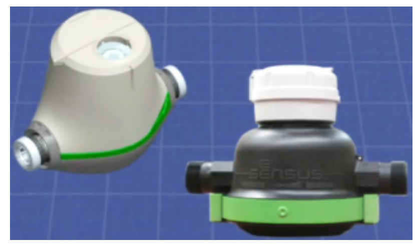
11.02.12 **Rev. 2**

City of League City
300 W. Walker St.
League City, TX 77573

INTRODUCTION

360°RF has been retained to perform measurements and an analysis of the RF emissions of two types of water meters, manufactured by Neptune and Sensus (Sensus is shown to the right). The following describes and details the results of 360°RF's measurements and analysis.



Executive Summary

The new Sensus water meters represent a calculated worst case RF exposure level at a distance of one meter that is 38 million times less than the limit set by the FCC and more than two hundred thousand times less than moonlight from a full moon. In normal operation, the likely exposure will be hundreds of millions of times less than the limits set by federal regulations.

The older Neptune water meters emitted less power and only transmit when read by a meter reader. They represent an even-lower source of RF exposure.

RF radiation and nuclear radiation are different. RF radiation is non-ionizing and causes heating, whereas nuclear radiation is ionizing and causes changes at the atomic level, potentially damaging cells and DNA.

While the Sensus water meters and cellular telephones can emit similar peak power levels, the Sensus water meters use much-lower transmit duty cycles and are generally located at far greater distances from the user. These factors mean that RF exposure from the water meter transceiver is lower by at least a factor of 100,000 and is likely to be several million times less than the already-low emissions level from a cellular telephone.

Radiation: Ionizing Versus Non-ionizing

There are two broad classes of electromagnetic radiation: ionizing and non-ionizing. Radio transmissions are non-ionizing. Non-ionizing radiation causes heating, often localized. This localized heating is exploited in industrial processes and some medical treatments, like diathermy.

Ionizing radiation imparts enough energy to modify material at the atomic level by stripping electrons from atoms. This requires both high frequency and energy. These modifications can damage cells and DNA, causing mutations and other damage. Radio frequencies are far below the visible light spectrum and are not ionizing.

Ultraviolet light is just above the visible light spectrum and is the crossover point between ionizing and non-ionizing radiation. Low-energy ultraviolet and very low energy x-rays can be non-ionizing, but higher levels are ionizing.

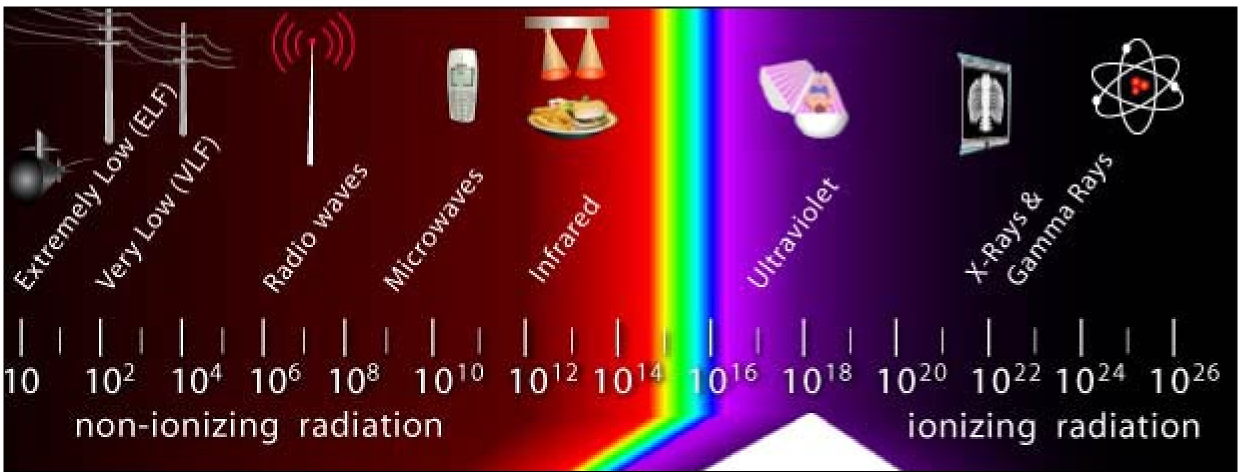


Figure 1 Ionizing and Non-ionizing Radiation [1]

Near Field vs. Far Field

It is important to understand that radio signals behave somewhat differently within a few wavelengths of the transmitting antenna. The behavior of electromagnetic waves in the far field is regular and reasonably easy to analyze and predict. Electromagnetic wave behavior in the near field is influenced by a number of factors, making prediction difficult and measurement essential where accurate information is required. This is why cellular telephone Specific Absorption Rate (SAR) is measured with a physical model and very specific test positions. There are many effects that can change measurement results in the near field, and the measurements are specified to provide valid bases for comparison.

