

Exhibit E

Tab E

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*Electrical Engineering & Computer
Science Practice*

**Report of Benjamin Cotts,
Ph.D., P.E.**

*Re: Francis and Michele Hriadil v. Duquesne
Light Company, Pennsylvania Public Utility
Commission Docket No.
C-2016-2571726*

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C-2016-2571726*

Prepared for

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Acronyms and Abbreviations

AM	Amplitude modulated
DLC	Duquesne Light Company
FM	Frequency modulated
FCC	Federal Communications Commission
GHz	Gigahertz
HAN	Home area network
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local area network
MHz	Megahertz
MPE	Maximum permissible exposure
mW/cm ²	Milliwatts per square centimeter
OET	Office of Engineering and Technology
RF	Radiofrequency
SAR	Specific absorption rate
W	Watt
W/cm ²	Watts per square centimeter
W/kg	Watts per kilogram
W/m ²	Watts per square meter

Executive Summary

Electric power utilities throughout the United States are in the process of modernizing their infrastructure in what has come to be known as a “smart grid.” In Pennsylvania, Act 129 of 2008 required the deployment of smart meters, and Duquesne Light Company (DLC) selected OpenWay Centron smart meters provided by Itron Inc. (Itron) for their network.

I have been retained in this matter by DLC in the matter of Francis and Michele Hriadil v. Duquesne Light Company, before the Pennsylvania Public Utility Commission No: C-2016-2571726 (the Proceeding). My services have been requested in order to provide context on radiofrequency (RF) exposures that are the focus of concerns raised by the Complainants in the Proceeding.

My report describes the RF signal technology that smart meters use to communicate and the relative levels of RF that are expected during transmissions. This provides a basis for describing the RF exposure from DLC smart meters and explaining how this exposure compares to the Complainants’ exposures from other RF sources, both natural and anthropogenic.

Through my investigation of the DLC Itron smart meters as well as existing RF sources inside or near the Complainants’ home, I have determined that the contribution of a typical smart meter to the RF exposure indoors would be about 0.00013% (1/780,000th) of the Federal Communications Commission’s (FCC) health-based exposure limit. Furthermore, potential exposures from DLC smart meters are substantially less than the RF exposures from existing external sources such as radio and television broadcast as well as from devices currently used within the Complainants’ residence.

Based on my review of the facts in this case, the available material, my background, experience and training, and my work completed to date, the following opinions are submitted within a reasonable degree of engineering and scientific certainty:

- 1) The Itron smart meters operated by DLC will represent a negligible contribution to the overall RF exposure of the Complainants.
- 2) The RF exposures from other existing sources both inside and outside the residence are many times greater than from a typical DLC smart meter.
- 3) The RF exposure from a typical DLC smart meter, whether evaluated inside or outside the Complainants' residence, represent a fraction of the allowable FCC limit and complies with applicable industry standards.

I reserve the right to revise or amend these opinions and conclusions if additional information becomes available or if further analysis is performed.

Introduction

Electric power utilities throughout the United States are in the process of modernizing their infrastructure in what has come to be known as a “smart grid.” One component of this modernization is termed advanced metering infrastructure, also known as a “smart meter.” A hallmark feature of smart meters that sets them apart from their predecessors is the capability of using radiofrequency (RF) signals for two-way wireless radio communication. Two-way wireless radio communication is supported by miniature radio transceivers that communicate electricity consumption back to the utility and receive signals from the utility.

Pennsylvania’s Act 129 of 2008 required the deployment of smart meters and Duquesne Light Company (DLC) selected OpenWay Centron smart meters provided by Itron Inc. (Itron) for their network. Similar to many other smart meter mesh networks, the DLC network operates in the license-free 902-928 megahertz (MHz) portion of the electromagnetic spectrum.

DLC has requested that I provide the scientific background underlying the nature of electromagnetic fields, their natural and manmade sources, and standards relating to human exposure to these fields.

My educational background, qualifications, and Curriculum Vitae are summarized in Appendix A. Appendix B includes a figure from the Federal Communications Commission (FCC) that depicts the various portions of the RF spectrum. The figure illustrates the uses and applications of the many hundreds of RF communication frequency bands licensed in the United States. Appendix C summarizes the methods and results of calculations of exposure to RF at the Complainants’ residence.

1. Basic Physics of Electromagnetics

Though not widely recognized, the most common electromagnetic field to which we are exposed every day is naturally-occurring visible light. There are other natural sources as well as man-made sources. There are extremely low frequency sources such as the fields from power transmission and distribution lines and higher frequency sources that are associated with transmission of radio and television broadcast signals as well as from various wireless personal communication devices used daily in modern society.

The primary defining characteristic of electromagnetic fields is their frequency. The frequency of an electromagnetic field is determined by the number of times it oscillates (i.e., changes direction) each second, and frequency is what governs how these fields interact with humans in their daily lives.¹

Electromagnetic Waves

It is difficult to intuitively understand electromagnetic waves because not only are most invisible to the human eye but they cannot be heard, tasted, touched, or smelled. Other types of waves such as sound waves or water waves on the other hand are quite familiar and can be used through analogy to illustrate some of the relevant properties of electromagnetic waves. For instance, when one drops a rock in a pond, the rock creates a water wave, which expands outward from the source. The wave propagating on the surface of the pond does not actually carry water molecules with it, rather the wave spreads to adjacent water molecules (propagates) when adjacent water molecules move up-and-down. The wave that has the highest amplitude (height above the pond) is at the source and as it spreads outward the height of the waves gets successively smaller. Figure 1, taken with a high-speed camera, illustrates how the up and down motion of the wave is largest at the source and diminishes as it expands outward.

¹ Both electromagnetic fields and electromagnetic waves are used concurrently in this report depending on which is more intuitive and more readily understandable, but in all instances, their meaning is the same.

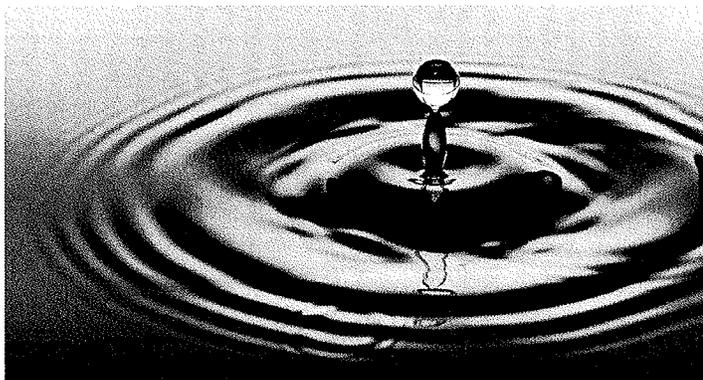


Figure 1. Illustration of the concept of wave energy movement from a source.

Electromagnetic waves are made up of individual electric fields and magnetic fields and, similar to water waves, as electromagnetic waves propagate away from the source the amplitude (i.e., the strength of the constituent electric and magnetic fields) decreases.

The Electromagnetic Spectrum

Though often assumed to include only RF fields, the electromagnetic spectrum in fact includes all forms of electromagnetic fields. As shown in Figure 2 electromagnetic fields are broadly classified as either *non-ionizing radiation* or *ionizing radiation*.² *Non-ionizing radiation* includes well-known RF broadcast signals such as those from amplitude-modulated (AM) and frequency-modulated (FM) radio stations as well as television broadcasts, while light from the sun or from a flashlight are common examples of electromagnetic fields in the visible portion of the electromagnetic spectrum. Between these portions of the spectrum are the microwave (sometimes included in the definition of RF) and infrared portions of the electromagnetic spectrum. Each of these types of fields is too weak to break the bonds within atoms or molecules. In contrast *ionizing radiation* such as from X-rays or gamma rays is strong enough to break molecular or atomic bonds.³

² The term “radiation” simply means “energy propagated through space.” It is used to describe energy emitted from any particular source such as heat from a campfire, light from a flashlight, acoustic energy from a stereo system, or the broadcast signal from an FM radio antenna ([http://er.jsc.nasa.gov/seh/e.html#electromagnetic radiation](http://er.jsc.nasa.gov/seh/e.html#electromagnetic_radiation) and <http://er.jsc.nasa.gov/seh/r.html#radiation>).

³ http://www.who.int/ionizing_radiation/about/what_is_ir/en/

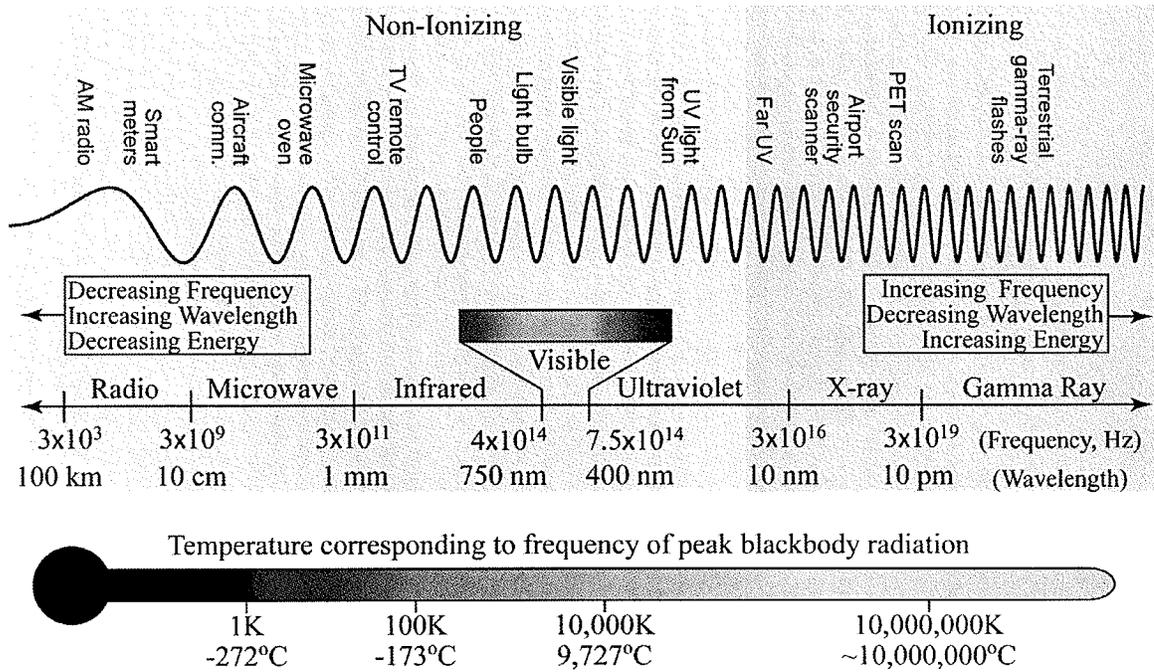


Figure 2. The electromagnetic spectrum and the relationship between frequency, wavelength, energy, and temperature.

Common Sources of Electromagnetic Fields

Modern technologies such as broadcast transmissions, radar, cellular phones, and Wi-Fi are some of the most common man-made sources of electromagnetic fields, but in fact natural sources of RF are far more common and include lightning, the earth itself, and even other organisms, including humans.

Although it is a common phenomenon, the concept that the earth and humans, as well as virtually all objects, are sources of electromagnetic fields warrants additional attention. Extremely hot objects such as the sun produce electromagnetic fields primarily in the visible and ultraviolet portions of the spectrum, while colder objects such as the earth produce fields primarily in the infrared portion of the spectrum. This phenomenon is called thermal radiation or heat radiation, while scientists refer to it as blackbody radiation.

Blackbody Radiation

Any object (i.e., blackbody) that has a temperature above absolute zero⁴ will radiate electromagnetic energy; the temperature of the object determines the frequency at which most of the electromagnetic energy will radiate. Hotter objects emit both more energy and energy at higher frequencies than colder objects.

Blackbody radiation from man-made sources

An electric stove provides a good example to illustrate how the electromagnetic energy emitted by a blackbody changes at colder and hotter temperatures. When the stove burner is first turned on it begins to heat up and produces stronger electromagnetic fields in the infrared portion of the spectrum than in the visual portion. This means that the burner still appears the same (black) but the electromagnetic energy can be felt by placing a hand nearby and feeling the infrared heat. Once the burner gets hot enough it begins to glow reddish-orange, which is electromagnetic energy in the lower part of the visible spectrum. Household burners cannot heat beyond this point; however if the temperature did increase further it would begin to glow a yellowish-white color (in the higher portion of the visible spectrum). At still hotter temperatures such as from a welder's torch, the light would become bluish (the highest part of the visible spectrum), and at even higher temperatures, the light from the welder's torch would be in the ultraviolet range.⁵

Blackbody radiation from natural sources

As noted above, any object that has a temperature above absolute zero radiates electromagnetic energy and it does so at all frequencies (although very small amounts at very low or very high frequencies). Since humans and the earth both have a temperature of ~300 Kelvin, they emit the most electromagnetic in the infrared portion of the electromagnetic spectrum (i.e., it can be seen with the use of infrared imagers), but a very small portion of that energy is also emitted in the

⁴ Absolute zero is the temperature at which the motion of molecules theoretically stops, which is 0 on the Kelvin scale and equivalent to about -273 degrees Celsius or about -460 degrees Fahrenheit.

⁵ The emission of this intense heat and ultraviolet light are among the reasons that welders need to wear protective glasses when performing their work.

radio and microwave portions of the electromagnetic spectrum. Humans and the earth are therefore sources of RF energy (albeit very small sources).

Radiofrequency Communications

RF fields are an integral part of modern technology; they are used in emergency beacon services, air traffic control systems, cell phones, and smart meters, to name a few. RF fields are also widely used in scientific research and many more industrial, commercial, medical, and personal applications. In addition to frequency discussed above, **power, duty cycle, reflection, and attenuation** are concepts that are common to most RF communication; these concepts are particularly important to understand how much RF energy a person may be exposed to from a variety of RF sources including smart meters. The importance of power is obvious, as higher output powers lead to higher RF signal levels. The other factors are discussed in greater detail below.

Duty Cycle

One of the important ways in which man-made sources differ from one another is in how often and in what patterns they transmit. Some sources transmit all the time at relatively constant power levels (e.g., FM radio and television broadcasts) while others transmit all the time but vary how much power is transmitted (e.g., Wi-Fi, and AM radio). Intermittent operation is used by technology that only transmits based on data transfer needs and user demand. For example, smart meters transmit only when they need to transfer data; microwave ovens only emit RF fields when they are used; and cell phones transmit both based on user demand and when they interact with the mobile network.⁶

In the case of RF exposure to sources, these transmission patterns can be simplified into a “duty cycle” of a source. Duty cycle is determined as a percentage of time a source is used based on how often the source transmits information, and the duty cycle of a device that utilizes an intermittent transmission pattern can be reported as either an operational duty cycle or an

⁶ Some cell phones may also change transmission power output based upon circumstances while smart meters always transmit with the same power output.

average duty cycle. For example, sources that transmit continuously, whether at constant or varying power, have a duty cycle of 100%.

The duty cycle of a source with an intermittent transmission pattern will vary depending on use. For example, a CDMA cell phone used for 6 minutes in a 30-minute period has an *operational* duty cycle of 20%, while one used for 1.5 minutes in a 30-minute period has an *operational* duty cycle of 5%.^{7,8} In contrast, a smart meter sends information in a series of short transmissions typically of a few hundred milliseconds or less. The duty cycle of DLC smart meters depends on a number of factors (discussed in more detail in the following Section); these units have an *average* duty cycle near 0.06% (transmitting for only a few seconds per day) and a maximum expected duty cycle is 0.58%.⁹

Reflection and Attenuation

When an electromagnetic wave reaches a boundary (such as the ground or a wall) part of the energy from the wave will reflect from that boundary and some will be transmitted through. The amount of energy reflected and the amount that passes through depends both on the frequency of the electromagnetic wave and on the material properties of the boundary.

The building materials of an individual's home can therefore have a significant effect on a person's RF exposure from external sources. For an example at the frequency of smart meters or cellular phones, an 8-inch thick concrete wall allows less than 1% of incident RF energy

⁷ CDMA stands for "Code-Division Multiple Access." When a call is made, a CDMA phone transmits continuously. This calculated *operational* duty cycle example should not be confused with the duty cycle of the emission of a CDMA telephone when in use.

⁸ GSM stands for "Global System for Mobile" communications and is another communication technology used by cellular phones. Rather than transmitting continuously, a GSM phone transmits only 1/8th of the time, but at 8 times the power of a CDMA transmission. The duty cycle *of the emissions* from a GSM telephone when in use is therefore 12.5%. If a GSM phone is used for 6 minutes in a 30-minute period then the total duty cycle is the product of the operational duty cycle and the duty cycle of the emissions: 20% x 12.5% = 2.5%.

⁹ Respondent's Responses to Set #1 of Discovery Requests, Question 1f.

through; while a 3.5-inch thick brick wall allows about 45% of the energy through, and a 0.75-inch thick plywood wall allows over 80% of the energy through (NIST, 1997).¹⁰

Distance from the Source

While a boundary will cause some of the energy in an electromagnetic wave to reflect (i.e., attenuate), distance from the source also causes attenuation, even if the wave does not pass through any material that causes it to lose energy. This attenuation is due simply to the expansion of the wave, similar to the motion of water described above. When the wave is transmitted, it has a finite amount of energy concentrated at the source. As the wave expands, this same amount of energy is spread out over a larger and larger area so that the amount of energy in any particular location decreases as the wave gets farther from the source. The power density of the RF field decreases with the square of the distance from the source according to the inverse-square law.¹¹ So, an individual located 10 yards away from a source will be exposed to 100 times less RF energy than an individual located 1 yard away from the same source.

