ELECTRIC POWER RESEARCH INSTITUTE

EPRI Comment: Sage Report on Radio-Frequency (RF) Exposures from Smart Meters

Electric Power Research Institute (EPRI)

Summary

A report by Sage Associates dated January 1, 2011 and entitled, "Assessment of Radiofrequency Microwave Radiation Emissions from Smart Meters" was posted on the internet. The "Sage Report" uses various approaches to characterize radio-frequency (RF) field levels and to compare them to the exposure limits published by the Federal Communications Commission (FCC) in FCC OET Bulletin 65, Edition 97-01, dated August 1997. The report concludes that, "FCC compliance violations are likely to occur under normal conditions of installation and operation of smart meters and collector meters in California." The report also compares field levels from smart meters to those from studies reporting biological and health effects. However, the research findings referred to in the Sage Report have not been replicated or are inconsistent with the results of other studies. Furthermore, virtually every recent mainstream expert scientific review of the RF health literature conducted in North America and Europe has not recognized the effects cited by the Sage Report as confirmed or definitive. This commentary deals with the engineering and source characterization aspects of the Sage Report.

The Sage Report misapplies the specifications in the FCC rule as follows:

Time averaging exposure: Exposures from smart meters may be time-averaged according to the FCC statement in OET Bulletin 65 that, "'source-based' time-averaging based on an inherent property or duty-cycle of a device is allowed." Clearly, smart meters fall into the "source-based" category of emitters. An extensive analysis of smart meter transmissions for almost 47,000 units in southern California was conducted for EPRI ("An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter" EPRI Report 1021126 December 2010; available to the public at www.epri.com). The report estimated that 99.5% of the sample was operating at a duty cycle of about 0.22% or less, a value that translates to 3 minutes and 10 seconds of transmitting over a day; the maximum duty cycle in any residence did not exceed 5%. The duty cycle for cell relays (referred to as "collectors" in the Sage Report) within the same sample did not exceed 1%. The Sage Report defaults to compute exposures based on a 100% duty cycle, thus over-estimating exposure in the sample cited above by no less than 20-fold and more typically more than 400-fold.

Spatial averaging of exposure: The FCC states that to characterize a person's exposure properly, the RF power density should be averaged across the entire volume of an exposed body. An example in the EPRI Report indicates that power density averaged over the body of a 6-foot person situated one foot in front of a meter is less than approximately one-quarter of the emission at the point of the wavefront's peak at that distance. The Sage Report assumes a uniform field across the body that is equal to the peak power density within a body's cross-section, thus overestimating an individual's exposure.

Reflections: Radio frequencies "bounce" or reflect off of surfaces exactly the way light is reflected off the surface of a mirror. The level of a reflected wave that is present at any point is expressed as a percent of the electric field of the incident wave, which is the free-space wave in the absence of any reflection. The power density at that point is the incident power density multiplied by [1+(percent of reflection/100)]^2. The FCC's worst-case scenario is a 100% reflection (4-fold increase in power density), with a less conservative though more realistic value of 60% (2.56-fold increase in power density) used in many cases as an upper bound (e.g., see EPRI White Paper 1020798, "A Perspective on Radio-Frequency Exposure Associated With Residential Automatic Meter Reading Technology"). A key element to factoring reflections into an exposure calculation is that, for RF emitters like smart meters in real-world residential environments, the percent reflection diminishes as one approaches the meter. Thus, at the distance at which incident power density is maximal, the contributions of reflections to total power density are minimal. The Sage Report assumes that incident power density is enhanced by reflections uniformly throughout the space surrounding the meter. Furthermore, in adopting reflection values from one particular study (Hondou et al., 2006), it uses reflection factors that, in terms of power density, are between 30 and 110 times greater than the worst-case power density enhancement due to reflections identified by the FCC.

In addition, this commentary points out several other pertinent issues:

- The Sage report, in discussing exposure with relation to specific anatomic sites that include eyes and testes, referred to stipulations in an outdated 1999 IEEE standard. The current IEEE standard, published in 2005, with extensive documentation on the topic, removed any exceptions for such anatomic sites.
- In comparing field calculations to the FCC limits, the Sage Report did not frequency weight the contributions from the end-point meter (~900 MHz), the Home Area Network (HAN) antenna (~2,400 MHz) and the cell relay (~850 MHz). Because the FCC exposure limits are frequency dependent, a simple arithmetic addition of contributions from various sources is an inappropriate approach to compliance assessment.

Therefore, the Sage Report, for the reasons enumerated in this commentary, has over-estimated exposures from smart meters using assumptions and calculations that are inconsistent with the FCC's rule and that do not recognize the basic physical characteristics of RF emissions.

Section I: Background

A report by Sage Associates dated January 1, 2011 and entitled, "Assessment of Radiofrequency Microwave Radiation Emissions from Smart Meters" was posted on the internet; it will be referred to here as the Sage Report for short. The report's authorship was not specifically identified. The proprietor of Sage Associates, Ms. Cindy Sage, also coordinated the BioInitiative Working Group (BWG) report that was published in 2007. That report included chapters by about a dozen scientists known in the EMF research field. Ms. Sage and Dr. David Carpenter the report's other signatory concluded that health effects of various kinds result from low-level radio-frequency exposure, and:

> There may be no lower limit at which exposures do not affect us. Until we know if there is a lower limit below which bioeffects and adverse health impacts do not occur, it is unwise from a public health perspective to continue "business-as-usual" deploying new technologies that increase ELF [extremely-low-frequency] and RF exposures, particularly involuntary exposures.

The BWG report, which covered RF as emitted from various sources (cell phones, base stations) suggested that safety standards for RF exposures, as specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the U.S. Federal Communication Commission (**FCC**[1]), are not sufficiently conservative. EPRI's commentary (EPRI publication #1016233) on the BWG Report can be found at www.epri.com.

The recently issued Sage Report takes a two-fold approach. First, it uses a number of engineering assumptions to calculate presumed exposure levels from one or more smart meters with or with out a **cell relay** (referred to as "collectors" in the Sage Report) also present, and to then identify "violations" of FCC exposure limits for the general public. The Sage Report concludes that:

> FCC compliance violations are likely to occur under normal conditions of installation and operation of smart meters and collector meters in California. Violations of FCC safety limits for uncontrolled public access are identified at distances within 6" of the meter. Exposure to the face is possible at this distance, in violation of the time-weighted average safety limits. FCC violations are predicted to occur at 60% reflection (OET Equation 10 and 100% reflection (OET Equation 6) factors, both used in FCC OET 65 formulas for such calculations for time-weighted average limits. Peak power limits are not violated at the 6" distance (looking at the meter) but can be at 3" from the meter, if it is touched.

Secondly, it compares these exposure levels with those in selected studies that have reported biological or health effects resulting from RF exposures that are considered adverse. However, the research findings referred to in the Sage Report have not been replicated or are inconsistent with the results of other studies. Furthermore, virtually every recent mainstream expert scientific review of the RF health literature conducted in North America and Europe has not recognized the effects cited by the Sage Report as confirmed or definitive.

