MR 1965

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DATE: 1977

TITLE: A study of environmental electromagnetic radiation levels, Serial No 4.

SOURCE: Federal Communications Commission, Research & Standards Division, Technical Memorandum, Dec 5, 1977, 15 pp

MAIN SUBJECT HEADING:

AN	HU	AT	IH	M
ANALYTICS	HUMAN EFFECTS	ANIMAL TOXICITY	WORKPLACE PRACTICES-ENGINEERING CONTROLS	MISCELLANEOUS

SECONDARY SUBJECT HEADINGS: AN HU AT IH M

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MR 1965

RESEARCH & STANDARDS DIVISION

TECHNICAL MEMORANDUM

FEDERAL COMMUNICATIONS COMMISSION WASHINGTON, D.C. 20554

Serial No. 4 December 5, 1977

A STUDY OF ENVIRONMENTAL ELECTROMAGNETIC RADIATION LEVELS

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I. INTRODUCTION

The purpose of this technical memorandum is to summarize some FCC work in evaluation of environmental electromagnetic radiation levels in selected cases and to serve as a contribution to the continuing comprehensive study of the electromagnetic environment. Calculations and measurement data, if available, are presented.

II. RESEARCH ON NON-IONIZING RADIATION AND THE FCC

The Commission has been observing the research work in the area of electromagnetic radiation hazards for a number of years and became directly involved in this subject since 1969 when the Electromagnetic Radiation Management Advisory Council (ERMAC) was established. The purpose of ERMAC is to advise the Director, Office of Telecommunications Policy (OTP), on possible side effects and the adequacy of control of electromagnetic radiation associated with the use of the radio frequency spectrum. On the recommendation of ERMAC, a multiagency Federal Government program was established in 1972 to assess the biological effects of electromagnetic radiation. This program calls for coordination by OTP of individually funded activities of several federal agencies. At present, the program consists of approximately 116 projects, including FCC's "Electromagnetic Pollution Measurement Program". Reports [1] summarizing these activities have been issued annually, by OTP, since 1973.

The objectives of this program are to determine what effects electromagnetic radiation has on living organisms under different conditions of exposure, to assess the potential hazards with reference to realistic exposure environments, and to establish a sound scientific basis for appropriate remedial and/or control measures which appear warranted.

Present activities under the program include systematic investigation of biological effects, including genetic and metabolic effects, effects on the blood and nervous system, for short-term and long-term exposure at high and low levels of radiation. At the same time new equipment and techniques are being developed for making accurate near-field measurements.

Current safety standards in the U.S. as adopted by OSHA, HEW, and DOD are based on power densities of 10 mW/cm^2 and 1 mW/cm^2 for short-term and long-term exposures, respectively. Exposure of the general public from even the most powerful television station is several orders of magnitude less than these levels.

Biological effects have been observed and reported at scientific meetings and in the literature at levels below 10 mW/cm^2. Such reports frequently cause apprehension, can be misinterpreted and could lead to premature conclusions as to whether health hazards exist at these levels. It is important that these findings be viewed in perspective. They may result from preliminary experiments and further investigation may show that they were not repeatable, were influenced by other factors, or were not applicable to humans. Such observations must be subjected to systematic review and the conditions under which they occur determined before they can be meaningfully interpreted.

The current position of the ERMAC is that continued research is required to establish a consistent picture before dependable conclusions can be drawn. Meanwhile, on the basis of current findings on biological effects, measured data, and theoretical calculations, exposure of the general public appears to be relatively low.

People who work in the immediate vicinity of high-power transmitters or their antennas are subject to much higher levels of exposure than the public at large. A number of measurement programs and surveys have been carried out by various government agencies and representatives of the broadcasting industry to establish the power density levels in these areas. Engineers from the Commission's Office of Chief Engineer and Field Operations Bureau carried out a measurement survey at a number of broadcasting and television stations. This data was published in an FCC Technical Memorandum [2], which represents the latest data of a continuing program. A paper dealing with a theoretical analysis of near-field power density of a small linear antenna has also been published by the FCC [3].

III. RF INTENSITY STUDY

A. Standard Broadcast Transmitters

The wavelength of standard broadcast band (535-1605 kHz) varies from 187 to 560 meters. Thus, in many cases, the near field would extend beyond the limits of a station's property. It has been suggested [4] that the field strength in the immediate vicinity of an AM tower is given by:

$$E = \sqrt{30P_rG}/R \tag{1}$$

Where E = field strength in volts/meter,

P_r = radiated power in watts,

G = antenna gain, and

R = distance in meters.

It is common practice to consider the ground reflection which could increase the field strength by as much as 100% [5]. Hence, a factor of 2 should be included in the right-hand side of equation (1). For an antenna having a nominal height of 1/4 of the wavelength, G = 1.64. This figure has been used for this study. Thus, equation (1) becomes:

$$E = 14\sqrt{P_r}/R \tag{2}$$

In the United States the maximum allowed radiated power for any station in the standard broadcast band is 50 kW. Figure 1 shows calculated field strength vs. distance for different radiated power levels. Figure 2 shows a comparison of calculated and measured [2] field strengths. The difference may be attributed, in part, to the fact that the reflection is not 100%.

