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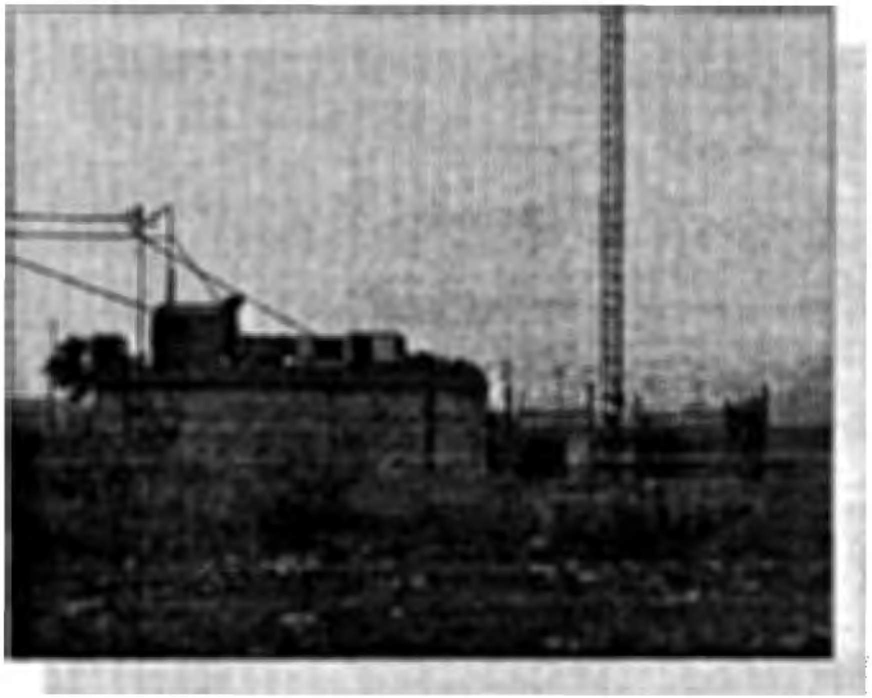
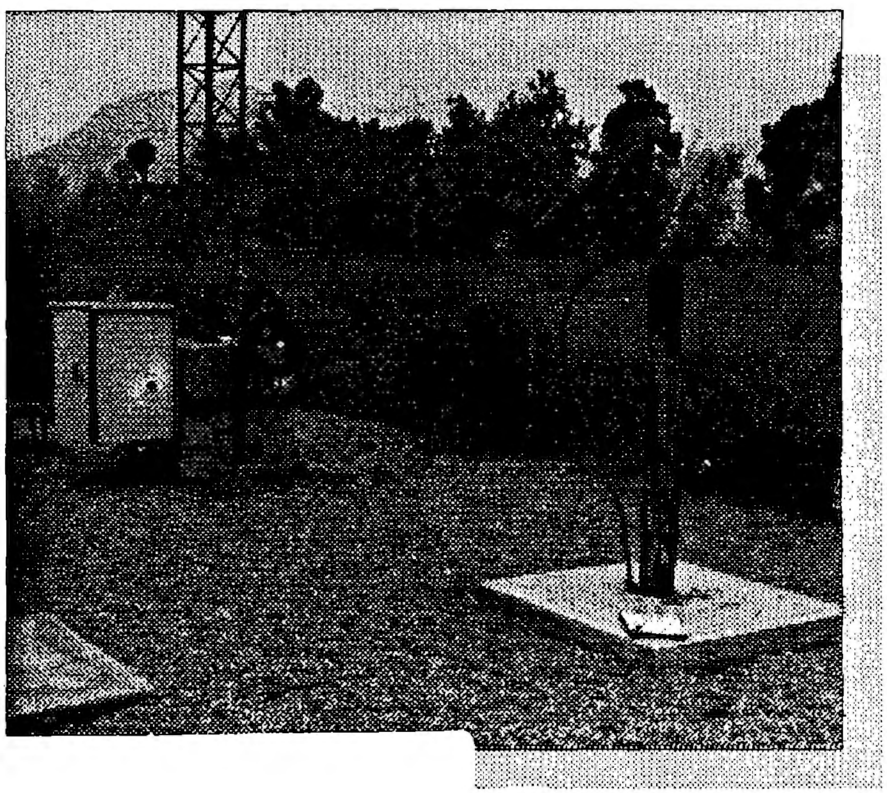
Radiation

# Electric and Magnetic Fields Near AM Broadcast Towers





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The purpose of this study was to obtain actual measurement data in the close-in near field of representative AM boradcast antennas and compare the data to values predicted by a Numerical Electromagnetic Code (NEC) model. Measurements of Electric and Magnetic fields were made along several radial directions at distances from 1 to 100m from the transmitting towers of eight AM broadcast stations. These stations operated at various frequencies, electrical heights, and power outputs.