This commentary will not deal any further with the health aspect of the report, and will focus primarily on its technical assumptions, treatment of engineering factors, and source characterization. This commentary will also draw from

[1] Bolded terms are defined in the Glossary

measurement and modeling data published in an Electric Power Research Institute (**EPRI**) study of smart meters ("An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter" EPRI Report 1021126, December 2010; available to the public at www.epri.com). In the commentary that follows, Section II deals with the Sage Report's understanding of the FCC rule governing RF exposures. Section III comments on how the FCC formula for computing RF field levels was used in the Sage Report, and Section IV provides conclusions.

Section II: Sage Report's Interpretation of the FCC Rule Specifying Exposure Limits for Radio-Frequency Electromagnetic Fields

The Federal Communications Commission established limits for exposure to radio-frequency electromagnetic fields, which are published in FCC OET Bulletin 65 (August 1997), and codified in the Code of Federal Regulations (47 CFR § 1.1310). The FCC rule was adopted from two previous guidelines, one published by the National Council on Radiation Protection and Measurements (NCRP Report No. 86) in 1986, and the other by the Institute for Electrical and Electronic Engineers (IEEE C95.1 1991) in 1991. Both had extensively reviewed the biological and health literature, concluding that the only established effects were associated with tissue heating and no confirmed effects below heating thresholds were identified. The effects associated with heating, so-called "thermal effects", concerned diminished response rates in food-motivated behavioral experiments in laboratory animal subjects (rhesus monkeys and rats) and were accompanied by a rise in body core temperature of about 1° C. Such behavioral changes are considered amongst the most sensitive indicators of potentially adverse effects. In the absence of heating, there have been no consistently demonstrated "non-thermal" mechanisms that could lead to adverse biological or health effects either acutely or chronically. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the IEEE have since developed guidelines very similar to the FCC's based on the same behavioral effects following for each a comprehensive review of the scientific literature. Prior to its publication, the FCC rule received endorsements from the U.S. Environmental Protection Agency (EPA), the U.S. Food and Drug Administration (FDA), and the U.S. Occupational Safety and Health Administration (OSHA). The EPA reaffirmed its opinion in letters written in 1999 and 2002.

There are four aspects of the Sage Report that are examined in the ensuing discussions within this section. The first three relate to the basis for the FCC rule, as follows: (1) averaging exposure over time (2) averaging exposure across space, and (3) **reflections**. The 4th item concerns the Sage Report's understanding of the most recent exposure standards as published by IEEE, as they relate to specific anatomic sites, namely the eyes and testes.

<u>Time Averaging</u>

FCC OET Bulletin 65 states:

> …exposures, in terms of **power density**…may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure…the averaging time for occupational/controlled exposures is 6 minutes, while the averaging time for general population/uncontrolled exposures is 30 minutes. (page 10)

The OET further states:

> Time-averaging provisions may not be used in determining typical exposure levels for devices intended for use by consumers in general population/uncontrolled environments. However, "source-based" time-averaging based on an inherent property or duty-cycle of a device is allowed. (page 74)

In this context, smart meters fall into the "source-based" category, and time averaging is completely appropriate. The Sage Report claims that time averaging does not apply to assessing exposures from smart meters, and continuous operation should be assumed for compliance assessment, which represents a misinterpretation of the FCC rule. The applicability of time averaging to smart meters was reaffirmed in a letter dated August 6, 2010 to Ms. Sage from the FCC's Julius Knapp, Chief, Office of Engineering and Technology, stating:

> For exposure evaluations, however, the average power is relevant, which is determined by taking into account how often these devices [smart meters] will transmit.

To illustrate the amount of time a meter may actually transmit, data were collected from the transmitting records from almost 47,000 meters over a nearly three month period, amounting to more than four million readings in all. The capability to accomplish this was enabled by special software developed by the smart meter manufacturer (Itron) to acquire transmit data. The analysis enumerated the data

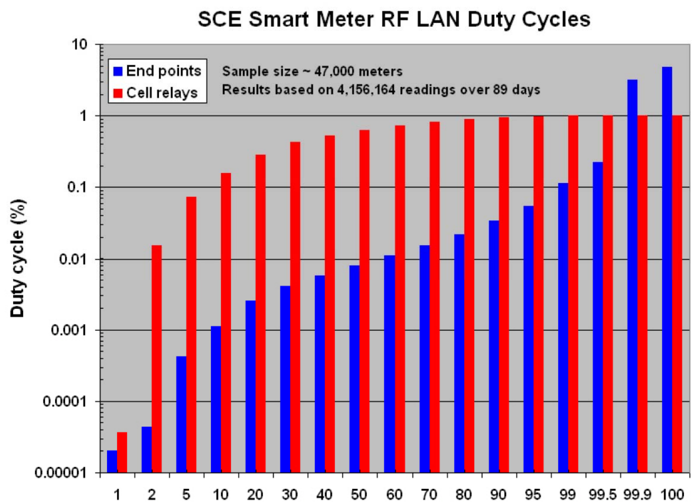

Figure 1

Analysis of SCE daily average duty cycle distribution for different percentiles based on 4,156,164 readings of transmitter activity from an average of 46,698 Itron Smart Meters over a period of 89 consecutive days. Analysis based on estimated transmitter activity during a day. (From EPRI Technical Report 1021126, December 2010)

"packets" associated with uplink and downlink communication to and from end-point and cell relay meters to serve as surrogates for transmission time. The study estimated (Figure 1) a maximum duty cycle of under 5%, with 99.5% of the sample operating at a duty cycle of about 0.22% or less, a value that translates to 3 minutes and 10 seconds of transmitting over a day (a 5% duty cycle, worst case in this study, translates to 72 minutes of transmitting). The duty cycle for cell relays within the same sample did not exceed 1%. Assuming these data are representative of smart meter function in general, the Sage Report using a 100% duty cycle, over-estimates exposure by no less than 20-fold and more typically more than 400-fold. In a smaller study of over 6,800 meters, end-point and cell relay meters were monitored for the number of bytes of data transmitted over an observation period of one day. This method provided a direct (exact) measure of time, and reported duty cycles even lower than those in the larger sample, with no one-day average duty cycle exceeding 1%.

Thus, as an example of examining smart meter duty cycle from the compliance perspective, the EPRI study estimated a nominal exposure of about 12 microwatts per square centimeter (μW/cm^2) for a person a foot from a 250-mW **end-point meter** while the meter is transmitting. Assuming the worst case duty cycle of 5% for that meter, the "source-based" time-averaged exposure would be 0.6 μW/cm^2, which is 0.1% of the FCC's **MPE** (maximum permissible exposure); for a 1% duty cycle, the average exposure would be 0.02% of the FCC limit. This value does not yet account for the FCC's stipulation for spatial averaging dealt with in the next discussion.[2]

Spatial Averaging

FCC OET Bulletin 65 states:

> Limits for General Population/Uncontrolled exposure: 0.08 W/kg as averaged over the whole-body and spatial peak **SAR** not exceeding 1.6 W/kg as averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). (page 75)

Exceptions are made for the extremities that have higher SAR permitted. Earlier in the document, FCC states as a general principle:

> A fundamental aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions. Spatially averaged RF field levels most accurately relate to estimating the

[2] The FCC rule is not specified to account for the fraction of transmitting time over the course of a day that a person would actually traverse the area within a given distance to the meter. Using the example in the text, a person doing yardwork for 2 hours and 24 minutes (one-tenth of a day) close, say a foot (30 centimeters) from a single meter operating with a 5% duty cycle mounted on the external wall of a residence, would nominally receive an exposure equivalent to 0.01% of the FCC exposure limit for the general public (one-ten thousandth of the exposure limit).

whole body averaged SAR that will result from the exposure and the MPEs … (page 10)

The Sage Report presumes a uniform exposure level across the volume of an exposed person that corresponds to the maximum level in the wavefront at a given distance. However, in fact, the exposure level varies across the dimensions of a body. Figure 2 depicts the general idea of averaging across a body's volume in which 10 or more measurements along the body's axis are averaged in terms of their power density (often measured as the electric field, which is then squared to represent power density).