It is unlikely that any user will spend a significant amount of time close to their water meter, much less in direct contact with its transmit antenna. In residential installations, it is most likely that the water meter will be near the street or alley. In most cases, this will place the meter and its transmitter more than 35 feet (>10 meters) from living spaces. Even in dense commercial and multi-family dwellings, the location of the meter and its transmitter will average far more than one meter (39 inches) from the closest point in the living and working space.

At the operating frequency of the water meters (about 900 MHz), one wavelength is about a foot. At any distance beyond one foot, the transmissions from a water meter become far field,

[1] Source: US Occupational Safety and Health Administration (OSHA)

and conventional far field analyses apply. For this analysis, an extraordinarily-conservative distance from the water meter's transmitter of one meter, or about three inches more than three feet, are assumed. Normal placement will have a water meter tens of feet distant from customers.

Field Intensity
Electromagnetic field intensity diminishes with the square of the distance from the source. At twice the distance, the field intensity drops by a factor of four. At ten times the distance, the field intensity has dropped by a factor of 100. This is because the same energy is distributed evenly over the surface of a sphere whose radius is the distance from the radio source.

This is similar to the effect of a pebble dropped in a pool of water: the wave caused by the pebble diminishes in height as the distance increases.

FCC Regulations
The Federal Communications Commission establishes and enforces regulations on the use of the electromagnetic spectrum in the United States. The FCC has implemented regulations to meet the requirements of the National Environmental Policy Act of 1969[2] (NEPA), which are based on the recommendations of ANSI[3] and IEEE[4] in ANSI/IEEE C95.1-1992[5] and NCRP[6] Report 86[7].

The FCC regulates radio-frequency Maximum Permissible Exposure (MPE) limits in Code of Federal Regulations Title 47, parts 1 and 2, specifically 47 CFR §2.1091 and in 47 CFR §1.1310. The FCC regulations differentiate between "portable" and "mobile" devices according to their proximity to exposed persons. Portable devices are designed to be worn or used in close proximity to a user and are covered under 47 CFR §2.1093. RF evaluation for portable devices must be based on specific absorption rate (SAR) limits measured with a standard model.

The FCC also differentiates between user populations. The Occupational / Controlled Exposure category is applied to cases where exposure can be controlled and predicated. An example of this would be an FM broadcast antenna tower. The General Population / Uncontrolled Exposure category is designed for the case where people are unlikely to even be aware of the RF exposure source. The limits are set far below the Occupational / Controlled category.
For this analysis, the limits for *Mobile Devices, General Population / Uncontrolled Exposure* are used. These are the most restrictive limits for devices in the far field. Limits for "portable"

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[2] National Environmental Policy Act of 1969, 42 U.S.C. Section 4321

[3] American National Standards Institute – a standards body ANSI/IEEE C95.1-1992, Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz Copyright 1992, The Institute of Electrical and Electronics Engineers, Inc., New York, NY. The 1992 ANSI/IEEE exposure guidelines for field strength and power density are similar to those of NCRP Report No. 86 for most frequencies except those above 1.5 GHz.

[4] Institute of Electrical and Electronic Engineers – a professional society and standards body

[5] ANSI/IEEE C95.1-1992, *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz* Copyright 1992, The Institute of Electrical and Electronics Engineers, Inc., New York, NY. The 1992 ANSI/IEEE exposure guidelines for field strength and power density are similar to those of NCRP Report No. 86 for most frequencies except those above 1.5 GHz.

[6] National Council on Radiation Protection and Measurements - The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations concerning radiation protection.

[7] NCRP Report No. 86 (1986,) *Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields*

devices assume that the device is in contact with the user, or worn on the body, and do not apply to the water meter case. While it might seem that the water meter transceivers are "Fixed Stations" by FCC definitions, those rules are formulated to address applications such as large radio base stations that are transmitting from rooftop antennas, and are *less* restrictive than the limits for mobile devices. The Mobile Devices category is most appropriate for this case and more conservative.