¹⁰ At lower frequencies, such as those used in television or radio broadcast, the fraction of energy that passes through these materials is substantially higher.

¹¹ A discussion of the inverse square law specific to smart meters is provided in Appendix C.

2. Smart Meters and Mesh Networks

The primary purpose of smart meters in the DLC network is to record electricity usage at residences and other buildings and transmit that usage wirelessly back to DLC. The smart meters used by DLC communicate in the frequency range of 902 to 928 MHz.¹²

Most radio communication devices used in the United States must be certified by the FCC. The FCC certification number for the Itron Centron smart meters deployed by DLC is SK9AMI7, according to which, the transmission power of these smart meters is less than 1 watt (W).

Smart Meter Mesh Network

A smart meter mesh network is a collection of smart meters deployed in the same geographic area. The term mesh network derives from considering each smart meter as a node and visualizing the communication paths between each node as lines. When all the nodes in their respective locations are connected to one another by drawn lines, the resulting picture looks like wire mesh. Each smart meter in the network has the capability of communicating with other nearby smart meters as well as with cell relays, which act as collection units. The role of the collectors within the mesh network is to gather the data from the individual smart meters and send the information back to the utility company.

A smart meter network operates by transmitting information at a low power level to a nearby neighbor (a 'hop'). This second smart meter transmits information onward, also at a low power level, and this step is repeated from smart meter to smart meter in several hops until the information from all the smart meters in the chain reach the collector. Figure 3 illustrates the hopping process to a collector (cell relay). The most efficient communication paths are shown by solid black arrows, typically using the shortest individual hops to get back to the cell relay. The gray arrows show alternate paths that can be used if a bottleneck or fault occurs.

¹² The Itron Centron smart meters are also capable of communicating in Industrial, Scientific, Medical (i.e., ISM) radio bands in the 2.4 to 2.5 GHz range via an IEEE standard 802.15.4 Zigbee Radio, at much lower power output of approximately 65 mW.

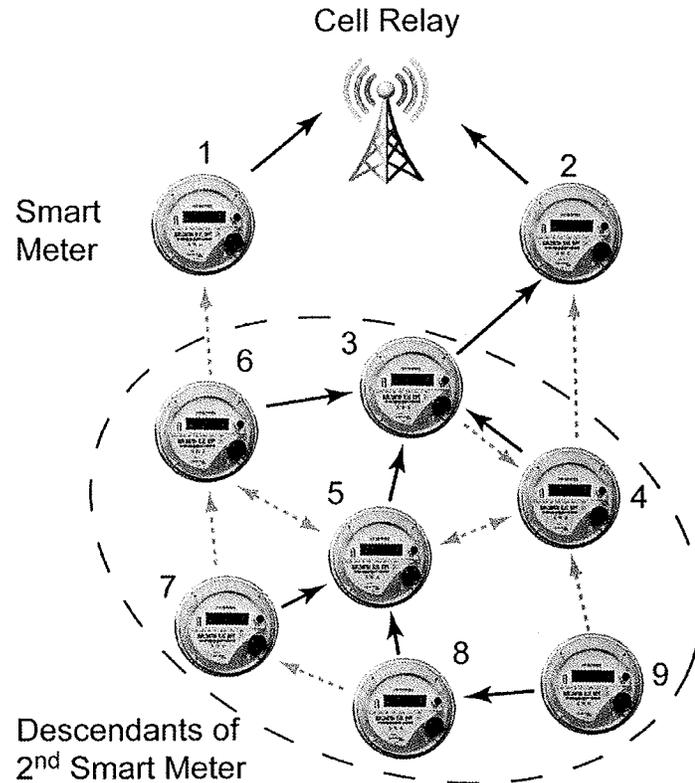


Figure 3. Illustrative example of a smart meter mesh network.

The close proximity of neighboring smart meters and the ability to communicate with one another is one of the primary advantages of a mesh network. Transmissions between nearby smart meters can be made with relatively low power levels while if meters could only communicate with the collectors then only smart meters physically close to collectors could transmit efficiently at lower power; more distant smart meters would need to transmit significantly more power.¹³ In Figure 3, smart meters 1 and 2 are close enough to interact directly with the collector while smart meters 3 through 9 are too far from the collector to interact directly and use hops to transmit to smart meter 2 for transmission to the collector. Since smart meters 3 through 9 eventually transmit their data to smart meter 2, they are called descendants of smart meter 2. This scenario illustrates that while many smart meters will transmit only their own data, most meters will also transmit the data of descendant meters.

¹³ For example, a smart meter located approximately 500 yards from a communicator would need to transmit a signal about 10,000 times stronger than a smart meter located 5 yards away from the collector.

Typical Smart Meter Operation

Unlike other common devices that communicate using RF fields, the amount of data a smart meter transmits is very small so they only need to communicate for a very short time each day. According to DLC, there are two to three scheduled data requests from each smart meter every 24 hours. In addition to these scheduled data requests, each smart meter must confirm its capability to connect with at least one other smart meter to maintain the communication capability of the network. This communication occurs approximately every 30 minutes by sending out a very brief beacon signal transmission.¹⁴

Smart Meter Duty Cycle

The amount of data each smart meter transmits will vary widely depending on where it is located within the mesh network and the amount of data it must transfer from descendants. The minimum, average, and maximum duty cycles in the DLC smart meter network are summarized in Table 1. Additional analysis regarding the OpenWay network indicates that the vast majority (97.95%) of smart meters in the DLC network transmit for less than 100 seconds per day, a duty cycle of less than 0.12% per day (Itron, 2011).

Table 1. Duty cycle of DLC smart meters*

Duty Cycle Description	Duty Cycle Value
Minimum	0.02% (18.31 seconds per day)
Average	0.06% (53.14 seconds per day)
Maximum	0.58% (497.8 seconds per day)

* Information received from DLC

Home Area Network

In addition to the RF signals used by smart meters to communicate within the mesh network (the Local Area Network [LAN]), each smart meter is also equipped with a second RF transmitter (i.e., a Zigbee Radio) that transmits at 2.4 gigahertz (GHz) and allows the smart meter to communicate over a Home Area Network (HAN). If the consumer chooses, the HAN

¹⁴ A description of how a new smart meter initially connects to the mesh network is described in Respondent's Responses to Set #1 of Discovery Requests, Question 1k.

allows compatible appliances in the home to interact with the smart meter and evaluate how much power that appliance consumes relative to the total power consumption of the home. The transmission power of the Zigbee Radio is approximately 10 times lower than that of the RF LAN signal from the smart meter due to the smaller distance over which communication needs to take place. The duty cycle of the Zigbee Radio is shown below in Table 2 for an idle Zigbee Radio (with no devices joined) or a meter with an example device joined (an In-home display).

Table 2. Duty cycle of the Zigbee Radio in DLC smart meters

Duty Cycle Description	Duty Cycle Value
Idle Zigbee Radio (no devices joined)	0.01% (9.9 seconds per day)
Meter with Tendril HD (In Home Display)	0.15% (132 seconds per day)

* Information received from DLC

3. Standards for Radiofrequency Fields

In the United States, the government agency responsible for regulating RF-emitting devices is the FCC. These regulations are included in the Code of Federal Regulations Title 47 (§1.1310 and §2.1093) and are based upon the recommendations of organizations such as the National Council for Radiation Protection and the Institute of Electrical and Electronics Engineers (IEEE), and input from federal health agencies including the Environmental Protection Agency, National Institute for Occupational Safety and Health, and the Occupational Safety and Health Administration. The IEEE developed exposure limits for electromagnetic fields based on lengthy and comprehensive assessments of the scientific literature, a process also undertaken by other international agencies such as the European-based International Commission on Non-Ionizing Radiation Protection (ICNIRP).

These limits restrict the amount of energy the FCC has determined that the body can safely absorb without adverse effect. This is described as the specific absorption rate (SAR) and is measured in units of watts per kilogram (W/kg). This quantity is difficult to measure in practice, so the FCC also provides a maximum permissible exposure (MPE) which limits the strength of an RF field outside the body which is more easily measured. The FCC limits for the general public at frequencies of smart meter transmissions (900 MHz and 2.4 GHz) are summarized in Table 3 along with the current IEEE and ICNIRP standards, which incorporate safety factors of 50 or more.^{15,16}

¹⁵ The FCC, in OET 56, 1999, states that the, "...exposure criteria are based on a determination that potentially harmful biological effects can occur at an SAR level of 4 W/kg as averaged over the whole-body. Appropriate safety factors have been incorporated to arrive at limits for both whole-body exposure (0.4 W/kg for "controlled" or "occupational" exposure and 0.08 W/kg for "uncontrolled" or "general population" exposure, respectively) and for partial-body (localized SAR), such as might occur in the head of the user of a hand-held cellular telephone."

¹⁶ Additional details regarding the exposure limits, averaging times and body locations where SAR limits are defined are provided in OET 65, 1997, and OET 56, 1999, among others.

Table 3. Exposure limits specified by the FCC, IEEE, and ICNIRP

Agency	Power Density Limit at 900 MHz (W/m ²)	Power Density Limit at 2.4 GHz (W/m ²)	SAR Limit (W/kg)
FCC (CFR §1.1310 and §2.1093)	6	10	0.08 (Whole body) 1.6 (over any 1 gram of tissue)
ICNIRP (1998)	4.5	10	0.08 (Whole body) 2 (over any 10 gram of tissue)
IEEE, (C95.1, 2005)	4.5	10	0.08 (Whole body) 2 (over any 10 gram of tissue)

4. Sources of Radiofrequency Fields

General Sources

There are a multitude of RF sources in modern society each of which has the potential to contribute to the RF exposure of the Complainants either in their home, work, or other places they may frequent. A graphic illustration in Appendix B, Figure B-1, depicts these various RF portions of the radio spectrum, and illustrates how the many hundreds of RF communication bands are used. For simplicity the many potential sources described in this figure are not included in the below assessment although clearly the Complainants are potentially exposed to numerous sources beyond those considered here.

Natural Sources

As discussed in the introduction, RF is produced through blackbody radiation from warm objects such as from the earth itself and from people. The representative RF exposure values for the earth and humans are summarized in Table 4 (ICNIRP, 2009).

Table 4. RF exposure values for common natural RF sources

Source	RF Exposure (mW/cm ²)	RF Exposure (% of FCC Limit)
Blackbody radiation from the earth	1.3	0.0027
Blackbody radiation from humans	3	0.0054

Sources Specific to the Complainants

In Response to Question 1 of DLC's Second Set of Discovery Requests Directed to Complainants (hereafter referred to as DLC's Question 1), the Complainants provide a list of some RF devices used within the residence including a cellular phone, a Wi-Fi router, a custom computer with a USB Wi-Fi adapter, and a video game console, among others. The RF emissions from each of these devices have been evaluated according to the FCC equipment authorization program (as are all RF emitting devices sold in the United States), administered by the Office of Engineering and Technology (OET).

During the certification process each device is assigned an FCC ID number, and is referenced for all associated records. The FCC-reported RF exposure, for five of the devices identified by the Complainants, as well as for the Itron smart meters, is summarized below in Table 5.

The FCC evaluates the mobile phones on the basis of SAR, which is a measure of how much energy is absorbed by the body and is measured in units of W/kg. The FCC evaluates other sources in terms of power density, which is a measure of the strength of the electromagnetic wave and is reported in units of watts per square meter (W/m^2) or milliwatts per square centimeter (mW/cm^2) where $1 mW/cm^2$ equals $10 W/m^2$.

Of note is that these results are presented for a specific scenario (e.g., mobile phone held against the head of an RF phantom, or calculation of power density at a distance of 20 centimeter from the smart meter) and do not include the effects of either distance or duty cycle on the potential exposure of persons within the Complainants' residence. A discussion of how these factors may affect RF exposure is presented in the following section.

Table 5. RF exposure from sources within the Complainants' residence as well as from the Itron smart meters as reported in FCC compliance filings.

Device/module	FCC ID	Compliance Test	Applicable FCC Limit	Location of Compliance Measurement	Measured RF Exposure	Percent of FCC Limit
Mobile Phone	A3LSMN900V	SAR	1.6 W/kg	Head	0.63 W/kg	39%
Wireless USB Adapter (from desktop computer)	PY309300115	Power Density	1 mW/cm ²	3 m from device*	0.000024 mW/cm ²	0.0024%
Wireless Router	LNQMI424WR1			20 cm from device	0.059 mW/cm ²	5.9%
Video Game Controller	C3K1403				0.00044 mW/cm ²	0.044%
Video Game RF Module	C3K-RF02				0.00056 mW/cm ²	0.056%
Smart Meter (LAN Radio)	SK9AMI7	Power Density	0.6 mW/cm ²	20 cm from device	0.227 mW/cm ²	38%
Smart Meter (Zigbee Radio)			1 mW/cm ²		0.031 mW/cm ²	3.1%

* The wireless USB adapter also reported a localized exposure (1 gram SAR) of 1.04 W/kg (65% of the applicable 1.6 W/kg FCC limit).

5. RF Exposure Assessment

An RF exposure assessment requires the evaluation of the total RF exposure of a person to all RF sources in his or her environment. In this assessment, it is important to include all sources (both natural and man-made) because any potential effects of RF fields on humans will be based upon the total exposure from all sources, not the incremental exposure to a single source.

The approach that all RF sources need to be included in an RF exposure assessment is also the conclusion adopted by the FCC and the IEEE standard upon which the FCC limits are based (as well as those of other national and international organizations such as ICNIRP [ICNIRP, 1998]). Since the FCC specifies different exposure limits for different frequencies within the RF spectrum, they recommend that total exposure be calculated from the weighted sum of RF exposure from each of those sources.

RF Exposure from Sources Specific to the Complainants

In the previous section the RF emissions reported by the FCC were discussed and listed in Table 5, but did not account for important factors such as distance from the source, duty cycle, or attenuation from wall materials. A discussion of the effects of each of these parameters is outlined below to provide a background in the exposure assessment for the Complainants. The calculation methods are described in Appendix C.

The most important factors to consider in the exposure scenario are those of distance from the source and duty cycle (or equivalently, usage). To illustrate the potential effect these factors may have on the total exposure, the values reported by the FCC and listed in Table 5 are re-calculated to account for an example distance from the source and a typical duty cycle. The results of this analysis are shown in Table 6. Comparison with Table 5 shows that distance and duty cycle can have a large effect on the potential level of exposure. The FCC reports that use of the cellular phone for 30 minutes would result in an exposure of 39% of the FCC limit (as shown Table 5) while a 5-minute phone call results in only 6.6% of the FCC limit. Similarly, exposure at a distance of 20 centimeters (~8 inches) directly in front of the smart meter for

constant transmission (100% duty cycle) results in an exposure of 38% of the FCC limit as shown Table 5, while at the average duty cycle of 0.06%, the exposure at 1 yard directly in front of the smart meter is 0.0029% (1/35,000th) of the FCC limit and at 1 yard behind the smart meter is 0.00013% (1/780,000th) of the FCC limit (Table 6).^{17,18}

Table 6. Example calculations of RF exposure for sources at the Complainants' residence

Source	Distance from source	Duty Cycle (in a 30-minute period)*	Calculated value (% of FCC limit)
Mobile Phone	Used at head	5 minute call	6.6
Wireless Router	10 feet	5 minutes of use	0.0042
Video Game Controller	1 foot	5 minutes of use	0.0031
Video Game RF Module	1 yard	5 minutes of use	0.00045
Wireless USB Adapter (from desktop computer)	10 feet	5 minutes of use	0.00040
Smart Meter LAN (Inside, Average) ^{†,§}	1 yard	0.06%	0.00013
Smart Meter LAN (Outside, Average)	1 yard	0.06%	0.0029

* The FCC specifies a 30-minute averaging period in assessing RF exposure.

† The exposure from the smart meter inside the home will be reduced by the exterior wall material, assumed to be brick. As described in Table 5, only 45% of the energy incident on the outer wall will penetrate into the residence. This factor is included in the calculation of exposure due to the smart meter inside the residence.

§ The smart meter preferentially transmits in the forward direction. The amount of energy transmitted toward the back of the smart meter is approximately 10% that of the forward direction (EPRI, 2010). This factor of 10% is included in the calculation of exposure due to the smart meter inside the residence.

RF Exposure Scenario for the Complainants

The previous discussion described the RF exposure from sources at the Complainants' residence over which the Complainants have varying degrees of control. Like all people in modern society, however, the Complainants encounter a large number of other RF sources in their daily lives, the exposure from which they will have little or no control. Some examples of these

¹⁷ Note that calculations both 1 yard in front of and 1 yard behind the smart meter include a 'ground reflection' increase factor of 2.56, which is not included in the FCC certification document. This factor of 2.56 is referenced by the OET for powerful distant sources such as radio or television transmissions. It is included here in an abundance of caution so as to overestimate the contribution of the smart meter.

¹⁸ These exposures are also far below the IEEE and ICNIRP guidelines discussed above.

sources include the local television stations WPCB-TV, WTAE-TV, WQED, etc., as well as local radio stations such as WAMO, WEDO, KQV, WPGR, WZUM, etc.^{19,20} In addition, both the earth and other people also are sources of RF exposure in the form of blackbody radiation as discussed in Section 1 and quantified in Section 3.

