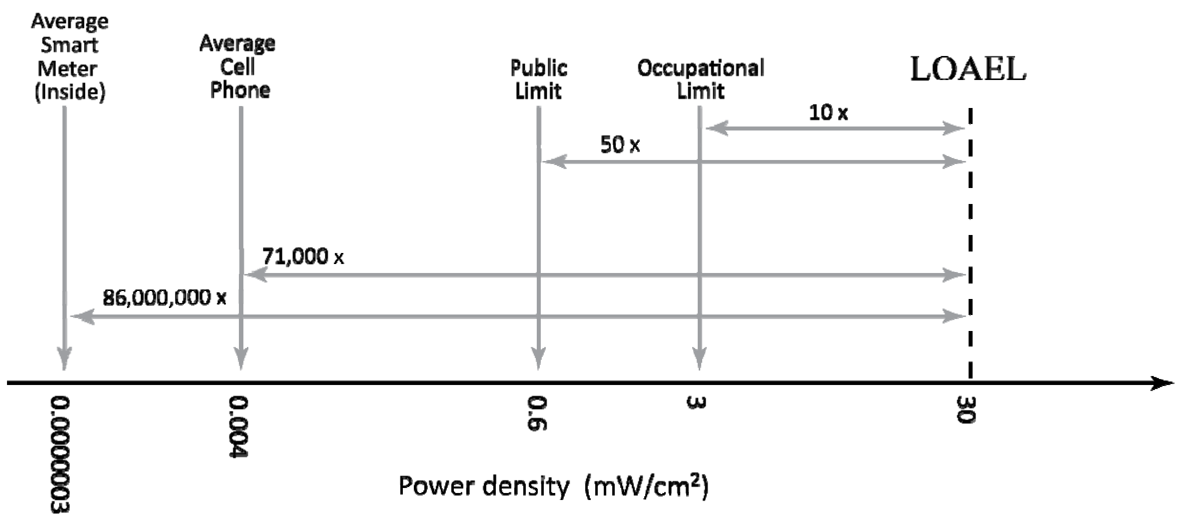

Figure 8. Relationship of RF power density from Vermont smart meters and mobile phones to FCC exposure limits and LOAEL (graph not to scale).

Federal Communications Commission Limits

History of Radio Frequency Exposure Standards

Research results related to RF have been reviewed by scientists since the 1950s for the purposes of setting exposure standards. The formulation of the American National Standard Institute's Standard C95.1 in 1982 represented a major step in this process (ANSI, 1982). The NCRP, a non-governmental, not-for-profit, public service organization with a "mission to formulate and widely disseminate information, guidance and recommendations on radiation protection and measurements," also initiated a standard-setting process that began with reviewing RF exposure parameters and mechanisms of interaction. This review was summarized in 1981 in NCRP Report No. 67, "Radiofrequency Electromagnetic Fields – Properties, Quantities and Units, Biophysical Interaction, and Measurements." In 1986, NCRP published a comprehensive review of RF research literature on biological effects and human studies and a proposed standard for RF exposure—NCRP Report No. 86, "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields" (NCRP, 1986). In 1993, the World Health Organization (WHO) also reviewed research results on the effects of electromagnetic fields in the frequency range of 300 Hertz (Hz) to 300 GHz in its evaluation of human health risks (WHO, 1993).

In the United States, exposure from RF-emitting devices is regulated by the FCC. In 1985, the FCC, based on advice from the IEEE, adopted the ANSI C95.1–1982 standard (FCC, 1985). The FCC modified and updated the standard in 1996, based on the ANSI and NCRP standards, with input and advice from other agencies including ANSI, NCRP, the Environmental Protection Agency, the Food and Drug Administration, and IEEE (FCC,1996b). The current FCC limits for exposure to RF are published in FCC Office of Engineering and Technology Bulletin (FCC, 1997) and in the Code of Federal Regulations (FCC, 1996a).

Current Federal Communications Commission Limits

The FCC standard is designed to protect all members of the population, including children and the elderly, from all adverse effects known to occur with sufficiently high exposure to RF. The only consistently confirmed adverse effects are related to an increase in the temperature of exposed body tissues. No consistently demonstrated adverse effects are known in the absence of heating due to low-level RF exposure. The goal of the standard, therefore, is to limit warming of tissues, since even modest warming of the body can be distracting. More serious adverse effects could occur at higher levels of exposure; therefore, the FCC exposure limits are set below the level at which even minor effects from heating might occur.

The basis for the scientifically-derived FCC exposure limits on RF exposure is the SAR averaged over the whole body. As described earlier in this report, extensive systematic reviews of the relevant scientific literature on the potential biological and health effects of RF have concluded that the only established effects are related to heating of the tissue; no other effects below this level are confirmed. Laboratory animal experiments in several species have indicated that potentially adverse behavioral changes may be observed with a core body temperature increase of 1 degree Celsius. This core body temperature change may be achieved by a SAR of 4 watts per kilogram (W/kg) of body mass. To this level a safety factor of 10 is applied to arrive at the occupational exposure limit of 0.4 W/kg, and a safety factor of 50 is applied to obtain the general public exposure limit of 0.08 W/kg. While the actual limits are based on thermal effects, the limit-setting process considers all available evidence at both thermal and non-thermal levels; however, the only established adverse effects of RF are related to tissue heating.

The FCC's RF standard provides exposure limits on the amount of RF energy measured in watts on the surface of the body (i.e., the MPE). This exposure is expressed as RF strength (i.e., power density) and the MPE is designed to prevent energy absorption by tissues at potentially harmful levels. As noted above, power density is measured in units of mW/cm^2, W/m^2 or $\mu W/cm^2$. The MPE varies over the range of radio frequencies because the human body absorbs some radio frequencies more than others. Whatever the frequency, exposures below the MPE will maintain thermal energy absorption in the human body well below any hazardous level. The FCC standard includes different MPEs for the general public and for those occupations in which workers are trained to work in an RF-exposed environment. The MPEs for the general public are five-fold lower than those for occupational environments.

Power density is analogous to the concentration of a chemical dissolved in water or to the brightness of a light focused on an area. Imagine a flashlight shining on a piece of paper held 1 foot away, compared with the dimmer light on a paper from a flashlight held 10 feet away. For practical purposes, the MPE is estimated at the closest point where a person could be exposed to RF fields, because this would be the location of the highest exposure given that the strength (power density) decreases rapidly with distance from the source. The MPE levels for the approximately 900 MHz and the 2.4 GHz RF frequency ranges emitted by smart meters are 0.6 and 1 mW/cm^2, respectively, for members of the general public.

To assess compliance with the MPE, the power density is measured or predicted based on engineering calculations for areas where people may come in contact with RF. For the process of obtaining equipment authorization from the FCC, exposure levels are evaluated 20 centimeters (7.9 inches) from the antenna. For compliance purposes, the exposure may be time-averaged over 30 minutes and spatially averaged over the dimensions of the human body.

Recent Activities of the Federal Communications Commission

On March 29, 2013, the FCC released a First Report and Order and a Further Notice of Proposed Rule Making in Engineering and Technology (ET) Docket No. 03-137, and a Notice of Inquiry in a new docket, ET Docket No. 13-84 (FCC, 2013). The purpose of the Order and Further Notice in ET Docket 03-137 is to ensure compliance of the FCC's rules with the National Environmental Policy Act as the rules relate to guidelines for human exposure to RF fields. The Notice of Proposed Rule Making proposes an evaluation that would exclude a low-power device from a routine evaluation of exposure; however, this is an exemption from evaluation, but not from compliance. The rationale for this exemption is that if the exemption criteria are met, then there is minimal likelihood for the exposure limits for the general public to be exceeded. Exemptions are proposed to be based on meeting conditions for SAR and MPE values. The proposed exemption from SAR evaluation is based on the maximum time-averaged power delivered to the antenna, as averaged over any 30-minute period for fixed sources and averaged over a period inherent to the device transmission characteristics for mobile and portable sources. The evaluation criterion is based on the effective radiated power. If the maximum time-averaged effective radiated power value (in units of milliwatts) from a transmitter is less than the values listed in the Notice, then the device would be exempt from a Routine Environmental Evaluation.