The limit for the Mobile Devices, General Population / Uncontrolled Exposure category in the frequency band at which the Sensus water meter operates, is frequency (in MHz) /1500 mw/cm^2. This equates to roughly 600 μW/cm^2. While the water meters momentarily transmit at most once every four hours, the regulations for this category require that power be averaged over a period of 30 minutes. This means that the long-term average exposure will be even lower than calculated here for FCC limits.

The Sensus water meters are specified to generate a peak power of 1.8 watts maximum into a roughly 0 dBi (dB relative to isotropic) gain antenna for, at most, 120 milliseconds[8], no more often than once every four hours. This results in a calculated exposure of 15.9 X 10^{-9} mW/cm^2 or 0.0000000159 mW/cm^2. This is 38 million times less than the limit set by the FCC.

Relation to Familiar Devices and Sources: Cellular Telephones

Cellular telephones are difficult to compare without being misleading. Some contributing factors are:

- The power output of phones varies continuously. The network operator strives to minimize this power level to maximize battery life. The output power of the phone can vary by a factor of 1000 depending on the user's location.
- Modern cellular phones are carefully designed to minimize the user's exposure. The design of a phone and how it is held can easily vary exposure by multiple factors of 100.
- Cellular phones are worn or held to the ear, not located several feet from the user, as the water meter transmitter will be.
- The amount of time the phone is in use determines exposure. If all other factors are constant, exposure is proportional to overall time of use.

Keeping all of the above caveats in mind, cellular phones and the water meters are in *roughly* the same peak power class (about 2 watts peak power); but because of the very-low duty cycle, the water meter average power is 120,000 times less than this peak power. Actual water meter power is also at least an additional factor of 1,000 lower because of the extraordinarily-conservative 1-meter distance used for calculating exposure. This means that the average power is a factor of 120,000,000 (120 million) times less than the peak listed power, or .0016 *micro*watts. For a heavy phone user, the average power might "only" be a factor of one hundred thousand less, or 20 *micro*watts. The user is generally exposed to less than 20% of this energy, or 4 microwatts. Remember that this is very rough comparison with many simplifying assumptions. The point here is that the water meter transceiver emissions are a factor of at least one thousand less energy than a cellular phone, and in reality, are likely to be a factor of 100,000 or as much as several million less.

[8] 360°RF measured data revealed bursts of 65 milliseconds, which will further reduce exposure by almost one half.

Relation to Familiar Devices and Sources: Wi-Fi Access Points
While the Sensus water meters do not use Wi-Fi access points, access points can be a useful and familiar point of comparison. Most consumer access points transmit at peak power levels of 10 to 100 milliwatts. The frequency is much higher than a water meter, so the FCC limit is proportionately higher, about a factor of 2.5. Access points, however, can transmit at duty cycles of greater than 70% depending on demand. This is particularly true for applications like streaming video. A reasonable average assumption is on the order of 30% for a typical residential network. This means that at a distance of one meter, the effective average power is a factor of 30,000 less or 0.3 - 3 microwatts. This value also varies with transmit duty cycle and distance.

If a 1 meter distance and an unrealistically-conservative *100%* transmit duty cycle are assumed, the calculated exposure will be 0.000795775 mW/cm^2 vs. the FCC limit of 1.6 mW/cm^2, or 2,000 times below the limit. Many access points use antennas with gain which will raise the emitted power in some directions and reduce it in others, but with realistic duty cycles, will still be better than 2,000 times less than the limit. The Sensus water meters are 38 million times less than the FCC limit and are usually much further away. Neither the Access Point nor Water Meter can even approach the FCC limits.

Relation to Familiar Devices and Sources: Moonlight
Light is electromagnetic radiation that happens to be visible to humans. Moonlight is simply sunlight reflected from our moon. The amount of light reflected and observed is a function of many variables such as the phase and position of the moon, location of the observer, weather, and others. The peak observed level of moonlight in the visible spectrum is approximately 6 mW/m^2 for a full moon.[9] The electromagnetic radiation value from the water meters at one meter distance is more than two hundred thousand times *less* than the light of a full moon.

