FCC RFR Guidelines: Is Your Facility *Really* in Compliance?

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ABSTRACT

The FCC adopted new two-tier guidelines limiting human exposure to RF energy, effective October 15, 1997. Over the past one and a half years, some of the implications of the new guidelines have been seen and new policies implemented. Various methods for conducting spatial measurement averaging are considered, along with studied techniques that may be useful in converting previous peak measurement values to average values. Applications for new DTV facilities have triggered accelerated RFR compliance obligations for stations who had certified compliance under the prior guidelines. The FCC has, in some cases, taken a newly active role in the field measurement and verification of compliance with the new guidelines. Further, the FCC has held up the license renewals of some stations that complied with the previous requirements but that now find it difficult or impossible to comply with the present requirements. Potential mitigation measures are presented, based on experiences with recent FCC policies and measurement techniques.

BACKGROUND

RFR Standards History. Anecdotal and pseudo-scientific reports of biological effects of radio frequency radiation were first reported shortly after the commercial development of radio. Outrageous claims of the curative properties of intense exposure made RF energy the "snake oil" of early 20th century. Although many of these claims proved false, RF energy clearly can affect biological tissues and, at sufficiently high exposure levels, the effects may be adverse to human health. Reports of eye damage and other adverse effects resulted in the 1950s in the establishment of the first exposure guidelines to protect humans exposed to RF energy.[1]

As research has identified the conditions under which RF exposure is harmful, these guidelines have been refined. Today, there is broad agreement worldwide among scientists having appropriate expertise that established safety standards are adequate to protect health both in the workplace and among the public. In the U.S., there are two exposure guidelines that are considered prevailing. These are ANSI/IEEE Standard C95.1-1992 and NCRP Report No. 86 (1986). The FCC adopted the latter standard in 1996,[2] concluding its Docket ET 93-62 proceeding to update its former standard.

Docket 93-62 History. Under the National Environmental Policy Act of 1968, the FCC has an obligation to ensure that its actions do not have a significant impact on the human environment. Since 1985, the FCC has had codified regulations to limit the potential for human exposure to RF energy. In 1993, following the adoption by ANSI of IEEE Standard C95.1-1991 (now properly called ANSI/IEEE Standard C95.1-1992), the FCC in ET Docket No. 93-62 proposed adopting the new ANSI/IEEE joint standard. Because compliance difficulties were anticipated with the new standard, the FCC proposal generated a large number of comments from industry, which effectively delayed the proceeding.

Meanwhile, to accommodate substantial growth in cellular telephone subscribership and to permit the competitive deployment of nascent Personal Communications Services, the nationwide wireless infrastructure had to be rapidly enlarged. The proposed construction in residential neighborhoods of many "radio transmission towers" led to heightened public awareness of and concern about RF safety. These concerns frequently led to delays in the construction of new cell sites and caught Congressional attention. In 1996, Congressional pressure to preempt local regulation of RFR resulted in a mandate that the FCC complete work on Docket 93-62 within 120 days, and a new *de facto* nationwide standard was adopted by FCC Report and Order (R&O) on August 1 of that year.

Section 705 preemption. When Congress ordered the FCC to adopt an RF exposure standard, it simultaneously established a limited federal preemption over state and local regulation of RF exposure. The preemption, contained in Section 705 of the Telecommunications Act, is limited, because it applies only to "personal wireless services."[3] Broadcast services were *not* included in the Congressional preemption, meaning that local authorities are free to adopt whatever exposure standards they wish for broadcast sites.[4] The lack of a Federal preemption in this area has already resulted in the required preparation at great expense of a detailed Environmental Impact Report for a site where worst-case power density levels at ground level were calculated to be less than 1% of the applicable public limit.

Although most jurisdictions have been reasonable in their regulation of RF exposures, the presence of multiple standards can sometimes create difficulties. For example, although included in both standards, the FCC does not routinely require evaluations of contact (shock/burn) currents at broadcast sites. It is imprudent, however, to simply ignore this provision of the standards. Apart from this evaluation possibly being required by a local ordinance, intentional disregard of an established safety standard might lead to a successful tort lawsuit being brought by an allegedly injured party.