In ET Docket No. 13-84, the FCC opened an Inquiry that seeks to determine whether there is a need for reassessment of the FCC RF exposure limits and policies. The Inquiry focuses on three elements: (i) the propriety of the existing standards and policies, (ii) possible options for precautionary exposure reduction, and (iii) possible improvements to the equipment authorization process and policies as they relate to RF exposure.

In launching this Inquiry, the FCC states that it still has confidence in the current exposure limits, given that more recent international standards have a similar basis. As part of the reason for the Inquiry, the FCC references the recent recommendation by the U.S. Government Accounting Office calling for the FCC to reassess its current RF limits to determine whether they need to be more restrictive, less restrictive, or remain the same to ensure consistency with international standards and current scientific knowledge since the current standards were adopted in 1996 (U.S. GAO, 2012). In the Inquiry, the FCC also notes that the current limit is readily justified when taking into account known health effects and added safety factors. Although the Inquiry states that there have been discussions as to the need for more stringent limits to guard against the possibility of risks from non-thermal biological effects of RF, the FCC specifically notes that "such risks have not been established by scientific research" (FCC, 2013).

International Exposure Limits

Since the FCC limits were established, a number of other organizations have reviewed the literature and set RF exposure guidelines similar to the FCC limits (ARPANSA, 2002; IEEE, 2006; ICNIRP, 1998; ICNIRP, 2009b). These all concluded that at "non-thermal" exposure levels, that is, below exposure levels that may result in tissue heating, no adverse effects or biological mechanisms could be consistently demonstrated.

The most recognized international scientific organizations that have recommended RF exposure limits following the review of scientific literature include the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2009 (ICNIRP, 2009b) and the International Committee on Electromagnetic Safety (ICES) (IEEE, 2006). ICNIRP is a committee of independent scientific experts that disseminates information and advice on the potential health hazards of exposure to non-ionizing radiation. ICES is a committee within the IEEE that is responsible for the development of standards for the safe use of electromagnetic energy, including RF. While IEEE refers to its recommended exposure limits as standards, these and ICNIRP's exposure limit guidelines are recommendations that do not have the force of law unless adopted by a country, state, or other political entity. The WHO recommends that countries adopt the ICNIRP guidelines (WHO, 2014). Both of these organizations have reviewed research published after the 1996 FCC regulation was enacted.

The basis for the exposure limits set by these organizations, like that of the FCC, is the tissue-heating property of RF observable at sufficiently high exposure levels. Similar to the FCC exposure limits, both the ICNIRP and the IEEE limits are frequency-dependent in the RF range, thereby reflecting the varying energy absorption rate of the human body due to the varying relative ratio of a human body's dimensions to the wavelength.

For the frequencies applicable to Vermont's smart meters (900 MHz and 2.4 GHz), the exposure limits set by the FCC, ICNIRP, and ICES are similar. At 900 MHz, the ICNIRP and IEEE exposure limits for the general public are 0.45 mW/cm^2, whereas the corresponding FCC limit is 0.6 mW/cm^2. At 2.4 GHz, all three organizations recommend an exposure limit of 1 mW/cm^2 for the general public. The FCC, IEEE, and ICNIRP limits are applicable to spatially averaged values, averaged over the dimension of the human body. Compliance with the above exposure limits is also assessed via time-averaged values; the averaging time for the FCC and the IEEE exposure limits is 30 minutes, whereas for the ICNIRP limit it is averaged at 6 minutes.

In Canada, Industry Canada, which is responsible for regulatory standards of RF exposure limits to ensure public safety, has adopted the human exposure limits developed by Health Canada's Safety Code 6 (Health Canada, 2009). These guidelines, first developed in 1979, are the product of an ongoing review conducted by Health Canada of published scientific studies, reviews, and research. In addition, Health Canada requested a panel of scientists of the Royal Society of Canada to review the potential health risks of RF beginning in 1999. The scientific panel updated its review of the safety code in 2001, 2003, 2007, and 2009. The website of Health Canada notes: "This code is periodically revised to reflect new knowledge in the scientific literature. The current version of this code reflects the scientific literature published up to August 2009 and replaces the previous version published in 1999" (Health Canada, 2010). These Safety Code 6 standards are similar to the FCC limits, with the exception of the averaging time, which is 6 minutes according to the Canadian standards.

Conclusions

In conclusion, the exposures of Vermont residents to RF from smart meters are far below the limits posted by the FCC for exposure to RF to protect public health in the United States. This conclusion is based on measurements of the peak exposure allowed for these devices determined by the FCC and the extensive measurements of smart meters in Vermont summarized in the Tell report. In operation at residences, the measured RF exposure from these smart meters inside residences is tens of thousands of times below the FCC-designated threshold of thermal hazard from prolonged exposure to RF. In addition, no non-thermal adverse human health effects have consistently or convincingly been shown to be caused by RF below current regulatory limits emitted from any source.

A comprehensive series of measurements performed on smart meters deployed in Vermont showed that the average interior residential RF field was equivalent to 0.000058 percent of the MPE (more than 1.7 million times lower than the MPE limit) for the general public designated by the FCC. The MPE limit set by the FCC is designed to protect all members of the general public against all known health effects. The only consistently confirmed effects of RF are those due to tissue heating. The FCC limits for the public are set at 50 times below the exposure levels that could result in tissue heating. In recent years, numerous leading national and international regulatory, scientific, and health agencies have conducted systematic reviews of hundreds of relevant scientific studies, including epidemiologic, *in vivo* animal, and *in vitro* cell and tissue studies. These agencies have reached the conclusion that no adverse human health outcomes, including cancer, reproductive outcomes, cardiovascular outcomes, neurological and behavioral outcomes, and electromagnetic hypersensitivity, are known to result from RF exposure at "non-thermal" levels, that is, at exposure levels below which tissue heating may occur. Therefore, more complete measurements of RF emissions from smart meters deployed in Vermont and a more recent and expanded evaluation of agency reviews of the scientific literature, including two additional years of scientific evidence, reinforce the original conclusion of the Vermont Department of Health that the current regulatory standards for RF from smart meters are sufficient to protect public health.

Limitations

The findings presented herein are made to a reasonable degree of engineering and 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.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

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Appendix A

Conclusions of National and International Health and Scientific Agencies

Canadian National Collaborating Centre for Environmental Health, 2013

As part of a toolkit written by public health scientists to assist medical health officers and environmental health officers with public communication regarding evidence on potential hazards of RF, the National Collaborating Centre for Environmental Health (NCCEH) systematically reviewed the current scientific literature on potential biological and health effects associated with exposure to RF (NCCEH, 2013).

NCCEH summarized *in vitro* studies as demonstrating no consistent or convincing evidence that RF damages DNA, induces cell transformation, or affects calcium channeling, cell proliferation, formation of reactive oxygen species, apoptosis, or expression of genes or proteins indicative of cell death. On the basis of these studies, NCCEH concluded: "Overall, in spite of the many well-conducted cell culture experiments examining a number of putative effects, there is no convincing evidence that sub-thermal exposure to RF has adverse biological effects at the cellular level. On this basis, no biological mechanism proposed for such effects can be evaluated."