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# ELECTRIC AND MAGNETIC FIELDS NEAR AM BROADCAST TOWERS

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ABSTRACT

Only limited data have been available that can be used to define regions near AM broadcast towers where radiofrequency (RF) radiation safety standards are likely to be exceeded. In the past, computer models have been used to predict distances at which various field strength levels would occur in the near field of AM antennas. In particular, theoretical values for electric and magnetic fields have been determined using the Numerical Electromagnetic Code (NEC), a computer program developed by the Lawrence Livermore Laboratory, to calculate fields near wire antennas of arbitrary shapes.

The purpose of this study was to obtain actual measurement data in the close-in near field of representative AM broadcast antennas and compare the data to values predicted by a NEC model. Measurements of electric and magnetic fields were made along several radial directions at distances from 1 to 100 m from the transmitting towers of eight AM broadcast stations. These stations operated at various frequencies, electrical heights, and power outputs.

Reasonably good agreement was obtained between measurement data and the NEC models developed for the AM towers surveyed at distances greater than several meters form the tower's base. The agreement was generally not as good closer to the tower's base. Metal fencing or other metal objects near a tower base significantly affect close-in fields, especially electric fields. The effect of these objects was not modeled.

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# 1. INTRODUCTION

Over the past few years the Federal Communications Commission (FCC) and the U.S. Environmental Protection Agency (EPA) have jointly conducted several measurement surveys and other studies of radiofrequency (RF) radiation from FCC-regulated transmitting facilities. These studies were performed under the terms of an interagency agreement between the FCC and the EPA and have involved staff from both agencies. Broadcast stations have been the focus of most of these studies since their relatively high power levels increase their potential for environmental significance.

One area of interest has been to determine the electric and magnetic field strength in the near-field of AM broadcast towers. The data available to define regions near AM towers where RF safety standards may be exceeded is limited. Computer modeling techniques have been used in the past to predict distances at which various field strengths would occur in the near-field of AM stations. However, actual measurement data is needed for comparison with theoretical values. Such data should help refine prediction methods and point out potential problems involved in modeling techniques.

The purpose of this study was to begin collecting data on actual field strength values near AM broadcast towers. In the immediate vicinity of the tower, electric and magnetic field strength depends on a number of variables, including transmitting frequency and tower height. This study concentrated on tower sites that would be relatively easy to survey and model theoretically. A comparison of predicted field strength values versus actual measurements would be useful in determining the accuracy of methods presently being used for evaluating broadcast sites for environmental RF radiation. For example, the FCC's Bulletin No. 65 [1] uses computer modeling to determine areas that should be restricted in order to comply with RF protection guidelines. This bulletin generally defines "worst-case" scenarios; information on actual field values would be helpful.

In preparation for this study, questionnaires were sent to thirty-seven stations in the southern California area. These questionnaires requested the stations' cooperation and asked for specific information about their transmitting facilities. Southern California was selected for this study because of its proximity to the EPA laboratory in Las Vegas and because of the number and variety of stations in the area. The stations that were sent questionnaires were chosen based on their electrical heights, frequencies, number of transmitting towers, and power levels. Data were needed from stations representing a range of electrical heights and frequencies. Single towers or relatively simple tower arrays were preferred. The majority of stations contacted operate at power levels of 5 kilowatts or less.

However, absolute power was considered of secondary importance since fields can be scaled in proportion to the square root of power. Over 80% of the stations contacted responded favorably and were considered as study subjects. The stations ultimately chosen were those with relatively unobstructed transmitting sites where measurements could be made without major complications.

The study was carried out the week of August 8-12, 1988. A total of eight broadcast sites were surveyed. Pertinent characteristics of each station are given in Table 1 with stations identified by the letters A - H. Only station H transmitted from a self-supporting tower. All other active towers were guyed. Preliminary results of this study were presented at the Eleventh Annual Meeting of the Bioelectromagnetics Society in 1989 [2].

TABLE 1. AM BROADCAST STATIONS SURVEYED

| Station | Frequency (kHz) | Power (kW) | Tower Height (meters)* | Electrical Height (wavelength) | No. Transmitting Towers |
|---|---|---|---|---|---|
| A | 1350 | 1.0 | 54.9 | 0.25 | 1 |
| B | 1410 | 1.0 | 90.2 | 0.42 | 1 |
| C | 550 | 4.3 (Tower #1) | 99.1 | 0.18 | 2 |
| | | 0.63 (Tower #2) | 99.1 | 0.18 | |
| D | 1440 | 1.0 | 111.3 | 0.53 | 1 |
| E | 1410 | 4.2 | 56.7 | 0.27 | 1 |
| F | 1070 | 50.0 | 111.4 | 0.40 | **1 |
| G | 790 | 5.0 | 146.3 | 0.39 | **1 |
| H | 1450 | 1.0 | 70.1 | 0.34 | **1 |

*Tower height = height of radiator above insulator, not including obstruction lighting
**Second (de-tuned) tower also at site

## 2. INSTRUMENTATION

At each measurement location both the electric and magnetic field were determined. The electric field was measured using a broadband instrument. A narrowband check of the electric field at one location at each transmitter site was made using a fiber-optically isolated antenna and spectrum analyzer system. The magnetic field was measured using a loop antenna and field strength meter at every location.