More Surprises. The R&O contained a number of surprises, not the least of which was the adoption of the guidelines published as Report No. 86 by the National Council on Radiation Protection and Measurements (NCRP), rather than the more recent ANSI standard. Following the release of follow-up orders, it was decided that compliance with the NCRP guidelines for new stations would be required effective October 15, 1997, with licensees filing for new facilities, renewals, and modifications having to "bring their facilities into compliance,"[5] and *all* existing facilities having to comply with the new guidelines no later than September 1, 2000. Based upon these statements, many broadcasters who had renewed their licenses just prior to the adoption of the new guidelines thought they had until their next renewal (or September 1, 2000) to bring their facilities into compliance with the new guidelines. Largely unnoticed was a statement in the R&O "… that if a transmitter at a multiple-transmitter site is approved under one set of guidelines but, later, another transmitter locates at the site and, as is required, operates under the new exposure criteria, then the new criteria must be used to evaluate the entire site."[6] With this statement and the pending authorization of some 1,600 Digital Television (DTV) stations, the FCC created a time bomb.

Exempted versus excluded. When a broadcast station applies to modify its transmitting facilities or renews its license, it must certify that its operations are in compliance with the prevailing standard that the FCC has adopted. Note that the obligation to comply always exists; the periodic requirement to certify compliance does not relieve a station from the obligation to continuously comply. Similarly, although a station may fall under one of the "categorical exclusion" provisions contained in the FCC rules, the obligation to comply remains. An *exclusion* from the requirement to routinely demonstrate compliance does not imply an *exemption* from compliance.

SPATIAL AVERAGING

Traditionally, RF exposure conditions at broadcast sites have been reported using spatial peak values. That is, for a given point on the ground, the measurement probe would be moved vertically up to a height of perhaps 2 meters, with the maximum value encountered over this range being recorded. While the prevailing standards specify both whole-body and partial-body exposure limits, the ANSI/IEEE standard has been unclear, at least with regard to reliance upon whole-body spatial averaging to achieve compliance at broadcast sites. The unclear language was identified as early as 1993.[7] There being only cumbersome equipment available at the time to conduct spatially averaged measurements, the several attempts at clarification failed due in large part to lack of interest. Finally, in response to a 1998 petition from Hammett & Edison, the applicable IEEE Standards Coordinating Committee (SCC-28) Interpretations Working Group released a finding "... that C95.1-1991 requires the spatial averaging of measured uniform or non-uniform fields..."[8]

Description of techniques. While both standards now clearly require assessment of "whole body SAR," difficulties have been encountered in defining just what constitutes a "body." An adult male, a child in a wheelchair, a fetus? Because the underlying data upon which the standards are based include a variety of human body types (not limited to the 60 kg, 1.75 m "standard man"), there is some inherent safety factor built in. Measurement techniques based upon the "standard man" are, however, consistent with past recommendations of SCC-28.[9] Compliance with the field limits is based strictly on a "go/no go" criteria, so the variation encountered in the different techniques becomes important. Attempts at determining blanket compliance with the standards in a given area are fully successful only if there is a prior knowledge of the “bodies” that will be in that area. Little has been published on the subject of spatial averaging.[10,11] No U.S. regulatory or standards-setting body has endorsed a particular measurement technique for spatial averaging, although work on this topic is presently underway within IEEE. Discussions with persons who routinely conduct such measurements suggest that two different techniques are presently in common use at broadcast sites.

Vertical line method. In this method, depicted in Figure 1.a), the probe is swept with uniform velocity from the ground to a height of about 1.8 meters (6 feet), with the average power density over the line being calculated automatically by the instrument. The authors’ firm has used a PVC pole with base to ensure that measurements are taken along a vertical line and to ensure that repeated measurements are at the same location.

Planar equivalent methods. In this method, the probe scans a planar area approximating the adult trunk, as shown in Figure 1.b). This method, which is defined in Canadian Safety Code 6 (SC-6),[12] was originally designed for use with meters having no automated averaging capability. A total of nine discrete measurements are made over a 1.0 by 0.25-meter rectangle as shown in Figure 1.c), with the result being the average value. With the availability of commercial equipment having automated spatial averaging capabilities, Hammett & Edison has explored several possible means of adapting the SC-6 method to current measurement technologies. All of these methods involve continuous collection of data within the measurement rectangle. Two of these alternative methods are called here the “zig-zag” and “two-pass” methods and are depicted graphically in Figures 1.d) and 1.e), respectively.