NCCEH summarized *in vivo* animal studies as demonstrating no consistent or convincing evidence that RF initiates or promotes cancer development, affects the central nervous system, alters blood-brain barrier permeability, causes DNA damage, micronucleus formation, apoptosis, formation of reaction oxygen species, or gene expression change, or affects learning or cognitive function, immune function, endocrine function, or reproductive function. On the basis of these studies, NCCEH concluded: "Overall, the research studies to date have not provided convincing evidence that RF-field exposure produces adverse biologic effects in animals."

On the basis of epidemiologic studies of patients and health care workers exposed to RF from medical devices, NCCEH concluded: "No long-term effect of EMF [electromagnetic field] exposures to MRI [magnetic resonance imaging] patients on reproductive, cardiovascular, and cognitive function outcomes have been reported, and there is no indication of chronic effects attributed to occupational exposure to the EMF fields."

On the basis of epidemiologic studies of industrial workers occupationally exposed to RF, such as from industrial microwave ovens, induction and dielectric heating, radio and television broadcasting applications, and radar, NCCEH concluded that "no increased risk for any cancer site has been observed. The cardiovascular mortality studies of industrial workers also have been consistently negative … Although there was some indication of adverse sperm effects, the studies were generally poorly done. The quality of exposure assessment and low statistical power are major limitations of observational studies."

NCCEH summarized epidemiologic studies on mobile telephones in association with head and neck tumors and cancers as demonstrating some positive associations with risk of gliomas and benign acoustic neuromas, but not meningiomas or parotid tumors, especially with longer-term use of mobile telephones or use of mobile telephones preferentially at the same side of the head as the tumor. On the basis of these studies, NCCEH concluded: "Because of study design issues and positive findings that have not been replicated by other researchers, doubts remain about whether exposure to RF increases the risk of brain and other cancers of the head and neck."

NCCEH summarized epidemiologic, *in vitro*, and *in vivo* studies as suggesting decreased sperm motility associated with exposure to RF from mobile telephones, but cautioned that "[b]etter exposure assessment is needed in future studies." The relevance of these findings to clinical reproductive outcomes is unclear.

Primarily on the basis of experimental human studies of neurophysiologic and cognitive performance after exposure to RF from mobile telephones, as well as recent reviews of this literature, NCCEH concluded that "cumulative evidence to date does not support exposure to RF as having adverse effects on cognitive performance, as demonstrated by current neurobehavioral tests of memory and inattention … Whether effects on brain activity or physiology translate to adverse behavioural or health effects remains unclear."

On the basis of epidemiologic and experimental (provocation) human studies of RF exposure and non-specific symptoms that some individuals attribute to exposure to RF (i.e., electromagnetic hypersensitivity), NCCEH concluded: “Findings from population health studies of exposures from mobile telephones and mobile telephone base stations are mixed and inconsistent and are prone to study design issues including poor exposure assessment … In general, subjects who are self-declared with ‘EHS’ [electromagnetic hypersensitivity] do not reliably detect RF when blinded to the source, and RF fails to trigger symptoms in self-declared EHS individuals in a reliable, reproducible, and consistent way.”

EMF-NET: European Commission 6th Framework Programme Coordination Action, 2009

EMF-NET was a coordination action financed by the European Commission to assemble the results of ongoing research on the effects of EMF that was funded by the European Commission or under other national or international actions, and to use these results to provide advice and information relevant to the development of policy options by the European Union and other stakeholders concerning public health, consumer protection, and occupational health and safety (EMF-NET, 2009a, 2009b).

Based on its systematic review of published epidemiologic studies on RF and health, EMF-NET (2009a) concluded that “because of the inconsistencies of results and the limitations of these studies, it is not possible to evaluate at this time whether there exists a health risk from exposure to RF radiation, particularly at the levels of concern for mobile communication.” Although some recent studies suggested a positive statistical association with brain tumors, EMF-NET stated, “It is unclear, however, whether the observed associations are real, reflecting a causal association, or artefactual, reflecting differential reporting between cases and controls.”

European Health Risk Assessment Network on Electromagnetic Fields Exposure, 2010

The European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN) built on the expertise and experience of EMF-NET by conducting a health risk assessment of EMF with four objectives: 1) to monitor and search for evidence of health risks related to EMF exposure, 2) to characterize and, where appropriate, quantify potential health risks posed by EMF exposure, 3) to provide the European Commission with a scientifically sound basis to respond rapidly to health issues and concerns related to EMF, and 4) to improve the compilation of knowledge and its dissemination on issues related to EMF and health (EFHRAN, 2010a, 2010b). As part of this risk assessment, EFHRAN systematically reviewed the scientific evidence of health effects of EMF in humans (EFHRAN, 2010a) and in animals, and tissues and cells (EFHRAN, 2010b).

EFHRAN summarized the human epidemiologic and experimental data on cancer (including leukemia in children, brain tumors in children and adults, breast cancer in adults, and all other cancers), neurodegenerative diseases (including Alzheimer's disease, amyotrophic lateral sclerosis, and other diseases), reproductive outcomes, cardiovascular diseases, and other symptoms as being inadequate to demonstrate a causal association, and the data on electromagnetic hypersensitivity as suggesting a lack of effect. Specifically, EFHRAN (2010a) concluded: "For none of the diseases is there sufficient causal association between exposure and the risk of the disease, and the strength of evidence for many outcomes remains as inadequate."

Based on its review of the *in vitro* and animal *in vivo* experimental evidence on health effects of RF, EFHRAN found limited evidence of genotoxic effects *in vitro* but evidence suggesting a lack of a genotoxic effect *in vivo*; inadequate evidence of non-genotoxic carcinogenic effects *in vitro* and *in vivo*; limited evidence of effects on the stress response and in *in vitro* studies related to the nervous system; evidence suggesting a lack of an effect on blood-brain barrier permeability; inadequate evidence of effects on neurological gene expression, neurodegenerative disease, neurogenesis, and behavior; inadequate evidence of effects on development, teratology, reproduction, and *in vitro* developmental and reproductive outcomes; inadequate evidence of effects on *in vitro* and *in vivo* immunological outcomes; and evidence suggesting a lack of an effect on auditory outcomes. In summary, EFHRAN (2010b) concluded the last 15 years of searching for non-thermal health and biological effects of RF exposure had been "unsuccessful." Moreover, "[t]he collection of recent papers does not change the overall picture and, on the contrary, it appears that the quality of the work in particular in terms of exposure systems and dosimetry has not been satisfactory, despite the availability of such devices and methods. Results from the high-quality studies are mostly negative."

French Agency for Food, Environmental and Occupational Health & Safety, 2013

The French Agency for Food, Environmental and Occupational Health & Safety (ANSES), which aims to ensure environmental, occupational, and food safety and to evaluate the potential health risks they may entail, convened a permanent working group on RF and health with the following four missions: 1) to regularly update the scientific expert appraisal of health effects potentially related to RF exposure, 2) to answer questions raised by the development of new technology using RF, and to respond to requests received by ANSES for expert appraisals in this area, 3) to make annual research recommendations to support the call of ANSES for research projects in this area, and 4) to inform stakeholders of the results of new research and thereby contribute to public debate on this topic (ANSES, 2013). The most recent ANSES expert appraisal on RF and health updated a previous report published in 2009, and was based on a systematic literature review focusing on three major health areas: central nervous system outcomes, other non-carcinogenic outcomes, and carcinogenic outcomes.

In the area of non-carcinogenic central nervous system outcomes, ANSES concluded that the collective scientific evidence from *in vitro*, *in vivo* animal, and experimental and epidemiologic human studies is "inadequate" to conclude that there is a causal effect of RF on cognitive function, short-term sleep pathology, circadian rhythms, short-term auditory pathology, multiple sclerosis, amyotrophic lateral sclerosis, epilepsy, and Alzheimer's disease. ANSES also concluded that there is an "absence of data" on a causal effect of RF on long-term sleep pathology and long-term auditory pathology. Although some possible non-thermal biological effects were observed *in vitro* and *in vivo*, ANSES noted that "it is not currently possible to establish a causal relationship between these biological effects and resulting potential health effects."

