McKnight v. PECO
Pa. PUC Docket # C-2017-2621057

Dr. Christopher C. Davis

March 27, 2018

Qualifications

PECO CD-1

Educational and Training

B.A., with Honors, Natural Sciences, Trinity College, Cambridge University (England).

Diploma, with Distinction, Advanced Studies in Science (Physics), University of Manchester (England).

M.A,. Natural Sciences (Physics), Trinity College, Cambridge University (England).

Ph.D. Physics, University of Manchester (England).

Post-Doctoral Fellow, Applied and Engineering Physics, Cornell University (United States).

Present Position

Minta Martin Endowed Professor of Engineering and Professor of Electrical and Computer Engineering, University of Maryland.

Research Experience

Conducted a wide variety of scientific studies in the fields of physics, biophysics, and electrical engineering, and particularly studies on electromagnetics, bioelectromagnetics, and radio frequency electromagnetics, bioelectromagnetics, and dosimetry.

Conducted a substantial amount of research on radio frequency fields of the type produced by PECO's AMI electric and gas smart meters.

Publications

Authored or co-authored two books, twelve book chapters, 252 articles published in peer-reviewed scientific journals (principally reporting on studies conducted) and 321 papers

presented at scientific conferences. Among those publications: 2 book chapters on radio frequency fields and 24 articles published in peer-reviewed scientific journals on radio frequency fields. Presented 55 papers at scientific conferences on radio frequency fields.

Teaching Experience

Students seeking Bachelor's degrees, Master's degrees, and Doctor of Philosophy (Ph.D.) degrees, on subjects including those in the fields of Physics and Electrical Engineering, particularly Electromagnetics (which includes radio frequency).

Supervised 71 students who ultimately earned Master of Science or Ph.D. degrees in Electrical Engineering, Physics, or Biophysics.

Professional Recognition

Fellow of the Institute of Electrical and Electronics Engineers (IEEE). Previously Chair of Subcommittee on Radio Frequency Fields of IEEE Committee on Man and Radiation (COMAR).

Fellow of the Institute of Physics.

Reviewer of papers for a number of scientific publishers, including: American Industrial Hygiene Association Journal, Australian National Health Research Council, Bioelectromagnetics, Cambridge University Press, Radiation Research, Biochimica et Biophysica Acta, Environmental Biophysics, Applied Physics Letters, The British Council, IEEE Journal of Quantum Electronics, IEEE Journal on Selected Areas in Communication, IEEE Transactions on Biomedical Engineering, International Journal of Modern Physics, Journal of Applied Physics, Journal of Manufacturing Science and Engineering, Microelectronic Engineering, Radiation and

Environmental Biophysics, Physiological Measurement, Physics in Medicine and Biology, Environmental Biophysics, National Institutes of Health, National Science Foundation.

Expert Advice Experience

Provided expert advice on both power frequency and radio frequency fields, including dosimetry and proposed mechanisms for biological effects, to the United Kingdom Health Protection Agency, the U.S. National Institutes of Health, and the U.S. Food and Drug Administration's Center for Devices and Radiological Health.

Fields of Expertise Related to Testimony In This Case

Physics, Biophysics, Chemistry, Electrical Engineering, Electromagnetics, Bioelectromagnetics, and Radio Frequency Bioelectromagnetics and Dosimetry.

Recognized as an expert in those fields in several Pennsylvania Public Utility Commission proceedings in 2016, 2017, and 2018.

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Terminology and Some Basic Concepts Relevant to My Testimony in This Case
PECO CD-2

"**EMF**" is used as an abbreviation for several somewhat different terms. Sometimes it is used as an abbreviation for "electric and magnetic fields," particularly those around electrical appliances and powerlines, which can be easily separately measured; sometimes it is used as shorthand to refer to just the "magnetic fields" around electrical appliances and powerlines; and sometimes it is used as an abbreviation for "electromagnetic fields," particularly by physicists and electrical engineers. (I use it as an abbreviation for electromagnetic fields at frequencies where the electric and magnetic fields are normally measured together rather than separately.)

A "**field**" is an area around an object where an electric and magnetic component can be detected. An easy way to understand what a field is to think about the gravitational field we have on Earth, or the cool temperature field near an open refrigerator.

"**Dosimetry**" is the measurement and calculation of the level of electric and magnetic fields produced from a source. At the low frequencies used by powerlines and appliances, electric and magnetic fields are sometimes measured or calculated and referred to separately. At higher frequencies, such as radio frequency, the fields are normally measured or calculated together and referred to together as an electromagnetic field.

"**Radiation**" is a scientific term that describes how energy travels from a source, i.e., it "radiates" out from the source. An example of radiation is the waves that radiate out in a circle when a stone is tossed into a pond. TV and radio broadcast towers, powerlines, appliances, home wiring, and TV remote controls all produce fields that radiate out from the source. NASA has a good and simple statement about radiation on its website: "Radiation is energy that travels and

spreads out as it goes - the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation." It is technically accurate to refer to radio frequency "radiation," but doing so sometimes confuses people into thinking about radio signals as though they can be harmful like sources of ionizing radiation such as medical X-rays.

There are 2 basic categories of electromagnetic radiation based on their fundamental capability and within those categories there are different types of electromagnetic fields that have different properties and thus different uses.

Physicists list sources of electromagnetic radiation on an electromagnetic spectrum in order from the longest wavelength, which has the lowest energy, to the shortest wavelength, which has the most energy. (A simplified representation of the electromagnetic spectrum is shown in exhibit CD-4.) The two fundamental categories of the electromagnetic spectrum are Non-ionizing radiation and Ionizing radiation.

The Ionizing Radiation category consists of the sources of waves that have enough energy to break chemical bonds in DNA. The Ionizing radiation category includes several types of ionizing radiation, such as Medical X-rays and Radioactive Sources, like the uranium used in bombs. The Ionizing radiation category also includes the Ultraviolet Light from the Sun (which we know can damage our skin).