Probe orientation. Regardless of the method used, it is recommended that the measurement probe be placed at an angle of about 90° relative to the dominant RF source, as shown in Figure 2. This orientation minimizes the effect of the operator’s body on the measurement, and typically provides the most conservative (highest) reading. As is seen in Table 1, readings can vary by almost 2 dB, depending upon the orienta-

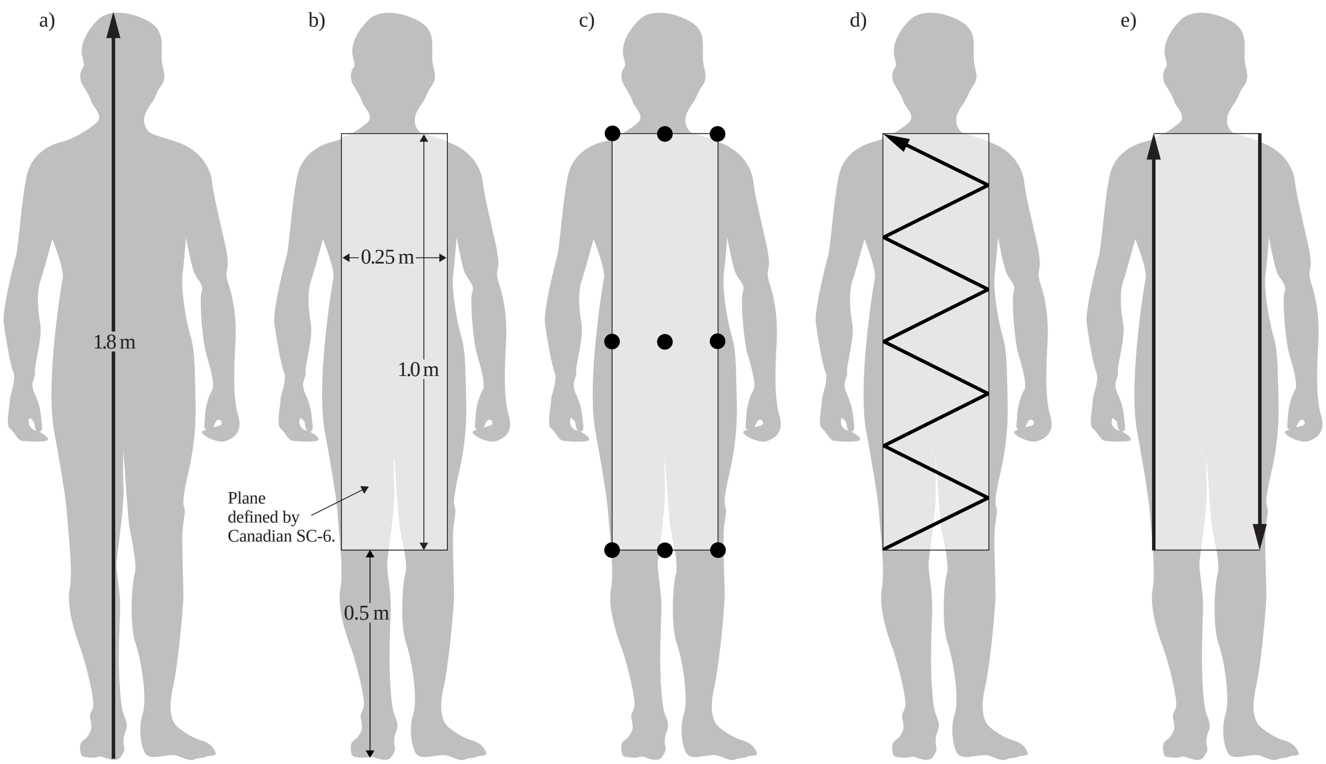

Figure 1. *The commonly used spatial averaging techniques are divided into two types as discussed in the text. The Vertical Line technique a) involves sweeping the probe from near the ground up to some height, typically 1.8 meters. The planar equivalent techniques involve moving the probe over an area approximating the trunk of the “standard man,” as shown in b). Four different techniques (a, c, d, and e) were evaluated.*