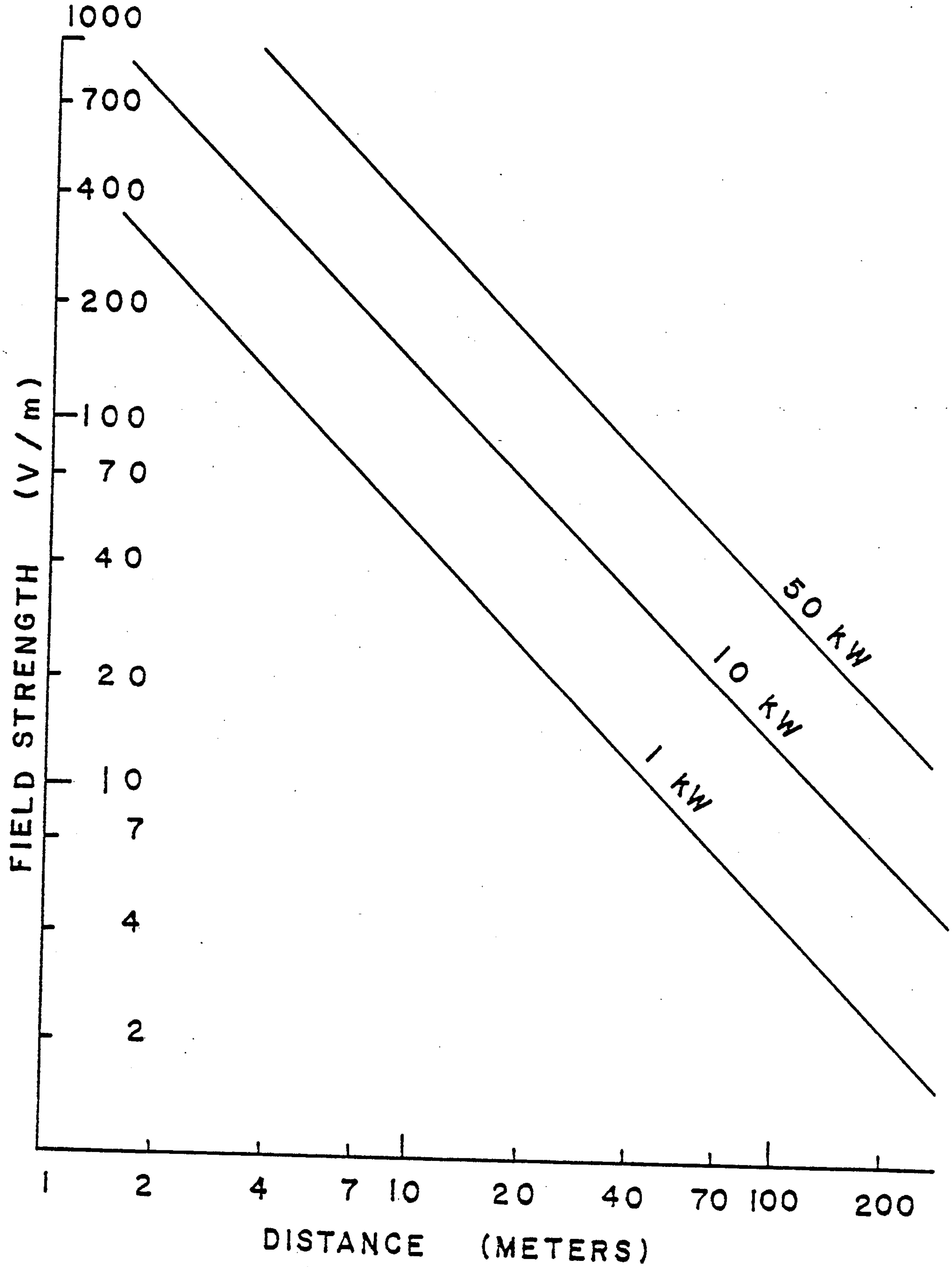

Figure 1 Calculated Field Strength vs. Distance in the Vicinity of a Standard AM Broadcasting Antenna