Figure 4 shows a graphic comparison of the estimated exposure for the sources at the Complainants’ residence as outlined in Table 6. Also included are the blackbody exposure from the earth and people as well as the cumulative contribution of local radio and television broadcast signals. The exposure of each source relative to the FCC limits (sorted from smallest to largest) is shown beneath a graphic of each source, as well as the factor describing how much larger that exposure is than the exposure from an average smart meter. This figure demonstrates that not only does the RF exposure from a smart meter inside a residence represent a tiny fraction of the FCC allowable limit, but that the exposure from other sources both inside and outside the residence are many times greater than that from the smart meter.

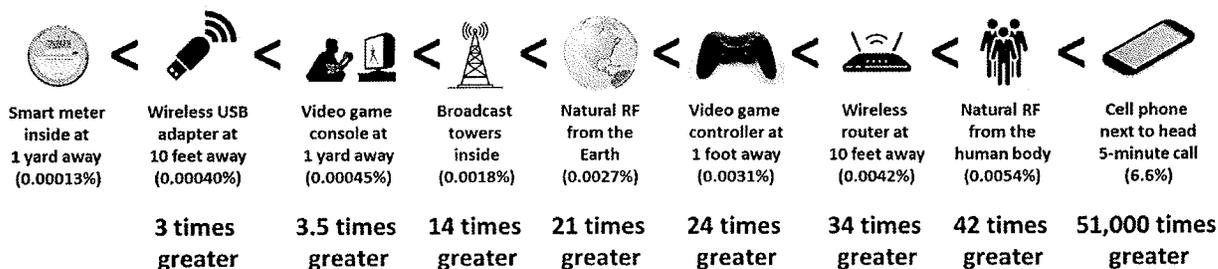


Figure 4. RF exposure of smart meters relative to other RF sources.

The RF exposure as a percentage of FCC limits is shown beneath each graphic in parentheses and a comparison of how much greater each exposure is than the smart meter is shown below that in bold font.

¹⁹ The calculated value for “Broadcast towers inside” includes the same ~45% transmission factor as was used for the smart meter. In reality a much higher fraction of the incident energy from television or radio broadcast will pass through the walls. The exposures of the Complainants from these sources is therefore likely to be much higher than presented here.

²⁰ Other sources such as mobile phones and other communication devices used by friends and neighbors in their neighborhood are not included so the calculated level in the category “Broadcast towers inside” is lower than what is likely present at the Complainants’ residence.

The comparison of exposures shown in Figure 4 represents a simple comparison of some of the relevant exposures for a specific scenario. A more detailed description of the exposure scenarios is shown below in Figure 5 in which the RF exposures are plotted as a percentage of the FCC limit in a bar graph. In order to show the very small exposures on the same scale as the larger sources, the results are presented on a logarithmic scale where each vertical tick in the axis represents an increase by a factor of 10. The graphic is divided into two sections. The “RF Exposures in General Environments” portion shows the general background of RF energy encountered in rural, suburban, and urban environments, and is included to provide context of typical background levels reported in peer-reviewed literature (Joseph et al., 2012). The “Local RF Sources” portion compares the RF exposures from each of the items discussed above in Figure 4. In this figure, additional scenarios for the DLC smart meter are shown for potential exposure to a smart meter outside, as well as potential exposure inside from the Zigbee Radio.

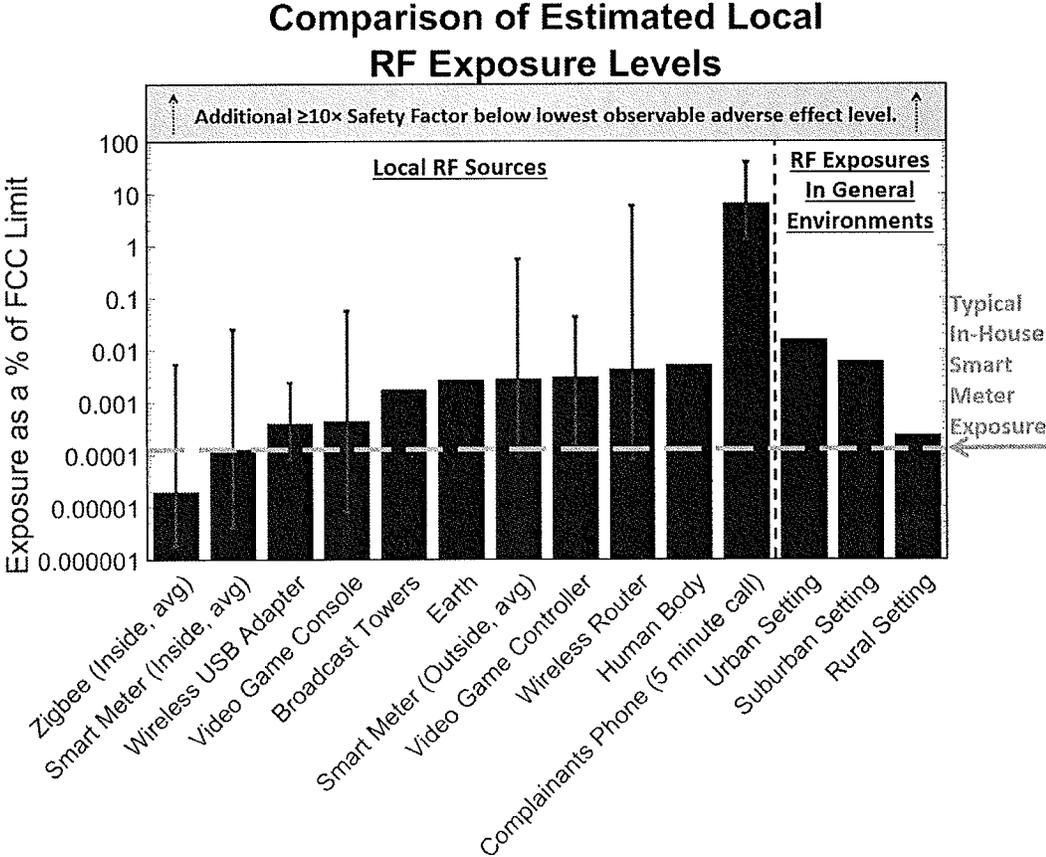


Figure 5. Comparison of RF exposure from the RF-LAN and Zigbee signals to RF exposure from other sources under typical use. The RF exposures in general environments are reported in Joseph et al. (2012).

In addition to the bar graphs, a red line is shown above the sources particular to the Complainants to provide an indication of the potential variability in the exposure of some of the sources. As an example, the exposure from the hypothetical smart meter (both inside and outside) is detailed in Table 7. The “Inside Average” exposure (first blue bar in Figure 5) is calculated at a distance of 1 yard behind the smart meter using an average duty cycle of 0.06%. In addition, this calculation accounts for smart meters preferentially transmitting in the forward direction so that the amount of energy directed toward the house is approximately 1/10th that transmitted away from the house (EPRI, 2010). The calculation also accounts for attenuation of the signal when passing through the bricks on the front of the house (only about 45% of the signal penetrates through the bricks).²¹ Similar variability estimates are also provided for the other sources identified by the Complainants. Details of these calculations are provided in Appendix C.

Table 7. Example variability of smart meter in different exposure scenarios

Scenario	Forward/Back Transmission factor	Transmission through Wall Material (%)	Distance from Smart Meter	Duty Cycle	Calculated Value (% of FCC Limit)
Inside Minimum	0.1	0.45	10 feet	0.02%	0.0000041%
Inside Average	0.1	0.45	1 yard	0.06%	0.00013%
Inside Maximum	0.1	0.45	~8 inches	0.58%	0.025%
Outside Minimum	1	1	10 feet	0.02%	0.000091%
Outside Average	1	1	1 yard	0.06%	0.0029%
Outside Maximum	1	1	~8 inches	0.58%	0.56%

Additional Discussion

The highest calculated exposure due to the smart meter at the residence was evaluated at a distance of 20 centimeters (approximately 8 inches) from the smart meter at the maximum duty cycle of 0.58% (approximately 500 seconds per day). This maximum calculated exposure is approximately 0.56% of the FCC limit directly in front of the smart meter or 0.025% of the FCC limit behind the smart meter in the house. This duty cycle is far higher than average and far higher than the vast majority of smart meters because 97.95% of DLC smart meters transmit for less than 100 seconds per day, a duty cycle of less than 0.12% per day (Itron, 2011). The

²¹ Both indoor and outdoor calculations also include the conservative ‘ground reflection’ factor of 2.56 included by the OET 65 (FCC 1997)

exposure then would be about five times lower than calculated above for the maximum duty cycle. Furthermore, the calculations above are performed at a close distance of approximately 8 inches in front of or behind the smart meters. At greater distances, the exposure from smart meter signals will be far less. The RF exposure from a smart meter approximately 6 feet away will be only $\sim 1/100$ that of the exposure of the meter at approximately 8 inches.²² As noted by the FCC, the RF from smart meters would comply with the FCC's limits on SAR even if held against the body or clustered together at one location (Knapp, 2010).

Another way to contextualize RF exposure from different sources is to determine the distance from a particular source at which the RF exposure from that source is the same as RF exposure from the earth. For a DLC average smart meter indoors (shown in Table 7), this distance is approximately 8 inches from the smart meter.²³ At distances greater than approximately 8 inches, the RF exposure from an average DLC smart meter is less than the RF exposure one constantly receives from the earth.

²² For the unrealistic scenario in which the smart meter performs all transmissions within a single 30-minute period, the duty cycle would be approximately 28% and the exposure from the smart meter at a distance of 1 yard behind the smart meter in the residence would be about 0.57% of the FCC limit in that 30-minute period. At a distance of ~ 8 inches in front of the smart meter and assuming that all transmissions occur within a single 30-minute period, the exposure from the smart meter would be less than 27% of the FCC limit, while at a distance of 1 yard the exposure for this scenario would be approximately 4% of the FCC limit.

²³ This calculation assumes the decrease in field level follows the inverse square law.

6. Conclusions

A smart meter mesh network operates by transmitting information to neighboring smart meters and passing this information from smart meter to smart meter in several hops. This network architecture allows the smart meters to operate using low power levels. Furthermore, since required information transfer is relatively limited, smart meters only transmit a small fraction of the time.

An investigation into the potential RF exposure from smart meters in the context of other sources has shown two key features. Not only does the RF exposure from a smart meter inside a residence represent a tiny fraction of the FCC allowable limit, but that the exposure from other sources both inside and outside the residence are many times greater than from a DLC Itron smart meter.

In particular, calculations have shown that the contribution of a typical smart meter to RF exposure indoors would be more than 40 times less than the natural RF emitted by people and thousands of times less than the RF exposure from devices currently used within the Complainants' residence. The contribution of a typical DLC smart meter to the Complainants' exposure indoors is less than the RF exposure from other existing internal and external sources and only 0.00013% (1/780,000th) of the FCC's health-based exposure limit.

7. Facts Relied Upon

In this analysis, I have relied upon facts about the characteristics of the DLC smart meters manufactured by Itron, as summarized in Table 8.

Table 8. Characteristics of Itron smart meters relied upon

Parameter	Value	Reference
Power Output of Itron Smart Meters	688.65 mW	FCC ID: SK9-AMI7
Gain of Itron Smart Meter Antenna	1.66	FCC ID: SK9-AMI7
Minimum Duty Cycle of DLC Smart Meters	0.02%	Third Supplemental Responses to Set #1 of Discovery Requests
Average Duty Cycle of DLC Smart Meters	0.06%	Third Supplemental Responses to Set #1 of Discovery Requests
Maximum Duty Cycle of DLC Smart Meters	0.58%	Third Supplemental Responses to Set #1 of Discovery Requests

In this report I have also relied upon the FCC certification reports of other products listed in the Complainants' response to DLC Question 1 as well as peer-reviewed research papers, comprehensive reviews of subject matter by internationally-recognized organizations, and publications of national standards. The information relied upon is cited in text and the full source is documented in Section 8 – References.

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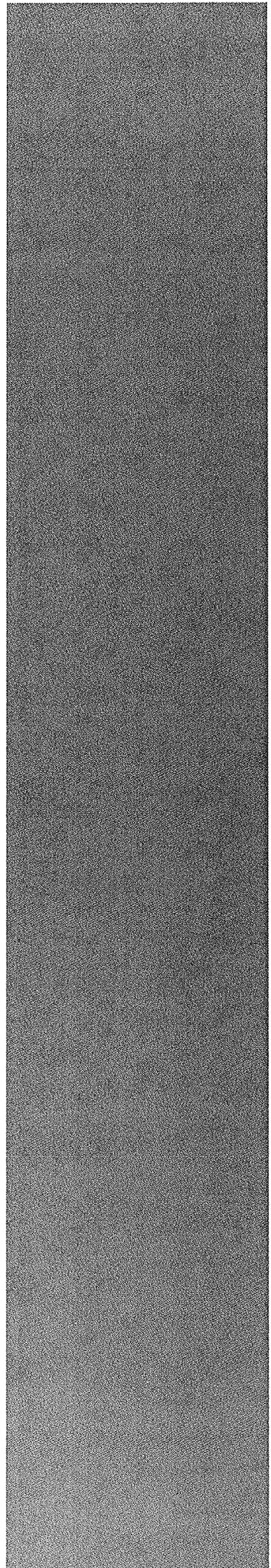
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Limitations

At the request of DLC, I performed an assessment of RF fields related to Itron smart meters deployed by DLC. The scope of services was determined by the circumstances associated with this case as well as applicable codes, rules, and regulations. The findings presented herein are made to a reasonable degree of engineering and scientific certainty. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation.

Appendix A

Educational Background, Qualifications, and Curriculum Vitae



Qualifications and Education

I am a Senior Managing Engineer in the Electrical Engineering and Computer Science Practice at Exponent Inc., an international science and engineering firm. My work address is 17000 Science Drive, Suite 200, Bowie, MD 20715.

I earned my Bachelor of Science degree *summa cum laude* in Electrical Engineering from the University of Portland as well as a Master's of Science degree and a Doctor of Philosophy degree in Electrical Engineering from Stanford University. I am a member of several technical organizations including the IEEE and the International Council on Large Electric Systems. I am a member of the IEEE Power Engineering Society Corona and Field Effects Working Group as well as the International Committee on Electromagnetic Safety, Subcommittees 3 and 4.

I am the author of numerous peer-reviewed papers and conference presentations on the topic of electromagnetic fields and the earth's geomagnetic field, as listed in my *curriculum vitae*. I was also the co-founder of an international conference series established under the auspices of the United Nations with the purpose of bringing the science of electromagnetics to developing countries and to assist in starting doctorate-level research programs in electromagnetics in those countries.

I have expertise in both applied and theoretical electromagnetics including modeling, measurement, and analysis studies of natural and manmade radiofrequency (RF) fields in the earth's environment. I regularly assist clients in evaluating RF fields from varied sources ranging from portable diesel generators to *ad hoc* networks (such as the mesh network established by smart meters) to government/military communication facilities (high-frequency band through microwave-frequency band). My work includes the evaluation of RF exposure with respect to electromagnetic interference to devices and the safety of medical and non-medical devices. My expertise is requested by federal agencies, utilities, construction developers, and patients with implanted medical devices, their physicians, and their employers.



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Professional Profile

Dr. Cotts is experienced in both applied and theoretical electromagnetics and plasma physics including modeling and measurement analyses of natural and anthropogenic electromagnetic fields such as space weather, and geomagnetic storms as well as in the initiation, field effects, and characteristics of lightning discharges. Dr. Cotts performs modeling and measurement studies of power system (AC and DC), field effects including EMF, audible noise, and radio noise as well as radiofrequency EMI and EMC assessments for clients such as federal agencies, utilities, construction developers and the U.S. military.

Dr. Cotts also performs various types of electromagnetic field evaluations for devices and systems including portable diesel generators, smart meter mesh networks, government/military communications facilities, and transmission and distribution lines (including corona and field effects). In addition, Dr. Cotts regularly receives requests to perform exposure assessments for patients with pacemakers, ICDs, and other implantable medical devices and is an officer in the IEEE working group for Corona and Field Effects overseeing IEEE standards 644, 430, 656, 1542, 1227 and 1308.

Dr. Cotts has been a leading figure in coordinating scientific outreach to developing countries through the United Nations International Heliophysical Year (IHY) and International Space Weather Initiative (ISWI) programs and was a founding member of a NASA/UN-sponsored conference series organized and led multiple conferences on atmospheric and space science.

Dr. Cotts's has a decade of experience with the initiation, field effects, and propagation of lightning discharges; combining remote sensing measurements of ionospheric disturbances with numerical modeling of atmospheric, ionospheric, and magnetospheric interactions to determine the role of global lightning on the removal of radiation belt electrons. These radiation belt electrons are a critical factor in space weather for determining the effective lifetime of spacecraft with electronics that can be irreversibly damaged by radiation belt electrons.

Additionally, Dr. Cotts software engineering experience includes the use of Matlab, C, C++, and a variety of other scientific packages including Mathematica and COMSOL. He has experience with auditing software processes and algorithms used during his investigations related to control systems involved in failure events.