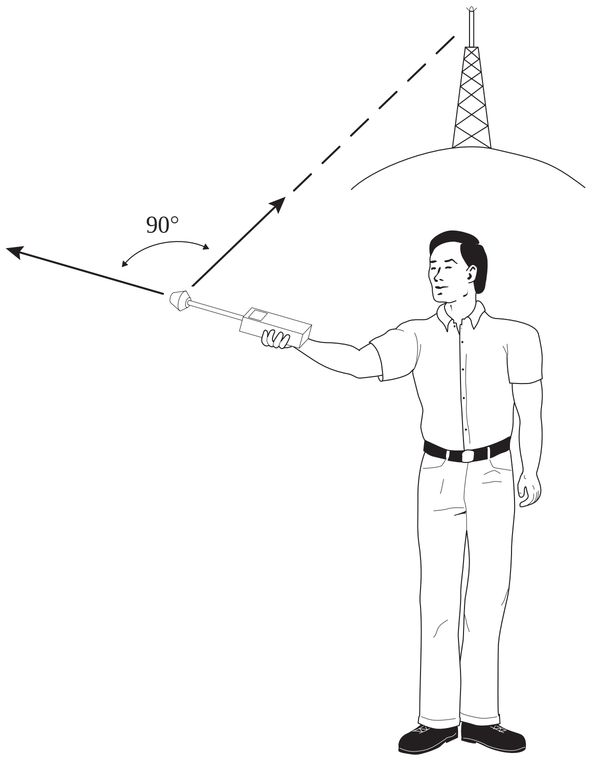

Figure 2. *Proper orientation of the measurement probe.*

Point	Measured Power density (% of limit) Orientation with Respect to Source 0°	90°	180°
1	10.7%	14.0%	10.6%
2	11.1	15.8	11.5
3	9.3	11.4	7.5
4	5.2	7.4	5.9
5	9.7	14.7	9.6
6	8.6	11.3	8.4
7	14.5	19.2	—
8	14.3	18.6	—
9	10.7	16.3	—
10	7.2	9.5	—
11	13.5	19.9	—
12	11.0	15.3	—
Average Difference from 90°	-1.4 dB	0.0 dB	-1.4 dB

Table 1. *Variation with probe orientation of spatially averaged measurements. To ensure a conservative measurement, the probe should be oriented approximately 90° with respect to the dominant RF source. This orientation is contrary to some manufacturer's recommendations. Due to interaction with the operator and instrument, however, other orientations may produce results that are too low.*

tion of the probe and operator with respect to the source. If there is no dominant source, or if the location of the dominant source is uncertain, it is recommended that four readings be taken at each point with the operator moving around the point 90° between each sweep; the highest of the four readings would be recorded for that location.

Comparison of methods. Table 2 compares statistically the vertical line and three planar equivalent methods. The data suggest that all of the planar equivalent methods produce similar results, which are all conservative (higher) compared to the vertical line method. Because of the small number of points studied (N=8), the data do not support a clear conclusion that any of the three planar equivalent methods is superior to another, but certain methods are inherently more practical. For example, the 9-point SC-6 method requires considerably more time than either of the other two.

Method	Average Difference with Respect to 2-Pass Method	Standard Deviation
Vertical Line	-0.9 dB	0.7 dB
9-Point	-0.1 dB	—
Zig-zag	0.2 dB	0.6 dB
Two-Pass	0.0 dB	0.5 dB

Table 2. *Comparison of four different spatial averaging techniques. Although the small number of points considered (N=8) does not support a conclusion that any method is clearly superior, it appears that the vertical line method gives results that are low compared to the other (planar-equivalent) methods. The standard deviations, a measure of the repeatability of several measurements at the same point, are similar for all of the methods.*

Spatial average-to-peak comparisons. Because measurements of RF exposure conditions at broadcast sites historically have been based upon spatial peak readings, it is of interest to know how such peak data might compare with spatial average readings. Although the spatial average/peak ratio is theoretically dependent upon several factors (see *e.g.*, Effect of Ground discussion below), considerable measurement data has been collected and analyzed by the authors to determine whether a "rule of thumb" conversion factor value might be applicable. As shown in Figure 3, the distribution of ratios follows an almost linear distribution over a range of 0.4–0.9 and has a mean value of 0.6. While this suggests that a value of 0.6 could be applied as an estimate, it does not eliminate the requirement to measure sites that are calculated to exceed the applicable limit using standard spatial peak calculation methods (*i.e.*, OET-65).