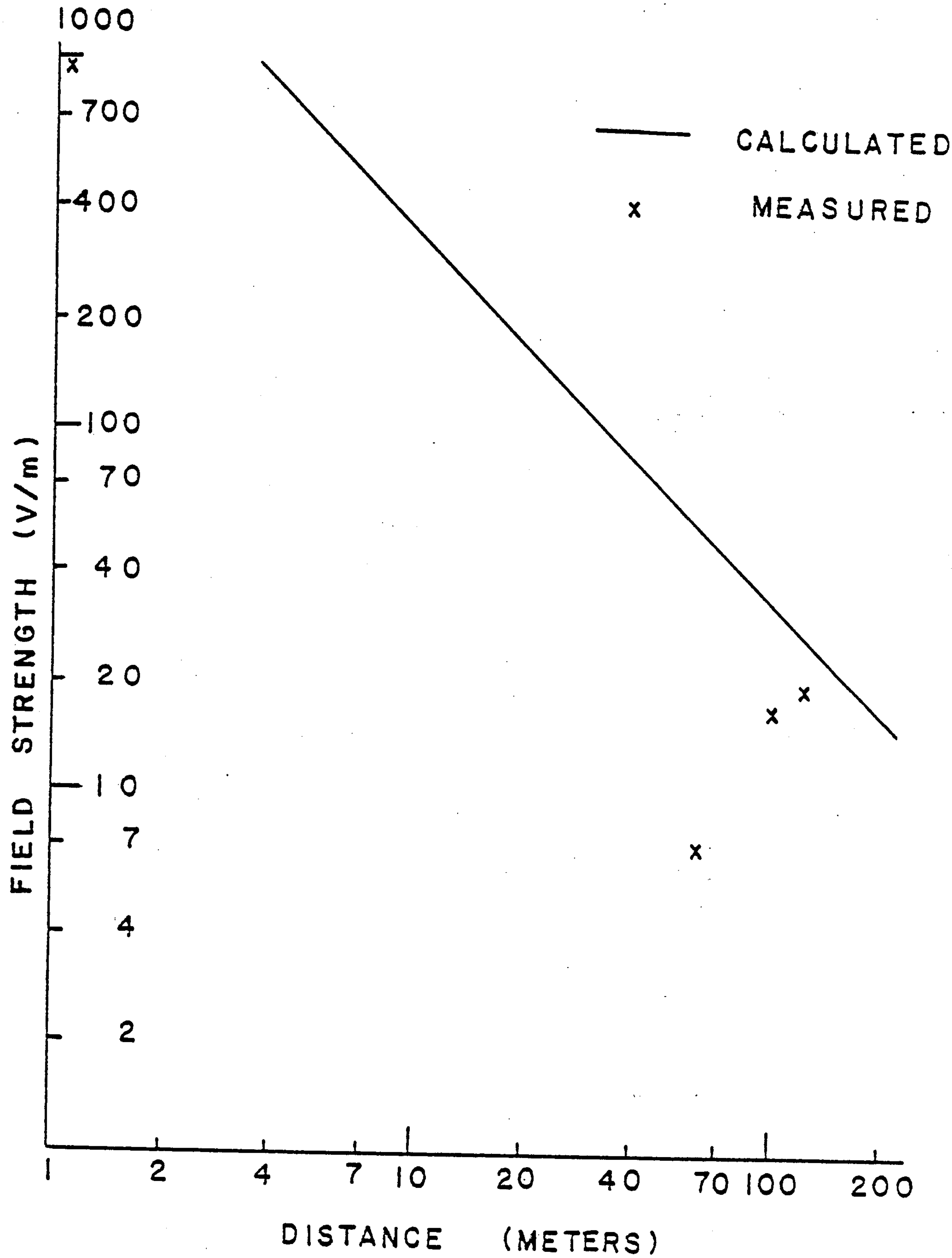

Figure 2 A Comparison of Calculated and Measured Field Strengths in the Vicinity of a Standard AM Broadcasting Antenna (WTOP, Wheaton, MD, 1500 kHz, 50 kW)

An alternate method of calculating the field strength in the immediate vicinity of an AM tower is the ground wave approach. From the propagation point of view, this method offers greater accuracy because it takes into account the influence of frequency, ground constants, etc. The ground wave approach has been discussed by many authors, including Terman [9]. For the purpose of estimating the worst-case field strength, however, equation (2) is adequate.

B. FM Transmitters

There are three classes of FM stations. The maximum effective radiated powers in any direction are as follows: 3 kW for a class A station; 50 kW class B; 100 kW class C.

The near field only extends to a fraction of a meter away from an FM antenna. Hence, only the far-field calculations are relevant. In the far field when the distance is considerably greater than the largest dimension of the antenna, the free space power density may be computed from

$$W = 0.1\ P_e/4\pi R^2 \quad \text{in the absence of reflection, or} \tag{3}$$

$$W = 0.1\ P_e/\pi R^2 \quad \text{in the presence of 100\% reflection} \tag{4}$$

Where W = power density in mW/cm^2,

P_e = effective radiated power in watts, and

R = distance from antenna in meters.

Equation 4 may be rearranged:

$$R_W = \sqrt{P_e/10W\pi} \tag{5}$$

where R_W = distance from antenna, in meters, corresponding to a far-field power density of W mW/cm^2. Figure 3 shows the worst-case (maximum gain, 100% reflection) power density around each class of FM transmitters. Normally, the main beam of a well-designed antenna used for FM broadcasting should be pointing near horizontal. However, it has been reported [6] that occasionally an antenna may have an undesired vertical main beam in addition to the desired horizontal main beam.