Academic Credentials & Professional Honors

Ph.D., Electrical Engineering, Stanford University, 2011

M.S., Electrical Engineering, Stanford University, 2004

B.S., Electrical Engineering, University of Portland, summa cum laude, 2002

Outstanding Student Paper Award, AGU Fall Meeting, San Francisco, California, 2004

Tau Beta Pi Engineering Honor Society

Delta Epsilon Sigma, National Scholastic Honor Society

Awarded the "2014 Fire Protection Research Foundation Medal" by the NFPA's Fire Protection Research Foundation for the 2013 research project ("Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results") that best exemplified the Foundation's fire safety mission at the National Fire Protection Association's Conference & Exposition, June 2014

Licenses and Certifications

Licensed Professional Electrical Engineer, California, #21277

Prior Experience

Post Doctoral Scholar, University of Colorado, Denver, 2011

International Science Outreach Manager, Stanford University, 2007-2011

Research Assistant, Stanford University, 2002-2011

Energy Research Fellow, Stanford Linear Accelerator Center, 2001

Professional Affiliations

Institute of Electrical and Electronics Engineers — IEEE

International Committee on Electromagnetic Safety — ICES

International Council on Large Electric Systems — CIGRÉ

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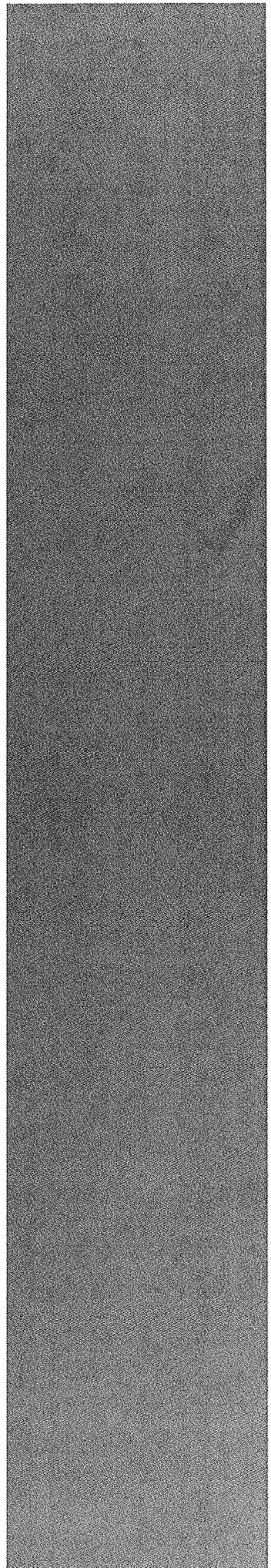
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Appendix B

FCC RF Usage Spectrum Charts



UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

ADMINISTRATIVE MOBILE	MARITIME MOBILE	AMATEUR SERVICE
ADMINISTRATIVE MOBILE SATELLITE	MARITIME MOBILE SATELLITE	AMATEUR SATELLITE
ADMINISTRATIVE MOBILE EARTH STATION	MARITIME MOBILE EARTH STATION	AMATEUR EARTH STATION
ADMINISTRATIVE MOBILE EARTH STATION IN SPACE	MARITIME MOBILE EARTH STATION IN SPACE	AMATEUR EARTH STATION IN SPACE
ADMINISTRATIVE MOBILE EARTH STATION IN SPACE (SECONDARY)	MARITIME MOBILE EARTH STATION IN SPACE (SECONDARY)	AMATEUR EARTH STATION IN SPACE (SECONDARY)
ADMINISTRATIVE MOBILE EARTH STATION IN SPACE (PRIMARY)	MARITIME MOBILE EARTH STATION IN SPACE (PRIMARY)	AMATEUR EARTH STATION IN SPACE (PRIMARY)

ACTIVITY CODE

PRIMARY/EXCLUSIVE	SECONDARY/NON-EXCLUSIVE
-------------------	-------------------------

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Power	F5073	Coastal Station
Service	Mobile	10 GHz will only use 100m

The data in this publication is derived from the Federal Register, Notices and Orders of the FCC and the FCC's Bureau. It is not intended to be a substitute for the FCC's rules and regulations. For more information, please visit the FCC's website at www.fcc.gov.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
JANUARY 2016

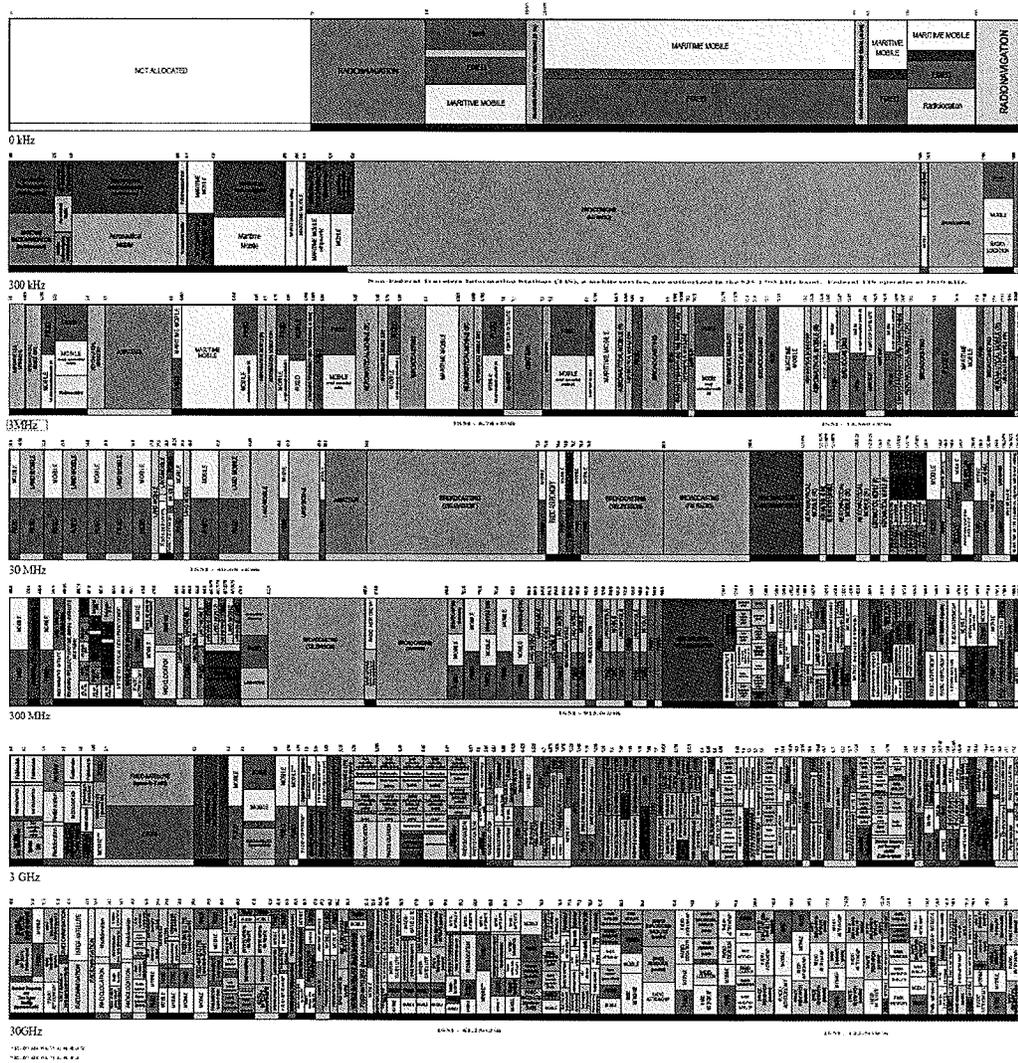
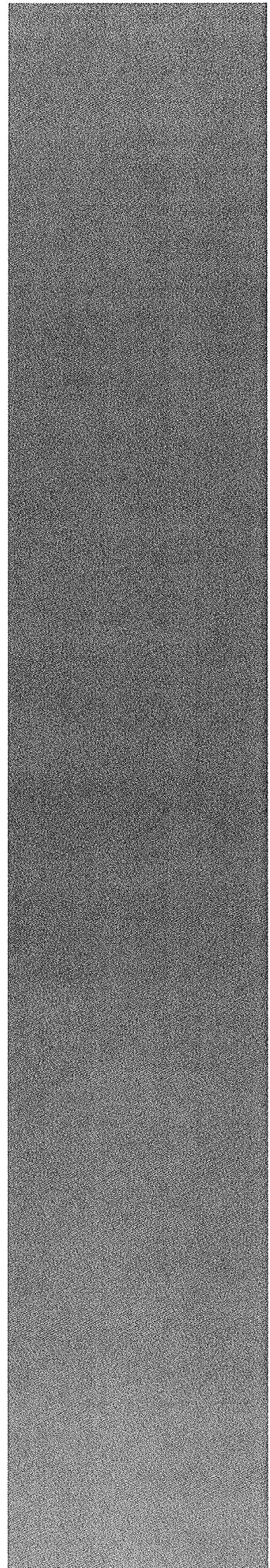


Figure B-1. Radio Spectrum Allocations in the United States

Appendix C

Example Exposure Assessments for the Complainants



When an Itron smart meter is transmitting, the power of that transmission is constant and so the variation in the potential exposure level (excluding the effect of any external environmental factor such as walls or distance) is determined by the duty cycle of a particular smart meter. Using a duty cycle consistent with the minimum, average, and maximum duty cycles of Itron smart meters (0.02%, 0.06% and 0.58%, respectively), it is possible to calculate exposure levels from a smart meter based upon the duty cycle (at a particular distance).²⁴

Exposure calculation formula

The exposure to RF energy from a smart meter (as well as most other sources of RF not used in close proximity to the body) is based upon computational modeling recommended by the FCC (OET 65) which is used to calculate the power density (S) of a signal at a distance R from the transmitter, with an input power P, an antenna gain G, transmission coefficient, T and a duty cycle of δ . The applicable formula is:

$$S = 2.56 \frac{PGT}{4\pi R^2} \delta$$

The factor of 2.56 is used to include the potential reflection of the signal from the ground that may increase the exposure above the case using the standard the inverse square law. This factor of 2.56 is applied by the OET to far-away sources such as television or radio broadcast signals and is not generally applicable to the signal from a smart meter. It is included here, however, to provide a very conservative calculation of the RF exposure from the Itron smart meters. In addition, when a signal passes through some material such as a wall a portion of the energy is reflected, reducing the amount of energy that is transmitted through the material. The transmission coefficient, T, depends on the wall material, its thickness, and the frequency of the wave. For the Itron smart meters, several exposure calculations using the above formula and sources listed by the Complainants are summarized below in Table B-1.

²⁴ A smart meter transmits about one-tenth as much power in the backward direction as in the forward direction. Additional factors, such as the metal backplane on a smart meter and type of wall construction are not considered in this illustrative comparison (Electric Power Research Institute [EPRI]. An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter. Palo Alto, CA: EPRI, 2010).

Table C-1. Calculations of RF exposure for sources at the Complainants' residence

Scenario	Power (Watt)	Gain	Ground Reflection Factor (δ)	Transmission through Wall Material (T)	Distance from Source	Duty Cycle (%)
Smart Meter (Inside, min)	0.689	0.166	2.56	0.45	10 feet	0.02%
Smart Meter (Inside, avg)	0.689	0.166	2.56	0.45	1 yard	0.06%
Smart Meter (Inside, max)	0.689	0.166	2.56	0.45	~8 inches	0.58%
Smart Meter (Outside, min)	0.689	1.66	2.56	--	10 feet	0.02%
Smart Meter (Outside, avg)	0.689	1.66	2.56	--	1 yard	0.06%
Smart Meter (Outside, max)	0.689	1.66	2.56	--	~8 inches	0.58%
Zigbee (Inside, min)	0.065	2.40	2.56	0.45	10 feet	0.011%
Zigbee (Inside, avg)	0.065	2.40	2.56	0.45	1 yard	0.011%
Zigbee (Inside, max)	0.065	2.40	2.56	0.45	~8 inches	0.15%
Cellular Phone (min)	Measured SAR from FCC Certification document is 0.63 W/kg			--	Used at head	1 min call
Cellular Phone (avg)				--	Used at head	5 min call
Cellular Phone (max)				--	Used at head	30 min call
Wireless Router (min)	0.186	1.585	1	--	10 feet	1 min use
Wireless Router (avg)	0.186	1.585	1	--	1 yard	5 min use
Wireless Router (max)	0.186	1.585	1	--	~8 inches	30 min use
Wireless USB Adapter (min)	Measured power density at 10 feet is 0.00024 W/m ² *			--	10 feet	1 min use
Wireless USB Adapter (avg)				--	10 feet	5 min use
Wireless USB Adapter (max)				--	10 feet	30 min use
Video Game Console (min)	0.002	1.349	1	--	10 feet	1 min use
Video Game Console (avg)	0.002	1.349	1	--	1 yard	5 min use
Video Game Console (max)	0.002	1.349	1	--	~8 inches	30 min use
Video Game Controller (min)	0.002	0.955	1	--	2 feet	1 min use
Video Game Controller (avg)	0.002	0.955	1	--	1 yard	5 min use
Video Game Controller (max)	0.002	0.955	1	--	~8 inches	30 min use

* The wireless USB adapter also reported a localized exposure (1 gram SAR) of 1.04 W/kg (65% of the applicable 1.6 W/kg FCC limit)

Exponent®

Health Sciences Practice

**Report of Gabor Mezei, M.D.,
Ph.D.**

*Re: Francis and Michele Hriadil v.
Duquesne Light Company, Pennsylvania
Public Utility Commission Docket Number
C-2016-2571726*

**Report of Gabor Mezei, M.D.,
Ph.D.**

*Re: Francis and Michele Hriadil v. Duquesne
Light Company, Pennsylvania Public Utility
Commission Docket Number C-2016-2571726*

Prepared for

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Prepared by

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April 30, 2018

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Appendix A – Curriculum vitae of Gabor Mezei, M.D., Ph.D.

Appendix B – Agency Reviews and Opinions on Exposure to RF Fields and Health

Summary of Opinions in the *Hriadil* Matter

Based on my knowledge and familiarity with the relevant scientific literature, including the relevant weight-of-evidence reviews conducted by a number of international multidisciplinary expert panels, and the case materials presented to me in relation to the Complaint filed with the Pennsylvania Public Utility Commission against Duquesne Light Company on behalf of Francis and Michele Hriadil (*Hriadil* matter), my opinions are as follows:

1. A causal relationship between environmental exposure to radiofrequency (RF) fields, including RF fields specifically from smart meters owned and operated by Duquesne Light Company, and claims of adverse human health effects, including any cancer and non-cancer health effects in the Complaint, is not established.
2. Exposure to RF fields that is estimated in the Hriadil residence, as a result of the operation of smart meters or other sources within or outside the residence, does not have any proven adverse effect on health.
3. The materials included in the Complaint or submitted in response to the discovery requests by the Hriadils do not provide a basis for a valid scientific conclusion that low-level RF exposure, including RF fields associated with the operation of smart meters, is known to cause or contribute to the development of any adverse health effects, including cancer and non-cancer health outcomes.
4. Exposure to RF fields from smart meters does not have any proven adverse effect on health, thus, scientific research does not support the claim that RF fields from smart meters would adversely affect the health of Ms. Hriadil, who according to the Complaint is in good general health and does not claim any specific medical or health conditions.
5. Exposure to RF fields from smart meters does not have any proven adverse effect on health, thus, scientific research does not support the claim that RF fields from smart meter would adversely affect the health of Mr. Hriadil. In addition, the overall scientific evidence does not establish a causal relationship between RF exposure and any of Mr. Hriadil's medical conditions, which include, according to the medical records received,

“severe degenerative disc disease of all the lumbar spine with severe degenerative levoscoliosis”; “degenerative joint disease of the right hip”; “lumbar radiculopathy”; “colitis”; and heart palpitations with “sinus tachycardia.”

6. The overall scientific evidence does not establish a causal relationship between RF exposure and any of the medical conditions listed in the family medical history of Mr. and Ms. Hriadil, which include, according to the Complaint and the medical records received, cardiomyopathy, chronic obstructive lung disease, congestive heart failure, hypertension, peptic ulcer, mitral regurgitation, tricuspid regurgitation, aortic regurgitation, and pulmonary hypertensions.

My opinions are expressed herein to a reasonable degree of scientific and medical certainty. I reserve the right to revise my opinions as more information becomes available.

Introduction and Purpose

On October 3, 2016, a Complaint was filed in the *Hriadil* matter. Among other complaints, Mr. and Ms. Hriadil allege health risks due to exposure to RF electromagnetic fields from smart meters.

Counsel for Duquesne Light Company has asked me to evaluate case documents and the relevant scientific literature in relation to the *Hriadil* matter. I was specifically asked to provide an overview of the scientific evidence on potential health effects of RF fields, evaluate whether exposure to RF fields from the smart meters owned and operated by Duquesne Light Company near the Hriadil residence presents any health risk to Mr. and Ms. Hriadil or others, and provide a scientific evaluation of documents or other information submitted in this matter. This report summarizes my findings and opinions based on my professional qualifications, work experience, knowledge of the scientific literature on RF exposure assessment, epidemiology related to RF exposure and related scientific fields, and the reviewed case documents received in this matter. The specific materials received from Duquesne Light Company in this matter, and which I reviewed, are as follows:

1. The Complaint, including various documents attached to the Complaint by Mr. and Ms. Hriadil;
2. Responses and various documents produced by Duquesne Light Company in response to discovery requests;
3. Responses and various documents produced by Mr. and Ms. Hriadil, electronically and in hard copy, in response to discovery requests; and,
4. The Report of Benjamin Cotts, Ph.D., P.E., in the Hriadil matter.

My opinions are expressed herein to a reasonable degree of scientific and medical certainty. I reserve the right to revise my opinions as more information becomes available.

Background and Qualifications

I am a medical doctor and an epidemiologist with over 25 years of experience in health research including the conduct of epidemiologic studies of both clinical outcomes and environmental and occupational health issues. I have considerable experience in conducting and evaluating epidemiologic studies and complex health assessments and exposure characterization studies related to power-frequency and RF electromagnetic fields (EMF). I am currently a Senior Managing Scientist in the Health Sciences practice of Exponent, a scientific and engineering firm headquartered in Menlo Park, California.