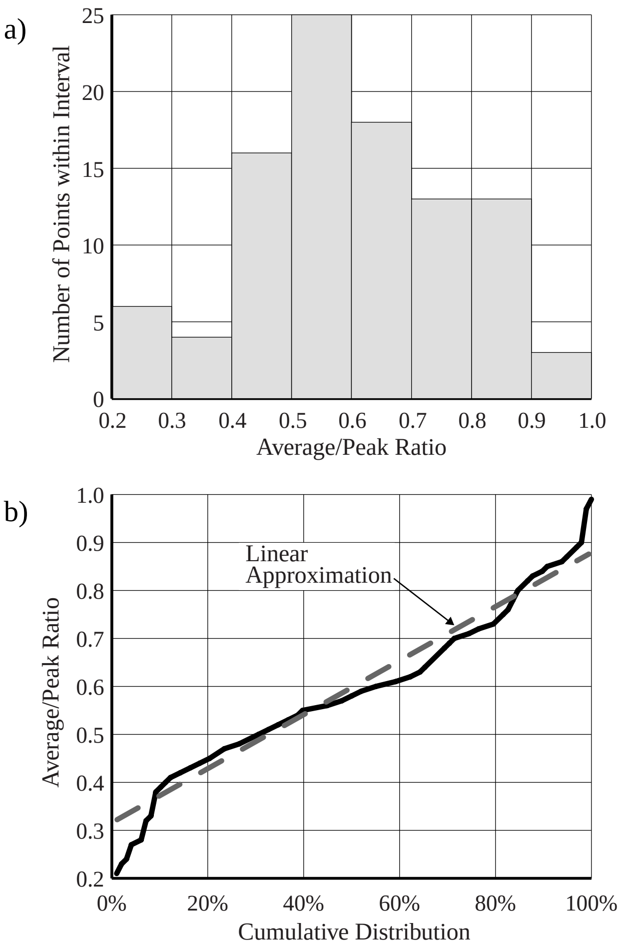

Figure 3. *The histogram a) and cumulative distribution function b) show the distribution of measured spatial average/peak ratios for a number of points (N=98). The mean and median values are 0.6, but the data are almost linearly distributed over the range 0.4–0.9. While the mean value may be used for estimating purposes, sites that calculate close to the limit using standard techniques would still have to be surveyed.*

ACCURACY ISSUES

Unlike many physical quantities that can be measured with great accuracy, the uncertainty associated with the measurement of RF fields at broadcast sites is relatively high. This uncertainty arises from meter and probe limitations, site variability, and interaction of the electromagnetic fields with the instruments and operator. Because uncertainties may be on the high or low side, because of the large safety factors included in the standards themselves, because most RF "hot spots" are small in extent, and because of site variability, it is customary not to apply calculated uncertainties to RFR measurements. Despite this, a recognition of measurement limitations is important to the analysis.

Instrument accuracy. In comparing specifications for RF survey meters, it is easy to become "spec happy." While one may be tempted to simply add up all of the uncertainties listed in the specifications, doing so is not representative of typical operating conditions. Overall accuracies may be analyzed in two ways: worst case and RSS. The worst case uncertainty comes about if all the possible sources of error were at their extreme values and in such a direction as to add together constructively. It is much more realistic to combine the uncertainties using the root-sum-of-the-squares (RSS) method. The RSS uncertainty is based on the fact that most of the measurement errors, although systematic and not random, are independent of each other. Since they are independent, they are random with respect to each other and combine like random variables:

$$\mathrm{RSS} = \sqrt{(U_1^2 + U_2^2 + U_3^2 + \ldots)}$$

where each U_i represents an uncertainty (expressed as a fraction or percentage). The worst case and RSS values for several popular instruments are shown in Table 3.