In the area of non-carcinogenic outcomes other than those affecting the central nervous system, ANSES concluded that the collective scientific evidence from *in vitro*, *in vivo* animal, and experimental and epidemiologic human studies is "inadequate" to conclude that there is a causal effect of RF on male fertility, female fertility, height/weight/viability of descendants, teratogenic effects and *in utero* development, immune system outcomes, endocrine system outcomes, vasomotricity of blood vessels, heart rate, blood pressure, well-being and reported health in the general population, and overall health/all-cause mortality. ANSES also concluded that the absence of high-quality data makes it "impossible to evaluate" a potential causal effect of RF on sexual behavior or hematological parameters. Again, although some potential biological effects were inconsistently observed *in vitro* and *in vivo*, ANSES stated that "it is not possible at present to establish a relationship between these biological effects, a mechanism of action, and resulting effects on health."

In the area of cancer, ANSES concluded that the collective scientific evidence from *in vitro*, *in vivo* animal, and experimental and epidemiologic human studies is "inadequate" to conclude that there is a causal effect of RF on glioma at environmental exposure levels, meningioma after a latency period of <15 years, salivary gland tumors, leukemia, cutaneous or ocular melanoma, and overall cancer incidence and mortality. ANSES also concluded that an increased risk of glioma among intensive mobile telephone users with >1,640 hours of cumulative exposure "cannot be ruled out," and that "limited evidence … appears to leave open the hypothesis of an increased risk of acoustic neurinoma in long-term users of mobile telephones." ANSES also determined that "no permanent effect of RF fields on loss of DNA integrity has been demonstrated at low exposure levels," and certain transient changes in DNA oxidation and breakage, which appear to be rapidly repaired, "probably have no consequences on chromosomal integrity" and cannot be linked to a mechanism of action or resulting effects on health.

Health Council of the Netherlands, 2013

The Electromagnetic Fields Committee of the Health Council of the Netherland (HCN) conducted a systematic review of the epidemiologic literature focusing specifically on the association between mobile telephones and tumors of the head, including gliomas, meningiomas, acoustic neuromas, parotid gland tumors, and other tumors (HCN, 2013). Based primarily on its review of the Danish cohort study (Frei et al., 2011; Schüz et al., 2006), the

INTERPHONE case-control studies (Cardis et al., 2011; Cardis et al., 2007; Interphone Study Group, 2010, 2011), the Swedish case-control studies (e.g., Hardell et al., 2006a; Hardell et al., 2006b, 2011), and several ecologic studies of time trends in brain tumor incidence rates relative to the prevalence of mobile telephone use, HCN concluded that "there is no clear and consistent evidence for an increased risk for tumours in the brain and other regions in the head in association with up to approximately 13 years use of a mobile telephone, but such risk can also not be excluded. It is not possible to pronounce upon longer term use."

Regarding glioma, HCN concluded that "there are some weak and inconsistent indications for an association between prolonged and intensive use of a mobile telephone and an increased risk of gliomas. These might be explained by various types of bias and chance, but it cannot be excluded that there is a causal relation. However, the Committee estimates the likelihood for a causal relation to be very low."

Regarding meningioma, HCN concluded that "there are no clear and consistent indications for an increased risk of meningioma from using a mobile telephone."

Regarding acoustic neuroma, HCN concluded that "the data on an association between long term use of a mobile telephone and acoustic neuroma are inconsistent and do not really give an indication for an increased risk."

Regarding parotid gland tumors, HCN concluded that "there are no clear indications for an increased risk of parotid gland tumours from using a mobile telephone. Only one increased risk estimate in one subgroup in one study with limited numbers of cases has been observed. This could have been the result of chance. The incidence data, including those from the Netherlands, also do not show an increase."

Regarding other tumors of the head, HCN determined that for "pituitary tumours, melanoma eye tumours, intra-temporal facial nerve tumours and neuroblastoma tumours no conclusions regarding risks associated with the use of mobile telephones can be drawn."

In summary, HCN described its systematic analysis as demonstrating that "despite large research efforts, there is still no clarity regarding a possible association between mobile telephone use and an increased risk of tumours in the brain and other regions of the head."

International Agency for Research on Cancer, 2013

As an agency of the WHO, the International Agency for Research on Cancer (IARC) routinely assembles international working groups of experts to critically and systematically review and evaluate human, animal, mechanistic, and exposure-related evidence on the carcinogenicity of various human exposures as the first step (hazard identification) in a carcinogen risk assessment (IARC, 2013a). These evaluations are published as IARC Monographs, the 102nd of which was concerned with non-ionizing radiation, including RF.

On the basis of epidemiologic studies of RF exposure from mobile and cordless telephones, especially the Danish cohort study, the Swedish case-control studies, the INTERPHONE case-control studies, and a Japanese case-case study (Sato et al., 2011), IARC concluded that there was "limited evidence" for carcinogenicity of RF in relation to glioma and acoustic neuroma, with a minority opinion that the current evidence in humans was "inadequate." IARC also concluded that these studies "generally indicated no increase in risk" of meningioma.

On the basis of epidemiologic studies of RF exposure from mobile telephones, IARC "found the evidence to be insufficient to reach a conclusion as to the potential association of mobile-phone use and either leukaemia or lymphoma." Regarding other malignancies, including ocular or cutaneous melanoma, cancer of the testis, cancer of the breast, and tumors of the parotid gland, IARC concluded that "[e]vidence to date does not point to a causal association of mobile-phone use."

On the basis of epidemiologic studies of occupational exposure to RF, IARC concluded that "there is no clear indication of an association of occupational exposure to RF with risk of cancer of the brain." Regarding the potential association between occupational RF exposure and risk of leukemia or lymphoma, IARC concluded that "the limited exposure assessment and possible confounding make these results difficult to interpret." Likewise, regarding other malignancies, IARC concluded that studies of occupational RF exposure "had methodological limitations and the results were inconsistent."

Regarding epidemiologic studies of environmental exposure to RF from transmission antennas, IARC concluded that "these studies provide no indication that environmental exposure to RF increases the risk of brain tumours," that "no conclusions could be drawn on the risk of leukaemia or lymphoma from environmental exposure to RF radiation," and that the available evidence on other malignancies was "uninformative."

On the basis of experimental animal studies, including 7 two-year cancer bioassays of RF in rodents, 12 studies of tumor-prone animal models, 16 studies of cancer initiation and promotion in animal models of tumor development, and 6 co-carcinogenesis studies in animal models, IARC concluded that there is "limited evidence in experimental animals for the carcinogenicity of radiofrequency radiation."

Regarding mechanistic studies, IARC concluded that there is "weak" evidence that RF is genotoxic or alters gene expression, protein changes, cellular signaling, oxidative stress, reactive oxygen species levels, the blood-brain barrier, apoptosis, cellular replication, ornithine decarboxylase activity, or neural functions. IARC also concluded that there is "no evidence" for a mutagenic effect of RF and "insufficient evidence" whether immune function changes linked to RF affect carcinogenesis in humans, and that "the relationship between alterations in cerebral blood flow during exposure to RF radiation cannot be directly related to carcinogenesis," although IARC considered the latter results "sufficiently consistent to identify them as important findings."