Prior to joining Exponent, I was responsible for leading a multidisciplinary scientific research program at the Electric Power Research Institute (EPRI), a not-for-profit independent research organization. The research program's scientific work was aimed at addressing potential human health effects associated with residential and occupational exposure to power-frequency and RF EMF. I have submitted expert testimony on EMF and health, and have appeared as an EMF health expert before the Alberta Utilities Commission, the Connecticut Siting Council, the Kentucky Public Service Commission, the Virginia State Corporation Commission, and the *An Bord Pleanála* (the Planning and Development Board of Ireland). I was also consulted on potential health effects of EMF, including RF fields, by staff of the California Public Utilities Commission, by California Assemblyman Jared Huffman, by members and staff of the California Council on Science and Technology (CCST) during the preparation of the CCST report "*Health Impact of Radiofrequency Exposure from Smart Meters*" published in April 2011, and by the Joint Committee for Transport and Communications of the Parliament of Ireland. I was invited by the National Research Council to provide peer-review of the National Academy's Committee report titled "*Identification of Research Needs Relating to the Potential Biological or Adverse Health Effects of Wireless Communication Devices*" published in 2008.

Previous to employment at EPRI, I worked as an epidemiologist at the Toronto Western Hospital, University of Toronto, and as a practicing physician and epidemiologist at the National Institute for Dermatology in Budapest, Hungary. I trained as a medical doctor (M.D.) at the Semmelweis University of Medicine in Budapest, Hungary, and as an epidemiologist (Ph.D.) at the School of Public Health of the University of California in Los Angeles (UCLA). I

lectured at the UCLA School of Public Health, at Stanford University, and at the Electrotechnical Committee of the Hungarian Academy of Sciences, and I served as an affiliate associate professor in the Department of Environmental and Occupational Health Sciences of the University of Washington in Seattle, as a visiting scientist at the Hungarian National Research Institute for Radiobiology and Radiohygiene, and as an Associate Editor for the *Journal of Exposure Science and Environmental Epidemiology*. I was the recipient of Fogarty and Fulbright Fellowships. I am an author or co-author of over 60 scientific publications and book chapters on topics related to epidemiology of a wide range of environmental and occupational exposures (with a focus on exposure to EMF, including RF fields) and chronic diseases. A copy of my curriculum vitae is provided in Appendix A.

Health Complaints and Allegations of Health Effects in the *Hriadil* Matter

Summary of Mr. and Ms. Hriadil's Medical History

According to the case-specific materials received, Ms. Michele Hriadil is 62 years old, “elderly and generally in good health, and desires to stay that way.” Responses to discovery requests indicated that Ms. Hriadil’s family medical history includes cardiomyopathy and chronic obstructive lung disease. No further information regarding Ms. Hriadil’s past medical history was provided in the case-specific materials received. According to the Hriadils’ responses to discovery requests, Ms. Hriadil “is making no claim of a specific or unique medical/health condition.”

According to the case-specific materials received, Mr. Francis Hriadil is 66 years old, “elderly and currently has chronic musculoskeletal and digestive conditions that would be adversely affected by continued and increased exposure to RF and LF radiation.” Responses to discovery requests also indicated that Mr. Hriadil “noticed a recent increase in tinnitus,” which he is in “the process of having medically evaluated,” and that Mr. Hriadil has “a family history of certain chronic conditions which are relevant.” According to the case-specific documents received, Mr. Hriadil’s past medical history include “severe degenerative disc disease of all the lumbar spine with severe degenerative levoscoliosis”; “degenerative joint disease of the right hip”; “lumbar radiculopathy”; “colitis”; and heart palpitations with “sinus tachycardia.” Responses to discovery requests indicated Mr. Hriadil’s family medical history included cardiomyopathy (mother) and chronic obstructive lung disease (father). Medical records of Ms. Stella Hriadil, Mr. Hriadil’s mother, who was 88 years old in 2004, indicate the diagnosis of congestive heart failure, cardiomyopathy, hypertension, history of bleeding peptic ulcer, mitral regurgitation, tricuspid regurgitation, aortic regurgitation, pulmonary hypertensions, and personal history of tobacco use.

Allegations of Health Effects

The Complaint, in addition to other allegations, includes allegations of various health effects in association with exposure to low-level RF fields, specifically including RF fields emitted by smart meters. In their original Complaint dated October 3, 2016, Mr. and Ms. Hriadil expressed their concern that exposure to “a new environmental factor” (such as RF fields emitted by smart meters) may worsen a “number of chronic conditions” from which they suffer and may “create new problems.” The original Complaint did not list the specific health effects that are alleged to be associated or caused by exposure to low-level RF fields. Mr. and Ms. Hriadil submitted a large number of documents, however, attached to the Complaint and to the responses to discovery requests in both electronic format and hard copy, that allege a wide range of health effects, including, for example, various types of cancer, and other chronic diseases, including neurodegenerative diseases, and the onset of non-specific symptoms, such as fatigue, headache, and “hypersensitivity” from exposure to electromagnetic fields at radiofrequencies.

The voluminous materials submitted in this matter by Mr. and Ms. Hriadil include a large number of non-peer reviewed documents, mostly obtained from the internet, including videos, websites, and testimonies from proceedings in various jurisdictions unrelated to this matter. The submissions also included references to peer-reviewed publications and a number of opinions and conclusions regarding potential health effects of exposure to RF fields proclaimed by various organizations and opinions offered by proposed witnesses in the current matter. The organizations, the conclusions of which were contained in the Hriadils’ submissions, included, among others, the International Agency of Research on Cancer (IARC) that issued its review and conclusions following a weight-of-evidence evaluation in 2011, and other organizations (e.g., the BioInitiative Working Group [BIWG] in 2012, and the American Academy of Environmental Medicine [AAEM] in 2012) that proclaimed an opinion without a demonstrated weight-of-evidence evaluation of the available scientific evidence. The submissions also included a letter from Dr. David Carpenter dated October 22, 2017, that concluded “The evidence for adverse effects of radiofrequency radiation is currently strong and grows stronger with each new study.”

Below I provide an overall evaluation of the Complaint, and address the specific health effects allegations made by Mr. and Ms. Hriadil in relation to RF fields. In support of my opinions and conclusions, I also describe the well-established scientific methods of weight-of-evidence assessments, provide an overview of health risk assessments of RF exposure conducted using the weight-of-evidence method by authoritative health, scientific, and government agencies, briefly review relevant scientifically-established exposure limits, and provide a brief review of key scientific research relevant to RF exposure and health.

Evaluation of the Complaint

The Hriadils submitted a large number of documents and other materials to support their allegations of health effects in association with RF exposure. These submissions, either considered separately or in combination, fail to establish any cause-and-effect relationship between RF exposure at levels below scientifically-based exposure limits and adverse health effects. The documents submitted by the Hriadils can be broadly grouped into five categories, which I evaluate below:

1. **Non-peer reviewed documents, mostly obtained from the internet, including videos, websites, and testimonies and exhibits from proceedings in various jurisdictions unrelated to this matter.**

I will not further consider most of these non-peer reviewed documents; these sources do not provide information that may serve as the basis of any valid scientific conclusion. Valid scientific conclusions about causality rely on systematic weight-of-evidence evaluations of peer-reviewed research results.

2. **Selected articles from the peer-reviewed scientific literature.**

Valid scientific conclusions can only be drawn following an assessment of the *entire* body of available scientific literature, as discussed in more detail in my report below. A specific study or selected set of publications cherry-picked from the literature cannot form the basis of any valid scientific conclusion. In addition, the peer-reviewed papers included in the Hriadil submissions predated and were available for evaluation in the weight-of-evidence assessments and systematic reviews conducted by national and international expert panels (e.g., the IARC, the Health Protection Agency of the United Kingdom [HPA], and the Scientific Committee on Emerging and Newly-identified Health Risks [SCENIHR] of the European Commission). These health risk assessment, after consideration of the available evidence, did not conclude that the evidence overall confirms the existence of any adverse health effects from RF exposure.

3. **Reference to weight-of-evidence evaluations (e.g., IARC evaluation of RF exposure).**

Weight-of-evidence evaluations conducted by multidisciplinary panels on behalf of national and international health and scientific agencies (e.g., IARC, HPA, and SCENIHR), after properly considering the available body of scientific literature, did not conclude that there are any confirmed adverse health effects of low-level RF exposure, and provide no support to the Hriadils' health effects allegations. The Complaint, in general, disregards these weight-of-evidence conclusions about the lack of established adverse health effects, and disregards the fact that these conclusions were based on a thorough review of an extensive body of scientific literature that has accumulated over several decades as a result of a worldwide research effort.

4. **Evaluations and proclamations by organizations that were *not* based on a proper weight-of-evidence evaluation of the available scientific literature (e.g., the BioInitiative Working Group [BIWG] report).**

As discussed in more detail in my report below, these “alternative views” were not reached using valid scientific methods. A number of scientific and government agencies strongly criticized the BIWG report for the lack of a scientific weight-of-evidence approach. The main limitations of the BIWG report include the selective referencing of studies believed to support a preconceived conclusions, systematic disregard of studies not in support of their opinion (including the laboratory animal studies not demonstrating an association), and the heavy reliance on *in vitro* studies. Similar conclusions reached by, for example, the American Academy of Environmental Medicine (AAEM) and the Santa Cruz County Health Services Agency, are also not based on an appropriate weight-of-evidence evaluation of the scientific literature, and thus could not be considered valid.

5. **Dr. David Carpenter's letter dated October 22, 2017, submitted in support of the Hriadils' allegation of health effects of RF fields.**

Dr. Carpenter expresses his opinion that the evidence is “strong” for adverse health effects, which is contrary to the conclusions of all authoritative health risk assessments. Dr. Carpenter also fails to provide any valid support for his opinion. In his letter, Dr. Carpenter references the BIWG report, the World Health Organization (WHO)

classifications of RF, and the recent reports of the National Toxicology Program (NTP) in support of his opinion. The BIWG report, as discussed in my report in more detail, does not provide any valid scientific conclusion on potential health effects due to its lack of proper scientific methods in evaluating the literature on RF exposure and health. Dr. Carpenter also misinterprets and misrepresents the WHO (i.e., IARC) classification. The IARC classification of RF, as discussed in more detail below, does not mean at all that a cause-and-effect relationship is established. To the contrary, the classification means that a cause-and-effect association cannot be established because alternative explanations, such as chance, confounding, and bias cannot be excluded with scientific certainty for the limited statistical association observed in some of the studies. In addition, the IARC report of the RF classification specifically states that the evidence from studies of environmental sources do not provide clear indication of an association between RF exposure and cancer development. Finally, as discussed in detail in my report below, the NTP study, due to the high level of RF exposure used in the study (i.e., levels close to those that cause a heating effect), is not informative with respect to potential effects of RF exposure at levels orders of magnitude below the levels that may result in tissue heating.

In response to discovery requests, the Hriadils submitted information on specific medical conditions with which Mr. Hriadil was diagnosed. As discussed above, the weight-of-evidence reviews of the scientific literature did not conclude that RF fields at levels below scientifically established guideline values cause or exacerbate any adverse health effects. In particular, based on the available scientific evidence, a causal relationship is not established between RF exposure and any of the specific medical conditions with which Mr. Hriadil was diagnosed.

Scientific Review Process

In this section, I provide an overview of the well-established and generally-accepted scientific methods (i.e., the weight-of-evidence evaluation), which is used by authoritative national and international health and scientific agencies for human health risk assessment. Types of health studies that are evaluated as part of risk assessments are also discussed.

Scientists around the world have conducted a large amount of scientific research and published their results on the potential health effects of RF fields over the past several decades in peer-reviewed scientific publications. The published peer-reviewed scholarly manuscripts published as part of this extensive research effort report on the results of these studies, which were conducted by a wide variety of scientists in related, but diverse, scientific disciplines. The WHO commented on this large body of research on electromagnetic fields, stating “[d]espite the feeling of some people that more research needs to be done, scientific knowledge in this area is now more extensive than for most chemicals.”¹ The WHO’s website cites their position: “[b]ased on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields.”²

Although much of the scientific research on electromagnetic fields and health and other scientific and health topics has been conducted by reputable scientists and laboratories, there is a large variability in the quality of scientific research, and the various types of scientific studies have varying strengths and limitations. Since it is difficult for an individual to synthesize all of this research, to impartially assess the quality of the research, and to recognize and weed out the unscientific and low-quality research results and publications, standard scientific methods have been developed by scientists to evaluate evidence to determine whether there is a cause-and-effect relationship between an exposure (e.g., RF fields) and adverse health outcomes. This

¹ <http://www.who.int/peh-emf/about/WhatisEMF/en/index1.html>

² Ibid.

section provides an overview of the well-established and generally accepted scientific review process.

The standard scientific method used by scientists to evaluate scientific research as it relates to potential adverse health outcomes is a health risk assessment, which includes a weight-of-evidence review of relevant scientific studies. Typically, multidisciplinary expert panels are convened by both national and international health and scientific agencies to conduct weight-of-evidence evaluations of the literature to arrive at a valid conclusion. It is important to note that no single study or limited group of studies can provide sufficient evidence to draw a scientific conclusion on a potential cause-and-effect relationship; the totality of the evidence needs to be considered.

Sources of Scientific Evidence for a Weight-of-Evidence Review

A systematic search of the scientific literature will identify relevant research studies to be considered in a weight-of-evidence review. Review panels typically consider the three main types of scientific studies: epidemiologic studies of human populations; experimental laboratory studies of animals or humans (*in vivo* studies); and laboratory studies of cells and tissues (*in vitro* studies). Epidemiologic, *in vivo*, and *in vitro* studies provide different but complementary information and since each type of study has particular strengths and limitations, a valid risk assessment will consider all three types of studies together.

Epidemiologic studies are classified as non-experimental because they observe human populations in their natural environment and scientists do not control the factors that influence study subjects' activity, nor can they control exposure to the agent of interest. The goal of an epidemiologic study is to measure statistical associations between exposure to a particular agent and health conditions. The two most commonly employed types of epidemiologic approaches are case-control and cohort studies. Case-control studies compare the occurrence of exposure among persons with a particular disease (cases) to that among persons who do not have that disease (controls). One of the measures of statistical association in case-control studies is an

odds ratio.³ Cohort studies follow a specific group of individuals over time, often in an occupational setting, who at the start of the study do not have the disease of interest. Scientists compare the frequency of disease occurrence among those who experience exposure to a particular agent to the frequency of disease occurrence among those members of the cohort who are not exposed to that same agent. Commonly used measures of association in a cohort study are the relative risk and risk ratio.⁴

The limitations of epidemiologic studies include the scientist's inability to control exposure in the population, as already noted. This, among other drawbacks, may result in "confounding" in a study. Confounding, which is a key concept in epidemiology, refers to, in the simplest terms, confusion of effects. Confounding occurs when the apparent effect of one exposure on disease risk is distorted by or mixed with the effect of another exposure (i.e., the effect of a confounder). Confounding may result in overestimation or underestimation of the potential effect of an exposure on disease risk. Statistical techniques, such as stratification and co-variate adjustment, are available to adjust for the potential effects of known and measured confounders; however, residual confounding may remain even after adjustment, when the confounder is, for example, misclassified or crudely measured.

In addition, the methods used to select or recruit study subjects can result in selection and participation bias if those who are selected or recruited have inherently different characteristics than those who are not selected or choose not to participate. Scientists have developed methods to reduce the effect of these and other limitations, and epidemiologic studies typically provide the most weight in the studies considered in a weight-of-evidence review because they study humans, the species of interest in a human health risk assessment.

In vivo studies of laboratory animals typically study the effects of the agent of interest at high levels of exposure and often for durations that span the animals' lifetimes. These studies compare the rate and severity of symptoms and disease in exposed animals compared to un-

³ An odds ratio is a measure of statistical association between exposure and outcome in case-control studies and is calculated as the ratio of the odds of being exposed among the cases and the odds of being exposed among the controls.

⁴ Relative risk and risk ratio are measures of statistical association between exposure and disease in a cohort study and is calculated as the ratio of the risk of diseases among the exposed and the risk of disease among the unexposed.

exposed animals. One of the benefits of the *in vivo* animal study is that scientists can control and accurately measure exposure and other environmental factors that may influence disease development and exposure levels can be greater than that experienced by humans. A major limitation of *in vivo* animal studies is that the findings in animal studies may not be directly extrapolated to humans due to differences in physiology, metabolism, size, and longevity. Experimental studies are also conducted involving humans, but these studies typically contribute to an understanding of short-term effects, not long-term effects. In addition, ethical considerations prevent testing of known toxic or carcinogenic agents on humans.

In vitro studies of cells and tissues in the laboratory examine whether exposure results in certain biological changes. These observations can expand scientists' understanding of biophysical mechanisms that may lead to disease processes. Since the response of cells and tissues *in vitro* to a particular exposure may be very different than the response in intact organisms (i.e., living animals or humans), the conclusions drawn from *in vitro* studies are extremely limited. Therefore, they receive less weight when considered in a weight-of-evidence review.

Weight-of-Evidence Review

After studies are systematically identified in the scientific literature, the strengths and weaknesses of each study are individually assessed and rated (i.e., given more or less weight) according to its overall quality. The quality of studies, among other factors, is determined by considering the number of study subjects, the design of the study, the methods used to collect data, the analysis of that data, and the potential for confounding, various biases, and random errors.