One means of increasing confidence in RFR measurements is the use of several meters (preferably of different manufacture and technology) to survey each

Meter Probe	Older analog (diode detector)	Digital #1A (diode/shaped)	Digital #1B (diode/shaped)	Digital #2A (diode detector)	Digital #2B (diode/shaped)
Worst case max	1.9 dB	2.8 dB	2.6 dB	3.5 dB	3.5 dB
Worst case min	-2.7	-4.6	-4.3	-7.9	-8.8
RSS max	1.2	2.1	1.8	2.5	2.4
RSS min	-1.3	-2.3	-2.0	-2.9	-2.9

Table 3. *Calculated worst case and RSS uncertainties for several popular RFR survey instruments. When comparing specifications, the RSS uncertainty is a better indicator of overall performance.*

location. The readings from the several meters can then be averaged together (a technique called *ensemble averaging*). Since it is unlikely that several meters would have the same accuracy profile for a given measurement situation, the uncertainty associated with the average of several meters' readings will generally be less than the uncertainty of any individual meter. Good agreement between several meters is a strong indication of an accurate measurement.

Most RF exposure measurement equipment is based upon traditional power meter designs, with an antenna substituted for the transmission line input. Consequently, diodes and thermocouples are the most common types of detectors used.

Diode detector issues. Detectors using metal-barrier or Schottky diodes are perhaps the most common type used at broadcast sites. They offer broad frequency response (0.1–4,000 MHz or greater), flat frequency response (±1 dB or better), and large dynamic range (1–1,000 V/m or about 0.1%–5,000% of the standards). Diodes do have a major limitation when used at typical broadcast sites: often, they do not respond properly in a multiple station environment. Multiple source and frequency (MSF) errors have been examined in some detail both theoretically[13] and empirically.[14] If a diode-type detector is not operating in the square-law region, the measurements will not be valid. The response will be the result of squaring the sums of the voltages rather than the summing of the squares. Although MSF errors can theoretically be positive or negative, *ad hoc* tests conducted by the authors appear to confirm earlier findings that the errors are always positive (*i.e.*, at multi-user sites, the measured results may be too high). Our results showed errors of 0–3 dB, with an average error of about 1.2 dB. Meters that include circuitry to compensate for this effect appear to be less susceptible to MSF errors.

Site accuracy issues. The question is sometimes asked how repeatable RF exposure measurements are at a given site. Unfortunately, RFR compliance measurements are usually conducted only once at a given site; additional measurements are conducted only if there is a change (such as an antenna replacement or when a new station is added). It is therefore difficult to calculate the repeatability of such measurements. For a variety of reasons, the electromagnetic compatibility (EMC) industry has historically been concerned about measurement repeatability and has published data that may be of use in estimating the repeatability of RFR measurements at broadcast sites.

For example, Kolb[15] reports that for five sites, the typical standard deviation at one site was 0.6 dB. Assuming a normal distribution, this would mean that 95% of the time readings would vary less than ±1.2 dB. In calculating this value, measurements were conducted five times at each site, usually on different days. EMC measurements are conducted using measurement equipment that is located with a fixed spatial relationship to the source. RFR measurement protocols call for spatial averaging, which tends to reduce variation at specific points. So day-to-day variation at broadcast sites could be expected to be somewhat better than ±1.2 dB.

Effect of ground. A single reflection from a perfectly conducting earth can double the electric field strength at certain locations in space, thus quadrupling the power density. However, the earth is not perfectly conducting, and the efficiency with which it reflects radio waves, called the coefficient of reflection, ρ_r, is always less than 1. It may be calculated[16] from knowledge of the grazing angle (the angle between flat earth and the antenna), ground conductivity, and dielectric constants of the site. In its Bulletin OET-65, the FCC recommends that power density calculations near broadcast sites assume $\rho_r = 0.6$.

Considerable field experience has shown the recommended value for ρ_r, which increases the power density by a factor of 2.56 above free space, to be conservative over a wide variety of ground types and measurement heights. This result is expected, because at the typically large grazing angles (>30°) encountered at broadcast sites, ρr would theoretically be expected to lie in the range 0.2–0.85, depending upon conductivity and dielectric constant, for horizontally polarized waves and 0.05–0.85 for vertically polarized waves.[17,18] Examination of the mean values of these two ranges suggests that the 0.6 assumption lies on the conservative (high) side. Furthermore, at locations near the tower on which a source is mounted, the reflected wave is typically dominated by a single polarization. So the common practice of multiplying *both* the horizontally and vertically polarized components simultaneously makes this calculation additionally conservative.