According to measurements reported in the EPRI study, power densities vary across the measurements' angle of elevation. Figure 3 illustrates how the power density varies along a circular trajectory from above to below the meter. The color coded graphic on the right-hand panel of the figure indicates that, in the case of the meter characterized, power density may be lower at the top by roughly a factor of 3 (~5 dB), and at the bottom by up to a factor of about 10 (~10 dB). In a crude fashion, one could liken the variation of power to the beam from a flashlight, which is maximal head on and diminishes as one moves further from the center of the beam (Figure 4). Qualitatively, it is fairly apparent that the power density in the center of the beam can significantly overestimate the power density averaged over one's body dimensions. An example of a vertical profile measured 1 foot in front of a continuously transmitting 900-MHz, 250-mW end-point smart meter (i.e., transmitting to the **LAN**), as reported in the EPRI study cited above, is shown in Figure 5. Note that at its peak the emission is just below 2% of the FCC's MPE for 900 MHz, but the vertical average, which is the basis for the FCC rule is 0.44% of the FCC MPE, more than 4 times less than the peak.

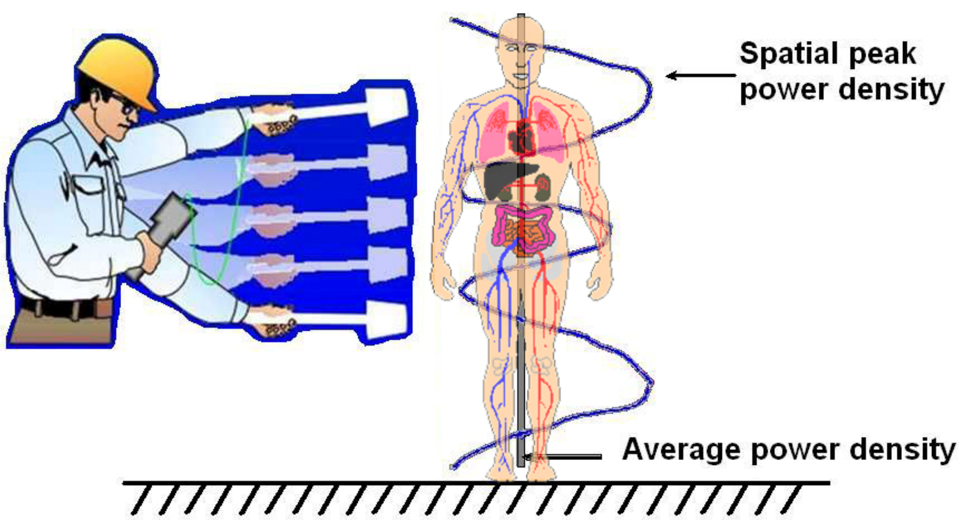

Figure 2
Estimating whole-body SAR with measurements of the power density along the axis of a person in the location to be occupied. (adapted from EPRI Resource paper 1014950, December 2007)

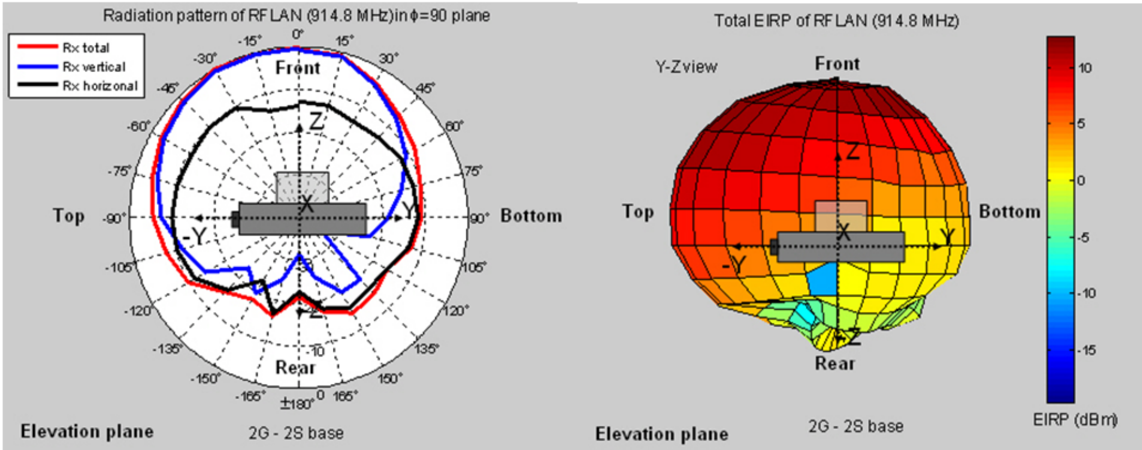

Figure 3
Left: Elevation plane pattern of the 900 MHz RF LAN transmitter in an end point meter showing the horizontal, vertical and total pattern. The scale is in dB with the maximum field at the outer edge of the pattern circle. Right: Elevation plane view of the total EIRP of the 900 MHz RF LAN transmitter in an end point meter. (From EPRI Technical Report 1021126, December 2010)

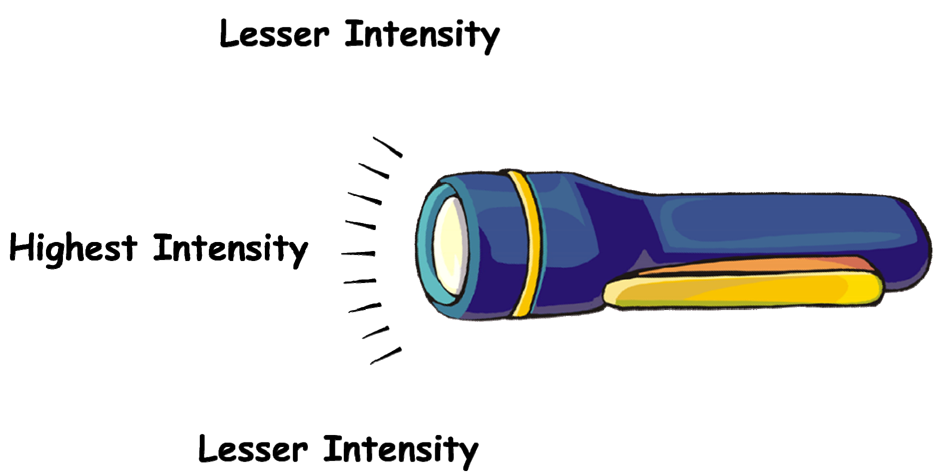

Figure 4
Depiction of beam from a flashlight as a crude analogy of the vertical gradient of the power density from a smart meter