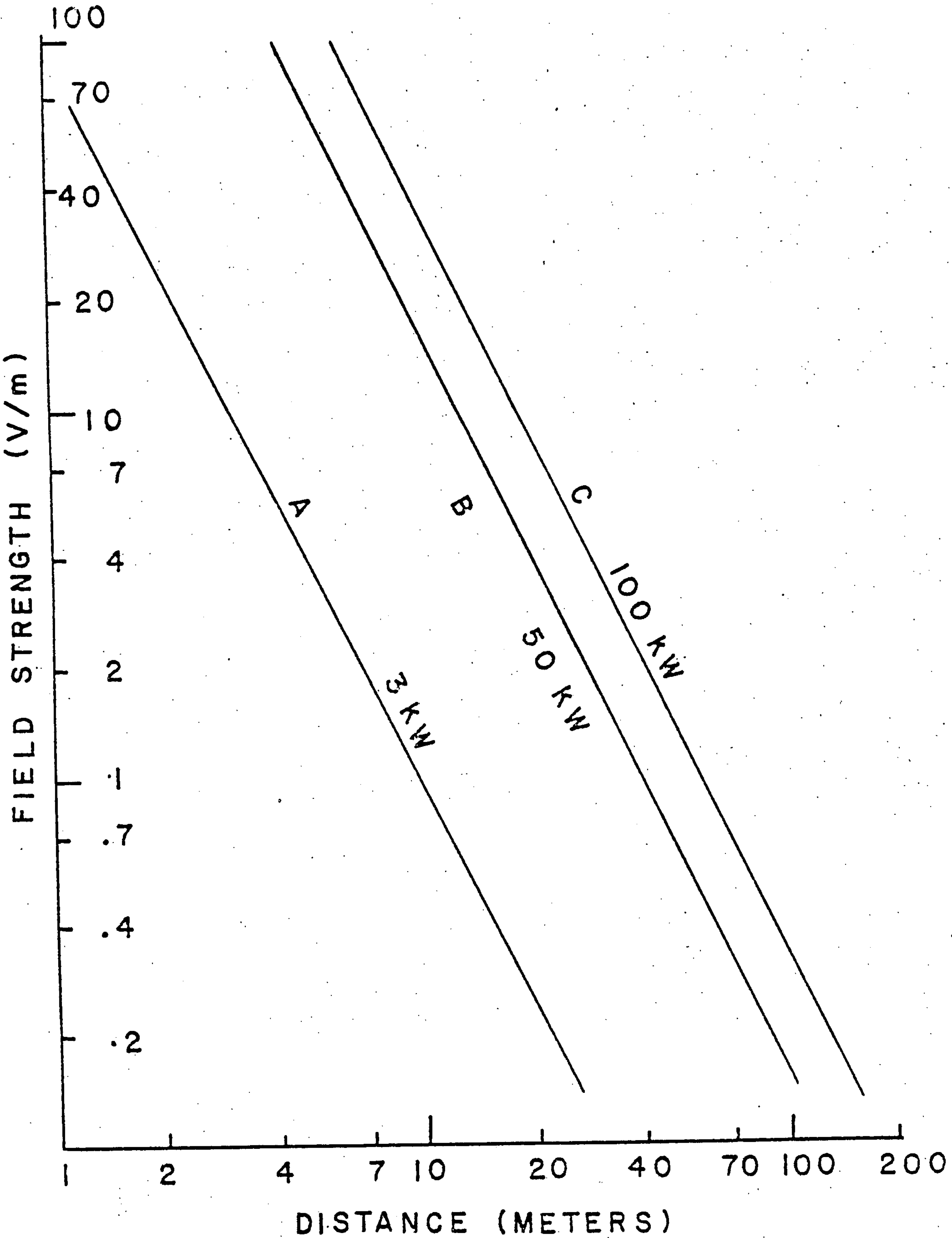

Figure 3 Calculated Power Density vs. Distance for 3 Different Power Levels Used in FM Broadcasting

C. TV Transmitters

The maximum visual effective radiated power of a low VHF (channels 2 to 6) station in the United States is 100 kW. It has been reported [7] that about 70% of all the low VHF stations are operating within 10 kW from the maximum. The maximum visual effective radiated power of a high VHF (channels 7 to 13) station is 316 kW. About 58% of all high VHF stations are operating with near maximum power. The maximum visual effective radiated power of an UHF (channels 14 to 83) is 5,000 kW. However, more than 55% of all UHF stations in this country are operating with visial powers below 1,000 kW. Almost 90% are below 2000 kW.

Figure 4 presents the far-field power density vs. distance for different types of TV transmitting antennas under the condition of maximum gain with 100% reflection, calculated in accordance with equation (4).

D. Microwave Relay Systems

The maximum effective radiated power at 6 GHz is 55 dBW (316 kW). This means 10 mW /cm^2 occurs at 104 feet (31.7 meters) away from the antenna on the main beam in the presence of 100% reflection (52 feet without reflection). The maximum effective radiated power may differ slightly for systems using different frequencies. Although the radiation pattern varies from one type of antenna to another, it is reasonable to assume that the effective radiated power at 10 or more degrees away from the main beam is at least 35 dB lower than that of the main beam [8]. Conservatively, it is assumed that the effective radiated power decreases by 30 dB at 10 or more degrees away from the main beam. Hence, 25 dBW (316 watts) is used to calculate the power density level on the ground in the immediate vicinity of a microwave relay tower. Ten degrees away from the main beam is a very practical and safe choice. For a relay antenna located 50 feet above the ground, 10 or more degrees would cover anywhere on the ground within 287 feet from the base of the tower. For an antenna 300 feet above ground, 10 or more degrees would cover up to 1728 feet. Equation (4) is used for calculating the expected power density. Table 1 lists the results.