The Non-ionizing category of the electromagnetic spectrum consists of waves that do not have enough energy to break any chemical bonds including the chemical bonds in DNA. That category has a number of types of radiation grouped in order starting with lower frequencies:

from Extremely Low Frequency (produced from the electricity we use), up to Radio Frequency, and up to Infrared (e.g., used by TV remote controls), none of which has enough energy to break the chemical bonds in DNA and therefore are in the Non-ionizing Radiation category.

A radio frequency field is produced when an object sends a signal in the radio frequency range, most commonly for radio communications. The radio frequency range is generally considered to be from 3 kHz (kilo Hertz) to 300 GHz (Giga Hertz).

Microwave signals are the part of the radio frequency range between 300 MHz and 3GHz. Therefore, all microwave signals are radio frequency waves. When the term "microwaves" is used in communicating about devices that produce microwave signals but are not microwave ovens, people who are not physicists or electrical engineers can incorrectly assume that the devices have the same properties as microwave ovens.

Microwaves ovens are designed to produce radio frequency waves that are intense enough to quickly heat biological matter (food and liquids) to a very high temperature and exposure to those intense waves is dangerous. All devices that use radio frequency fields in the microwave portion of the radio frequency range, however, do not produce a wave that is intense enough to heat biological matter. Smart meters are a good example of those kinds of devices. They operate in the microwave frequency range but they do not produce a wave that is intense enough to heat biological matter. In communicating with people who are not physicists or electrical engineers, unless I am talking about the properties of a microwave oven, I use the term "radio frequency" to avoid giving a false impression that a particular device produces a wave that is as intense as that of a microwave oven.

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Almost all of the electricity we use in our houses and other structures has always been produced by rotating generators at power stations. Those generators produce electricity that is transmitted to us at 60 Hz (in the United States) but it also includes harmonic waves at multiples of 60 Hz (120 Hz, 180 Hz, 240 Hz, etc.). Harmonics are not considered "dirty electricity" because they are a natural byproduct of generating electricity. AMI meters do not *generate* electricity and therefore do not produce harmonics. They simply measure the electricity flowing into a house or other structure.

Some people have expressed concern about switching-mode power supplies in electrical devices like appliances and smart meters. Switching-mode power supplies generate radio frequency fields at up to about 10 MHz at very low levels. Many modern electrical appliances use switching mode power supplies. Switching mode power supplies have filters to reduce radio frequency and other signals to avoid interference with other devices.

AMI meters do not interfere with the operation of house wiring. In that regard, they behave no differently than old mechanical meters. The very low amplitude radio frequency signals generated by the power supplies in modern electronics, including smart meters, are largely filtered out and are heavily attenuated by resistance when they try to travel along house wiring. That is why, when we want to transmit radio frequency signals for cable TV, we use coaxial cables and not ordinary house wiring. Typical household appliances can generate radio frequency fields that are much larger than those generated by AMR or AMI meters.

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PECO's AMI Meters and
Federal Communications Commission Exposure Limits for Smart Meters
PECO CD-3

PECO's AMI meters only send radio signals. A natural result of sending a radio signal is the creation of a radio frequency field near the source of the signal. PECO's AMI meters produce radio frequency fields only when they are sending signals, not otherwise. PECO's AMI meters do not produce ionizing radiation.

There is nothing unusual about the radio frequency fields from PECO's AMI meters, other than that their level is extremely low. The fields from PECO's AMI meters are the same types of fields that are used for radio communications by common everyday equipment and devices, including radio stations, TV stations, garage door openers, baby monitors, cell phones, Wi-Fi, and other wireless communications devices.

In communications physics and engineering, "pulsed" means using 1) amplitude modulation that is 2) done in a way that produces a signal that has abrupt changes in the amplitude of the sine wave. PECO's AMI meters produce frequency modulated, specifically "frequency shift keyed," regular non-pulsed sine waves. PECO's AMI meters do not emit "spikes" – they send out regular sine waves. The sine waves are not amplitude modulated. Therefore, PECO's AMI meters do not send out pulsed signals.

There is a scientifically reliable basis for determining whether the radio signals periodically sent by PECO's AMI meters produce safe levels of radio frequency fields. That is by determining whether the radios in PECO's AMI meters exceed or do not exceed the Federal

Communications Commission's (FCC) Maximum Permissible Exposure Limits for non-portable devices that transmit radio frequency signals, which cover smart meters.

The FCC's Maximum Permissible Exposure limits vary depending on the frequency range used for the radio transmission. The FCC's limits for the general population are a 30-minute average power density.

The FCC's Maximum Permissible Exposure Limits for non-portable devices that transmit radio frequency signals are based on exposure guidelines issued by two expert organizations: 1) the U.S. National Council on Radiation Protection and Measurements (NCRP) and 2) the American National Standards Institute (ANSI).

In their exposure guidelines NCRP and ANSI specifically took into consideration studies of *both* thermal exposure levels (i.e., those that can produce tissue heating) and non-thermal exposure levels (i.e., those that are too low to produce tissue heating). Both found that the studies of non-thermal exposures did not show they caused any adverse biological effects. The FCC states on its website that the scientific evidence for adverse biological effects from non-thermal exposure levels remains "unproven." It explains: "A number of reports have appeared in the scientific literature describing the observation of a range of biological effects resulting from exposure to low levels of RF energy. However, in most cases, further experimental research has been unable to reproduce these effects. Furthermore, since much of the research is not done on whole bodies (in vivo), there has been no determination that such effects constitute a human health hazard." I agree with the FCC.

The FCC's view about non-thermal radio frequency field exposure is shared by the consensus of independent scientists who are expert in radio frequency bioelectromagnetics. The international expert group ICNIRP has found that "[t]he studies conducted so far have not provided consistent evidence of biological effects under non-thermal RF exposure conditions." [ICNIRP 2009, 155] A recent review by the New Zealand Ministry of Health concluded "thermal effects are the only ones for which there is clear evidence." [New Zealand 2015, 32] This view is also set forth in the recent finding by the expert committee advising the European Commission on EMF/RF issues. [SCENIHR 2015, pp. 24 and 59]. In sum, the scientific consensus is that exposure to non-thermal level radio frequency fields does not produce any "non-thermal effects."