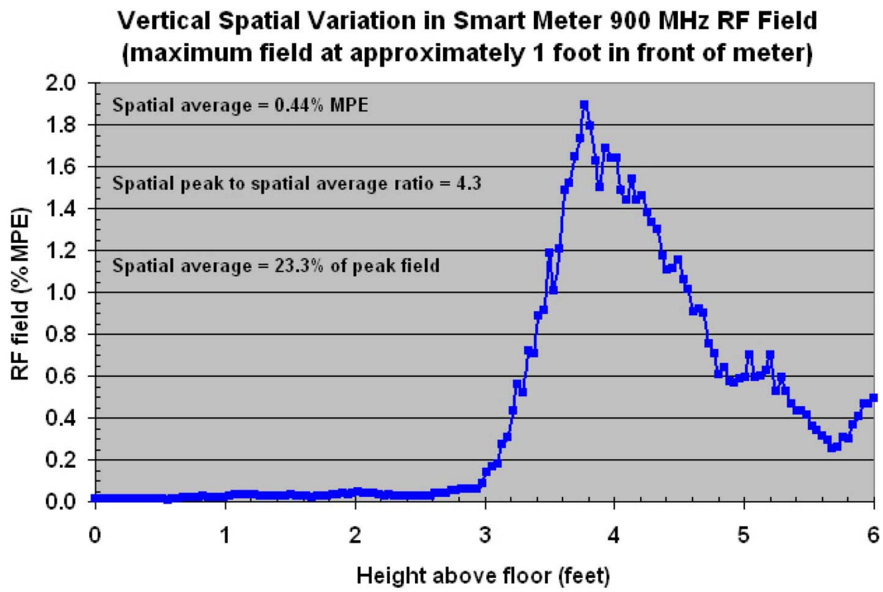

Figure 5

Vertical spatial variation in Smart Meter 900 MHz RF LAN field from 0 to 6 feet above the floor at a lateral distance from the Smart Meter of approximately 1 foot. (From EPRI Technical Report 1021126, December 2010)

Reflections

Electromagnetic waves may reflect off surfaces (Figure 6), which enables us to use rear- and side-view mirrors, which are highly reflective surfaces, to observe traffic traveling behind us. Though visible light is electromagnetic energy that propagates at frequencies 5 to 6 orders of magnitude greater than RF emissions from smart meters, the latter may likewise be reflected to some extent from floors, ceilings and walls depending on their reflective properties. However, most of the environments inhabited by people consist largely of indoor surfaces (wood or carpeted floors, plaster walls and ceilings, windows) and outdoor surfaces (exterior walls, lawns, sidewalks) of moderate reflectivity that may also absorb (and thus attenuate) or pass electromagnetic energy much as light passes through glass. Further, given that smart meters are very frequently on building exteriors facing open space (Figure 7), reflections in those cases would be very small contributors to overall exposure.

The extent of an added exposure due to reflection depends on the reflectivity of the surface (e.g., metallic surfaces are highly reflective; carpeted and wood floors are more absorptive and less reflective), the antenna's beam characteristics (e.g., its angular width and direction) the angle of reflection, and the distance traveled by the wave to an exposed person. For an analysis of RF fields that will result in a conservative estimate of the actual field, the FCC OET 65 Bulletin states:

> For a truly worst-case prediction of power density at or near a surface, such as at ground level or on a rooftop, 100% reflection of incoming radiation can be assumed, resulting in a potential doubling of predicted field strength and a four-fold increase in (far-field equivalent) power density. (Page 20)[3]

The Sage Report interpreted several studies to justify that a worst-case analysis would require increasing the power density of the free-space emissions to account for reflections. This approach was based primarily on a paper by Hondou et al. (J Phys Soc Jap 75:084801, 2006), which reported power density levels for an enclosure made entirely of perfectly reflective surfaces, as depicted in Figure 8 (right). Using the light analogy, this would be equivalent to an enclosed space whose walls, floor and ceiling were made entirely of mirrors. The Hondou et al. (2006) result adapted by the Sage Report is shown in Figure 8 (left), which shows the power density along a path leading away from the antenna.

[3] Reflection values are expressed in terms of the electric field. Thus, as power density is proportional to the electric field squared, a 100% reflection at a particular point in space corresponds to an enhancement of the power density by a factor of $(1+100/100)^2 = 4$. A more common upper bound estimate of 60% for reflection results in a power density enhancement of $(1+60/100)^2 = 2.56$.

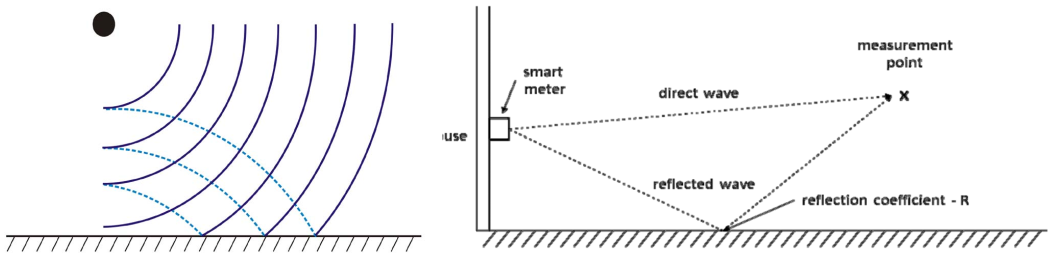

Figure 6
RF Reflections. Left: Wavefronts emitted (solid lines) by source (black dot) and reflected (dashed lines) from the ground. Far from the source (far field), these waves become nearly "plane waves." (From EPRI Technical Report 1014950, Dec 2007); Right: Exposure to incident and reflected wave as would occur at a measurement point; the two contributions may reinforce or cancel one another depending on their mutual phase relationships (Compliments of R.G. Olsen and R.A. Tell)

Figure 7
Measuring RF power densities in front of an outdoor bank of smart meters

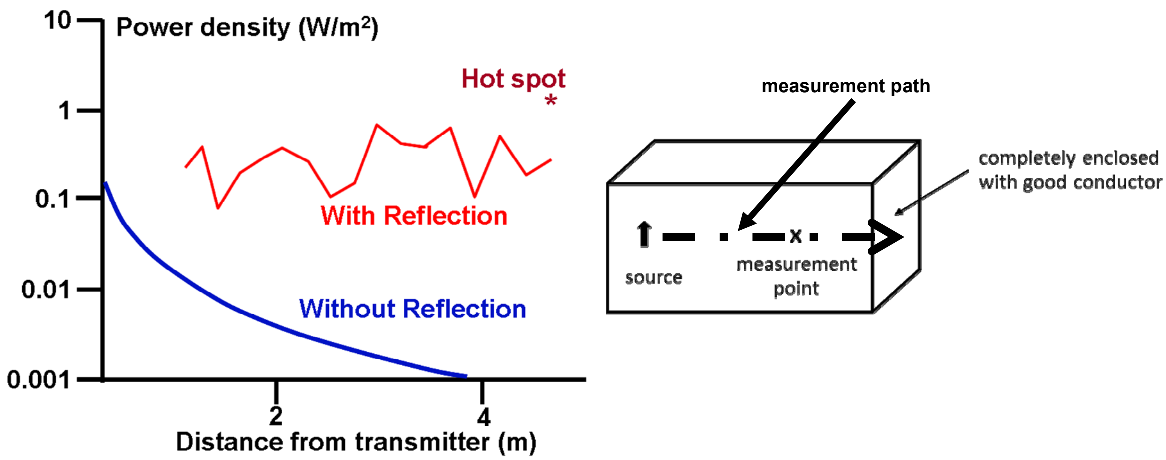

Figure 8
Right: Conceptualization of measurements conducted by Hondou et al. (Compliments of R.G. Olsen and R.A. Tell); Left: Measured power density in the conductive enclosure (red), and calculated free-space value (adapted from Hondou et al., 2006)