## 2.1 ELECTRIC FIELD INSTRUMENTATION

Two Instruments for Industry (IFI) model EFS-1 broadband electric field strength meters were used in this study. These instruments consist of a single short monopole on a conductive box. The box contains the readout electronics and acts as an integral part of the antenna. The instrument detects only the component of the field aligned with the monopole. For this study two orthogonal measurements were made using the IFI instrument, one vertical and one radial. In a few cases tangential measurements were also made. The instruments were calibrated in the EPA transverse electromagnetic (TEM) cell system using unmodulated fields [3]. The serial number 1060-E unit was used for all measurements below 300 V/m; its correction factor at 1 MHz was 0.98. The serial number 1059-E unit was used for all values above 300 V/m; its correction factor at 1 MHz was 0.87.

Since these instruments use diode detectors, the measured electric field strength is expected to be greater than the actual field strength in amplitude modulated fields. At each location maximum and minimum readings were taken during modulation, the minimum readings (corrected) are reported here. The maximum reading is typically 20% higher than the minimum value. The minimum reading will correspond more closely to the unmodulated field strength. By convention, transmitter powers and measured field strengths reported for AM radio stations refer to unmodulated carrier conditions.

An automated system consisting of a fiber-optically isolated spherical dipole antenna (FOISD), spectrum analyzer, and controlling computer was used to check the IFI reading at one location at each transmitter site. A detailed description of this system and discussion of measurement accuracy is contained elsewhere [4].

## 2.2 MAGNETIC FIELD INSTRUMENTATION

An Eaton model 92200-3, 15" loop antenna and Potomac model FIM-41 field strength meter were used to measure the magnetic field at each location. The Potomac meter had been recently calibrated by the manufacturer (4/25/88). This meter was used as a magnetic-field standard in the laboratory to calibrate the loop antenna in a Helmholtz coil at each AM frequency used in this study. During field work, the external input of the Potomac meter was calibrated for absolute RF voltage measurement using a synthesizer, power splitter, power meter, and 50-ohm, feed-through resistor. The Potomac was not used for direct magnetic-field measurement because levels above 0.0265 A/m would exceed the maximum meter reading. In the field, the Potomac was used as a tuned absolute voltmeter to read the voltage generated by the loop antenna in the magnetic field. The loop was oriented for a maximum reading on the Potomac meter; this direction was aligned with the circumferential magnetic field near the tower.

## 3. MEASUREMENT PROCEDURES

A primary objective of this study was to obtain values of electric and magnetic field strength near representative, and relatively simple, AM broadcast towers. At each of the eight sites visited, measurements were made in at least two radial directions from a transmitting tower. Both electric and magnetic field strengths were measured at most measurement points.

A non-conductive tape-measure, 100 meters (m) in length and appropriately marked, was used to define the radials along which measurements were made. Radial distances were defined from the center of a tower base. In the area immediately adjacent to the tower base, measurements were usually made at intervals of one or two meters out to a distance of ten meters. Field strength readings were then generally made at five- or ten-meter intervals out to 50, 75, or 100 m. In some cases obstructions such as fences were present near a tower and prevented readings from being taken at certain points.

All readings were made with the field probe one meter above ground. For electric field measurements, the IFI meter was set on top of a plexiglass platform supported by a section of PVC tubing mounted on an adjustable wooden base. The overall height of this apparatus (ground to plexiglass platform) was one meter. Readings were made by moving this apparatus along the radial so that the meter was positioned directly above the desired measurement point. Measurements were then made of both the vertical and radial components of the field by orienting the IFI meter with the monopole pointed: (1) vertically upward, or (2) parallel to the tape-measure and pointed away from the tower. In a few cases, very close to a tower's base, measurements were also made of the tangential electric-field component. However, those readings were generally negligible.

Readings were taken by watching the instrument needle while the observer stood at a distance of about 2-3 m away to avoid perturbation of the field by the observer. Both maximum and minimum values were recorded to establish effects of signal modulation. Total electric field was obtained by computing the vector sum of the components and multiplying by the appropriate correction factor. This usually involved combining only the vertical and radial components because of the minimal contribution from the tangential component. The radial component of the total field was only significant in the immediate vicinity of a tower base or other metallic objects, such as chain-link fencing. At locations more distant from the tower or from conductive objects the vertical component predominated and constituted most of the total field.