Based on the scientific studies, NCRP and ANSI both identified the same threshold level (i.e., lowest level) of radio frequency exposure at which a potentially adverse biological effect could occur, which was found to be at a level where there could be tissue heating. Before setting its maximum permissible exposure limits, the FCC consulted with the U.S. Food and Drug Administration, the Environmental Protection Agency, the Occupational Safety and Health Administration, and the National Institute of Occupational Safety and Health. Each of those agencies supported the FCC setting its exposure limits based on the threshold level identified by NCRP and ANSI. The FCC then applied safety factors to that threshold level, resulting in even more strict FCC Maximum Permissible Exposure limits.

The Electromagnetic Spectrum

IONIZING RADIATION

Gamma rays — 300 EHz

30 EHz

X-rays — 3 EHz

300 PHz

Ultraviolet light — 30 PHz

3 PHz

Radioactivity

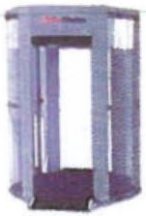
Medical X-Rays

NON-IONIZING RADIATION

Infrared light — 300 THz

30 THz

3 THz



Airport Terahertz Imager

Radio Frequencies — 300 GHz

30 GHz

Microwaves — 3 GHz

300 MHz

TV

30 MHz

Cell phone

Base Station

Smart Meter

3 MHz

AM/FM Radio

300 kHz

30 kHz

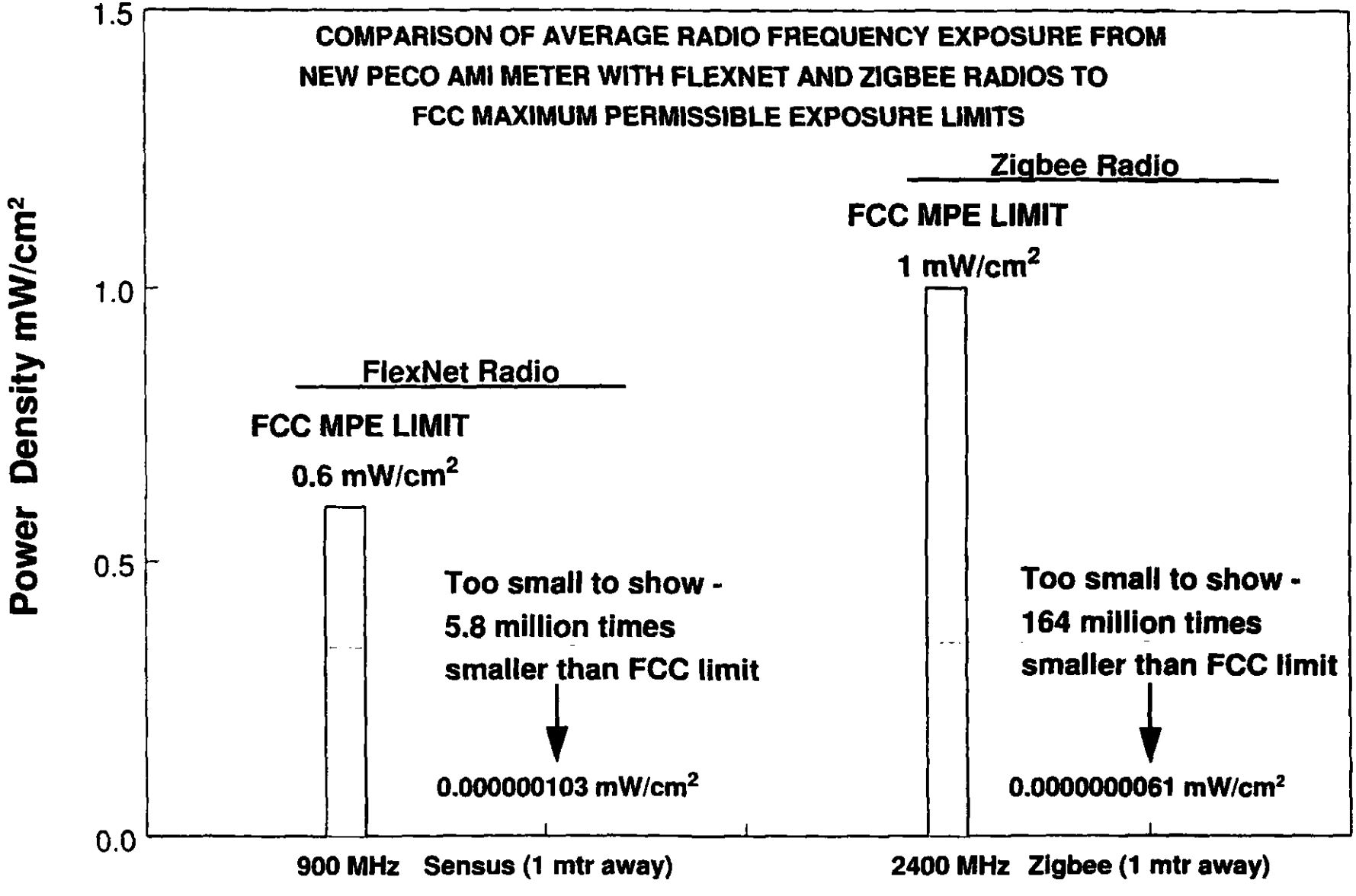
3 kHz

Power frequency — 50-60 Hz

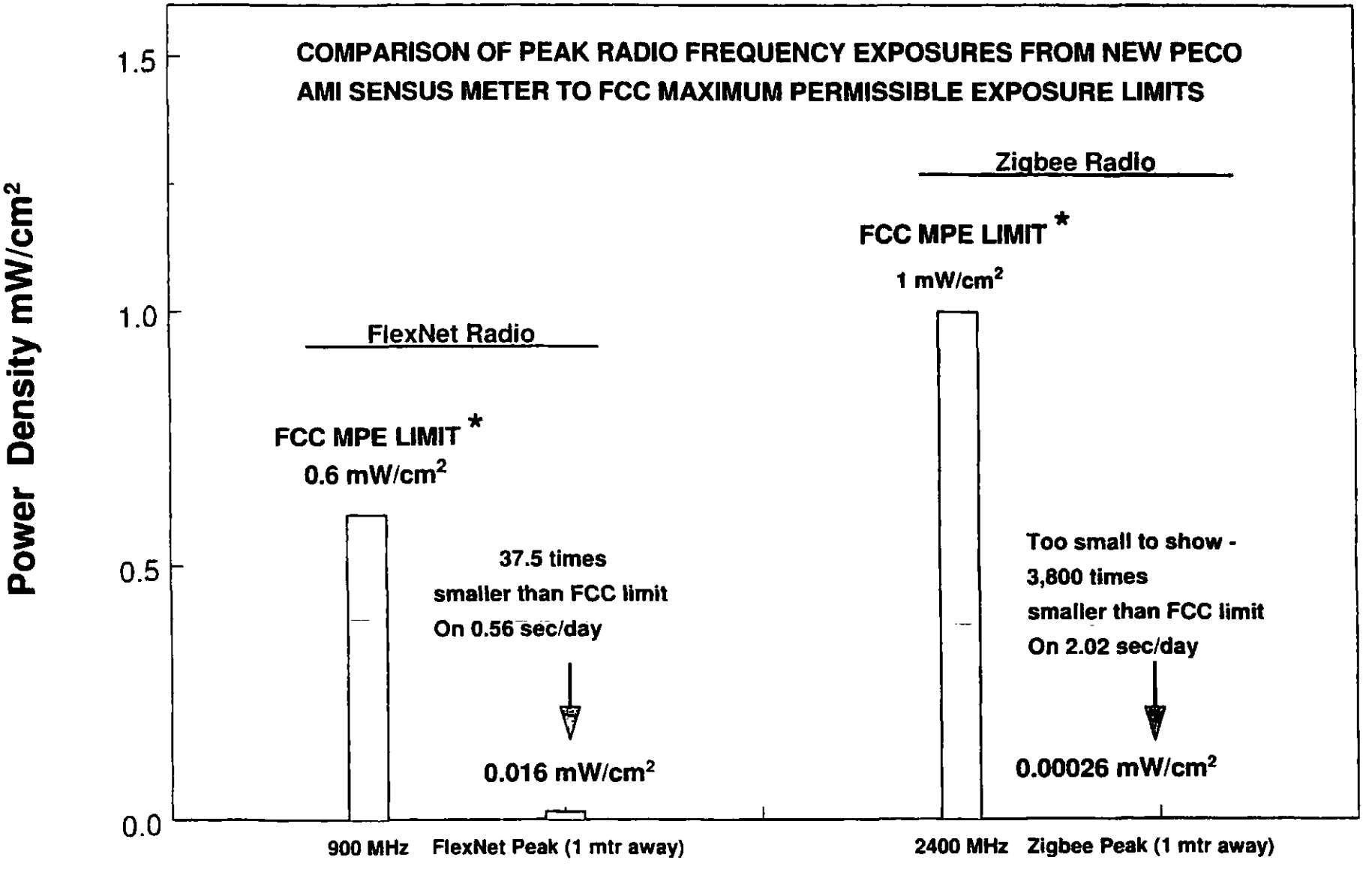
Earth's magnetic field — 0 Hz

Electric power

PECO CD-4

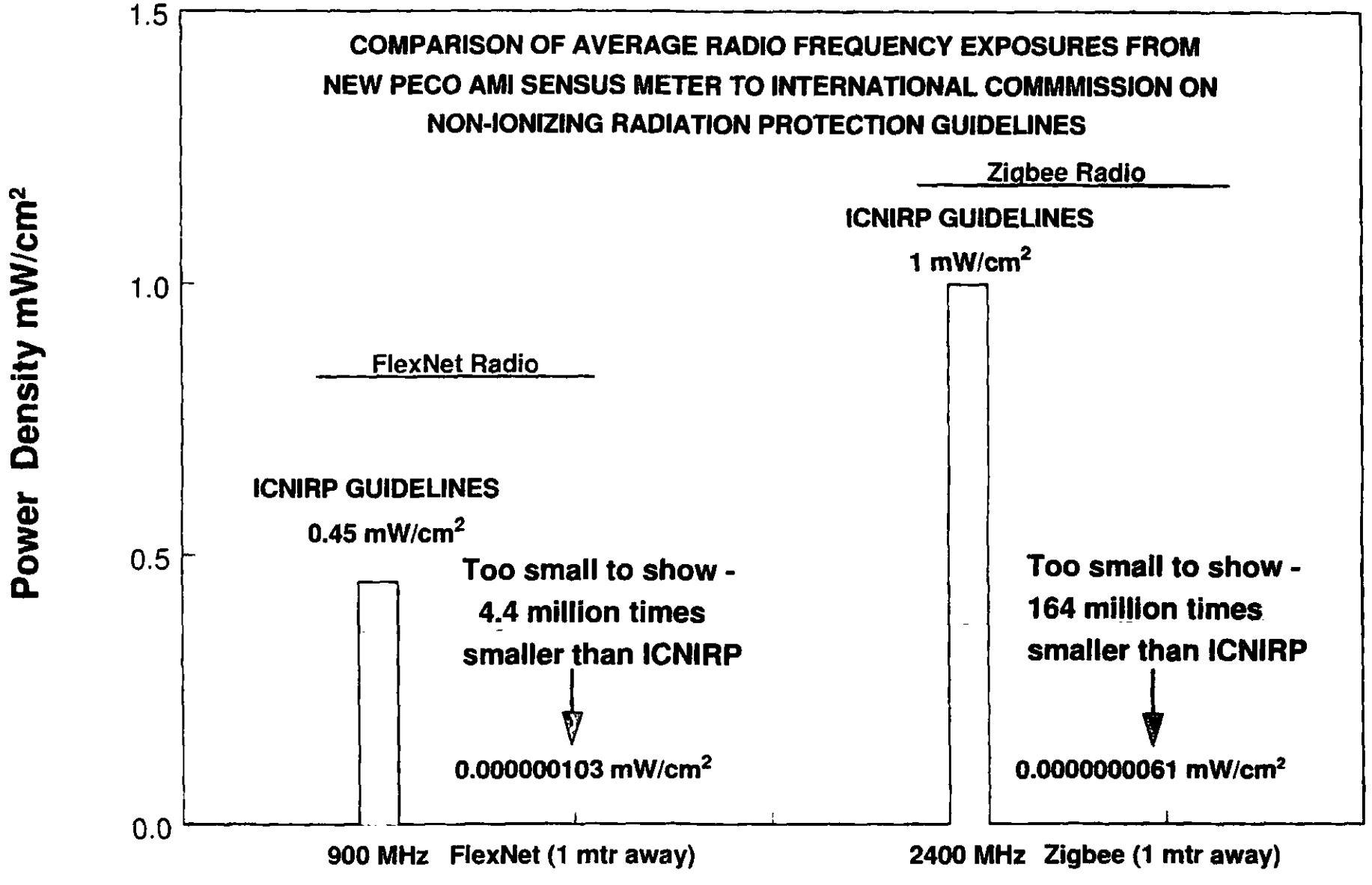

COMPARISON OF AVERAGE RADIO FREQUENCY EXPOSURE FROM
NEW PECO AMI METER WITH FLEXNET AND ZIGBEE RADIOS TO
FCC MAXIMUM PERMISSIBLE EXPOSURE LIMITS
Power Density mW/cm²
1.5
1.0
0.5
0.0
FlexNet Radio
FCC MPE LIMIT
0.6 mW/cm²
Too small to show -
5.8 million times
smaller than FCC limit
0.000000103 mW/cm²
900 MHz Sensus (1 mtr away)
Zigbee Radio
FCC MPE LIMIT
1 mW/cm²
Too small to show -
164 million times
smaller than FCC limit
0.0000000061 mW/cm²
2400 MHz Zigbee (1 mtr away)