Overall, based on "limited evidence in humans for the carcinogenicity of radiofrequency radiation" in relation to glioma and acoustic neuroma and "limited evidence in experimental animals for the carcinogenicity of radiofrequency radiation," IARC classified RF as "possibly carcinogenic to humans" (group 2B). It is worth noting that the other IARC classifications are group 1 ("carcinogenic to humans"), group 2A ("probably carcinogenic to humans"), group 3 ("not classifiable as to its carcinogenicity to humans"), and group 4 ("probably not carcinogenic to humans"). Since 1971, the IARC has evaluated more than 900 agents, over 80 percent of which are classified in group 2B or group 3. Only one agent has been classified in group 4, illustrating the conservative nature of their classification system (IARC, 2013b).

International Commission on Non-Ionizing Radiation Protection, 2009

ICNIRP is an independent, non-governmental scientific organization recognized by the WHO that develops independent, science-based international guidelines on limits of exposure to non-ionizing radiation, provides science-based guidance and recommendations on protection from exposure to non-ionizing radiation, and establishes principles of non-ionizing radiation protection for the formulation of international and national protection programs (ICNIRP, 2009a). To provide input to the WHO's health risk assessment of EMF and to update its guidance and advice on the health hazards of EMF exposure, ICNIRP systematically reviewed the current scientific evidence on exposure to high-frequency EMF and health, including numerical dosimetry, measurements, *in vitro* and *in vivo* biological laboratory studies, and epidemiologic studies.

Regarding experimental evidence for biological effects of RF, ICNIRP reached the following conclusions (directly quoted from the report):

- The mechanisms by which RF exposure heats biological tissue are well understood and the most marked and consistent effect of RF exposure is that of heating, resulting in a number of heat-related physiological and pathological responses in human subjects and laboratory animals. Heating also remains a potential confounder in *in vitro* studies and may account for some of the positive effects reported.

- Recent concern has been more with exposure to the lower level RF radiation characteristic of mobile telephone use. Whilst it is in principle impossible to disprove the possible existence of non-thermal interactions, the plausibility of various non-thermal mechanisms that have been proposed is very low.

- Concerning cancer-related effects, the recent *in vitro* and animal genotoxicity and carcinogenicity studies are rather consistent overall and indicate that such effects are unlikely at [specific absorption rate] levels up to 4 W kg^{-1}. With regard to *in vitro* studies of RF effects on non-genotoxic end-points such as cell signaling and gene/protein expression, the results are more equivocal, but the magnitudes of the reported RF radiation induced changes are very small and of limited functional consequence. The results of studies on cell proliferation and differentiation, apoptosis and cell transformation are mostly negative.

- There is some evidence of small changes in brain physiology, notably on spontaneous EEG [electroencephalogram], and somewhat more variable evidence of changes in sleep EEG and regional cerebral blood flow but these may be of limited functional consequence; no changes were seen in cognitive function. With regard to more general physiological end-points, the evidence suggests that there are no consistent effects of non-thermal RF exposures on cardiovascular physiology, circulating hormone levels or on auditory or vestibular function, except for the auditory perception of pulsed RF such as that characteristic of radar.

- 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.

- The experimental data do not suggest so far that children are more susceptible than adults to RF radiation, but few relevant studies have been conducted.

- Studies of the effects of RF modalities such as high peak power pulses have been somewhat diverse and sporadic; no effects have been seen other than those associated with heating and with acoustic perception.

Regarding epidemiologic evidence for associations with occupational exposure to RF, ICNIRP concluded that “there is no cancer site for which there is consistent evidence, or even an individual study providing strong evidence, that occupational exposure to RF affects risk”; this assessment covered brain tumors, leukemia, breast cancer, testicular cancer, ocular melanoma, and lung cancer. Concerning other health outcomes examined in relation to occupational RF exposure, ICNIRP concluded that “problems of exposure assessment temper any conclusions regarding reproductive outcomes, and no adverse effects of RF have been substantiated”; that “the literature on RF and cardiovascular symptoms and disease provides little suggestion of an association, but is at too rudimentary a level to draw firm conclusions”; and that studies of cataracts “are limited with respect to exposure assessment and selection of unexposed workers … The plausibility of a causal relation supports more extensive investigation.”

Regarding epidemiologic evidence for associations with environmental exposure to RF from transmitters, ICNIRP concluded that the methodologically “weak” results of studies of cancer risk “have not been consistent within or between studies, and do not show relations to RF exposure levels,” while “studies of symptoms and well-being find a higher prevalence of symptoms and less well-being among persons who are concerned about exposure from base-stations, whereas there is little evidence for an association between measured RF levels and the studied outcomes.”

Regarding epidemiologic evidence for associations with exposure to RF from mobile telephones, ICNIRP concluded that “while occasional significant associations between various types of brain tumor and analogue mobile telephone use have emerged (often seen after multiple [hypothesis] testing), no single association has been consistently reported across population-based studies … Thus current evidence is inconclusive regarding cancer risk following heaving RF exposure from mobile telephones.” With respect to symptoms, ICNIRP concluded that “the studies of symptoms to date do not suggest that a single exposure to RF from a mobile telephone results in immediately identifiable symptoms, but there are no adequate population-based data available about the symptomatic effects of repeated mobile telephone use, especially among those who claim hypersensitivity to RF.”

Overall, ICNIRP reached the conclusion that “[r]esults of epidemiological studies to date give no consistent or convincing evidence of a causal relation between RF exposure and any adverse health effect. On the other hand, these studies have too many deficiencies to rule out an association.”

Latin American Experts Committee on High Frequency Electromagnetic Fields and Human Health, 2010

To address public concerns in Latin American countries about the possible adverse health effects of exposure to non-ionizing EMF, a multidisciplinary panel of Latin American researchers in the areas of mobile communications, biology, medicine, and health was assembled as the Latin American Experts Committee (LAEC) to produce an independent, objective, systematic, critical review of the recent international scientific literature on the possible biological and health effects of exposure to low-level RF (LAEC, 2010).

Based on its review of *in vitro* studies, LAEC reached the conclusion that "there is, so far, inadequate evidence or a lack of consistent and validated evidence to establish [any] cause-effect relationship between exposure to low level RF and short-term effects on cell cycle and regulation, membrane transport, apoptosis, genotoxicity, mutation rates, gene and protein expression, damage to genetic material and cell proliferation, transformation and differentiation of cells and tissues." Given these results, LAEC found that "there is very little plausibility for effects at the cellular level that might lead [to] damage at the higher organ levels or for human health consequences."

Based on its review of *in vivo* animal studies, LAEC stated that "the general conclusion, after more than 20 years of *in vivo* studies, is that no consistent or important effects of RF could be demonstrated in intact animals below international safety standards. There seems to be no important pathophysiological effect of RF fields, apart from thermal effects caused by exposure to fields many times larger than those encountered in our living and working environments."

Based on its review of human experimental studies, LAEC concluded: "It is now generally accepted that there are no significant effects of cell telephone usage or reasonable proximity to radiating antennas of base stations on [cognitive and behavioral responses]. Other investigated effects on pain, vision, hearing and vestibular function, as well as on the endocrine and cardiovascular systems, were mostly negative." Moreover, concerning electromagnetic hypersensitivity, LAEC noted that "several studies, systematic reviews and meta-analyses in the last 15 years have concluded that hypersensitivity and the observed symptoms have no correlation to RF exposure of individuals. There is presently no scientific basis for characterizing RF hypersensitivity as a medical syndrome." The collective scientific evidence led LAEC to conclude that there are "no adverse effects in humans below thermal thresholds, no hazardous influences on the well-being and health status of users and non-users of cell telephones and people living near base stations, and that no convincing evidence for adverse cognitive, behavioral and neurophysiological and other physiological effects exist."