FCC COMPLIANCE ISSUES

The authors' firm has studied a number of broadcast sites that comply under the old FCC rules but that fail to meet the revised rules. The addition of public exposure limits that are generally five times more restrictive than occupational limits can create areas of noncompliance that were formerly well within the limits of the previous requirements.

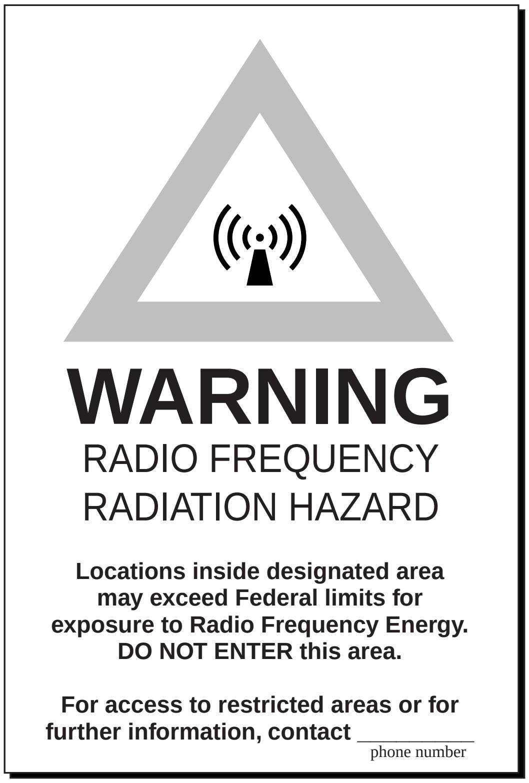

Figure 4. *Example of a warning sign appropriate for OSHA-mandated (controlled/occupational) exposure situations. Such signs should be placed on towers and at the entrances to controlled-access broadcast sites, as discussed in the text.*

Within fenced compounds. Areas within the fenced perimeter of a transmitting site usually would be considered subject to the occupational exposure limits, since only persons authorized for access within the fence would be present in those areas. One or more signs, as shown by the example of Figure 4, should be posted at entry points and other approaches to the fenced area.[19,20] OSHA-mandated warning signs should include four pieces of information:[21,22]

- The universal warning symbol
- The words "Radio Frequency Radiation Hazard"
- Specific site information describing the location of the hazardous area and how to avoid it
- A telephone number for further information.

Such signs provide some measure of assurance that persons unfamiliar with the site may seek guidance about which areas within the fence, if any, should be avoided with respect to prolonged exposure. Except for the differences noted earlier, the requirements for protection of workers and other authorized persons in a compound having RF emitters is essentially unchanged from the earlier FCC policies.

An important issue related to occupational exposure is on-tower access. The FCC generally requires that licensees at a common site cooperate such that occupational exposure limits are not exceeded for access on any tower at the site. For some sites, compliance will require systematic power cutbacks by stations to allow a worker to access a given transmitting tower. Sites should have in place[23] an "occupational exposure guide" (OEG) that specifies each station's responsibilities for access to any part of the site, including towers. It is important that such guides be updated regularly to account for changes and additions to transmitting facilities.

Outside fenced compounds. The vast majority of compliance difficulties at existing sites are related to exceeding continuous public exposure limits outside a site fence, *i.e.,* in publicly accessible areas. Before adoption of the FCC Docket 93-62 rules, there was no distinction between occupational and public exposure requirements. For FM and/or TV/DTV transmitter sites, allowable continuous public exposure is five times more restrictive than for occupational exposures. Especially for mountaintop sites having high-power transmitting antennas mounted on relatively short towers, measured exposure levels outside the typical site fence may approach occupational levels. In some cases, the FCC has required licensees to reduce power, such that measured exposure levels can be kept below public limits in public areas.