PECO CD-5

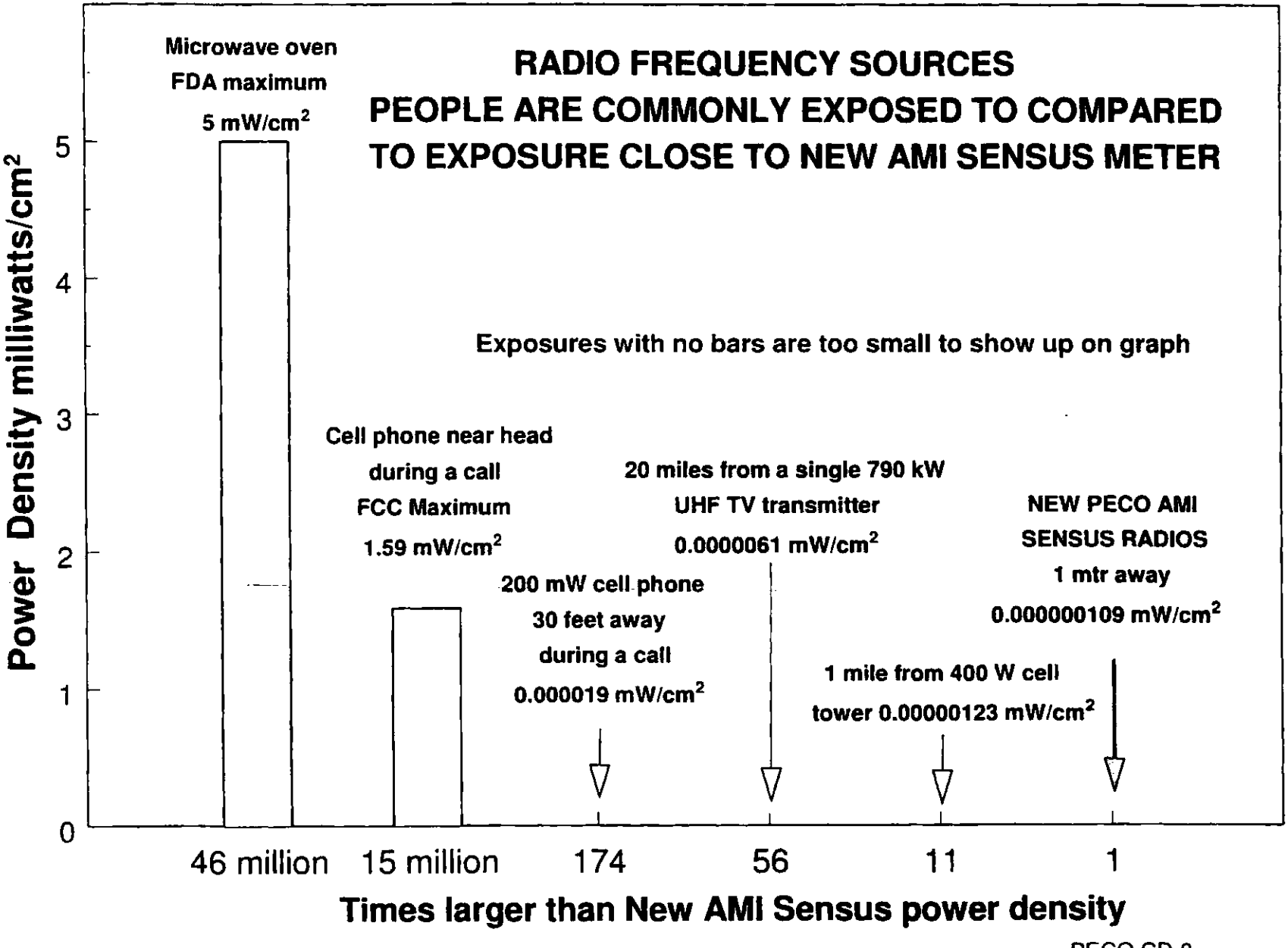


*FCC Limits are on radio's 30 minute average, not its peak

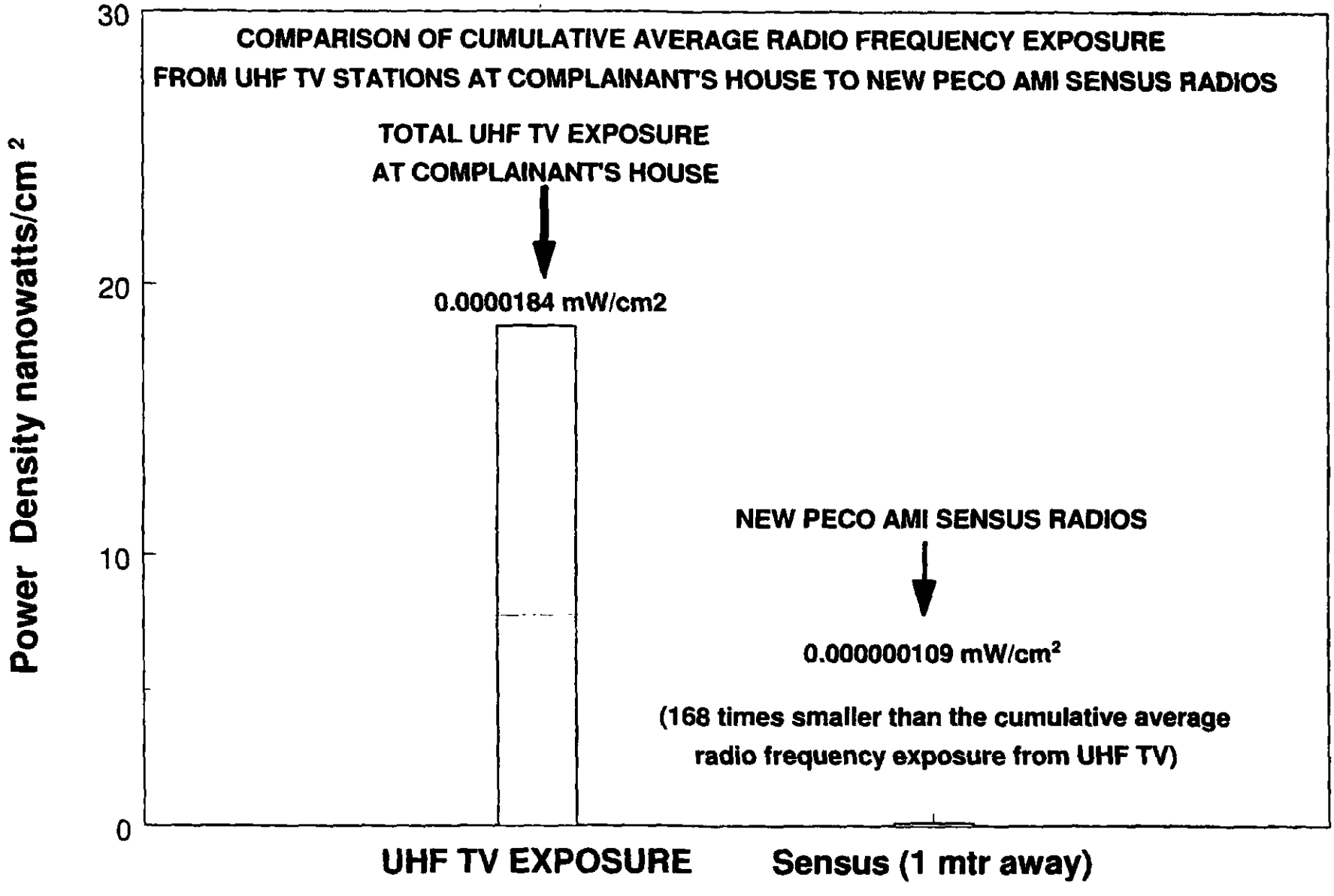
PECO CD-6


COMPARISON OF AVERAGE RADIO FREQUENCY EXPOSURES FROM
NEW PECO AMI SENSUS METER TO INTERNATIONAL COMMMISSION ON
NON-IONIZING RADIATION PROTECTION GUIDELINES
Power Density mW/cm²
1.5
1.0
0.5
0.0
Zigbee Radio
ICNIRP GUIDELINES
1 mW/cm²
FlexNet Radio
ICNIRP GUIDELINES
0.45 mW/cm²
Too small to show -
4.4 million times
smaller than ICNIRP
0.000000103 mW/cm²
Too small to show -
164 million times
smaller than ICNIRP
0.0000000061 mW/cm²
900 MHz FlexNet (1 mtr away)
2400 MHz Zigbee (1 mtr away)