Magnetic field readings were made by orienting the loop antenna until a maximum value was obtained. This orientation was such that the magnetic field existing circumferentially around the tower was perpendicular to the plane of the loop. At each transmitter site the Potomac meter was recalibrated to read absolute voltage at the external input. Tuning was checked every few measurements. The voltage was recorded to be corrected later using the loop calibration.

At each broadcast site an electric-field measurement was also made using the FOISD antenna to compare with the readings made with the IFI meter. For each of these FOISD readings a convenient point was chosen where an IFI reading had already been made, and the spherical-dipole antenna-mount was set up at that point. The FOISD was rotated through 360 degrees in three 120 degree increments to obtain readings in each of three orthogonal directions (vertical, radial, and circumferential). These readings were made using a computer-operated spectrum analyzer system to determine the electric field. Table 2 shows the results of the FOISD and IFI readings at the comparison points.

TABLE 2. ELECTRIC FIELD COMPARISON READINGS

| Station | IFI Minimum Reading (V/m) | FOISD Reading (V/m) | Measured Difference (dB)* |
|---|---|---|---|
| A | 4.5 | 3.8 | 1.5 |
| B | 8.6 | 8.0 | 0.63 |
| C | 21.0 | 18.9 | 0.92 |
| D | 6.2 | 5.1 | 1.7 |
| E | 15.8 | 11.7 | 2.6 |
| F | 40.2 | 39.2 | 0.22 |
| G | 21.7 | 19.2 | 1.1 |
| H | 2.6 | 2.4 | 0.70 |

*using FOISD as reference

## 4. ANTENNA MODELING

Theoretical values of the near electric and magnetic field of the AM broadcast antennas in this study were determined using the Numerical Electromagnetic Code (NEC). NEC is a computer program developed by Lawrence Livermore National Laboratory which can be used to calculate fields near wire antennas of arbitrary shape. The program version used here is NEC2 which is contained in the Numerical Electromagnetics Engineering Design System (NEEDS) package [5].

Wire antennas are modeled in NEC as a set of straight wires in free space or above ground. Each wire is specified by three coordinates in space for each wire end, by a wire radius, and by the number of segments into which the wire is divided. For a given excitation voltage applied across specified segments, NEC solves for the magnitude and phase of the current on every other segment. These currents are then used to calculate the near fields of the antenna.

Many rules apply when creating a model of a real antenna. For example, segment length cannot be too long or short relative to the free-space wavelength, wire radius cannot be too large relative to the segment length, and adjacent segments cannot change radius or length too rapidly. An important note is that several single-segment wires in a straight line are equivalent to one wire broken into several segments.

In principle, the detailed structure of each AM tower and its environment in this study could be modeled using NEC. Tower ironwork, feed point details, ground radials and ground conductivity, guy wires, conductive fences, boxes or buildings containing matching networks, and of course other towers in the system may be important especially when very close to any of these structures. However, our goal was to use the field data to find one simple modeling recipe which results in good agreement between measured and calculated fields one meter above ground at distances from the tower of one meter out to the edge of the ground radial system.

The model used for guyed towers without top loading is shown in Figure 1. The physical tower is shown on the left and the numerical model of the tower is represented on the right of the figure. For an AM radio station the entire tower is the antenna. The transmitter is connected to the insulated tower through a matching network. The ground plane is enhanced by buried ground radial wires approximately the same length as the tower height.

Guyed towers were modeled as three vertical wires having the same radius and spacing as the three tower legs. The base region was approximated by extending the three wires to ground. An excitation voltage was applied across the three wire segments at the height of the insulator. This voltage was adjusted until the antenna current matched the licensed value. The length of the wires above the excited segments was modified by up to 5.1% to obtain an approximate match between the measured value of the impedance listed in the station license and the impedance calculated by NEC. The ground was assumed to be a perfectly conducting plane. Electric and magnetic field components were calculated along a radial at one meter above ground, and the three components of each field were combined to give the resultant magnitude of the field vector or total field.