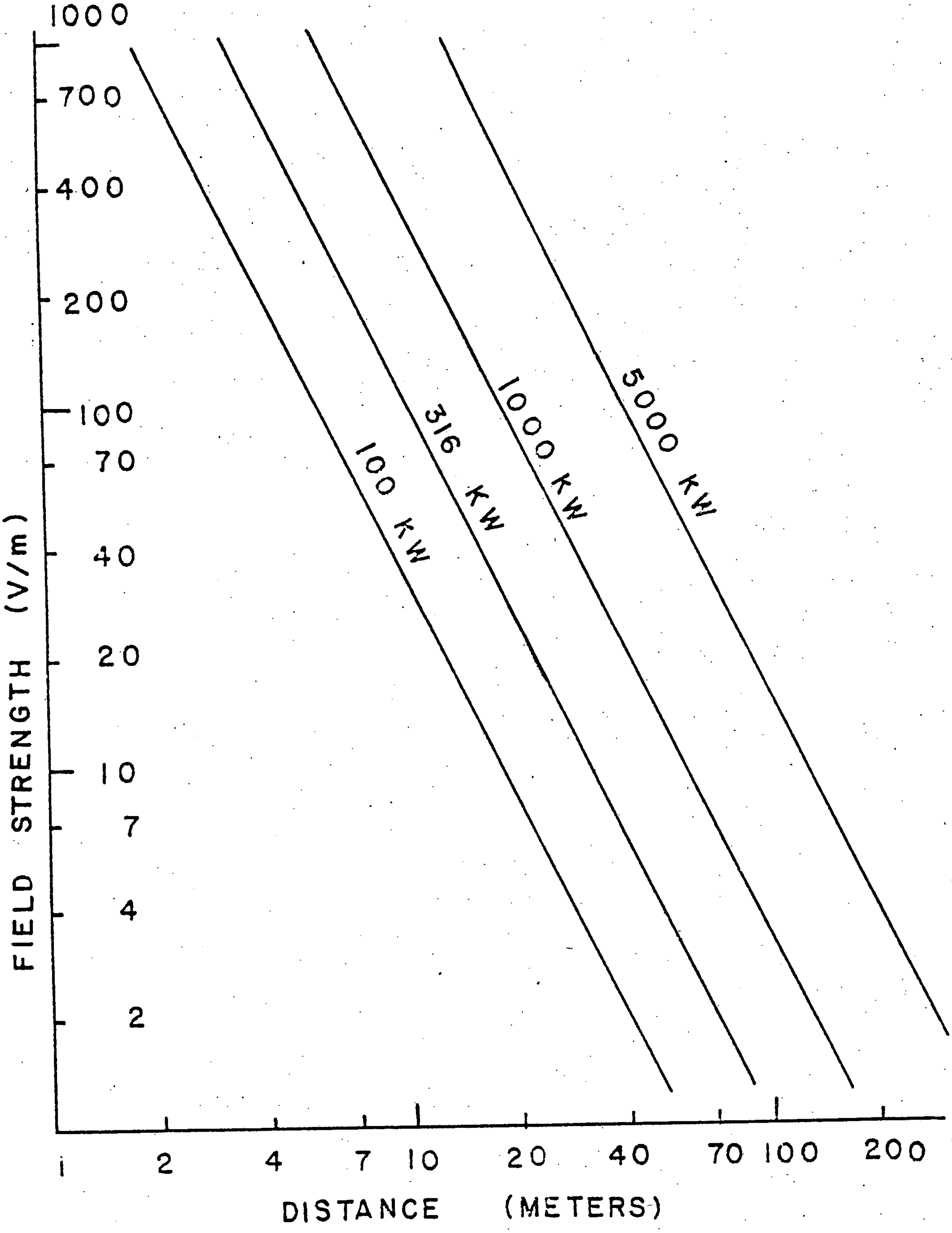

Figure 4 Calculated Power Density vs. Distance for 4 Different Power Levels Used in TV Broadcasting

Table 1

Power Density in the Vicinity of a Microwave Relay Antenna

Distance from Base of Tower Meters	Calculated Power Density* mW/cm^2	Calculated Power Density** mW/cm^2
0	0.043	0.018
10	0.03	0.009
20	0.015	0.0076
30	0.0089	0.0055
40	0.0055	0.0039
50	0.0037	0.0029

* Antenna is 50 feet (15.2 meters) above ground.

** Antenna is 100 feet (30.5 meters) above ground.

E. Devices Using Small Linear Antenna

It is almost impossible to calculate the near-field power density accurately. However, a worst-case analysis has been reported [3]. A concrete example is given here. In this example, a walkie talkie, 1.8 watts, 415 MHz, has been studied. Figure 5 shows the comparison of calculated power density against measured data.