[9] Source: Colorado State University Center for Geosciences/Atmospheric Research (CG/AR) Quarterly Report No. 8 by T.H. Vonder Haar and Collaborators – Cover figure; Example of lunar spectral irradiance as a function of lunar phase, showing high variability.

Water Meter RF Measurements

A test antenna was located at 1, 3, and 10 meters from the meters under test, and the peak signal level from the meters was measured by 360°RF with the test antenna at each distance then at 1 and 2 meter heights, in both the vertical and horizontal polarizations.

In free space, the Sensus meter peak signal strength is typically 15 to 30 dB higher than the Neptune meter in either polarization. This is because the Sensus meter's antenna is level with the ground while the Neptune meter's antenna is well under the surface of the ground.

The Neptune meter is intended for the reader to be nearby, while the Sensus meter uses 2-way pager technology and communicates with nearby towers. At the end of the era of pagers, several companies starting offering pagers that would reply, analogous to today's cell phone texting. Sensus bought out one of those pager companies and is using that technology for 2-way data transfer. The Sensus transmitters are not FCC Part 15 and generate more power. They also do not use frequency-hopping technology. The Neptune meter uses classic Part 15 frequency-hopping technology.

The 360°RF measured peak spectrum analyzer levels (in dBm) were as noted below:

	Pol.	1 Meter	3 Meters	10 Meters	
Sensus	V	-3.6 dBm	-12.7	-26.1	1 Meter Height
	H	-16.7	-29.7	-38.8	“
	V	-4.0	-11.6	-22.9	2 Meter Height
	H	-13.7	-22.4	-34.0	“
Neptune	V	-33.3	-48.2	Noise Floor	1 Meter Height
	H	-31.0	-47.4	Noise Floor	“ (less than -75 dBm)
	V	-26.3	-41.5	-67.8	2 Meter Height
	H	-26.7	-45.0	-70.5	“

The Antenna Factor at 915 MHz is 24.0, and the coax loss at 915 MHz between the test antenna and spectrum analyzer was 2.2 dB.