Based on its review of epidemiologic studies of humans, LAEC concluded that the results "have not shown any sizable, incontrovertible and reproducible adverse health effect, and that numerous methodological flaws, along with only the few outcomes examined so far, do not allow for firm conclusions, particularly as it relates to children and to continuous exposure for periods larger than 20 years." In particular, LAEC concluded that studies of mobile telephones and brain tumors "generally reported a lack of statistical associations, except for a disputable slighter [*sic*] higher risk of gliomas and acoustic neuromas for users with more than 10 years of use"; and that studies of neurodegenerative disorders, cardiovascular diseases, cataracts, reproductive health changes, behavioral changes, and non-specific symptoms have yielded "mostly statistically non-significant associations."

Norwegian Institute of Public Health, 2012

On the basis of public concerns about EMF and its potential health effects, the Norwegian Ministry of Health and Care services and the Ministry of Transport and Communications commissioned the Norwegian Institute of Public Health (NIPH) to assemble a cross-disciplinary committee of experts in environmental and occupational medicine, biology, physics, metrology, biophysics, biochemistry, epidemiology, philosophy, administration, and risk management to systematically review the scientific knowledge regarding exposure to RF (NIPH, 2012).

Based on its review of the scientific literature on RF and cancer, NIPH concluded that "the available data show no association between exposure to RF fields from a mobile telephone and fast-growing tumours, including gliomas in the brain which have a short induction period (time from exposure to disease)." NIPH added that "[f]or slow-growing tumours, including meningiomas and acoustic neuromas, the data available so far do not indicate an increased risk. However, it is too early to completely exclude the possibility that there may be an association with RF fields from mobile telephones, because the period of use of mobile telephones is still too short." For leukemia, lymphoma, salivary gland tumors, and other malignancies, NIPH concluded that "there are insufficient data to draw conclusions, but the available studies do not suggest an increased risk," and studies on trends in the occurrence of childhood and adolescent brain tumors "show no indication of increased disease incidence in these groups after the introduction of mobile telephones." NIPH noted that RF exposure from base stations and radio and television transmitters is substantially lower than from mobile telephones, and that "the available data do not suggest that such low exposure could increase the risk of cancer." According to NIPH, related results from animal and mechanistic studies also "provide further evidence that exposure to weak RF fields does not lead to cancer."

Based on its review of the scientific literature on RF and reproductive health, NIPH concluded that the results of recent experimental studies with "high methodological quality and good control of exposure," including control for thermal effects that are known to damage sperm, are "ambiguous," inconsistent, and of unclear relevance both to sperm quality in natural settings and to male fertility. NIPH also concluded that "there is little indication that exposure to weak RF fields adversely affects fertility. The few studies that do exist do not provide evidence that exposure to weak RF fields during pregnancy has adverse effects on the foetus," including childhood behavior and development.

Concerning electromagnetic hypersensitivity, NIPH concluded that "scientific studies indicate that electromagnetic fields are not the direct or contributing cause of the condition of health problems attributed to electromagnetic fields." NIPH also concluded that the available evidence presents no clear evidence that exposure to weak RF fields has adverse effects on the cardiovascular system, the immune system, the hormone (endocrine) system, the nervous system, or gene expression in humans. Overall, based on the collective scientific evidence from *in vitro*, *in vivo* animal, and human studies, NIPH concluded that "the large total number of studies provide no evidence that exposure to weak RF fields causes adverse health effects. Some measurable biological/physiological effects cannot be ruled out."

Scientific Committee on Emerging and Newly Identified Health Risks, 2013

The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) provides the European Commission with independent scientific advice for preparing policy and proposals relating to emerging and newly identified potential health and environmental risks including static, extremely low frequency, intermediate frequency, RF, and terahertz frequency EMF (SCENIHR, 2013). To this end, SCENIHR systematically and critically reviewed, evaluated, and summarized the recent scientific evidence from the physical, engineering, medical, and biological sciences on the potential health effects of exposure to EMF as a basis for updating its 2009 opinions on this issue.

With respect to potential effects of RF exposure on brain activities as measured by changes in electroencephalogram (EEG) patterns, SCENIHR concluded that "it is difficult to derive firm conclusions. For event-related potentials and slow brain oscillations results are inconsistent. Likewise, studies on cognitive functions in humans lack consistency. The biological relevance of reported small physiological EEG changes remains unclear, and mechanistic explanation is still lacking."

With respect to electromagnetic hypersensitivity, SCENIHR stated: "A reasonable body of experimental evidence now suggests that exposure to RF does not trigger symptoms, at least in the short-term. While additional observational studies are required to assess whether longer-term exposure could be associated with symptoms, the evidence to date weighs against a causal effect."

Pertaining to neurological diseases and symptoms, SCENIHR concluded that studies "show no clear effect, but the evidence is limited. Human studies on child development and behavioural problems provide only weak evidence because of conflicting results and methodological limitations. Direct effects of exposure from mother's mobile phone use during pregnancy are not plausible owing to extremely low fetal exposure to mobile phone EMF."

Pertaining to cancer, SCENIHR concluded: "Epidemiological studies on RF do not unequivocally indicate an increased risk of brain tumours, and do not indicate an increased risk for other cancer of the head and neck region, or other malignant diseases including childhood cancer … Based on the most recent cohort and incidence time trend studies, the evidence for glioma became weaker while the possibility of an association with acoustic neuroma remains open."

Regarding potential effects of RF on cancer in animals, SCENIHR concluded: "A considerable number of well-performed in vivo studies using a wide variety of animal models have been mostly negative in outcome. These studies are considered to provide evidence for the absence of a carcinogenic effect."

Finally, regarding potential carcinogenic effects of RF in cells and tissues, SCENIHR concluded: "A large number of in vitro studies pertaining to genotoxic as well as non-genotoxic endpoints have been publisher since the last opinion. In most of the studies, no effects of exposure at levels below exposure limits were recorded, although in some cases DNA strand breaks and spindle disturbances were observed."

On the topic of potential reproductive and developmental effects of RF, SCENIHR "concluded that there is strong overall weight of evidence against an effect of low level RF fields on reproduction or development," although studies of male fertility in particular "are of poor quality and offer little evidence."

Swedish Radiation Safety Authority, 2013

The international scientific council of the Swedish Radiation Safety Authority (SSM) follows and evaluates the development of scientific evidence on EMF for the Swedish government and prepares annual scientific reviews to inform a gradually developing health risk assessment of exposure to EMF (SSM, 2013). These reviews are based on a systematic evaluation of the relevant *in vitro*, *in vivo* animal, and human experimental and epidemiologic scientific literature.

In its eighth annual report, SSM concluded that the *in vitro* evidence on RF consists of "only a few positive studies in the RF range and … still little evidence of non-thermal effects. Recent data from laboratory studies related to cancer do not seem to support the conclusion of IARC that RF EMF is a possible carcinogen."

Regarding animal studies of RF, SSM concluded that "mixed effects in the carcinogenicity studies provide some, but unreplicated and not very reliable indications of increased DNA damage after RF EMF exposure. No increased cancer risks were observed, however." Regarding reproductive outcomes, SSM also concluded that "results of those fertility studies that have sufficient quality did not provide evidence for a detrimental effect of RF EMF exposure."

Regarding human experimental studies of RF, SSM concluded that "new studies support the lack of an exposure between acute mobile telephone exposure and cognitive performance. However, an association with EEG has been repeatedly observed," although "a substantial interindividual variation exists and this may explain some of the inconsistency observed between studies."

Regarding human epidemiologic studies of RF and cancer, SSM concluded: "The overall data on brain tumour and mobile telephony do not indicate an effect of mobile telephone use on tumour risk, especially not when taken together with national cancer incidence statistics from different countries. There is still only limited data regarding risks of long-term use of mobile telephones" beyond 13–15 years. Additionally SSM stated that "it is too early to draw firm conclusions about risk for brain tumours for children and adolescents, but the available literature to date does not indicate an increased risk." SSM also concluded that the available epidemiologic studies on leukemia and malignant melanomas are "very limited," but thus far do not indicate an association with mobile telephone use.