The next step in a weight-of-evidence review is to consider the totality of the evidence. The generally accepted guidance scientists use to weigh epidemiologic evidence includes the nine criteria outlined by Sir Austin Bradford Hill in his now seminal manuscript published in 1965. The nine criteria used to assess causality include strength of association, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment, and analogy. Hill recommended that these guidelines should be applied when a chance association (i.e., caused by systematic error, such as confounding, bias, classification error, or random

variability) could be ruled out with reasonable certainty, and cautioned that none of these criteria represent “*hard-and-fast rules*” and none of these criteria are “*sine qua non*” of causality, the more the epidemiologic evidence meets these guidelines, the more persuasive the evidence is for a potential causal relationship.

Scientists use similar guidance for laboratory animal studies to weigh *in vivo* studies, including, among other criteria, whether a sufficient number of animals and exposure levels were included in the study; whether the assignment of the animals to various exposure groups was random; whether the outcome assessment and statistical analyses were conducted in a blinded manner⁵; whether health effects can be consistently demonstrated by two or more independent laboratories and in two or more species; and whether health effects can be demonstrated under different laboratory protocol. Similar guidelines are also outlined in a joint publication by the Federal Judicial Center and the National Research Council, *Reference Manual on Scientific Evidence* (FJC-NRC, 2011).

Weight-of-Evidence Evaluation of Carcinogenicity

The IARC, the cancer research agency of the WHO, is one of the leading international organizations for cancer risk assessment. In its risk assessments, which are published as Monographs, IARC primarily considers epidemiologic and *in vivo* animal studies, and evaluates *in vitro* studies to provide supplemental evidence on potential biophysical mechanisms (classified as strong, moderate, or weak) that lead to disease processes. IARC classifies the overall evidence from epidemiologic and *in vivo* animal studies into one of three categories, defined as follows.

- **Sufficient evidence:** A causal relationship can be established between exposure and cancer. This determination is based on the overall epidemiologic evidence in which positive relationships have been observed between the exposure and cancer in studies in which chance, bias, and confounding could be ruled out with reasonable confidence and

⁵ Blinding in a study means that the investigators are not aware whether the animals were exposed or not exposed during the experiment and when the data are assessed. In a human experimental study, double-blinding means that neither the study participants nor the investigators are aware of participants’ exposure status during the study. The lack of blinding may lead to human error or bias in a study.

on overall *in vivo* evidence in which increased incidence of cancer was observed in high quality laboratory animal studies in at least two species or from two independent laboratories.

- **Limited evidence:** A credible positive association is observed in epidemiologic studies, but chance, confounding, or bias could not be excluded as explanations for that association, and if *in vivo* studies result in an association, but the association is limited to one experiment or there are unresolved questions about study design features.
- **Inadequate evidence:** Epidemiologic studies are of insufficient quality, consistency, or statistical power, and *in vivo* studies have major qualitative or quantitative limitations or lack of data.

Based on its risk assessment evaluation, the IARC places each agent or exposure it examines into one of five Groups:

- Group 1: Carcinogenic to humans;
- Group 2A: Probably carcinogenic to humans;
- Group 2B: Possibly carcinogenic to humans;
- Group 3: Non-classifiable as to carcinogenicity to humans; and,
- Group 4: Probably not carcinogenic to humans.

Group 2B, possibly carcinogenic to humans, denotes substances and exposures for which there is limited evidence in epidemiologic studies and limited or inadequate evidence in *in vivo* studies. IARC has reviewed over 1,000 substances and exposure circumstances to evaluate their potential carcinogenicity and classified them as follows: Group 1, 120 agents; Group 2A, 81 agents; Group 2B, 299 agents; Group 3, 502 agents, Group 4, 1 agent. About 80% of the IARC's classifications fall into the possibly carcinogenic or non-classifiable category.⁶ Since it is impossible in science to prove the absence of an effect, IARC has classified only one substance (caprolactam) in Group 4, which illustrates the conservative nature of IARC's risk evaluation process and the difficulty in proving the absence of an effect beyond all doubt. Only about 20% of the substances examined by the IARC showed a clear-cut carcinogenic risk

⁶ <http://monographs.iarc.fr/ENG/Classification/> (Last accessed on April 18, 2018.)

(Group 1, ~10%) or probable carcinogenic risk (Group 2A, ~8%); most agents were categorized in either Group 2B or Group 3.

Key Recent Reviews of RF Health Studies

In this section, I provide a summary of key recent reviews of the scientific literature on RF exposure and potential health effects. None of the comprehensive reviews that applied the scientific weight-of-evidence process concluded that the scientific evidence confirms the existence of any health effect of low-level RF exposure.

Numerous international and national governmental, health, and scientific agencies have conducted thorough weight-of-evidence reviews of the available scientific literature to evaluate whether exposure to RF fields may result in potential adverse health effects. To account for the large volume and complexity of available scientific information, these reviews were performed by panels assembled and appointed by these agencies, representing multiple scientific disciplines (e.g., epidemiology, toxicology, exposure assessment) with relevance to research areas related to RF fields and potential health effects. These weight-of-evidence evaluations represent scientifically based consensus opinions that provide guidance for governmental and standards setting agencies to establish exposure limits or regulations to protect the health and safety of the public, and guide future scientific research by identifying potential research gaps and priorities.

In the past several years, a number of major scientific reviews have evaluated the weight of evidence regarding RF and health including the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2009, the HPA in 2012, the IARC in 2013, and the European Commission's SCENIHR in 2015, which I briefly review below. None of these reviews that conducted a proper weight-of-evidence evaluation of the scientific evidence concluded that there is sufficient evidence to conclude that exposure to low-level RF fields (i.e., below currently existing scientifically-based exposure guidelines) causes any adverse health effects, including cancer among children or adults, and health effects other than cancer, such as adverse nervous system effects, immunological effects, cognitive effects, cardiovascular effects, reproductive effects, developmental effects, self-reported symptoms (including tinnitus), or hypersensitivity to RF fields. Additional agency reviews on exposure to RF fields and health, all expressing similar conclusions (i.e., lack of established health effects of RF exposure at levels below scientifically-established guideline values), are listed in Appendix B.

International Commission on Non-Ionizing Radiation Protection (2009)

ICNIRP is the preeminent independent, non-governmental scientific organization for setting guidelines to protect the public from potential harmful effects of exposure to EMF, including RF fields, and it is the formally recognized organization for providing guidance on standards for non-ionizing radiation exposure for the WHO. ICNIRP systematically reviewed the available 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. With respect to laboratory studies, ICNIRP concluded that while there are well-understood effects of RF exposure through tissue heating, the overall evidence from experimental studies does not provide consistent support for carcinogenic effects of RF exposure at non-thermal levels. ICNIRP described that there is some evidence of small changes in brain activity, but these do not represent any adverse effects.⁷ ICNIRP also concluded that 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.” With respect to epidemiologic studies, ICNIRP concluded that results of available and reviewed epidemiologic studies provide no consistent or convincing evidence of a causal relationship between RF exposure and any adverse health effect.

Health Protection Agency (2012)

The independent Advisory Group on Non-Ionizing Radiation (AGNIR) of the HPA (now part of Public Health England), the United Kingdom’s primary governmental authority on public health protection, conducted its systematic review of the *in vitro*, *in vivo* animal, experimental human, and epidemiologic literature in 2012. With respect to *in vitro* and *in vivo* animal studies, AGNIR concluded that these studies provided no consistent evidence of adverse health effects of RF exposure at levels below those that produce heating. With respect to human experimental

⁷ Normal physiological changes (e.g., constriction of pupils or changes in brain activity) may occur as a result of everyday environmental stimuli, such as light and sound. These physiological changes, however, cannot be considered as adverse effects.

studies of acute effects of RF exposure 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.” While their review identified some scientific evidence that RF-field exposure may affect a person’s brain activity, they 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.”

AGNIR found that epidemiologic studies of long-term exposure to RF fields below established guidelines provides no substantial evidence of effects, particularly those studies of cardiovascular morbidity, reproductive function, and non-cancer mortality, although they note that the literature “has been very limited.” They similarly concluded that studies examining cancer risk in relation to occupational RF exposure and residential proximity to RF transmitters suffer from methodological limitations and provide no evidence for a causal relationship between exposure to RF fields and any adverse health effects. Finally, they conclude that the overall evidence from epidemiologic studies of mobile phone use and cancer risk “does not suggest that use of mobile telephones causes brain tumours [*sic*] or any other type of cancer,” but they qualify this assessment by noting that “[t]he data, however, are essentially restricted to periods of less than 15 years from first exposure.”

Overall, they concluded “... 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.”

International Agency for Research on Cancer (2013)

The IARC reviewed the scientific literature to evaluate potential carcinogenic effects of RF fields in 2013. The IARC expert working group classified RF fields as possibly carcinogenic (Group 2B) based on “limited evidence” for carcinogenicity of RF fields in relation to glioma and acoustic neuroma from mobile phone epidemiologic studies, and on “limited evidence” from experimental animal studies. The IARC concluded that results from epidemiologic studies

of mobile phones and all other types of cancer, and from epidemiologic studies of occupational and environmental exposure to RF provided no clear indication of an association between RF exposure and cancer development. The IARC Group 2B classification does not imply that a cause-and-effect relationship is established between exposure and cancer. To the contrary, it means that artifacts, such chance, confounding and bias cannot be ruled out with scientific certainty as an explanation for the limited statistical association reported in some of the studies, because of the limitations of those studies.

Scientific Committee on Emerging and Newly Emerging Health Risks (2015)

SCENIHR is made up of independent scientific experts assembled to provide advice on public health and risk assessments to the Department of Health and Consumer Protection of the European Commission. SCENIHR provides opinions on emerging or newly-identified health and environmental risks and on broad, complex, or multidisciplinary issues requiring a comprehensive assessment of risks to consumer safety or public health and related issues not covered by other community risk assessment bodies. The mandate of SCENIHR includes the evaluation of potential health effects of EMF, including RF fields. SCENIHR's most recent report was issued in 2015.

With respect to epidemiologic studies of cancer, SCENIHR concluded that “[o]verall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumours [*sic*]. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region. Some studies raised questions regarding an increased risk of glioma and acoustic neuroma in heavy users of mobile phones. The results of cohort and incidence time trend studies do not support an increased risk for glioma while the possibility of an association with acoustic neuroma remains open. Epidemiological studies do not indicate increased risk for other malignant diseases, including childhood cancer.” With respect to potential effects of RF exposure on brain physiology, SCENIHR noted that while some studies indicated that RF may affect brain activity, “the relevance of the small physiological changes remains unclear and mechanistic explanation is still lacking.” They note, however, that “overall, there is a lack of evidence that mobile phone RF EMF affects cognitive functions in humans.”

With respect to “symptoms that are attributed by some people to various RF EMF exposure,” SCENIHR concluded that, based on available evidence, “RF EMF exposure is not causally linked to these symptoms.” SCENIHR further concluded that evidence does not show a consistent association between RF exposure and neurological diseases, reproductive and developmental effects, and male fertility.

Reviews of Smart Meter RF Emission and Health

In this section, I provide a brief overview of evaluations conducted by various state and government agencies in the United States and other countries specifically on potential health effects in relation to RF fields from smart meters. These evaluations concluded that there are no established health effects in relation to smart meter RF fields.

In response to public concern about potential health effects related to RF emission from smart meters, several states in the United States have formally assessed the scientific evidence on smart meters and health effects and issued their reports or statements with their conclusions and opinions.

A review conducted in Maine by the Maine Center for Disease Control in 2010 concluded in their summary statement 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).

In California, the state assembly commissioned the CCST to perform an independent study to inform the debate among policy makers and the general public about the potential risk of adverse health effects due to RF field emissions from smart meters. The CCST’s report concluded that “[t]he current FCC [Federal Communications Commission] standard provides an adequate factor of safety against know thermally induced health impacts of existing common household electronic devices and smart meters.” They further conclude that scientific studies have neither identified nor confirmed any negative health effects from RF emissions produced by smart meters and other common electronic devices (CCST, 2011).

The Colorado Department of Public Health and the Environment issued a fact sheet in 2012, which concluded that “[s]mart 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).

The Michigan Public Service Commission issued a report in 2012 concluding 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).

The Oregon Health Authority concluded in 2012 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” (OHA, 2012).

The Public Utility Commission of Texas concluded in 2012 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” (PUCT, 2012). An order of the Public Utility Commission of Texas in 2013 similarly stated that “[t]he commission evaluated health, privacy, and operational concerns against advanced meters and concluded that the concerns are unwarranted” (PUCT, 2013).

The Arizona Department of Health Services conducted a study of smart meters that included measurements of RF signals at a random selection of single family residences and apartment complexes within the state. The average and peak levels of RF were measured at 1 foot in front of meters at three times during the day. All measurements were found to comply with FCC standards. A search and review of the literature on potential effects of RF on health was performed which led the Department of Health to conclude that “[e]xposure to electric meters (AMI [advanced metering infrastructure] and AMR [automated meter reading]) is not likely to harm the health of the public” (ADHS, 2014).

A review of scientific and public health agency perspectives on RF fields related to smart meters commissioned by the Vermont Department of Health and the Vermont Public Service Department in 2014 concluded that “[b]ased 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” (VDH/VPSD, 2014).

The legislature of North Carolina asked the Division of Public Health to perform an evaluation of existing information on RF and health related to smart meters. The team from the Division concluded that “[r]adiofrequency waves have demonstrated subtle biological effects on certain cellular systems; however there is no conclusive evidence that these changes have clinical significance ... Major reviews by various governmental organizations, both U.S. and global, have not found sufficient evidence that non-thermal effects of radiofrequency waves are a significant risk to humans accepted criteria to justify the application of the Precautionary Principle are not met for RF exposures from smart meters” (NCDHHS, 2015).

A fact sheet issued by Health Canada in 2011 states that based on its review “Health Canada has concluded that exposure to RF energy from smart meters does not pose a public health risk” (Health Canada, 2011). A similar fact sheet issued by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) in 2015 concluded that “there is no established scientific evidence that the low level RF EME exposure from smart meters causes any health effects including symptoms of ill health communicated by some people” (ARPANSA, 2015). More recently, Public Health England in the United Kingdom concluded in 2017 that “[t]he evidence to date suggests exposures to the radio waves produced by smart meters do not pose a risk to health” (Public Health England, 2017).

RF Exposure Standards and Guidelines

Current scientifically derived RF exposure guidelines are based on avoiding the risk to health that results from localized temperature increases in tissues and from physiological stress due to excessive whole-body heat load. A whole-body averaged energy absorption rate or specific absorption rate (SAR) of 4 watts per kilogram (W/kg) of body mass is required to result in an increase of 1 degree Celsius in the tissue temperature that may be associated with behavioral disruption. With the application of safety factors of 10 and 50, for occupational and public exposures, respectively, limits are derived on the strength of external RF fields.

Federal Communications Commission

In the United States, the FCC is the government agency responsible for regulating RF-generating devices. Their regulations specify the limit on the maximum level of permissible exposure to RF of varying frequencies, from 300 kilohertz (kHz) to 100 Gigahertz (GHz) (CFR, 2013). The FCC based their standards on the work of organizations such as the U.S. National Council for Radiation Protection (NCRP) and the Institute of Electrical and Electronic Engineers (IEEE).

The FCC established maximum permissible exposure (MPE) limits for exposure to RF (FCC, 1997) based on the recommendations of the NCRP and IEEE, as well as the Environmental Protection Agency (EPA) and the Food and Drug Administration. The FCC's MPE limits are set to protect against effects from RF exposure that can induce electric fields and currents in body tissues and cause tissue heating. Exposure, in the frequency range relevant to smart meters, is described in terms of power density, and measured in watts per square meter (W/m^2), or milliwatts per square centimeter (mW/cm^2). These units may be used to directly compare to either calculated or measured levels of RF. The FCC's MPE limits are evaluated in terms of 30-minute time-averaged values as averaged over the body dimensions. The reference levels set by ICNIRP are comparable to the FCC limits for frequencies that are typically used in smart meter communication systems (i.e., frequencies of 900 MHz [megahertz] and 2.4 GHz), with the exception of averaging time, which is 6 minutes for ICNIRP limits.

Alternative Views

In this section, I provide specific examples of views that are not based on valid scientific methods to assess the available evidence, which thus arrive at invalid conclusions regarding the existence of health effects in relation to low-level RF exposure, and are contrary to conclusions of properly conducted weight-of-evidence reviews (e.g., reviews by IARC, HPA and SCENIHR).

As discussed above, none of the authoritative scientific reviews by government or scientific agencies that were properly conducted using standard scientific methods concluded that the evidence confirms the existence of any adverse health consequences in association with exposure to low-level RF fields in our daily environments.

Alternative views, such as that put forward by the BIWG in their 2007 report and their 2012 update, are not based on proper and rigorous evaluation of the scientific evidence. The BIWG report suffers from the following several deficiencies: the report was authored by a self-organized group of individuals from academic institutions and public interest groups, and not under the auspices of any recognized scientific organization; the conclusions expressed in the individual chapters of the document did not represent consensus opinions, rather they were the opinions of the individual contributors; the authors did not follow a weight-evidence approach, and selectively reported on studies that, in their opinions, showed some effect and supported their views; the authors mostly disregarded studies that did not show an effect, including the entire body of literature on long-term animal bioassays; and the authors did not thoroughly assess the quality of studies they evaluated. These deficiencies are likely to explain why the BIWG's conclusions are completely inconsistent with conclusions of other risk assessments that followed the generally-accepted scientific methods of weight-of-evidence evaluations.