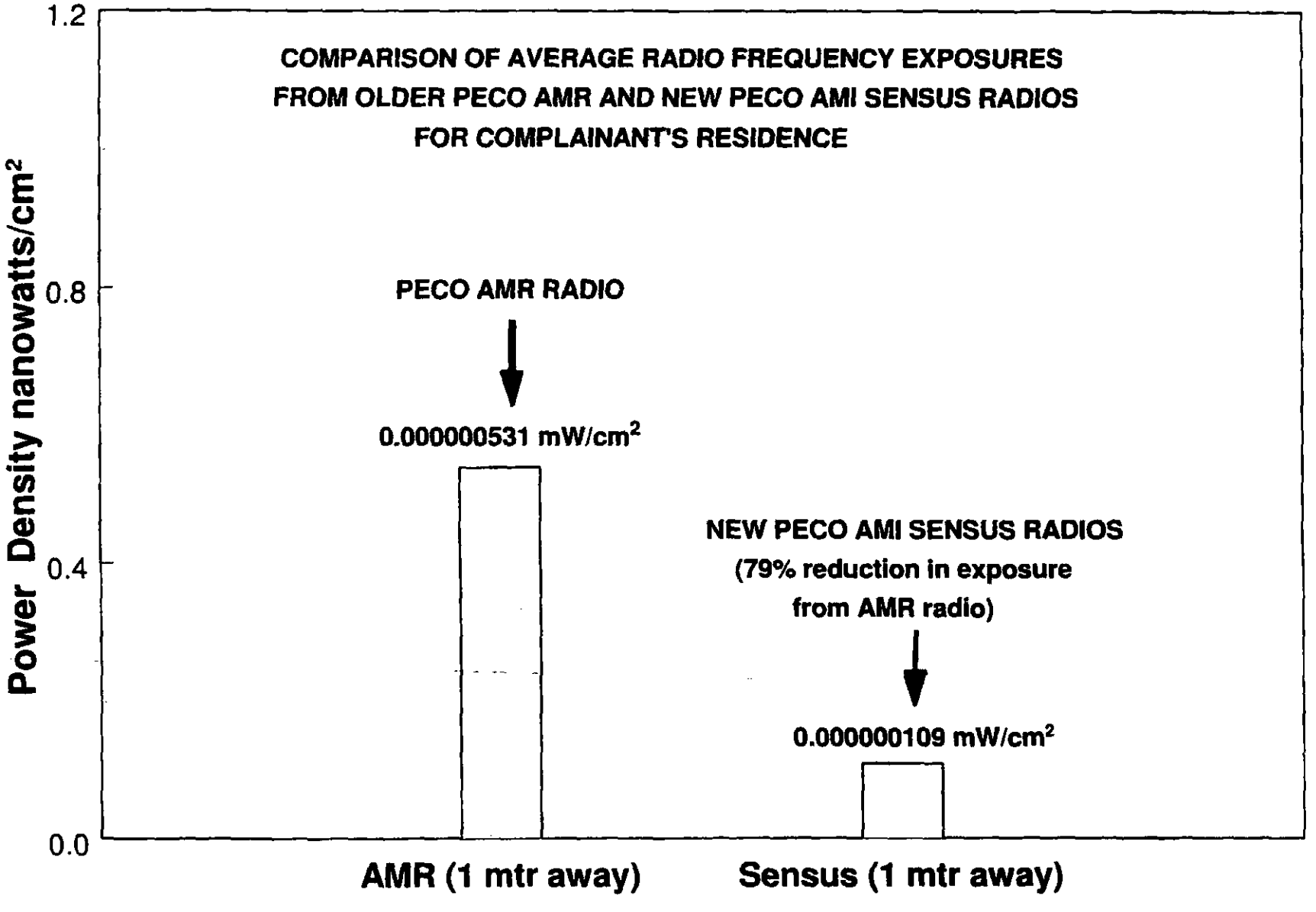
PECO CD-7


RADIO FREQUENCY SOURCES
PEOPLE ARE COMMONLY EXPOSED TO COMPARED
TO EXPOSURE CLOSE TO NEW AMI SENSUS METER
Power Density milliwatts/cm²
0
1
2
3
4
5
Microwave oven
FDA maximum
5 mW/cm²
Exposures with no bars are too small to show up on graph
Cell phone near head
during a call
FCC Maximum
1.59 mW/cm²
200 mW cell phone
30 feet away
during a call
0.000019 mW/cm²
20 miles from a single 790 kW
UHF TV transmitter
0.0000061 mW/cm²
1 mile from 400 W cell
tower 0.00000123 mW/cm²
NEW PECO AMI
SENSUS RADIOS
1 mtr away
0.000000109 mW/cm²
46 million
15 million
174
56
11
1
Times larger than New AMI Sensus power density