F. Transmitting Earth Stations

A large transmitting earth station has been used for this study. The technical parameters of this station are as follows:

Frequency: 6 GHz (wavelength = 0.05 meter),

Power fed to antenna: 6744 watts,

Antenna: Circular dish, diameter = 30 meters.

Thus, the near field extends to 7068 meters or 4.39 miles (antenna area divided by two times the wavelength). Four regions have been examined: the near-field region of the main beam, the far-field region of the main beam, the region below the antenna, and the region behind the antenna.

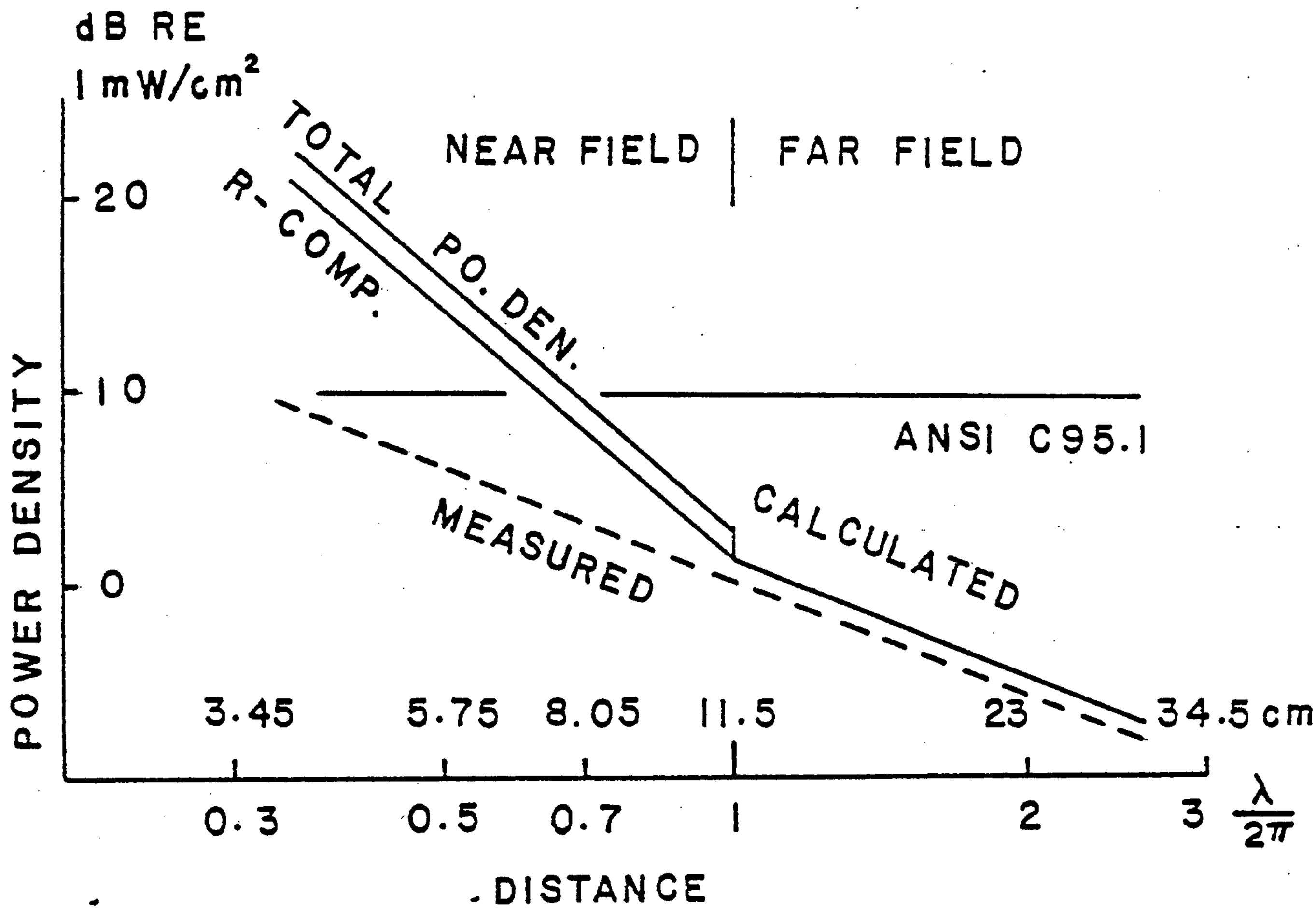

Figure 5 Power Density vs. Distance of a Walkie Talkie (Motorola Model HT-220, 1.8 watts, 415 MHz, see Reference 3)