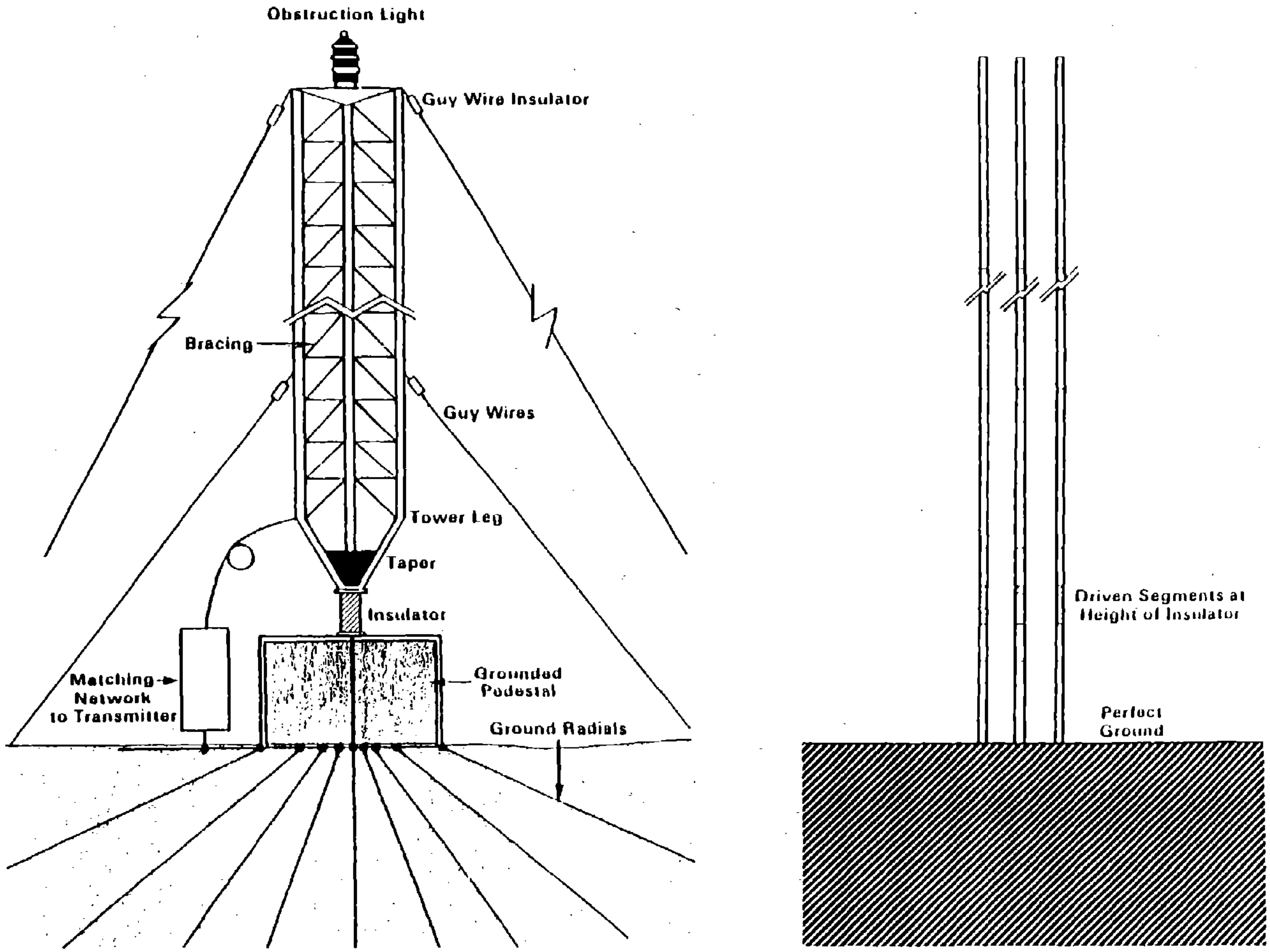



Figure 1. The Physical and Numerical Model Tower

For example, the physical tower description used to create the NEC model for station A is as follows. The tower is stabilized by insulated guy wires and supported by a grounded concrete pedestal 31 in. (0.787 m) high. A 9 in. (0.229 m) long cylindrical ceramic insulator separates the tower from the pedestal. The steel tower is constructed from three parallel, braced tower legs. A horizontal cut through the tower results in an equilateral triangle 15 in. (0.381 m) on a side. The legs are 0.5 in. (0.0127 m) in radius, and 180 ft (54.9 m) long. The tower legs are welded to a flat plate that rests on the insulator. The other guyed towers have a section above the insulator where the legs taper together. This section is modeled as a continuation of the parallel tower legs and is included in the length of the tower legs.

The NEC model for station A was constructed in rectangular coordinates from three wires extending in the z or vertical direction each having a radius of 0.0127 m. A horizontal cut through the wires results in an equilateral triangle similar to one for the actual tower legs. However, the wires in the model extend to a perfect ground (the x, y plane at $z = 0$) with the center of the triangle at the origin. The horizontal coordinates in meters of the wire centers are $x = 0$, $y = 0.172$; $x = 0.191$, $y = -0.158$; and $x = -0.191$, $y = -0.158$. Note that the fields are calculated at $z = 1$ m above ground and along a radial in the x direction for all towers. This radial is at right angles to a radial along y.