Regarding human epidemiologic studies of RF and non-cancer health outcomes, including child development, reproductive health, multiple sclerosis, age-related cognitive decline, auditory functions, bone mineralization, and hypertension, SSM concluded that the small number of studies and methodological limitations of those studies "prevent from firm conclusions in terms of causal associations."

Regarding human epidemiologic studies of RF and electromagnetic hypersensitivity and symptoms, SSM concluded that "the new epidemiological studies on symptoms using an improved design rather indicate the absence of a risk from RF-EMF exposure on health-related quality of life. Uncertainty concerns mainly high exposure levels from wireless telephone use and longer follow-up times than one year."

Swiss Federal Office for the Environment, 2013

In a brief report, the Swiss Federal Office of the Environment (FOEN) systematically reviewed the findings of scientific studies of human exposure to RF from fixed installations such as broadcasting transmitters and mobile telephone base stations (FOEN, 2013). FOEN found that despite improvements in exposure models and measurement instruments, "due to the remaining uncertainties regarding the interpretation of the findings and existing gaps in knowledge it is still not possible to draw definitive conclusions" about the potential contribution of RF to any health outcomes evaluated, including sleep disturbances, general well-being and non-specific symptoms, childhood leukemia, childhood brain tumors, cancer in adults, physiological parameters, cognitive functions, cardiovascular outcomes, reproductive and developmental outcomes, and hormone balance. Available epidemiologic studies of typical low-level whole-body exposure to RF from fixed transmitters "indicate no changes in physiological parameters or effects on wellbeing or health," but results on higher and long-term exposures are lacking. In summary, FOEN concluded that "no new confirmed health effects of exposure to high-frequency fields from transmitters were observed in the dose range below the recommended reference levels of the International Commission for Non-Ionising Radiation Protection (ICNIRP) … From the scientific point of view, this means that protection against acute effects is assured as before."

U.K. Advisory Group on Non-Ionising Radiation, 2012

The Advisory Group on Non-Ionising Radiation (AGNIR) is an independent advisory group that reports to the board of the Health Protection Agency (now part of Public Health England), the United Kingdom's primary governmental authority on public health protection, with the charge of reviewing work on the biological effects of non-ionizing radiation relevant to human health and to advise on research priorities (AGNIR, 2012). Its systematic review of the *in vitro*, *in vivo* animal, experimental human, and epidemiologic human scientific literature reflects the consensus of AGNIR members, who include scientists from the United Kingdom and Sweden.

Concerning *in vitro* studies, including attempts to replicate previous findings, AGNIR concluded: "No consistently replicable effects have been found from RF field exposure at levels below those that produce detectable heating. In particular, there has been no convincing evidence that RF fields cause genetic damage or increase the likelihood of cells becoming malignant."

Concerning *in vivo* animal studies, covering a broad range of biological models, exposure levels, and signal modulations, AGNIR concluded: "Taken together, these studies provide no evidence of health effects of RF field exposure below internationally accepted guideline levels. In particular, well-performed large-scale studies have found no evidence that RF fields affect the initiating and development of cancer, and there has been no consistent evidence of effects on the brain, nervous system or the blood-brain barrier, on auditory function, or on fertility or reproduction."

Concerning experimental human studies of acute exposure to RF below guideline levels, AGNIR concluded that the evidence suggests that such exposure "does not cause acute symptoms in humans, and that people, including those who report being sensitive to RF fields, cannot detect the presence of RF fields. Similarly, well-conducted studies do not suggest that exposure to RF fields gives rise to acute cognitive effects." Although AGNIR identified some scientific evidence that RF may affect EEG and other markers of brain function, it cautioned that "the size of these reported effects is often small relative to normal physiological changes, and it is unclear whether they have any implications for health."

Concerning epidemiologic studies of long-term exposure to RF below guideline levels, AGNIR concluded that although such research "has been very limited, the literature provides no substantial evidence of such effects, in particular in relation to cardiovascular morbidity, reproductive function and non-cancer mortality." AGNIR stated that studies of cancer risk in relation to occupational RF exposure and residential proximity to RF transmitters "give no evidence of any causal effect but also give no strong evidence against it," whereas the overall evidence from epidemiologic studies of mobile telephone use and cancer risk "does not suggest that use of mobile telephones causes brain tumours or any other type of cancer. The data, however, are essentially restricted to periods of less than 15 years from first exposure."

Overall, AGNIR concluded: "In summary, although a substantial amount of research has been conducted in this area, there is no convincing evidence that RF field exposure below guidance levels causes health effects in adults or children."

Alternative Views

A minority of opinions, such as the ones expressed in short statements by the American Academy of Environmental Medicine (AAEM) (2012) and in voluminous reports by the BioInitiative Working Group (BWG) (2012), express concerns that current exposure limits for RF are not sufficient and call for more stringent limits of RF exposures or for use of non-RF based technologies. These and similar conclusions appear to have been arrived at after evaluations that did not follow well-established methods for weight-of-evidence assessment of the available scientific literature. The authors of the AAEM and BWG reports apparently did not attempt to assess the entire literature available on RF and health. Rather, they selectively cited studies with positive findings to support their views, without appropriately assessing the quality and validity of the studies, and disregarding the vast amount of literature that does not support their conclusions. Proper evaluations of the scientific literature need to consider all available evidence, giving more weight to studies with higher quality and validity. The disproportional reliance on *in vitro* studies in the AAEM (2012) and BWG (2012) reports is also noteworthy. Most authoritative human health risk assessments, as discussed earlier, are based primarily on epidemiologic and *in vivo* laboratory animal studies, with *in vitro* studies providing mostly supplementary information on potential biological mechanisms. Moreover, the AAEM and BWG reports do not appear to reflect a consensus opinion of expert panels, but rather consist of an assemblage of varied individual opinions.

Appendix B

Measurement Detail and Hypothetical Transmission Scenarios

As discussed in this report, the Vermont Department of Health also performed measurements of RF from smart meters. Table B-1 compares the results of those measurements to the measurements taken by Tell and Associates as presented in the Tell Report.

Table B-1. Comparison of measurements from Tell Report with measurements by the Vermont Department of Health in 2012

	Tell Report		**Vermont Department of Health**	
Measurement Location	**Power Density (mW/cm^2)**	**Fraction of MPE Limit (%)**	**Power Density (mW/cm^2)**	**Fraction of MPE Limit (%)**
Maximum at 1 foot from smart meter outside a residence	0.023	3.9	0.010 to 0.050	1.7 to 8.3
Maximum at inside wall of residence behind smart meter	0.00048	0.08	Background*	Background*

* Measurements were below the background levels insofar as the measurement setup was able to discriminate RF signals from the smart meter from other signals present.

The peak power density, average power density, and duty cycle are all interrelated. Figure B-1 illustrates different types of transmission patterns: a) continuous transmission, b) periodic transmission, c) clustered transmission, d) and e) intermittent transmission, and f) periodic transmission with variable power. Each of these plots show illustrative examples of both peak power density and 30-minute average power density. The duty cycle in each plot (except for continuous transmission) is related to the length of each of the transmissions. For the purposes of these hypothetical examples, each transmission (shown by the vertical green bar) is assumed to last for 5 seconds and each plot has 20 transmissions within the two 30-minute-long periods displayed.