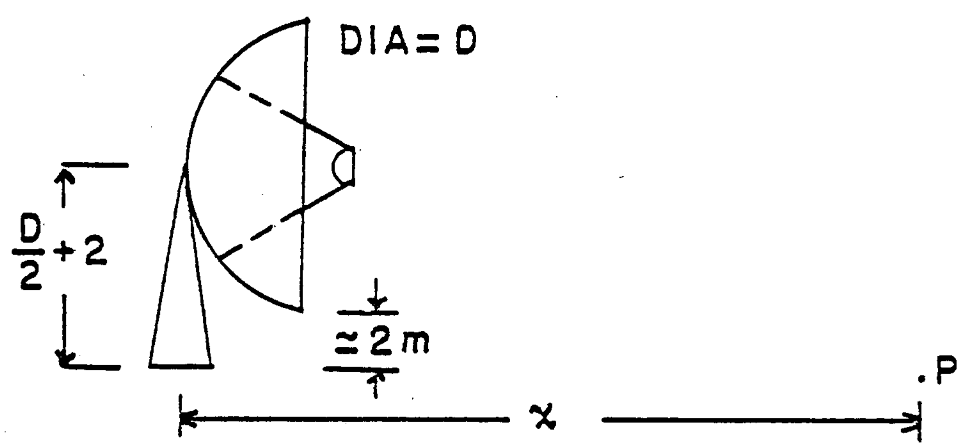

Figure 6 A Typical Earth Station

(1) The Near Field Region

In the near field, the power density is very difficult to calculate accurately. However, it has been reported [5] that the maximum power density for a circular dish antenna perfectly focused is given by:

$W = 0.4P/A$ in the absence of ground reflection (6)

$W = 1.6P/A$ in the presence of 100% ground reflection (7)

where W = power density in mW/cm^2,

P = average power, in watts, fed into antenna, and

A = area of antenna in square meters.

When the elevation angle is near zero, ground reflection is possible and equation (7) should be used. In practice, the elevation angle is usually greater than 5 degrees and ground reflection is unlikely to take place. For the antenna under study, the maximum power density is 3.82 mW/cm^2, neglecting ground reflection. It should be pointed out, however, that there can be localized "hot spots" in the near field, such as the region between the feedhorn and the subreflector, where the power density may exceed this figure.

(2) The Far-Field Region

The maximum power density in the far-field region of a transmitting earth station antenna can be calculated. For the station under study, the far field begins about 7068 meters (4.39 miles) from the antenna with a maximum power density of 3.82 mW/cm^2. As the distance doubles, the power density decreases by 6 dB. FCC Rules require an earth station to maintain the elevation angle of at least 5 degrees. This means the far field main beam of the antenna under study is at least 616 meters (2020) feet above ground at 7068 meters away from the antenna. Since earth stations are usually located in the remote areas, two thousand feet (or more) above ground is more than likely not a populated area.

(3) Region Between Antenna and Ground

The maximum power density in this region can be estimated. First, assume the lower edge of the antenna is 2 meters above the ground when the elevation angle is zero (radiating toward the horizon). This is a conservative assumption since the typical figure is normally 8 feet (2.4 Meters). In order to estimate the maximum power density at point P on the ground X meters away from the base of the antenna, the linear distance between P and the center of the antenna must first be determined. This is given by $d = \sqrt{x^2+(15+2)^2}$ meters. Thus, point P may be considered on the edge of an imaginary circular antenna whose diameter is d meters. Since ground reflection is likely to take place, equation (7) is used to investigate the radiation in this region. Table 2 summarizes the results.

Table 2

Maximum Power Density Below the Antenna

Distance to Antenna Base Meters	Distance to Antenna Center Meters	Maximum Power Density mW/cm^2
0	17	11.88
1	17.05	11.81
5	17.7	10.96
10	19.7	8.85
20	26.2	5
50	52.8	1.23

(4) Region Behind the Antenna

FCC Rules require the off-beam gain of a transmitting earth station antenna to be less than -10 dB between the angles of 48 and 180 degrees. Thus, the maximum effective radiated power in this region is less than 674.4 watts for the station under study. The imaginary antenna (with reflection) approach is used. By equation (7), 10 mW/cm^2 occurs no more than 5.86 meters (19.2 feet) away from the center of the antenna and 0.1 mW/cm^2 occurs no more than 58.6 meters (192 feet) away from the center of the antenna.

G. Radars

Generally speaking, radars may be analyzed either by equation (6) or equation (7), depending on the likelihood of ground reflection. Conservatively, ground reflection should be assumed and equation (7) used. The following example serves as an illustration. The radar under study is a weather radar. The technical parameters are:

Frequency: 5.625 GHz,

Antenna Diameter: 1.82 meters (6 feet),

Power: 157 watts average,

Model No.: WR-100, Enterprise Electronics

By equation (7), the maximum near-field power density is 95.5 mW/cm^2. The near field extends to approximately 24 meters (81 feet). In the far field, the power density decreases from 95.5 mW/cm^2 at 24 meters to 47.75 mW/cm^2 at 48 meters. FCC field engineers have conducted some measurements. The equipment used was a power-density meter manufactured by NARDA, model 8310. See Figure 7 for a comparison of calculated power density against measured data.