Each of the three vertical wires for the station A model was divided into 27 segments such that the total number of segments used in the model was 81. These segments are described starting from the ground and going up. The first 3 segments represent the pedestal. These segments are 0.279, 0.279, and 0.229 m long. Segments adjacent to the insulator or driven segment are set to the same length as the insulator segment, here 0.229 m. Eight (8) segments above the insulator increase in length such that the ratio of length of any one segment to the next lower segment is 1.4; the bottom segment is 0.229 m long and the top segment of this group is 2.41 m long. Finally, there are 15 segments, each 3.13 m in length which complete the tower. The segments are chosen to model the base region in some detail, avoid changing the lengths of segments adjacent to the driven segment or changing the lengths of any adjacent segments abruptly, and minimize the total number of segments.

The measured impedance for tower A is known from the license to be 49.3 + j 93.4 ohms. For the above model the calculated impedance was 42.3 + j 42.3 ohms (initial calculated impedance). To better match the measured impedance, the model tower height was revised using successive approximations. This process resulted in increasing the length of the top 15 segments to 3.42 m each. This revision increases the modeled tower height above the insulator from 54.9 m (tower height) to 57.7 m (adjusted tower height), changes the calculated impedance to 54.9 + j 85.2 ohms (revised calculated impedance), and apparently improves the agreement between measured and calculated fields near the tower. This process of adjusting tower height to match measured impedance was not successful for all of the towers. Adding capacitance across the driven segments has been suggested as an alternative to adjusting tower height.

Finally, the drive voltage for tower A across each insulator segment was adjusted to obtain a drive current of 1.51 A rms on each of the three segments for a total current equal to the licensed base current value of 4.52 A.

Similar information for all of the towers modeled is given in Table 3.

TABLE 3. MODELING INFORMATION

Part I.

| Station Code | Pedestal Height (m) | Insulator Height (m) | Leg Spacing (m) | Leg Radius (m) | Tower Height (m) | Total Segments |
|---|---|---|---|---|---|---|
| A | 0.787 | 0.229 | 0.381 | 0.0127 | 54.9 | 81 |
| B | 0.762 | 0.305 | 0.432 | 0.019 | 90.22 | 73 |
| C | 0.820 | 0.500 | 0.457 | 0.015 | 99.06 | 84 |
| D | 1.000 | 0.203 | 0.432 | 0.019 | 111.25 | 105 |
| E | 0.475 | 0.225 | 0.400 | 0.019 | 56.69 | 69 |
| F | 2.000 | 0.650 | 0.940 | 0.025 | 111.40 | 69 |
| G | 0.920 | 0.450 | 0.920 | 0.050 | 146.30 | 87 |
| H | 0.000 | 1.000 | 3.5-0.0 | 0.050 | 70.10 | 37 |

Part II.

| Station Code | Measured Impedance (ohms) | Initial Calculated Impedance (ohms) | Adjusted Tower Height (m) | Revised Calculated Impedance (ohms) | Licensed Base Current (Amps) |
|---|---|---|---|---|---|
| A | 49.3 + j93.4 | 42.3 + j42.3 | 57.7 | 54.9 + j85.2 | 4.52 |
| B | 659 - j412 | 849 + j368 | 101.5 | 833 - j547 | 1.2 |
| C | 22.1 - j65.7 | 19.5 - j173 | 109.06 | 25.3 - j128 | 14.2 |
| D | 78 - j250 | 244 - j525 | 126.25 | 71.7 - j288 | 3.58 |
| E | 70.5 + j118 | 55.1 + j54.6 | 61.90 | 78.0 + j111 | 7.55 |
| F | 197 + j335 | 365 - j1271 | 109.25 | 314 - j1278 | 15.9 |
| G | 670 + j276 | 404 + j353 | 155.78 | 659 + j328 | 2.67 |
| H | 275 - j86.2 | 81.1 + j16.8 | 79.55 | 275 - j79.9 | 1.91 |

Station C operates with the only tower in this study that is top-loaded. This loading is accomplished with uninsulated sections of guy wire connected at the top of each tower leg. These three guy wires extend from the top of each leg at a height of 99.1 m

(325 ft) to three ground anchor points at 69.2 m (227 ft) from the tower base. The top 9.14 m (30 ft) of each of these guy wires is electrically bonded to a tower leg. The remaining portions of the guy wires are insulated from the tower. The sections of guy wire bonded to the tower are modeled as downward extensions of the three tower legs at angles of 35 degrees to the tower. In order to maintain a constant wire radius in the model, the guy wire sections are modeled to have the same radius as the tower legs. These modeled guy wire sections are not changed in length but are translated vertically as the tower height is adjusted in the model to match impedance. Also, station C is the only station in the study using more than one active tower. A second tower is operated at only 15% of the power used for the tower studied. This tower was not modeled and its effect on measured fields is only seen at locations close to it.

Station H is the only self-supporting tower in the study. The model was similar to that used for the guyed towers except the three driven segments correspond to three physical insulators. The tower tapers gradually from the base up to about the mid-point and is then uniform in cross-section to the top. The three tower legs were modeled such that they converge to a single wire of radius 0.05 m at the mid-point of the tower. The legs are spaced 3.5 m apart at the tower base.