At a distance of about 4 meters the power density in this enclosure is between 100 to 1,000 times greater than would be the calculated free space value (blue curve), with a "hot-spot" noted with a power density about 2,000 times greater than the free space scenario. Also note in Figure 8 that as the distance to the antenna decreases, the discrepancy between the reflected and free-space values also decreases (see below for further discussion of reflections versus distance from an antenna). The Sage Report introduced enhancement factors of 1,000% and 2,000%, which translate to, respectively, 121- and 441-fold enhancements of the incident power density (see footnote 3). Despite the claim of adopting "conservative" reflection values based on Hondou et al., the Sage Report, nonetheless used power density enhancements roughly 30 to 110 times greater than the FCC's worst-case scenario, and, moreover, applied the enhancements uniformly to every point in space, which violates the laws of physics. In addition, there are no practical scenarios that simulate the conditions of the enclosure tested by Hondou et al. whereby an individual would be in a space occupied by a smart meter that was also entirely enclosed by conductive surfaces on all sides (floor, walls and ceiling).

Looking further at a realistic indoor case, one might consider rooms in the home (such as a bedroom) to be nearly fully enclosed; doors and windows do represent openings in the enclosure. But, even if this is said, there are two fundamental problems (see Figure 9). First, the source (i.e., the smart meter) is not within the room. It is possible for some of the RF electromagnetic waves to "leak" into the room, but only if the wall is partially transparent to electromagnetic waves from the meter on the exterior of the residence or in the garage. The leakage is small because a smart meter does not radiate much in the direction of the house; its radiation is intentionally directed away from the house. As an added note, though the HAN "Zigbee" antennas are designed to communicate to devices within a residence's interior, their transmission pattern measured in the EPRI study was also more heavily weighted outward much like the end-point meter's pattern. In addition, as the RF passes through the wall it is attenuated. The second problem is since the room is not completely enclosed and the enclosure is not a perfect (or nearly perfect) conductor, it will not behave nearly like the resonant cavity used by Hondou et. al. As a final note, if the wall is more transparent to RF so that attenuation of the RF into the room is small, then the room will look even less like a resonant cavity because its walls are more "leaky."[4]

Although the power density values in the Hondou paper in all likelihood correctly represent the experimental conditions they describe, the results were not utilized appropriately in the Sage Report. The Sage Report calculates the field at

[4] It is worth noting that Hondou et al. reported another scenario simulating an elevator with a mounted antenna. The "elevator" enclosure used by Hondou et. al. also has metallic sides floor and ceiling. It does have an open door, but given the orientation of the source antenna, only smaller fields are radiated towards the door opening. Thus the door does not degrade the properties of the elevator as a resonant cavity as much as it could if the source was oriented in a different direction.

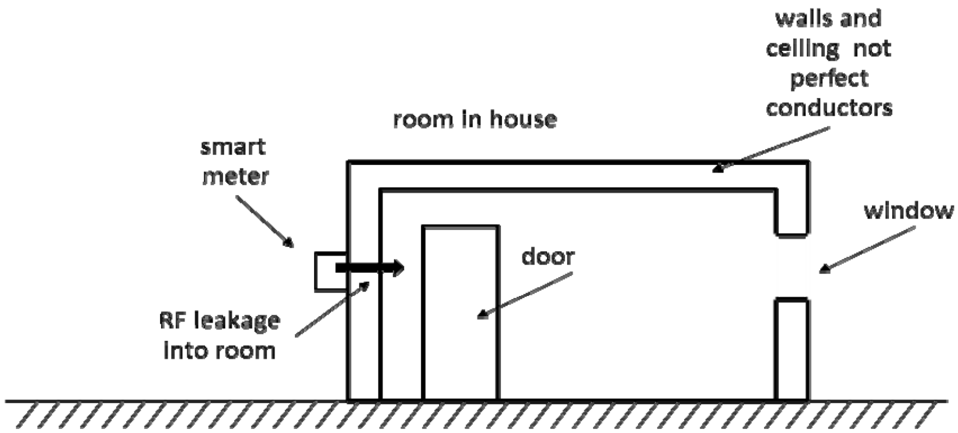

Figure 9

RF leakage into a room in a house which is not a good resonant cavity due both to openings in the walls and the imperfectly conducting enclosure. (Compliments of R.G. Olsen and R.A. Tell)

(for example) 0.15 meters (i.e., 6 inches) from the source and then increases the field by 1000% or 2000% to calculate an "actual" power density at that point. This is not a correct use of Hondou's data. The author of the Sage report incorrectly assumes that the factor of 1,000% or 2000% (10 or 20 fold enhancement of the electric field) may apply at every point in space as a multiplier to the "free space" value of the field. Based on fundamental laws of physics, it can be unequivocally stated that the closer the field point is to the source, the smaller any increase in the field due to reflections. In fact, this ratio approaches 1.0 as the field point becomes arbitrarily close to the source.

This aspect of exposure regarding reflections close to a source, included in the EPRI Technical Report, is illustrated in Figure 10 (left), which represents a calculated power density one foot from a smart meter placed at a height of 5 feet with and without a reflection. The values with reflections present (wavy blue curve) were calculated with a technique called "method of moments" that utilizes realistic characteristics of a ground surface to calculate reflected power density. With a reflection present in this model, the average power density over the vertical axis of a six-foot person standing one foot from the meter was 3.2% greater than the average with no reflections. Also, note how much smaller the exposure levels would be for a person shorter than 4-5 feet. Figure 10 (right) charts the contribution of reflections to the free space power density as distance from the meter increases. Though the relative contribution of reflection is shown to increase with distance from the meter, the total incident power density is simultaneously falling by a greater relative amount with increasing distance from a source. A key finding from this analysis of reflections is that for the distance range modeled, from 1 foot to 20 feet from the meter, the greatest enhancement in power density caused by reflections was only 65%, far smaller than the 256% value provided by FCC for conservatively estimating RF fields when reflections occur. Furthermore, these higher enhancements occurred for points furthest from the source for which the incident field is already smaller. A previous EPRI White Paper, "A Perspective on Radio-Frequency Exposure Associated With Residential Automatic Meter Reading Technology" (1020798), described 60% as a realistic upper bound reflection.

The Sage Report cites another paper (Vermeeren et al., Phys Med Biol 55:5541, 2010) in the context of supporting its enhancement factors which, in fact, it does not. This study models SAR resulting from a rooftop exposure to a base station antenna in the presence of a reflective rooftop (or ground plane) and wall. It reports that at 900 MHz – close to the frequency of the RF LAN (915 MHz) in the wireless smart meter under discussion here – the SAR (proportional to power density at any given frequency) could increase by as much as a factor of about 3.6 (5.5 dB) on a localized basis in 10 grams of tissue, and by a factor of about 2.8 (4.5dB) on a whole body basis, both of these values being consistent with the FCC OET 65 cited above (Figure 11, vertical blue bars). At the same time, reflections modeled at 900 MHz may also result in a reduction of SAR compared to the free-space scenario. At lower frequencies (300 and 450 MHz) reflections were slightly greater, and at higher frequencies, including 2,100 MHz, roughly a home area network's (**HAN)** operating frequency, the reflections were lower (vertical red bars).