At multi-user sites, it is not uncommon to have one or two "culprit" stations whose contributions account for the majority of the excessive fields measured in public areas. It is important to note that the FCC generally requires all stations identified as significant contributors,[24] either by calculation or by measurement, to cooperate in formulating a solution to the identified problem. The grant of an FCC license renewal for one contributing facility does not absolve it from responsibility. The FCC has, in the past, threatened revocation of licenses for quarreling contributors, but, to date, no actual actions of that type are believed to have been taken.

Solutions that may be employed to remedy excessive exposure in public areas could include one or several of the following:

- Expansion of the site fence to encompass areas exceeding public exposure limits
- Individually fencing areas exceeding public exposure limits
- Changing one or more transmitting antennas, usually FM broadcast transmitting antennas, to

types exhibiting lesser radiation at greater depression angles

- Relocating transmitting antennas of the "culprit" stations further inside the compound and/or increasing their radiation center height(s)
- Consolidating multiple stations onto one or two transmitting antennas that are located at greater height and/or use low-RFR antenna technologies
- For larger sites, relocating one or more contributing stations to other towers well away (several hundred meters or more) from the existing installation(s)
- Relocating stations to entirely different transmitting sites.

It is noted that all of these methods employ techniques that result in no need for direct involvement of an unsuspecting member of the general public. That is, it may not be assumed that the public can read and interpret a posted warning sign, and it should not be assumed that a readily accessible area exceeding the public limit is in compliance because it is in a usual "transitory location" where prolonged exposure would not be anticipated. That is, time averaging generally should not be relied upon to achieve compliance in publicly-accessible areas. Positive means provide the best assurance in preventing exposures exceeding public limits.

DTV facility construction. As mentioned previously, another aspect that has triggered the need for formerly compliant stations to take a proactive stance in RF radiation compliance involves the implementation of DTV facilities. Multi-user transmitting sites, especially those with several existing NTSC TV stations, likely will be subject to considerable change in RF radiation exposure characteristics. This will trigger, in numerous cases, an FCC requirement that existing stations make changes to reduce RF radiation characteristics in both occupational and public areas.

CONCLUSION

The key to avoiding possible problems related to RF radiation exposure at a given transmitting site is research, planning, and assumption of a proactive stance. Existing sites, if not already evaluated for compliance with present FCC requirements, should be studied without delay. Any proposed changes to an existing site should be carefully reviewed with respect to potential RF radiation exposure scenarios before project work begins. Any deficiencies noted at existing or planned facilities should be immediately addressed and corrected. Finally, spatially-averaged measurements used to establish compliance with the prevailing standards should use one of the planar equivalent methods.

REFERENCES

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[2] Report and Order, ET Docket 93-62, released August 1, 1996, FCC 96-326, ¶28.

[3] Personal wireless services are licensed under FCC Rule Parts 22 (cellular and paging), 24 (PCS), and 90 (SMR).

[4] See *e.g.*, Gray Frierson Haertig, "Compliance with Local Radio Frequency Radiation Regulations," *Proc. 47th Annual Broadcast Engineering Conference,* (Washington, DC: NAB, 1993), pp. 487-498.

[5] Second Memorandum Opinion and Order, ET Docket 93-62, released August 25, 1997, FCC 97-303, ¶113.

[6] *Ibid.* ¶75.

[7] Letter of Jules Cohen to Eleanor R. Adair and Om P. Gandhi, May 8, 1993.

[8] Letter of James B. Hatfield, Chairman, SC-4, SCC-28, IWG to Dane E. Ericksen, Hammett & Edison, October 30, 1998.

[9] See *e.g.*, Letter of Om. P. Gandhi, Co-Chair, SCC-28 to Linda A. Gargiulo, March 18, 1992.

[10] NCRP Report No. 119, *A Practical Guide to the Determination of Human Exposure to Radiofrequency Fields,* (Bethesda, MD: NCRP, 1993), p. 83.

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[18] US Environmental Protection Agency, *An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services*, (n.p.: April 1985).

[19] FCC Bulletin OET-69, Appendix B.

[20] 29 CFR §1910.268(p).

[21] 29 CFR §1910.97

[22] Robert Curtis, OSHA, Personal Communication.

[23] 29 CFR §1910.147

[24] A significant contributor is generally defined as any station whose individual contribution at the point in question exceeds 5% of the applicable limit. See 47 CFR §1.1307(b)(3).