These models were designed to produce fields as close as possible to the measured values; there was no explicit effort to generate field values from the model that will be consistently greater than measured values. For this reason some NEC values are higher and some lower than measured values. In general, considering the number of approximations made in the modeling process, the agreement between measured and predicted fields was reasonable.

## 5. RESULTS

A considerable amount of data was collected during the course of this survey. The results of the measurements and computer modeling of towers will be presented by individually discussing data obtained at each site. Every transmitter site is different, and we found that it would be difficult, if not impossible, to find an "ideal" site without any perturbing structures and with a "perfect" ground system. Thus, it is necessary to consider the actual layout of each site including such complicating factors as the presence of fencing, walls, conductive objects, terrain obstructions, etc. This is especially true very close to the antennas; i.e., within about ten meters.

In all of the figures that follow, measured electric or magnetic field values (after correction for calibration factors) are shown along with theoretical values obtained using the NEC model. The figures are given in Appendix A through H; the appendix letter is the same as the station code letter. The measured electric field values represent the total field; i.e., the resultant value obtained from combining the vertical and radial electric-field readings. Both maximum and minimum electric-field values were usually read at a given location. The minimum readings were used when calculating resultant electric fields in order to more closely approximate the field due to an unmodulated carrier. Formats for the various stations included both music and "all talk" or "all news." Table 1 (page 4) shows technical characteristics of all the stations studied. Note that, unless otherwise indicated, tower height refers to height of the radiator above the base insulator and does not include obstruction lighting.

## 5.1 STATION A

Station A transmits at a frequency of 1350 kHz from a single, guyed tower at a power of 1000 watts. The transmitter site is essentially flat and dry with scrub vegetation typical of southern California's central valley. Ground conductivity in this area is generally accepted to be about 4.0 mhos/m. However, ground conductivity is known to vary considerably in the valley. The tower height is 54.9 m, and electrical height is approximately 0.25 wavelengths. There are two chain-link fences around the tower. The first occurs close-in (about 1-3 meters from the tower base) and forms a rectangle around the tower base along with a small cinder block building, the closest wall of which is about two meters north of the tower base. The second fence is about 20 m from the tower base at its closest location. The outer fence surrounds the tower in the shape of an equilateral triangle with guy wires extending to just inside the vertices of the triangle. Both chain link fences are about 2 m high. The tower's ground system consists of 120 long (180 feet) equally-spaced ground radials alternating with 120 short (50 feet) ground radials. Figure 2 shows a diagram of the Station A site.

Field strength measurements were made in three directions radiating out from the tower base. "Radial 1" extended in a westward direction perpendicular to one side of the triangle formed by the outer fence; readings were made out to a distance of 50 m. "Radial 2" extended approximately toward the southeast, and readings were made out to 100 m. "Radial 3" extended eastwardly toward one of the vertices of the triangular fence and in the direction of one of the guy wires.

Figures A-1 and A-2 show the results of electric-field measurements made along the three radials. Measurements made within 10 m of the tower base are plotted in Figure A-1 to provide greater resolution. The remaining data, out to 100 m, are shown in Figure A-2. Predicted values obtained as a result of computer modeling using the NEC program are also shown. Measured values ranged from a high of about 110 V/m (1 m, Radial 3) to readings of about 3-5 V/m beyond 50 m.