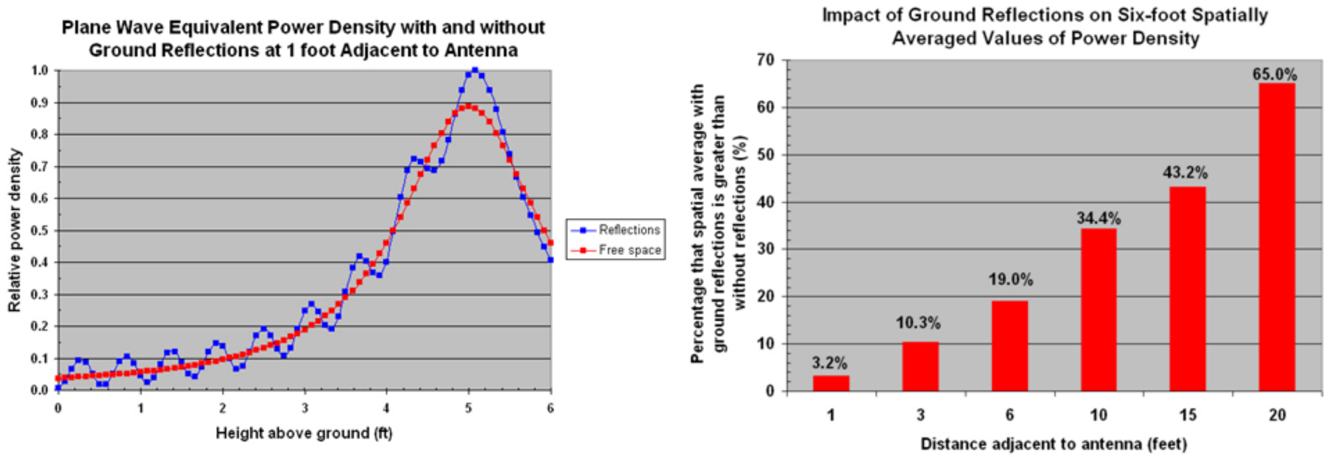

Figure 10
Left: Relative calculated plane wave equivalent power density along a six-foot vertical path, one foot adjacent from a 900 MHz half-wave dipole positioned at five feet above the ground. Power density values are compared with and without ground reflections. Right: Impact of ground reflections on six-foot spatial average of power density for different distances lateral to a 900 MHz dipole antenna mounted at five feet above ground. Vertical axis represents the percentage that the spatially averaged power density that includes any ground reflected fields is greater than the spatially averaged power density in free space (without any ground reflected fields). Ground reflection estimated by method of moments as described in the EPRI Report. (From EPRI Technical Report 1021126, December 2010)

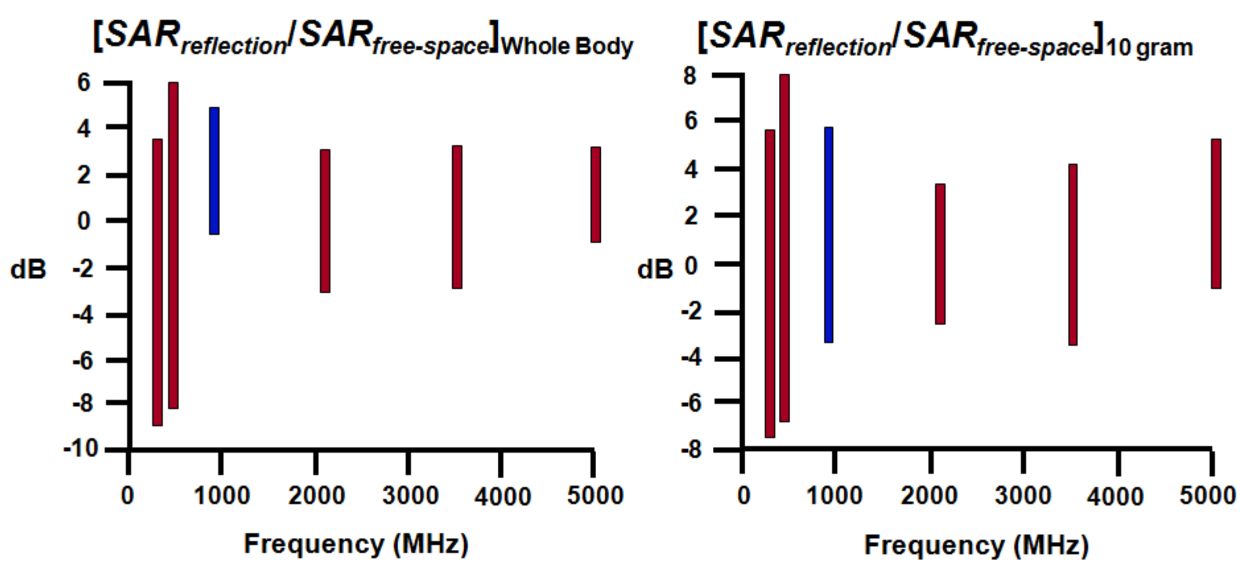

Figure 11
The range of whole-body and 10-gram SAR in the rooftop scenario with reflective ground and wall. Each frequency includes combinations of distance and reflective surface (ground, wall, ground + wall). The blue vertical bar corresponds to the power density range for 900 MHz. (adapted from Vermereen et al., 2010)

Worthy of note was that the Vermeeren et al. study modeled a vertical panel antenna that would intercept much of the body's dimension, leading to a much greater opportunity for whole body exposure than the case of the much smaller smart meter relative to the body's dimension.

Sage Report Interpretation of IEEE Standard Concerning Eyes and Testes

The Sage Report states the following:

> The ANSI/IEEE C95.1-1999 standard specifically excludes exposure of the eyes and testes from the peak power limit of 4000 uW/cm2* [asterisk is a reference to a footnote]. However, nowhere in the ANSI/IEEE nor the FCC OET 65 documents is there a lower, more protective peak power limit given for the eyes and testes.

However, in 2005, IEEE published a revised standard covering RF electromagnetic fields, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz (IEEE Std C95.1™-2005). The 2005 revision, working with additional research results available after the 1999 standard was published, removed the language and the intent of language in the 1999 standard regarding an exclusion for eyes and testes. IEEE Std C95.1™-2005 remains the current IEEE standard for RF exposures. The basis for the removal of the 1999 language regarding eyes and testes was extensively documented in the 2005 standard, with brief excerpts as follows:

> …localized exposure at the upper limit (10 W/kg averaged over 10 g of tissue) is protective against all adverse effects including those occurring in the fetus and testes, the two targets identified as most sensitive to thermal damage. (p. 86)
>
> In summary, adverse effects of RF exposure of the eye, i.e., cataracts, are associated with significant temperature increases due to the absorption of RF energy. The maximal permissible RF exposures in this standard are therefore protective against the significant temperature increases that can result in adverse effects on the eye, such as cataracts. There is no evidence of other significant ocular effects, including cancer, which would support a change in the adverse effect threshold of 4 W/kg. (p 60)

Thus, given that revised standards are designed to override their predecessors, the Sage Report relied on an outdated document to suggest an exclusion for eyes and testes.