Several scientific and governmental agencies strongly criticized the BIWG report. The Australian Centre for Radiofrequency Bioeffects Research wrote, “[a]s it stands it [the BIWG 2007 report] merely provides a set of views that are not consistent with the consensus of science, and it does not provide an analysis that is rigorous-enough to raise doubts about the scientific consensus.” The EMF-NET Steering Committee of the European Commission opined

the report was “written in an alarmist and emotive language and the arguments have no scientific support from well-conducted EMF research” and “[t]here is a lack of balance in the report; no mention is made in fact of reports that do not concur with authors’ statements and conclusions.” The Health Council of the Netherlands also questioned the authors’ motivation noting “[u]pfront, therefore, the reason for writing the report was not to give an objective analysis of the current state of science that would subsequently lead to recommendations. Instead, the aim was to present information to demonstrate why current standards are inadequate.” All of these agencies concurred that BIWG did not follow the methods of a standard weight-of-evidence review and, for this reason, its conclusions and recommendations were not convincing.

Similar alternative statements expressing concern about health effects related to exposure to RF fields from smart meters were issued by, for example, the AAEM and the Santa Cruz County Health Services Agency. These conclusions also 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.

RF Health Research

In this section, I provide a brief overview of the relevant scientific research conducted in the past several decades on low-level RF exposure and health. For a detailed and comprehensive discussion of the relevant scientific literature, I refer to the reviews and weight-of-evidence assessments conducted by ICNIRP, HPA, IARC, and SCENIHR, as described above. Overall, none of the comprehensive evaluations conducted by these agencies concluded that the evidence confirms the existence of any adverse health effects in relation to RF exposure below currently existing exposure guidelines. The current scientific consensus as exemplified by the conclusion of the WHO is that the “*current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields.*” Results of more recent studies published after the completion of the above-mentioned weight-of-evidence evaluations have not changed the overall conclusions expressed in these evaluations. Below I provide a brief overview of the key lines of scientific evidence related to exposure to RF fields and potential health effects.

Epidemiologic Studies of RF and Cancer

Epidemiologic studies examining potential effects of RF fields on human health outcomes can be broadly grouped into three categories: studies of occupational or military exposures to RF; studies of environmental exposure to RF (i.e., RF sources of fixed locations, such as radio and television transmitters and mobile phone base stations); and studies of personal exposure to cordless and mobile phones. In addition to these analytical epidemiologic studies, descriptive epidemiologic studies monitoring incidence trends of brain cancer are also used to assess the potential impact of mobile phone use on brain cancer development.

Epidemiologic studies of occupational and military exposures include cohort studies that follow well-defined populations exposed to RF from radar in military settings (e.g., Garland et al., 1990; Szmigielski, 1996; Szmigielski et al., 2001; Groves et al., 2002) or in the police force (e.g., Finkelstein, 1998), from use of amateur radio among operators (e.g., Milham, 1985), and from various sources in industrial settings (e.g., Armstrong et al., 1994; Morgan et al., 2000). Case-control studies of various cancer types have also assessed the potential relationship

between sources of occupational exposure to RF and cancer, and estimated exposure based on occupation or job category, used as a proxy for potential exposure to RF fields (e.g., Stang et al., 2001; Berg et al., 2006; Karipidis et al., 2007a, 2007b). While some earlier studies reported statistically significant associations between these proxy exposure measures and cancer, most recent studies have not consistently reported a risk of any type of cancer in association with occupational RF exposure.

Earlier studies of environmental RF exposures mostly consisted of studies with ecologic design or geographical correlations that compared cancer rates calculated for geographic areas (e.g., at various distances from antennae), but did not directly assess exposure of individuals (e.g., Hocking et al., 1996; Dolk et al., 1997a, 1997b; McKenzie et al., 1998; Cooper et al., 2001; Michelozzi et al., 2002; Park et al., 2004). Distance is another proxy exposure measurement used by scientists in the absence of direct measurements or modeled calculations of RF exposure; the interpretation of these results is constrained because not all people in an area have the same exposure, and it does not consider exposure from other RF sources. In addition, distance has limited accuracy because it does not consider characteristics of the source, topography, or the built environment that may also affect levels of RF fields. More recent studies of environmental RF exposure using case-control or cohort designs have improved exposure assessment and estimated RF exposure on the individual level, but none of these studies found any consistent, statistically significant positive association between total RF exposure and risk of childhood leukemia or brain cancer (Ha et al., 2007, 2008; Merzenich et al., 2008; Li et al., 2012; Hauri et al., 2014). Another study that estimated maternal exposure to RF from mobile phone base stations and the risk of cancer in their children also found no association with childhood leukemia/lymphoma or brain cancer (Elliott et al., 2010).

Cohort studies of mobile phone users with large sample sizes (Schüz et al., 2006; Frei et al., 2011; Benson et al., 2013a, 2013b) reported no associations with any types of cancer, including cancer of the head and neck, leukemia, and lymphoma. Some of these studies relied on mobile phone subscription records from mobile phone companies to determine use and estimate exposure (Schüz et al., 2006; Frei et al., 2011), which may result in exposure misclassification due to people sharing phones, using more than one phone, using company phones, and switching carriers.

A large number of case-control studies also have been conducted to assess mobile phone use and development of brain tumors. Most of these studies relied on self-reported mobile phone use to determine exposure, potentially resulting in well-documented recall bias and non-differential and differential exposure misclassification (e.g., Vrijheid et al., 2009; Toledano et al., 2018). Early case-control studies reported no association between mobile phone use and brain cancer, however, these studies included relatively short time periods of exposure (Muscat et al., 2000; Inskip et al., 2001).

Most of the more recent case-control mobile phone epidemiologic studies belong to one of two sets of studies: the multinational, comprehensive studies conducted by the INTERPHONE Study Group and the series of case-control studies conducted by a research group in Sweden. The INTERPHONE Study Group is comprised of a consortium of 16 research groups in 13 countries in Europe, Asia, North America, and Australia/New Zealand (Cardis et al., 2007, 2011; Interphone Study Group, 2010, 2011). The majority of studies by the INTERPHONE Study Group—both studies conducted in individual countries and pooled-analyses of data from several countries—show no significant positive association between self-reported mobile telephone use and risk of glioma, meningioma, and acoustic neuroma. The pooled analysis found that those who had ever been a regular mobile telephone user was associated with a significantly lower risk of glioma and meningioma, although this association was possibly due to selection bias, that is, greater participation among controls who had ever used mobile telephones than those who had not (Interphone Study Group, 2010; Cardis et al., 2011). A significant risk increase was observed in the highest of 10 categories of cumulative call time when all the data were combined in one analysis; however, the authors noted that there were implausible values of reported use in those highest categories, and they could not rule out chance or reporting bias as an explanation for the findings (Interphone Study Group, 2010, 2011).

Hardell and colleagues in Sweden conducted another series of case-control studies of malignant and benign brain tumors (e.g., Hardell et al., 1999, 2013). While all the Hardell et al., studies reported a significant positive association between mobile phone use and risk of brain tumors, with evidence of a positive exposure-response trend and especially with longer latency, concerns about selection bias, recall bias, interviewer bias, and multiple hypothesis testing,

along with unclear exposure definitions and study inclusion criteria, limit the strength of the authors' conclusions. The higher odd ratios reported in these studies are not consistent with results from other epidemiologic studies, including those from the Swedish INTERPHONE group (Lonn et al., 2005).

There is little epidemiologic evidence regarding mobile telephone use and risk of brain tumors in children. One case-control study of children and adolescents (aged 7–19 years) reported no exposure-response relationship between the amount of mobile telephone use and risk of brain tumors. In addition, the study did not detect an increased risk of brain tumors in those brain areas that received the highest amount of exposure (Aydin et al., 2011). Similarly, there are few case-control studies of mobile telephone use and the risk of parotid and salivary gland tumors, leukemia, non-Hodgkin lymphoma, uveal melanoma, testicular cancer, intratemporal facial nerve tumor. Existing studies on these outcomes do not reveal a consistent or convincing positive association and have the same general limitations as other case-control studies.

Because RF exposure from mobile phones has been hypothesized to affect primarily the development of brain cancer and because mobile phone use has dramatically increased in the past couple of decades in all modern societies, incidence trends of brain cancer have been examined in several countries in recent years. These studies, however, reported no observable increase brain cancer incidence during a period of substantial increase in mobile phone use (e.g., Cook et al., 2003; Rössli et al., 2007; Deltour et al., 2009; Inskip et al., 2010; de Vocht et al., 2011; Aydin et al., 2012; Shibui, 2012; McKean-Cowdin et al., 2013). While some studies reported an increase in the rate of glioblastoma multiforme (i.e., “high-grade” brain tumors), they also reported a corresponding decrease in other types of brain tumors, a change that more likely indicates the role of shift in tumor classification (e.g., Philips et al., 2018).

Laboratory Animal Studies of RF and Cancer

A review of experimental studies of studies of RF exposures in rats and mice between 1982 and 2011 was reported in by IARC in 2013. The conclusion was that, in aggregate, the studies provided “limited evidence in experimental animals for the carcinogenicity of radiofrequency radiation.” No rationale as to how the studies were rated or evaluated was provided. An updated

review of these and some newer studies and analyses prompted SCENIHR (2015) to conclude “[o]verall, because a considerable number of well-performed studies using a wide variety of animal models have been mostly negative in outcome, the animal studies are considered to provide strong evidence for the absence of an effect.” This review commented on the study by the U.S. NTP then underway, stating that “[l]ong-term absorption of RF energy at that level will have a considerable impact on thermoregulation, and induce compensatory changes in metabolism, as well as reducing food consumption and spontaneous activity.” The studies reviewed by these agencies applied exposures with SARs below 8 mW/kg, but several involved exposures to SARs at much higher levels between 2- 5 W/kg.

National Toxicology Program

In 2000, the NTP began the design and planning for a study of rats and mice to be exposed to RF fields simulated to be similar to those of mobile phones with signal modulations characteristic of 2G mobile phones (GSM) and 3G mobile phones (CDMA). The results have been summarized most completely in two draft technical reports (NTP, 2018a; 2018b). Final reports are due to be published towards the end of 2018.

Pilot studies of exposures for 5 days provided strong evidence confirming that exposure of rats to RF fields at 900 MHz and mice to RF fields at 1,900 MHz resulting in SAR levels of 10 W/kg or 12 W/kg for 10 minutes on and 10 minutes off for 18.3 hours per day produced excessive increases in body temperature leading to death in rats. In addition, the study reports that increases in body temperature above 1 degree Celsius (°C) may occur in rats and mice at exposure levels above 4 and 6 W/kg.

Twenty-eight-day studies involved the exposure of groups of pregnant females and groups of adult male and non-pregnant female rats to GSM or CDMA RF fields at 0, 6, or 9 W/kg, and adult male and non-pregnant female mice to GSM or CDMA RF fields at 5, 10, and 15 W/kg for 18.3 hours per day (cycles of 10-minutes on, 10-minutes off) for 28 days. Significant reductions in body weight were measured in rats post-pregnancy (in lactation) exposed to GSM or CDMA fields at 9 W/kg; dose-related reductions in body weight were also seen in the pups at 9 W/kg. Similar, but apparently not significant, trends were seen in male and female adult rats as well. The body temperatures of pregnant female rats were significantly increased at 6 and 9 W/kg

with GSM and CDMA exposure. Some significant decreases in the body temperatures of female pups exposed to GSM RF also were reported. In mice, exposures of males to GSM RF at 5 and 10 W/kg and CDMA at 10 and 15 W/kg significantly increased body temperatures. No effects of GSM or CDMA on the body weights of male or female mice were reported.

Two-year studies involved the exposure of rats to GSM or CDMA RF (1.5, 3, or 6 W/kg) beginning prior to birth (in utero exposure beginning on gestational day 5) through to the end of life. Mice were similarly exposed to GSM or CDMA RF (2.5, 5, or 10 W/kg) for their lifetimes, but these exposures began in adulthood. As in the shorter-term studies, significant reductions in body weight gains of pregnant female rats as well as their male and female pups were dose-related with GSM exposure. Significantly increased survival over the 2-year period of male rats exposed to GSM fields was reported at all SAR levels in a dose-related fashion. The survival of male rats exposed to CDMA at 1.5 and 3 W/kg was also increased. Similarly, survival of female rats increased in a dose-related fashion with exposure to CDMA and at 6 W/kg.

The examination of multiple organs of rats at the end of the study showed dose-related increased incidences of cardiomyopathy in the right ventricle of males at 3 and 6 W/kg (GSM) and at all SAR levels (CDMA). The rate at 6 W/kg was higher than the historical range among unexposed control rats in previous NTP studies. A trend for malignant schwannomas of the heart to increase with GSM and CDMA SAR level was observed in male rats, but the rate was only elevated above historical controls at 6 W/kg in CDMA males. An increase in the rate of brain glial tumors was not reported at any exposure levels in male rats exposed to CDMA, but a weak trend was noted.

Groups of 105 male and female mice exposed to GSM and CDMA also were evaluated after 2 years of exposure at different SAR levels than rats. The survival of male mice exposed to GSM at 5 W/kg and CDMA at 2.5 W/kg was higher than unexposed control mice. The examination of multiple organs of mice at the end of the study showed higher rates of malignant lymphoma in female mice exposed to GSM at 2.5 and 5 W/kg and to CDMA at 2.5 W/kg. Opposite effects of CDMA RF on liver cancer were reported for male mice (a decrease in carcinomas at 2.5 W/kg and an increase of hepatoblastoma at 5 W/kg). All tumor rates were within the range of historical rates of control rats reported in other NTP studies.

Tests for reparable DNA damage after 14 weeks of exposure showed trends for damage to increase with SAR level in 1 of 3 brain regions of male mice (CDMA and GSM) and female rats (CDMA), in 2 of 3 brain regions in male rats (CDMA), in liver in female mice (CDMA), and in blood of both sexes of rats exposed to CDMA. No damage to chromosomes in red blood cells in rats or mice exposed to GSM or CDMA was reported. These observations were not linked in the report to histological observations on the brain or any other tissues.

Overall, the draft results of the NTP study indicate that exposure to levels of RF that cause heating of the body,⁸ can have acute adverse effects, and that life-long exposure at slightly lower levels also may increase survival with increasing SAR exposure. Increased rates of malignant tumors above the rates in unexposed controls and historical controls in the hearts of GSM- and CDMA-exposed males provide, as the report states, “some evidence of carcinogenic activity” in rats. The report stated that data evaluated for mice only provided “equivocal evidence of carcinogenicity” with GSM and CDMA exposure. The data deserve additional scrutiny because, although the statistical testing for some measures such as body weight were adjusted for multiple comparisons, other measures like tumor incidence were not. Given the thousands of pair-wise and trend comparisons made between exposed and control rats and mice in these reports, one must assume that a substantial fraction of the statistically-significant differences reported were statistical false positive findings (i.e., occurred by chance alone). The SAR level that is considered the threshold above which adverse effects of whole-body RF exposure may be expected is 4 W/kg in rats, non-human primates, and humans (D’Andrea, 1999) and this has led for federal agencies in the United States to set the standard for whole-body exposure of the general public to 0.08 W/kg (FCC, 1997).

Ramazzini Institute

A recent study conducted at the Ramazzini Institute in Italy exposed rats to 1,800 MHz GSM RF fields for 19 hours per day from gestational day 12 (in utero) until the end of life at calculated SAR levels of 0.001 W/kg, 0.03 W/kg, or 0.1 W/kg. A partial summary of the results

⁸ Tissue heating is a well-established effect of RF exposure at sufficiently high levels. Scientifically-established RF exposure limits, however, are set well below levels at which adverse heating of the tissue or body may occur. Thus, the study findings of the NTP study are, in general, not informative with respect to potential effects of low-level RF exposure from everyday sources, including smart meters.

was selected by the authors for publication earlier this year (Falcioni et al., 2018). The exposures were planned to simulate RF exposures in the environment from a fixed mobile antenna, not a mobile phone. The rats were exposed in cages with 5 rats per cage with a minimum of approximately 200 rats per sex per group. Body temperature was not measured.

The investigators did not report that they had randomly assigned the rats to the control or treatment conditions, which is a major flaw in the design of the experiment (Hooijmans, 2014). No effects on food or water intake, body weight, or survival in male or female rats were reported. The investigators reported 120 additional statistical calculations to describe the potential differences between groups of rats exposed or not exposed to RF fields on numerous measures. Using a criterion of $p < 0.05$, one would expect about six statistically significant differences to be reported just by chance alone in the two tables of data presented. But from all the calculations, only one single table entry indicated a statistically significant difference. In male rats at the highest exposure of 50 V/m (said to correspond to a SAR of 0.1 W/kg), 1.4% were diagnosed with a schwannoma in the heart whereas no rats were diagnosed with this tumor among the control rats. No other differences in the entire report were statistically significant. If these calculations had been corrected for multiple comparisons as had been done in the NTP study, there would be no effect of RF exposure at all. Moreover, the claim of the investigators that the large number of rats in each group makes it a better study than the NTP study is undercut because they exposed the rats in cages of five and so the cage, and not the individual rats, should have been the experimental unit for analysis. Thus, observations on each rat were not necessarily independent of the others in the cage and so the sample size for all the analyses should have been divided by 5 for the calculations of statistical significance. Another reason to be cautious about this study is that EPA has criticized the Ramazzini Institute's assessments of histological data and EPA has "decided not to rely on RI [Ramazzini Institute] data on lymphomas and leukemias in IRIS [Integrated Risk Information System] assessments" (USEPA, 2013), and has warned risk assessors about problems with the cancer bioassays conducted by the Ramazzini Institute. These problems include the accuracy of the cancer diagnoses; the categorization of tumors; errors in identifying cellular changes such as leukemia/lymphoma in certain tissues that appear to be due to infections and tissue inflammation; a unexplained significant rise in the incidence of leukemia/lymphomas over time in control groups unrelated to the exposure under study; the lack of complete reporting and documentation of analytical

specifications; failure to control or analyze for potential litter effects; and the use of common controls for multiple studies (Gift et al., 2013).