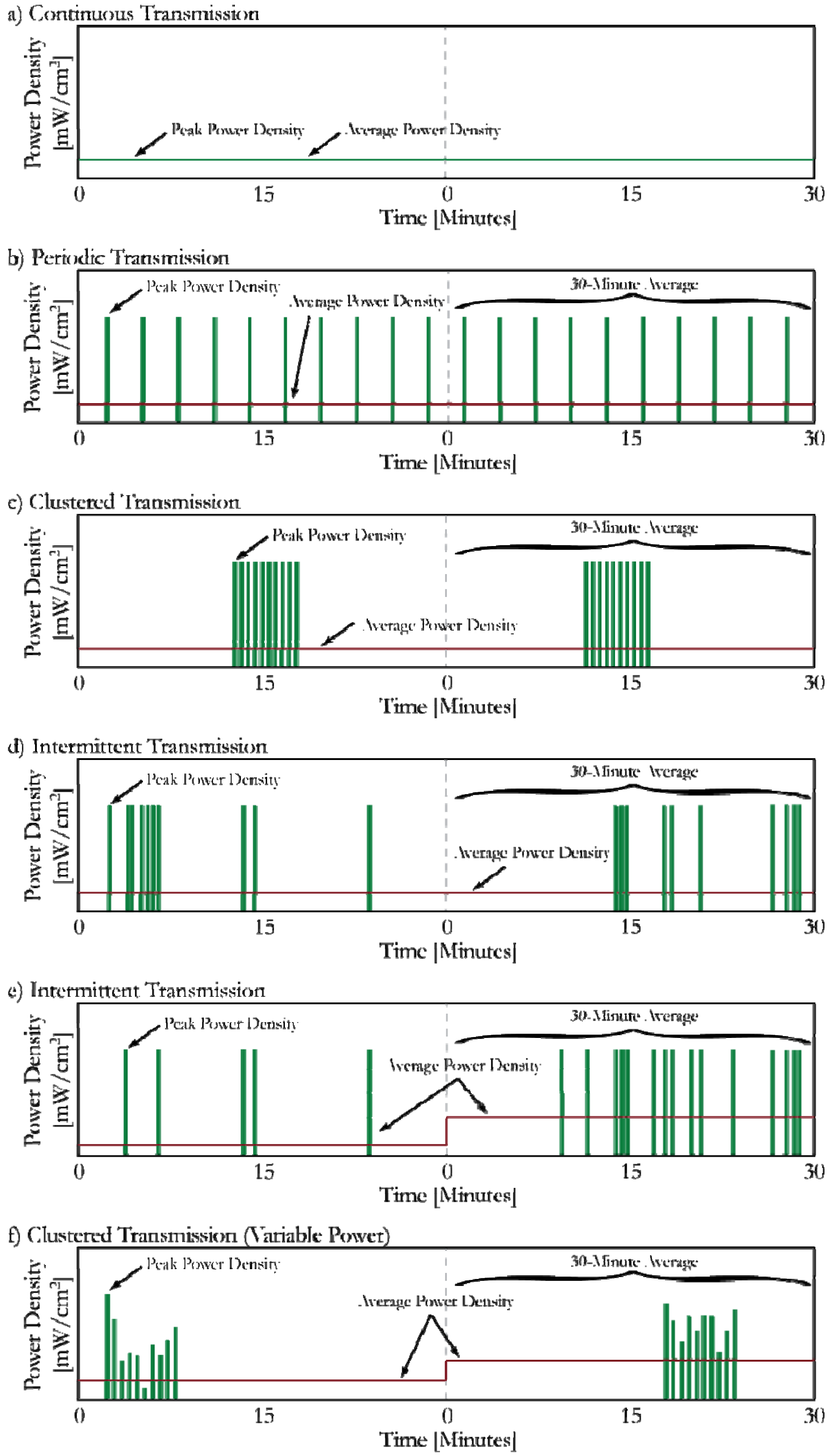

Figure B-1. Hypothetical examples of the correspondence between peak power density, duty cycle, and average power density for a variety of transmission patterns.

Continuous Transmission (plot a)

In continuous transmission systems, the output power is constant with time. In this scenario the peak power density will be equal to the average power density and the duty cycle is 100%. Examples of continuous transmission systems are AM/FM radio and TV broadcasts.[14]

Periodic Transmission (plot b)

In a periodic transmission system, the transmitted signal will repeat at fixed intervals.[15] The peak power density is shown graphically by the height of the green bar. In this example, the 20 transmissions (each with the same power density) are evenly spaced over 1 hour. Assuming each transmission lasts for 5 seconds, the 30-minute duty cycle is:

$$\frac{5\text{ seconds/transmission} \quad \text{x } 10\text{ transmissions}}{30\text{ minutes x } 60\text{ seconds/minute}} = \frac{5 \text{ x } 10}{30 \text{ x } 60} = 2.8\%$$

and the average power density is also 2.8% of the peak power density.

Clustered Transmission (plot c)

The particular clustered transmission example shown is very similar from an exposure perspective to that of the periodic transmission. In each 30-minute period, there are 10 transmissions, each lasting for 5 seconds. This results in a 30-minute duty cycle of 2.8% and an average power density that is also 2.8% of the peak power density.

Intermittent Transmission (plot d and plot e)

In an intermittent transmission scenario, the duty cycle and the average power density will depend on the precise transmissions for any given period. This scenario is most similar to that of smart meters, which always transmit at their peak power level, but at irregular intervals and for very short durations.

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14 The power density at a particular location may still change with time, but this will generally be due to environmental factors, not the characteristics of the transmitter.

15 From an exposure perspective, an example of a periodic transmission is that of a radar signal from a particular location. As the radar spins, each particular area will be illuminated at periodic intervals.

In the intermittent transmission example shown in plot (d), there are 10 transmissions in each 30-minute period, and similar to the periodic transmission and clustered transmission examples, the 30-minute duty cycle is 2.8% and the average power density is 2.8% of the peak power density.[16]

In the intermittent transmission example shown plot (e), there are an unequal number of transmissions in the two 30-minute periods shown. In the first 30-minute period there are 5 transmissions and in the second 30-minute period there are 15 transmissions. This results in different duty cycles and average power densities in the two periods. In the first 30 minutes, the duty cycle is:

$$\frac{5\text{ seconds/transmission } \times 5\text{ transmissions}}{30\text{ minutes} \times 60\text{ seconds/minute}} = \frac{5 \times 5}{30 \times 60} = 1.4\%$$

and the average power density is 1.4% of the peak power density. In the second 30 minutes, the duty cycle is:

$$\frac{5\text{ seconds/transmission } \times 15\text{ transmissions}}{30\text{ minutes} \times 60\text{ seconds/minute}} = \frac{5 \times 15}{30 \times 60} = 4.2\%$$

and the average power density is also 4.2% of the peak power density.

Clustered Transmission with Variable Power (plot f)

A clustered transmission with variable power is similar in concept to what occurs in a typical mobile telephone call. Mobile telephone calls often last for relatively short durations and occur in clusters. In addition, mobile telephones often adjust the power output to the minimum necessary to maintain connectivity. In this simplified exposure scenario, the duty cycle can be estimated in an analogous manner to the other plots since there are 10 transmissions in each 30-minute period and each lasts for 5 seconds resulting in a duty cycle of 2.8%. The average power density, however, will depend on precisely how much power is transmitted in each of the 10

[16] In this case, there are other 30-minute periods (e.g., between 10 minutes in the first block and 10 minutes in the second block), so the 30-minute duty cycle is 5 x 3/(30 x 60) = 0.83% and the average power density is also 0.83% of the peak power density. In this situation the intermediate duty cycle and average power density is lower than in other periods; however, the maximum duty cycle still remains 2.8%.

transmissions. In the example shown, total power transmitted in the first cluster is lower than in the second cluster, hence, the 30-minute average power density is lower in the first cluster than in the second cluster.