Section III: Sage Report Calculation of Exposure Levels

The formula used by the FCC for estimating emission levels from an RF source is:

$$S = \frac{P_t \times G_{\max} \times \delta \times R}{4\pi r^2}$$

Where,

S is plane wave equivalent power density (W/m^2)
P_t is maximum transmitter output power (W)
G_{max} is the maximum possible antenna power gain (a dimensionless factor); this means that the transmission has directionality with maximum power transmitted in one particular direction.[5]
δ is the duty cycle of the transmitter (dimensionless)
r is the radial distance between the transmitter and the point of interest (meters)
R is a dimensionless factor that accounts for possible ground reflections that could enhance the resultant field. For a 60% reflection of the electric field, a value typically used for assessing compliance, the power density, S, would increase of $(1.6)^2$ or 2.56 in the power density since it is proportional to the square of the electric field.[6]

The Sage Report used this formula to calculate RF power density levels as they compare to the FCC general public compliance levels under the assumptions that:

---

[5] The power density transmitted in this direction at a given distance is greater – by a factor, G_{max} - than the power density at the same distance were it transmitted symmetrically in all directions (or omnidirectionally) in a spherical pattern as from an isotropic source. This also means that there are areas near the antenna with transmitted power density lower than the power density from an omnidirectional source.

[6] The inclusion of the ground reflection factor of 2.56 makes this formula conservative since it assumes that the meter's signal emitted by a power meter is also reflected from the ground causing an enhancement of the resultant RF field due to what is called phase addition of the direct and reflected signals. If this occurs, it will only happen at very specific points above the ground while at other points, the signals will add destructively, reducing the signal intensity. Hence, when considering the body as a whole, the ground reflection will generally not affect the body's average exposure. Nonetheless, it is common when performing FCC compliance analyses to include the possibility of ground reflections.

1. Duty cycle need not be taken into account, and that continuous exposure should be assumed.

2. Implicitly, space averaging across the volume of an individual is unnecessary, with a uniform exposure at the maximum value occurring across all exposure space.

3. Reflections that may range from 60% to 2000% are uniform across the entire exposure volume.

4. Power densities from multiple meters can be added to calculate a cumulative power density, which can then be compared to the FCC limit.

Taking these in sequence:
(1) The discussion above clarified that as a source-based exposure, incorporating the duty cycle into the estimate of average power density (and average SAR) is appropriate.

(2) Furthermore, the FCC OET 65 indicates that exposure levels should be averaged over the volume of a person presumed to occupy the space where exposure occurs.

(3) In estimating the potential effect reflections may play, 60% is a highly conservative estimate for smart meters, with 100% a worst-case estimate. The reflective enclosure case modeled by Hondou et al. (2006) does not apply to any practical real world situations yet identified (see footnote 3 above concerning Hondou et al.'s elevator model). Uniform enhancement cannot be assumed because close to and in front of an emitter, where the emission is maximum, is exactly where the effect of reflections is at a minimum.

(4) When one is very close to a bank of meters (the Sage Report uses exposure to four meters), one cannot be in the direct path of the maximum emission for each, because (again using the crude flashlight model), the power density decreases to some degree with the azimuthal angle from the center of a propagated field. At the very closest distance in front of one emitter, the azimuthal angle from other emitters predicts lower exposures than derived from simple addition. With respect to this point, it should be pointed out that the exposure level in the 4-meter scenario in the Sage Report was unexplainedly not the 4-fold value expected; rather it was less (for example, see Sage Report, Tables 2 & 3). In Sage Report, Table 1, upper panel, the author reports values at 9 inches, rather than the stated 6 inches, such that the 4-meter scenario in the bottom pane is over 7 times the 1-meter scenario, which is clearly not possible even under the report's assumptions.

In terms of compliance assessment, when more than one source is present, each is weighted according to its frequency dependent FCC limit, as shown below Table 1 on the following page Thus, the Sage Report's approach of reporting a simple sum of power densities from sources at different frequencies is inappropriate in terms of assessing compliance.

In fact, the RF field levels from smart meters, even when grouped together, are not expected to exceed FCC limits. The graph in Figure 12 shows expected exposure levels, in terms of the fraction of the FCC limits appropriately weighted by relative contributions from each source. The specifications for the meters in these calculations, shown here in Table 1, correspond to those used in the Sage Report. The graph considers four end-point meters and three end-point meters combined with a cell relay for 60% and 100% reflections. The smart meters include both the end-point LAN emitter, and the HAN transmitting at 2,405 MHz. The Cell Relay includes these two transmitters, as well as a third transmitter for communicating over a wireless wide area network (**WWAN**) back to the utility company. The calculation assumes a duty cycle of 1%, which was applicable to over 99.5% of the readings from the data shown in Figure 1. Furthermore, the graph is extremely conservative in applying the reflection factor at every distance, and assuming that the peak power density in the wavefront is uniform in space (neither of these applies in actuality). These factors more than compensate for the fact that a small fraction of meters may operate at duty cycles up to 5%. Even at a distance of 8 cm (~3 inches) the power density is well below the FCC MPE.

Section IV: Conclusion

In assessing potential RF exposure levels from smart meters, the Sage Report misapplied the practices prescribed by the FCC in "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields" (OET Bulletin 65, Edition 97-01, August 1997). Both space and time-averaging are appropriate and reflections of 60% or even 100% may be included to provide conservative estimates. In addition, the Sage Report's author did not evaluate cumulative exposure weighted by MPE at the frequency of each source as instructed by the FCC. A more realistic estimate, even allowing for assumptions that overestimate exposure levels

Table 1
Antenna Values for Figure 12

Antenna	*TPO* (dBm)	*G* (dBi)	*EIRP* (dBm)	*EIRP* (mW)	*f* (MHz)	*MPE* (mW/cm²)
RF LAN	24.27	2.2	26.47	443.6	915	0.610
Zigbee	18.71	1	19.71	93.5	2405	1.0
Cell Relay	31.8	-1	30.8	1202.3	850	0.567

Fraction of FCC Limit = $n_1 S_{LAN}/0.610 + n_2 S_{Zig}/1.0 + n_3 S_{CR}/0.567$
Within a residence:
n_1=number of LAN meters; n_2=number of Zigbee meters; n_3=1=number of cell relays