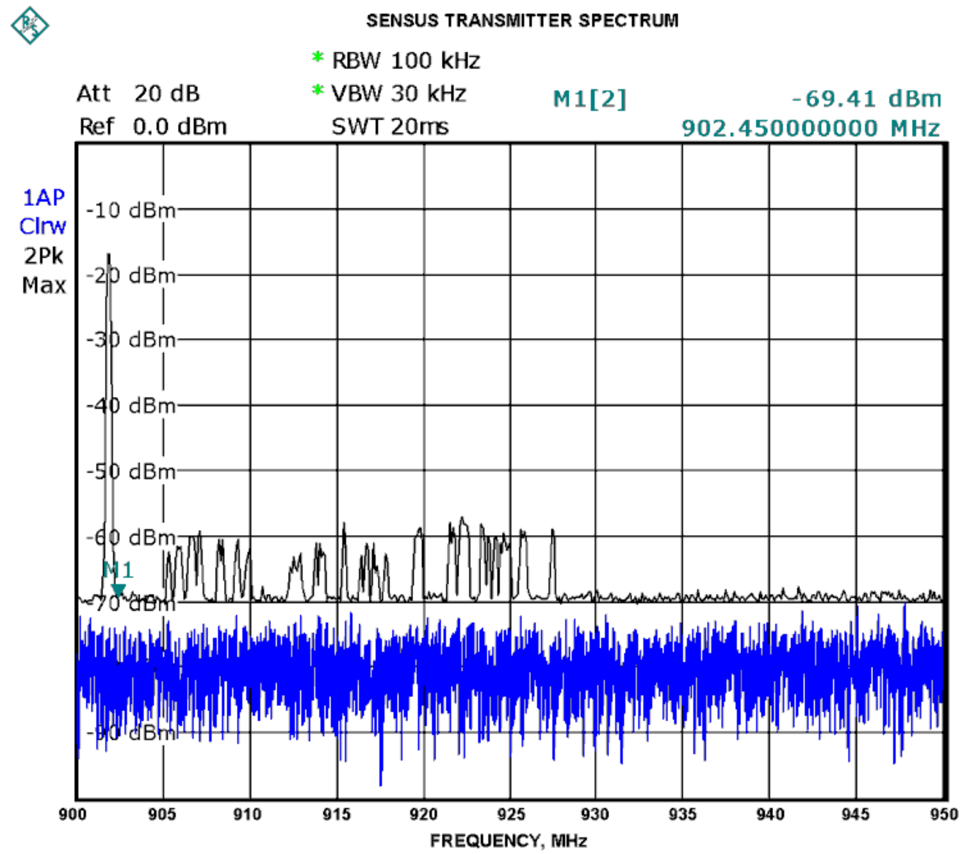
Test Setup

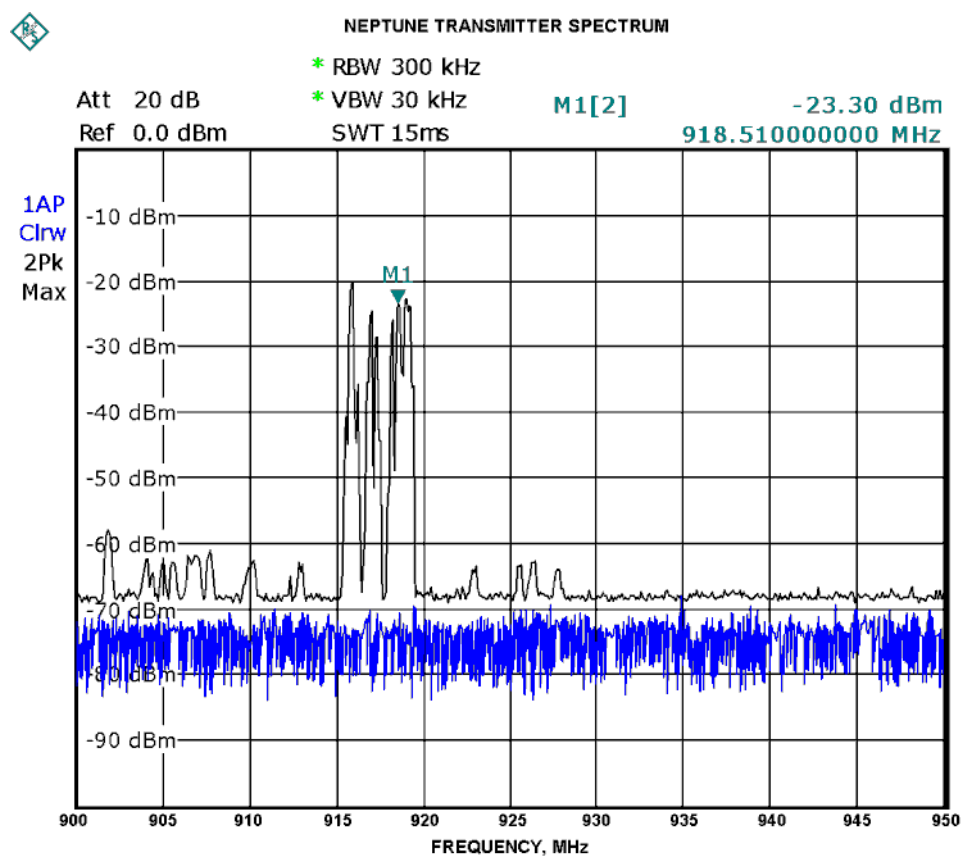
The following images show the RF measurement test setups for the Sensus and Neptune meters. Note that the Neptune meter and antenna is several feet inside the hole in the ground, while the Sensus meter antenna is located on top of a cast iron pipe cover. Plots showing the radiated spectrum of each transmitter follow the test setup photos.

The Neptune water meter located inside a hole in the ground, as it would be placed by the water company. The antenna is the small round bulge on the top of the right side of the meter body.

The Sensus water meter antenna is the small round bulge in the center of the cast iron pipe cover.

This image shows the test antenna in the right background with the Sensus cast iron pipe cap over the hole in the ground.


SENSUS TRANSMITTER SPECTRUM
* RBW 100 kHz
Att 20 dB
* VBW 30 kHz
M1[2]
-69.41 dBm
Ref 0.0 dBm
SWT 20ms
902.450000000 MHz
1AP
Clrw
2Pk
Max
-10 dBm
-20 dBm
-30 dBm
-40 dBm
-50 dBm
-60 dBm
M1
-70 dBm
-90 dBm
900
905
910
915
920
925
930
935
940
945
950
FREQUENCY, MHz


NEPTUNE TRANSMITTER SPECTRUM
* RBW 300 kHz
Att 20 dB
* VBW 30 kHz
M1[2]
-23.30 dBm
Ref 0.0 dBm
SWT 15ms
918.510000000 MHz
1AP
Clrw
2Pk
Max
-10 dBm
-20 dBm
M1
-30 dBm
-40 dBm
-50 dBm
-60 dBm
-70 dBm
-80 dBm
-90 dBm
900
905
910
915
920
925
930
935
940
945
950
FREQUENCY, MHz

FAQ

The following questions are from the City of League City forum.