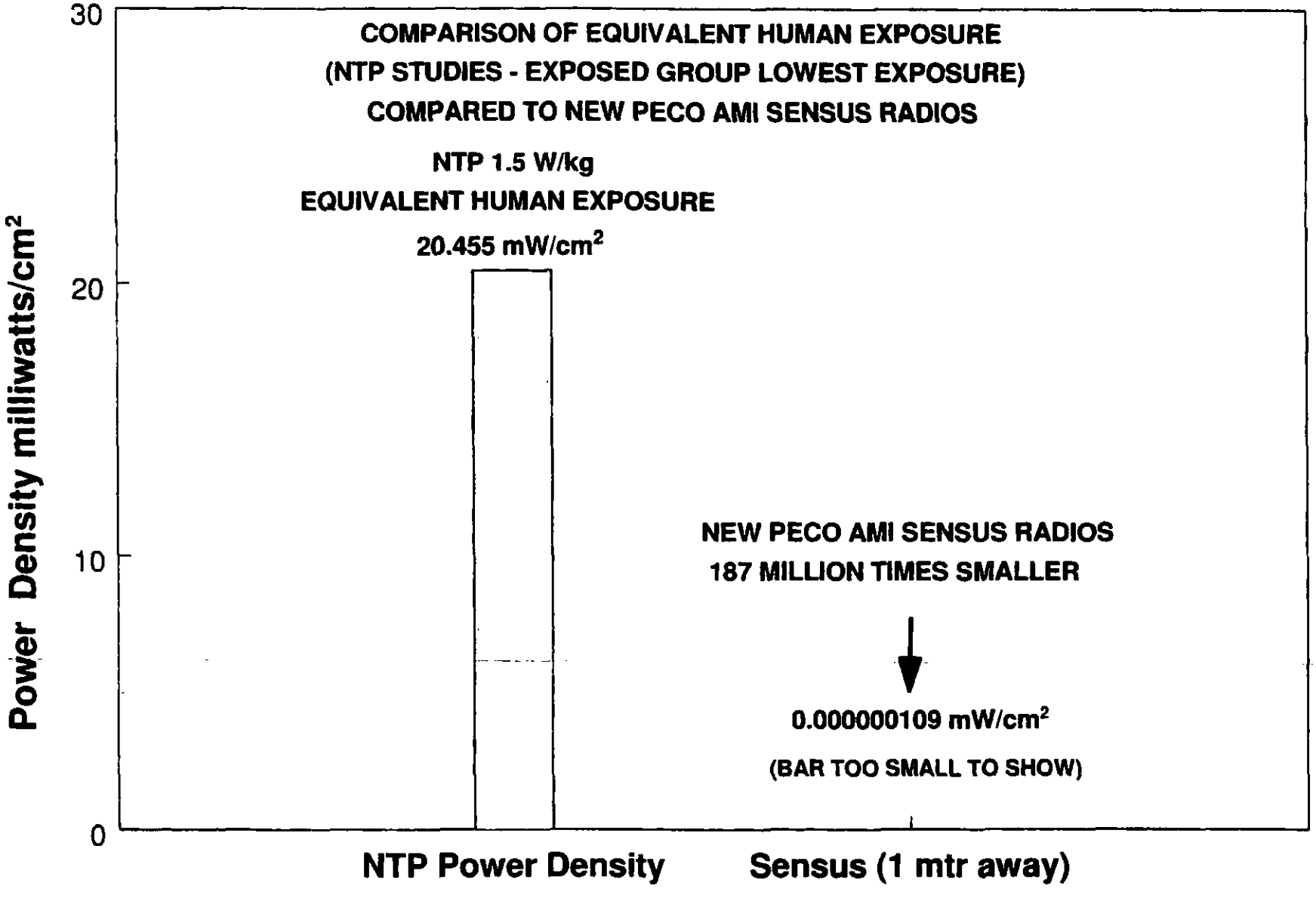
PECO CD-8


COMPARISON OF CUMULATIVE AVERAGE RADIO FREQUENCY EXPOSURE
FROM UHF TV STATIONS AT COMPLAINANT'S HOUSE TO NEW PECO AMI SENSUS RADIOS
TOTAL UHF TV EXPOSURE
AT COMPLAINANT'S HOUSE
0.0000184 mW/cm2
NEW PECO AMI SENSUS RADIOS
0.000000109 mW/cm²
(168 times smaller than the cumulative average
radio frequency exposure from UHF TV)
Power Density nanowatts/cm ²
30
20
10
0
UHF TV EXPOSURE
Sensus (1 mtr away)

PECO CD-9



PECO Exhibit CD-10


COMPARISON OF EQUIVALENT HUMAN EXPOSURE
(NTP STUDIES - EXPOSED GROUP LOWEST EXPOSURE)
COMPARED TO NEW PECO AMI SENSUS RADIOS
NTP 1.5 W/kg
EQUIVALENT HUMAN EXPOSURE
20.455 mW/cm2
NEW PECO AMI SENSUS RADIOS
187 MILLION TIMES SMALLER
0.000000109 mW/cm2
(BAR TOO SMALL TO SHOW)
Power Density milliwatts/cm2
30
20
10
0
NTP Power Density
Sensus (1 mtr away)

PECO CD-11

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Summary of What Exhibits CD-4 – CD-11 Show
PECO Exhibit CD-12

Exhibit CD-4 shows the Electromagnetic Spectrum and the frequencies used by various sources of electromagnetic fields, including natural sources and systems, equipment, and devices.

Exhibit CD-5 shows that the FlexNet radio in PECO's new AMI electricity meter complies with the FCC's Maximum Permissible Exposure Limits. Compared to the FCC's Maximum Permissible Exposure Limits, the FlexNet radio exposure is 5.8 million times smaller and the ZigBee radio is 164 millions times smaller.

Exhibit CD-6 compares the *peak* exposure from the FlexNet and ZigBee radios in PECO's new AMI electricity meter to the FCC Maximum Permissible Exposure Limits, even though those limits only apply to the 30-minute average exposure and not the peak exposure. It shows that, compared to the FCC limits, the peak exposure from the FlexNet radio is 37.5 times smaller and the peak exposure from the ZigBee radio is 3,800 times smaller.

Exhibit CD-7 shows that, compared to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure guidelines, the radio frequency exposure from the FlexNet radio in the new PECO AMI electricity meter is 4.4 million times smaller and from the ZigBee radio is 164 million times smaller. (The FCC has not adopted the ICNIRP guidelines).

Exhibit CD-8 compares the radio frequency exposure close to the FlexNet and ZigBee radios in the new PECO AMI electricity meter to the radio frequency exposure from sources of radio frequency fields people are commonly exposed to, showing:

1) people are and have been commonly exposed to radio frequency fields from a number of sources for many years that have much higher power density than the PECO AMI electricity meter;

2) compared to the exposure close to PECO's AMI electricity meter, the power density from:

(a) exposure 1 mile from a 400-Watt cell phone tower is 11 times larger,

(b) exposure 20 miles from a single 790-Kilowatt UHF TV broadcast transmitter is 56 times larger,

(c) exposure 30 feet away from a 200-milliwatt cell phone when someone else is making a call is 174 times larger,

(d) exposure allowed by the FCC from using a cell phone near the head during a call is 15 million times larger, and

(e) exposure allowed by the FCC from a microwave oven is 46 million times larger.

Exhibit CD-9 shows that at complainant's house the radio frequency exposure close to the radios in the new PECO AMI electricity meter is 168 times smaller than the cumulative average exposure there from UHF TV broadcast towers.

Exhibit CD-10 shows that installing the new PECO AMI electricity meter in place of the old AMR meter will reduce the radio frequency field exposure by 79%.

Exhibit CD-11 shows that compared to the equivalent human exposure at the lowest radio frequency field exposure of the exposed group in the National Toxicology Program (NTP)

studies (identified in draft Technical Reports issued by NTP February 2, 2018), the exposure close to the new PECO AMI electricity meter is 187 million times smaller.

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Opinions

PECO Exhibit CD-13

I hold each of the following opinions to a reasonable degree of scientific certainty:

1. The opinions in PECO CD-2 – CD-12.
2. The levels of radio frequency fields from PECO's AMI electricity meter comply with the Federal Communications Commission safety limits that apply to smart meters.
3. There is not a reliable scientific basis to conclude that radio frequency fields from PECO's AMI meters are capable of causing any adverse biological effects.