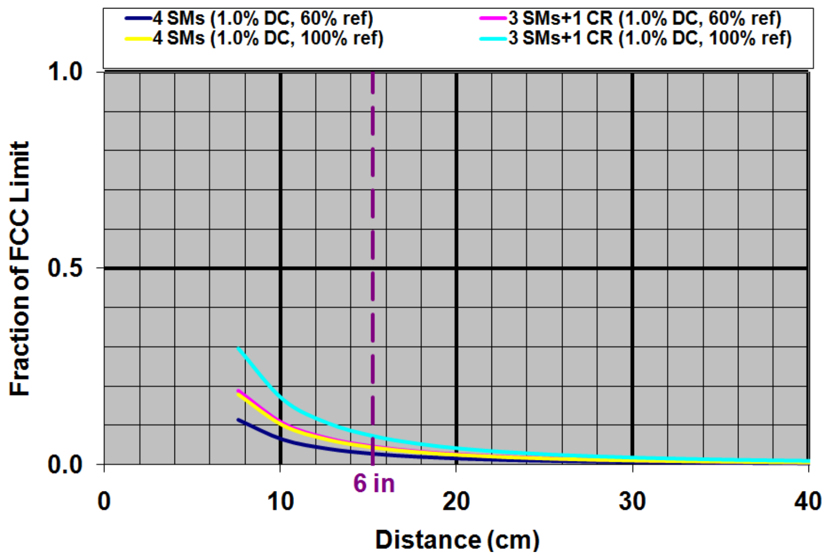

Figure 12
Calculated exposure levels from combinations of meters operating at 1% duty cycle with reflection values of 60% and 100% (see text)

by ignoring space averaging and declining RF levels at positions lateral to the center of a wavefront, reveals that FCC MPEs are very unlikely to be exceeded, even at distances very close to the source. This conclusion also applies to regions behind a meter bank owing to lower emissions in that direction and the attenuating properties of wall materials. These points were supported by measurements described in the EPRI Report, in which power density was measured in front of a rack of 10 ¼ watt (nominal power) continuously operating (i.e., 100% duty cycle) smart meters starting at a distance of 1 foot[7]. Under these circumstances, the frequency-weighted power density was 8% of the FCC MPE for the general public. For a realistic duty cycle of 1%, this would translate to 0.08% of the FCC MPE. For measurements taken immediately behind the rack, the field level for continuous transmission was 0.6% of the FCC MPE at a distance of 8 inches. It should also be pointed out that while the testing was conducted with end-point meters rated nominally at ¼-watt (~250 mW), the manufacturer's data illustrated in the EPRI Report allow one to estimate that, based on a sample of 200,000 meters, 99.9% operate at powers between 150 and 475 mW, with a possible maximum of 500 mW for no more than 0.05% of units. However, were all 10 meters rated at 1 W with the same spatial transmission pattern as the quarter-watt meters actually measured, the exposure at 1 foot would still be less than the FCC limit by a factor of three. Therefore, the Sage Report, for the reasons enumerated in this commentary, has over-estimated

[7] The meters were specially programmed to operate continuously for the measurement study. They do not operate in this manner when actually deployed, transmitting intermittently for very brief periods, as explained in the text.

exposures from smart meters using assumptions and calculations that are inconsistent with the FCC's rule and that do not recognize the basic physical characteristics of RF emissions.

Glossary

Cell relay: A form of Smart Meter that provides the normal function of an end point meter but also allows for data connectivity with the electric utility company via a wireless wide area network that functions in the cellular telephone or personal communications service (PCS) bands.

Duty Cycle: a measured of the percentage or fraction of time that an RF device is in operation. A duty cycle of 1.0, or 100%, corresponds to continuous operation. Also called duty factor. A duty cycle of 0.01 or 1% corresponds to a transmitter operating on average only 1% of the time.

End point meter: A term used to designate a Smart Meter that is installed on a home or business to record and transmit electric energy consumption but that does not provide access point features such as those provided by a cell relay.

EPRI, Electric Power Research Institute, Inc.: EPRI conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

FCC, Federal Communications Commission: the Federal Communications Commission (FCC) is an independent agency of the US Federal Government and is directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite, and cable. The FCC also allocates bands of frequencies for non-government communications services (the NTIA allocates government frequencies). The guidelines for human exposure to radio frequency electromagnetic fields as set by the FCC are contained in the Office of Engineering and Technology (OET) Bulletin 65, Edition 97-01 (August 1997). Additional information is contained in OET Bulletin 65 Supplement A (radio and television broadcast stations), Supplement B (amateur radio stations), and Supplement C (mobile and portable devices).

Gain, antenna: a measure of the ability of an antenna to concentrate the power delivered to it from a transmitter into a directional beam of energy. A search light exhibits a large gain since it can concentrate light energy into a very narrow beam while not radiating very much light in other directions. It is common for cellular antennas to exhibit gains of 10 dB (dB is a form of expressing power density on a logarithmic scale) or more in the elevation plane, i.e., concentrate the power delivered to the antenna from the transmitter by a factor of 10 times (10 dB = 10x; 20 dB = 100x) in the direction of the main beam giving rise to an effective radiated power greater than the actual transmitter output power. In other directions, for example, behind the antenna, the antenna will greatly decrease the emitted signals. Gain is often referenced to an isotropic antenna, that is one that transmits uniformly in all directions (spherical wavefront).

HAN, Home Area Network: In the context of Smart Meters, a local area network for communication between a personal computer and various electrical appliances, equipment or systems to accomplish optimized electric energy consumption at the home. Small sensors with low power radio transmitters are attached to the various electrical appliances for communication in the HAN.

LAN, Local Area Network: The wireless mesh (see below) network that interconnects end-point meters, which transmit data to the cell relay (collection point) for transmittal to the local utility. (**Mesh Network**: A term describing a network, typically wireless, in which multiple nodes communicate among themselves and data can be relayed via various nodes to some access point. Mesh networks are self healing in that should a particular pathway become nonfunctional for some reason, alternative paths are automatically configured to carry the data. Mesh networks can expand beyond the normal range of any single node (Smart Meter) by relaying of data among the different meters.)

MPE, Maximum Permissible Exposure: The value of an exposure that should not be exceeded. These include the electromagnetic field, expressed in terms of power density, or as either the electric or magnetic field, and induced or contact currents.

Power Density: The power per unit area, denoted by the symbol *S*, of an RF electromagnetic field normal (perpendicular) to its direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, milliwatts per square centimeter (mw/cm^2) or microwatts per square centimeter ($\mu w/cm^2$). For plane waves (i.e., those beyond the immediate proximity of an antenna operating in the frequency range of a smart meter), power density, electric field strength, *E*, and magnetic field strength, *H*, are related by the impedance of free space, whose value is 120π (377) ohms. In particular, the power density, $S = E^2/120\pi = 120\pi H^2$ (where *E* and *H* are expressed in units of V/m and A/m, respectively).

Reflection: An electromagnetic wave (the "reflected" wave) caused by a change in the electrical properties of the environment in which an "incident" wave is propagating. This wave usually travels in a different direction than the incident wave. Generally, the larger and more abrupt the change in the electrical properties of the environment, the larger the reflected wave.

SAR, Specific Absorption Rate: The time derivative of the incremental energy absorbed by (dissipated in) an incremental mass contained in a volume of a given density. SAR is expressed in units of watts per kilogram, W/kg (or milliwatts per gram, mW/g). Guidelines for human exposure to radio frequency fields are based on SAR thresholds for potential adverse biological effects. When the human body is exposed to a radio frequency field, the SAR experienced is proportional to the squared value of the electric (or magnetic) field strength induced in the body.

WWAN, Wireless Wide Area Network: WWANs are provided by several cellular telephone companies for wireless connectivity directly to the Internet for data transmission. WWANs are different from so-called wireless "hot spots" such as found in cyber cafés and operate in either the 850 MHz cellular or 1900 MHz PCS bands.

EPRI Contacts

Rob Kavet, ScD, MS, MEE
Senior Technical Executive
650-855-1061

Gabor Mezei, MD, Ph.D.
Program Manager
650-855-8909

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together...Shaping the Future of Electricity

1022639 February 2011

Electric Power Research Institute

3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA

800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com