1. **Is there a UL rating on the meters? If not, why?**
   Underwriters Laboratories (UL) is generally focused on matters of safety and insurance liability. Thus, UL is generally not relevant unless a device poses a conceivable energy, fire, or explosion hazard and there is no applicable standard or regulation. Battery operated items are rarely a concern, and those that are of concern are specifically controlled by specialized standards and regulations such as those imposed by the US Bureau of Mines on Explosion Proof Radios. Water meters do not fall into an associated category.

2. **Explain the difference between an electric meter and your water meter.**
   There are a wide range of features that may be provided by a modern, electronic water meter including variable rates driven by demand profiles, like highest rates on hot summer afternoons, and load shedding (remotely controlled service interruption). The replacement water meters are simply remote reading devices, i.e., an automation system that reduces labor costs and increases the accuracy of readings.

3. **Can you provide studies on emission of radiant / RF? (Nuclear studies)**
   No. RF (Radio Frequency) radiation and Nuclear Radiation are fundamentally different and act on the body in different ways. See the section on Radiation: Ionizing vs. Non-ionizing above. References to specific scientific papers on RF exposure can be supplied, but there is such a large body of work on such matters that any summary will be, by definition, incomplete. Potentially more useful are the Federal Regulations that limit the levels permitted. The meters being deployed emit electromagnetic radiation that is more than *38 million times* below the limits specified by these regulations. In normal operation, the likely exposure will be hundreds of millions of times less than the limits set by federal regulations.

4. **Can you provide studies on cumulative effects of RF from multiple appliances?**
   No. 360°RF is unaware of any studies that attempt to look at the cumulative impact of more than one source. While such studies might exist, the nature of the concern makes the highest-power field source the dominant concern and therefore the most common subject of study.

5. **Opt out plan?**
   360°RF cannot answer this question; however a cost-based strategy might be considered. For example, an opt-out option might be based on the cost of a fully burdened city employee and the related transportation. The employee would not be a full time meter reader, since full time meter readers will not be required. The cost might be based on worst case estimates because the number of cases will likely be small and therefore likely to be worst case cost items. By worst case, 360°RF would suggest the worst case travel time across the city, plus a half-hour of meter reading and manual reporting time. Given the 15 mile or so long dimension of the city, this will probably turn into an hour of round trip travel time, 10 minutes of read time, and 15 minutes of manual reporting time. Since these would be entirely-manual meters, there may be additional costs associated with maintaining this small pool. The city might be able to reduce the cost to the end user by only reading the meter every other month or quarterly, but intervening months should be conservatively estimated. It is likely that the city's billing software already accommodates this estimation option.

Bibliography

FCC OET, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields;* OET Bulletin 65, Edition 97-01, dated August 1997

FCC OET, *Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields;* OET Bulletin 56, Fourth Edition, dated August 1999

National Council on Radiation Protection and Measurements, "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," NCRP Report No. 86 (1986), National Council on Radiation Protection and Measurements (NCRP), Bethesda, MD.

ANSI/IEEE C95.1-1992, *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz* Copyright 1992, The Institute of Electrical and Electronics Engineers, Inc., New York, NY. The 1992 ANSI/IEEE exposure guidelines for field strength and power density are similar to those of NCRP Report No. 86 for most frequencies except those above 1.5 GHz.

Abbreviations and Glossary

Term	Definition
ANSI	American National Standards Institute – a standards body
EIRP	Equivalent (or effective) Isotropically Radiated Power
FCC	Federal Communications Commission
IEEE	Institute of Electrical and Electronic Engineers – a professional society and standards body
MPE	Maximum Permissible Exposure
NCRP	National Council on Radiation Protection and Measurements - The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations concerning radiation protection.
NEPA	National Environmental Policy Act of 1969, 42 U.S.C. Section 4321
OET	Office of Engineering Technology – The FCC technology arm