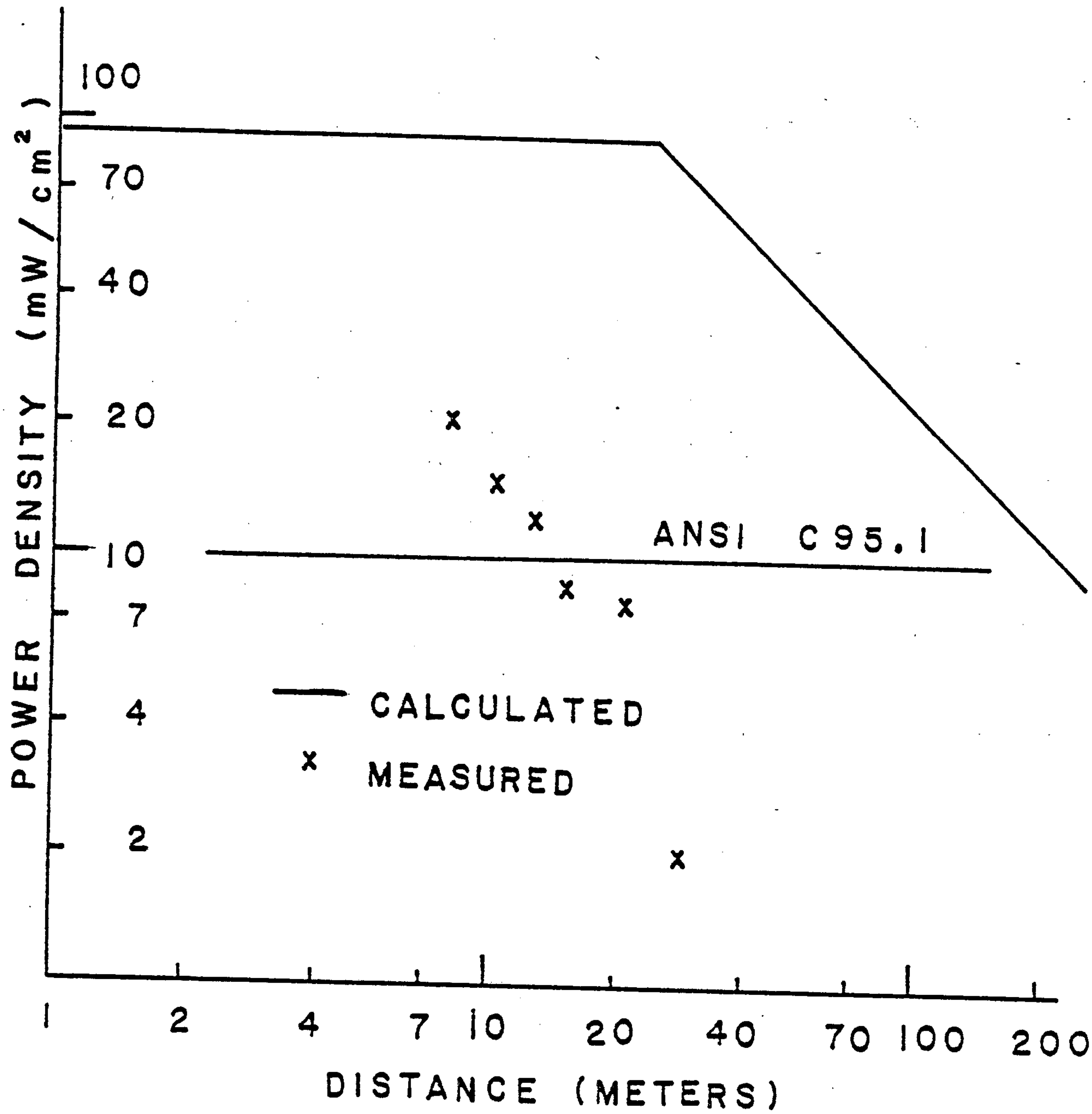

Figure 7 A Comparison of Calculated and Measured Power Densities vs. Distance of a Weather Radar (Enterprise Model WR-100, 5.625 GHz, 157 watts, 6 ft. Dish)

References

1. Office of Telecommunications Policy, "Fourth Report on 'Programs for Control of Electromagnetic Pollution of the Environment: The Assessment of Biological Hazards of Nonionizing Electromagnetic Radiation,'" June, 1976.

2. Wang, J. and Linthicum, J., "RF Field Intensity Measurements in Selected Broadcast Facilities," Federal Communications Commission Technical Memorandum Serial No. 3, August 1976.

3. Wang, J., "Power Density in Near Field of Small Linear Antennas," Federal Communications Commission Technical Memorandum Serial No. 1, Revised, November 1976.

4. Bullington, K., "Radio Propagation Fundamentals," The Bell System Technical Journal, Vol. XXXVI, No. 3, May 1957.

5. Mumford, W. W., "Some Technical Aspects of Microwave Radiation Hazards," Proc. IRE, Vol. 49, pp. 427-447, February 1961.

6. Tell, R. A., "A Measurement of RF Field Intensities in the Immediate Vicinity of an FM Broadcast Station Antenna," Environmental Protection Agency Technical Note ORP/EAD-76-2, January 1976.

7. Wang. J., "Antenna and Power Statistics of Television Stations in the United States," Federal Communications Commission Report RS74-04, December 1974.

8. Bell Telephone Laboratories, Transmission Systems for Communications, Revised 4th edition, December 1971.

9. Terman, F. E., Electronic and Radio Engineering, 4th edition, McGraw-Hill, N.Y., N.Y., 1955.