In summary, the newest animal studies of chronic exposure to RF fields do not add to the weight of evidence accumulated from previous research reviewed by scientific agencies, and thus do not change their overall conclusions. The NTP reports suggest potential adverse effects of short- and long-term exposure to RF at levels at or above historically recognized thresholds for causing increases in body temperatures and adverse effects of RF exposure upon which exposure standards are based. Further, the results of the Ramazzini study are consistent with no effect of RF at exposure levels that are about 100-fold lower than those of the NTP study, a finding consistent with prior research.

Studies of Potential Health Effects Other Than Cancer

While cancer development was the primary focus of many studies related to RF exposure and potential health effects, an important body of literature has also accumulated on potential health effects other than cancer. The examined non-cancer health outcomes included, among others, neurocognitive effects, reproductive and developmental effects, various cardiovascular conditions and diseases, nervous system effects, and immunological effects. Epidemiologic and laboratory studies on potential non-cancer outcomes of RF exposure have been systematically and repeatedly reviewed (e.g., Ahlbom et al., 2004, Feychting, 2005, 2011; HPA, 2012; SCENIHR, 2015). Overall, the scientific literature is not in support of a causal relationship between low-level RF exposure and any of the examined non-cancer health outcomes.

Studies Related to Non-Specific Symptoms and Hypersensitivity

A number of studies investigated the potential relationship between exposure to RF fields and various non-specific symptoms. Many of these studies relied on self-reported exposures, cross-sectional designs, and small sample sizes. These studies contributed little, if any, insight to our understanding of the potential effects of RF fields. Over 40 experimental studies examined the relationship between exposure to either EMF or RF fields and electromagnetic hypersensitivity, also called idiopathic environmental intolerance attributed to EMF (IEI-EMF). The symptoms

claimed to be associated with to IEI-EMF generally include dizziness, palpitations, skin itching, dry mouth, sleep disorders, and digestive problems. A number of the studies of IEI-EMF are limited because they did not utilize double-blinding techniques. A group of higher quality human experimental trials, epidemiologic studies and field intervention studies that examined the occurrence of headache, dizziness, concentration problems, sleep disturbances, or fatigue due to RF-field exposure did not provide consistent evidence of increased occurrence of symptoms or symptom patterns with exposure (Danker-Hopfe et al., 2010; Heinrich et al., 2010, 2011; Mohler et al., 2010, 2012; Rössli et al., 2010; Frei et al., 2012). Scientists recognize that a person's symptoms may be real, and in some cases severe, however, well-conducted provocation studies consistently demonstrate that those who reported RF sensitivity cannot differentiate between exposure and no exposure scenarios, and that the reported symptoms are not causally related to RF exposure (Rössli et al., 2010; Rubin et al., 2011).

Summary and Conclusion

A large body of scientific literature has accumulated over the past several decades about exposure to RF fields and potential health effects. This area has been extensively studied and the literature includes a variety of scientific studies, including epidemiologic studies of human populations, experimental studies of laboratory animals and humans (*in vivo* studies), and laboratory studies of cells and tissues (*in vitro* studies). As the WHO states, “*scientific knowledge in this area is now more extensive than for most chemicals.*”⁹ The WHO also notes that “[w]ith more and more research data available, it has become increasingly unlikely that exposure to electromagnetic fields constitutes a serious health hazard, nevertheless, some uncertainty remains.” The available scientific literature has been periodically and repeatedly reviewed by multidisciplinary panels convened by a number of national and international governmental health and scientific agencies to evaluate the overall scientific evidence on whether RF EMF at levels typically encountered in our environment pose any risk to human health. None of these expert panels, including those assembled for example by ICNIRP, HPA, IARC, and SCENIHR, has concluded that low-level exposure to RF fields (i.e., exposure below currently existing scientifically-established guideline levels) causes any adverse health effects, including cancer or any other chronic diseases. The IARC evaluation (IARC, 2013) and the press release issued in relation to the announcement of their main findings (IARC, 2011) specifically noted that the evidence from studies of environmental exposures (i.e., RF sources with fixed location, such as radio and television antennae, and mobile phone base stations) and cancer development was “judged inadequate” to suggest an association.

Evaluations of potential health effects of RF emission specifically from smart meters conducted by multiple states in the United States and other governmental agencies all concluded that the available scientific evidence does not support a claim for the existence of any health effects as a result of exposure to RF fields from smart meters.

The estimated potential exposure to RF fields from smart meters at the Hriadil residence is a small fraction of RF exposure from all other sources, and is well below internationally-accepted,

⁹ <http://www.who.int/peh-emf/about/WhatisEMF/en/index1.html>

scientifically-based exposure guidelines, such as those set by ICNIRP and specifically by the Federal Communications Commission. These exposure levels are also well within the range that could be experienced in other households in the United States

Based on my knowledge and familiarity with the relevant scientific literature, including the relevant weight-of-evidence reviews conducted by a number of international multidisciplinary expert panels, and the case materials presented to me in relation to the Complaint filed with the Pennsylvania Public Utility Commission against Duquesne Light Company on behalf of Francis and Michele Hriadil (*Hriadil* matter), my opinions are as follows:

1. A causal relationship between environmental exposure to radiofrequency (RF) fields, including RF fields specifically from smart meters owned and operated by Duquesne Light Company, and claims of adverse human health effects, including any cancer and non-cancer health effects in the Complaint, is not established.
2. Exposure to RF fields that is estimated in the Hriadil residence, as a result of the operation of smart meters or other sources within or outside the residence, does not have any proven adverse effect on health.
3. The materials included in the Complaint or submitted in response to the discovery requests by the Hriadils do not provide a basis for a valid scientific conclusion that low-level RF exposure, including RF fields associated with the operation of smart meters, is known to cause or contribute to the development of any adverse health effects, including cancer and non-cancer health outcomes.
4. Exposure to RF fields from smart meters does not have any proven adverse effect on health, thus, scientific research does not support the claim that RF fields from smart meters would adversely affect the health of Ms. Hriadil, who according to the Complaint is in good general health and does not claim any specific medical or health conditions.
5. Exposure to RF fields from smart meters does not have any proven adverse effect on health, thus, scientific research does not support the claim that RF fields from smart meter would adversely affect the health of Mr. Hriadil. In addition, the overall scientific evidence does not establish a causal relationship between RF exposure and any of Mr.

Hriadil's medical conditions, which include, according to the medical records received, "severe degenerative disc disease of all the lumbar spine with severe degenerative levoscoliosis"; "degenerative joint disease of the right hip"; "lumbar radiculopathy"; "colitis"; and heart palpitations with "sinus tachycardia."

6. The overall scientific evidence does not establish a causal relationship between RF exposure and any of the medical conditions listed in the family medical history of Mr. and Ms. Hriadil, which include, according to the Complaint and the medical records received, cardiomyopathy, chronic obstructive lung disease, congestive heart failure, hypertension, peptic ulcer, mitral regurgitation, tricuspid regurgitation, aortic regurgitation, and pulmonary hypertensions.

My opinions are expressed herein to a reasonable degree of scientific and medical certainty. I reserve the right to revise my opinions as more information becomes available.

Limitations

At the request of counsel for Duquesne Light Company, Exponent prepared this report that provides an overview of the scientific literature on potential health effects of RF electromagnetic fields and evaluates whether exposure to RF fields from smart meters owned and operated by Duquesne Light Company near the Hriadil family residence, presents any health risk to the Hriadil family or others. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, and 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 for other purposes are at the sole risk of the user. My opinions are expressed herein to a reasonable degree of scientific certainty. I reserve the right to revise my opinion as more information becomes available.

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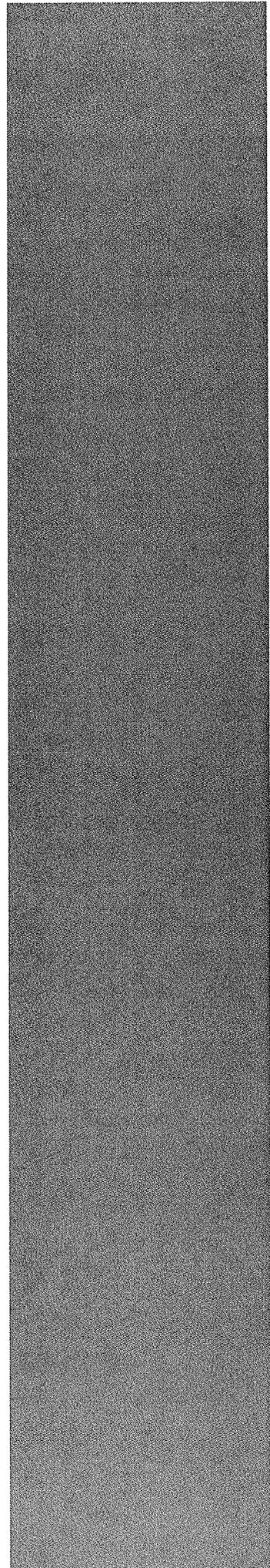
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Appendix A

**Appendix A – Curriculum
vitae of Gabor Mezei, M.D.,
Ph.D.**





Exponent[®]
Engineering & Scientific Consulting

Gabor Mezei, M.D., Ph.D.

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Professional Profile

Dr. Mezei is a physician and epidemiologist with over 25 years of experience in research of clinical outcomes and environmental and occupational health issues. He designed, conducted and evaluated epidemiologic investigations and directed multidisciplinary research programs related to children's health (including childhood leukemia and brain cancer), adult cancers (e.g., leukemia, brain and breast cancer), neurodegenerative diseases (e.g., Alzheimer disease and amyotrophic lateral sclerosis [Lou Gehrig disease]), reproductive health outcomes (including birth defects), occupational injuries and ergonomics. He has been involved in studies of various occupational and environmental exposures, including electromagnetic fields (EMF), mineral fibers (asbestos), air pollutants and metals (welding fumes). Dr. Mezei has expertise and experience in quantitatively and qualitatively aggregating epidemiologic evidence (via literature reviews, meta-analyses, and pooled analyses) for environmental and occupational risk assessments. Dr. Mezei appeared as an expert in hearings at several state (US) and provincial (Canada) public utility commissions and a parliamentary committee in Ireland.

Prior to joining Exponent, Dr. Mezei directed a multidisciplinary scientific research program at the Electric Power Research Institute designated to address potential human and animal health effects associated with residential and occupational exposure to power frequency and radiofrequency EMF. He also directed occupational health and safety research focusing on injury surveillance, ergonomics evaluations, and occupational exposure assessments. Earlier, at the Toronto Western Hospital, University of Toronto, he conducted research to identify clinical factors affecting hospital stay, adverse clinical and surgical outcomes and hospital readmissions following ambulatory surgery. He was a practicing physician at the National Institute for Dermatology in Budapest, Hungary.

Dr. Mezei trained as a physician (M.D.) at the Semmelweis University of Medicine in Budapest, Hungary, and as an epidemiologist (Ph.D.) at the School of Public Health of the University of California in Los Angeles (UCLA). He was the recipient of Fogarty and Fulbright Fellowships. He served as an affiliate associate professor in the Department of Environmental and Occupational Health Sciences of the University of Washington in Seattle, Washington, as a visiting scientist at the Hungarian National Research Institute for Radiobiology and Radiohygiene in Budapest, Hungary, and as an associate editor at the Journal of Exposure Science and Environmental Epidemiology. Dr. Mezei lectured at Stanford University, the UCLA School of Public Health, and the Electrotechnical Committee of the Hungarian Academy of Sciences. Dr. Mezei is an author or co-author of over 60 scientific publications and book chapters on topics related to the epidemiology of environmental and occupational exposures and chronic diseases (such as cancer and neurodegenerative diseases), adverse clinical outcomes, and environmental exposure assessment.

Academic Credentials & Professional Honors

Ph.D., Epidemiology, University of California, Los Angeles (UCLA), 1995

M.D., Medicine, Semmelweis University of Medicine, 1990

Fogarty Fellowship, 1992-1995

Fulbright Fellowship, 1994-1995

Languages

Hungarian

Publications

Mezei G, Chang ET, Mowat FS, Moolgavkar SH. 2017. Epidemiology of mesothelioma of the pericardium and tunica vaginalis testis. *Ann Epidemiol* 27(5):348-359.e11.

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Appendix B

Agency Reviews and Opinions on Exposure to RF Fields and Health

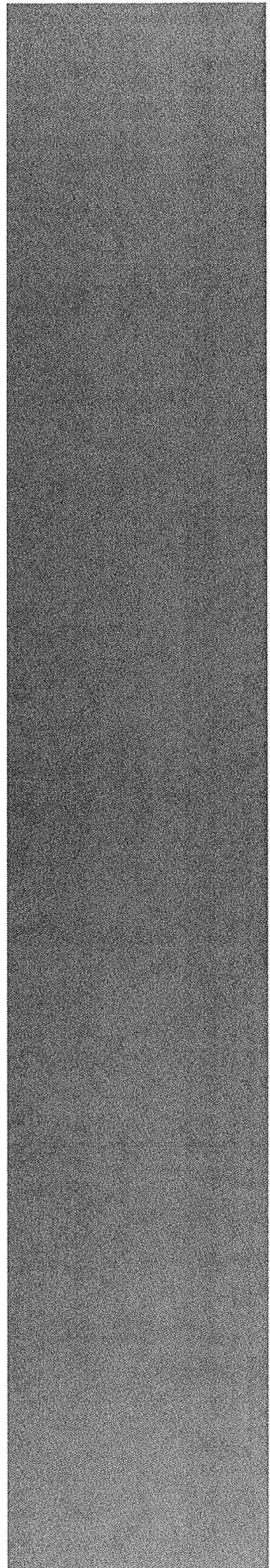


Table 1. Agency Reviews and Opinions on Exposure to RF Fields and Health

Year	Organization	Review	
2016	Swedish Radiation Safety Authority	Research 2016:15 – Recent Research on EMF and Health Risk – Eleventh Report from SSM's Scientific Council on Electromagnetic Fields, 2016	https://publii/protect
2015	New Zealand Ministry of Health	Interagency Committee on the Health Effects of Non-ionising Fields: Report to Ministers 2015	https://
2015	Scientific Committee on Emerging and Newly Identified Health Risks	Opinion on Potential Health Effects of Exposure to Electromagnetic Fields (EMF)	https://ees/e
2015	Swedish Radiation Safety Authority	Research 2015:19 – Recent Research on EMF and Health Risk – Tenth Report from SSM's Scientific Council on Electromagnetic Fields, 2015	https://ntent/a004/health/counc
2014	Swedish Radiation Safety Authority	Research 2014:16 – Ninth Report from SSM's Scientific Council on Electromagnetic Fields, 2014	https://ntent/e7d82/health/counc
2013	British Columbia Centre for Disease Control and Canadian National Collaborating Centre for Environmental Health	Radiofrequency Toolkit for Environmental Health Practitioners	http://conte/Toolk
2013	French Agency for Food, Environmental and Occupational Health & Safety	OPINION of the French Agency for Food, Environmental and Occupational Health & Safety Concerning the Update of the "Radiofrequency Electromagnetic Fields and Health" Expert Appraisal"	https://a0150
2013	Health Council of the Netherlands	Mobile Phones and Cancer. Part 1: Epidemiology of Tumours in the Head	https://proce/health
2013	International Agency for Research on Cancer	IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 102. Non-Ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields	https://vol10/

Year	Organization	Review	
2013	Swedish Radiation Safety Authority	Research 2013:19 – Eighth Report from SSMs Scientific Council on Electromagnetic Fields	https://content.68e30.scient
2013	Swiss Federal Office for the Environment	Radiation from Transmission Installations and Effects on Health	https://cs/elestudie/transrhealth
2012	Advisory Group on Non-ionizing Radiation for the Health Protection Agency of the United Kingdom	Health Effects from Radiofrequency Electromagnetic Fields	https://content.2.pdf
2012	Norwegian Institute of Public Health	Low-Level Radiofrequency Electromagnetic Fields - An Assessment of Health Risks and Evaluation of Regulatory Practice	https://hoyfre.vurde
2011	Health Council of the Netherlands	Influence of Radiofrequency Telecommunications Signals on Children's Brains (2011)	http://es/20
2010	European Health Risk Assessment Network on Electromagnetic Fields Exposure	Deliverable Report D2 - Risk Analysis of Human Exposure to Electromagnetic Fields	http://pdf
2010	European Health Risk Assessment Network on Electromagnetic Fields Exposure	Deliverable Report D-3 - Report on the Analysis of Risks Associated to Exposure to EMF: <i>In Vitro</i> and <i>In Vivo</i> (Animals) Studies	http://EFHR
2010	Latin American Experts Committee on High Frequency Electromagnetic Fields and Human Health	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	http://health.ceRev
2010	Swedish Radiation Safety Authority	Recent Research on EMF and Health Risk – Seventh Annual Report from SSMs Independent Expert Group on Electromagnetic Fields	http://likatio

Year	Organization	Review	
2009	EMF-NET: European Commission 6 th Framework Programme Coordination Action	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	https:// public/ Interp/ 0heal
2009	Health Council of the Netherlands	Electromagnetic Fields: Annual Update 2008	http:// es/20
2009	International Commission on Non- ionizing Radiation Protection	Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 kHz – 300 GHz)	https:// f-revie
2009	Scientific Committee on Emerging and Newly Identified Health Risks	Health Effects of EMF Exposure	http:// /04_s