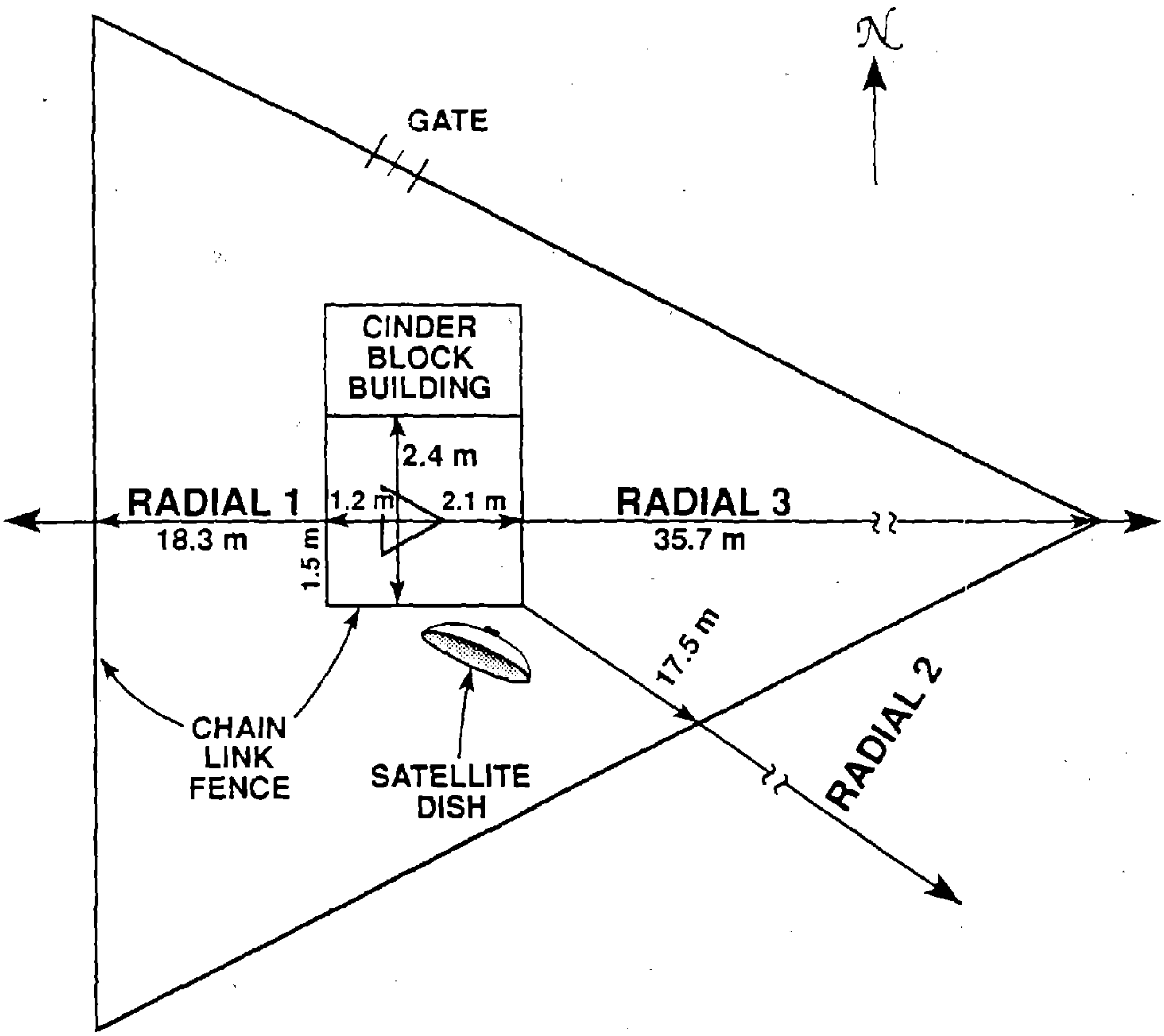



Figure 2. **DIAGRAM OF STATION A SITE (NOT TO SCALE)**

The perturbing effect of the chain-link fences on field values can be seen in both of these figures. The fences were located at approximately 1.2 and 19.5 m along Radial 1, at approximately 3 and 20.5 m along Radial 2, and at approximately 2 and 39 m along Radial 3. Readings were generally reduced near the fences. For example, along Radial 3 there was a large drop in field intensity between the 1 m reading and the 3 m reading (Figure A-1). The reductions are not predicted by the NEC model of the tower, which did not include a model of the fence. Similarly, in Figure A-2 the dip in values along Radials 1 and 2 at the 20 m point correlates with the position of the outer fence.

Figures A-3 and A-4 show results of magnetic field readings around station A. The NEC model clearly over-predicts field values within 4-5 m of the tower base. However, good agreement is obtained farther out. Measured values ranged from slightly over 0.2 A/m to below 0.01 A/m.

Figures A-1 through A-4 show that the measured field values for both electric and magnetic field were generally lower than would be expected based on the NEC model for distances within about 5 m of the tower. This overprediction is probably related, at least partially, to the perturbing effect of the metallic fencing surrounding the tower. Although the electric field at the top of a metallic fence (at 2 m height) would be expected to be enhanced, values measured immediately adjacent to the fences (at 1 m height), especially on the sides away from the tower, were generally reduced relative to nearby readings. Farther out from the tower there was generally good agreement between measured field values and NEC predictions.

## 5.2 STATION B

Station B is a 1000 watt station transmitting from a single, guyed tower at a frequency of 1410 kHz. Tower height is 90.2 m (electrical height about 0.42 wavelengths). The station B transmitter site is quite similar to that of Station A and is only a few miles away. The terrain is flat and dry, and there is a single chain link fence around the tower. The fence is about 3.5 m south and about 7.5 m east and west of the tower base forming a rectangle around it. A metal building is within this enclosed area about two meters north of the tower base. Also within the fenced area are two satellite dish antennas and a metal tank. The ground system of Station B consists of 240 alternating radials: 120, 50-foot radials interleaved with 120, 300-foot radials. A diagram of the site is shown in Figure 3.

Measurements were made in two directions, one west and perpendicular to the fence (Radial 1) and the other south and perpendicular to the fence (Radial 2). The chain-link fence is located at approximately 7.5 m along Radial 1 and at approximately 3.5 m

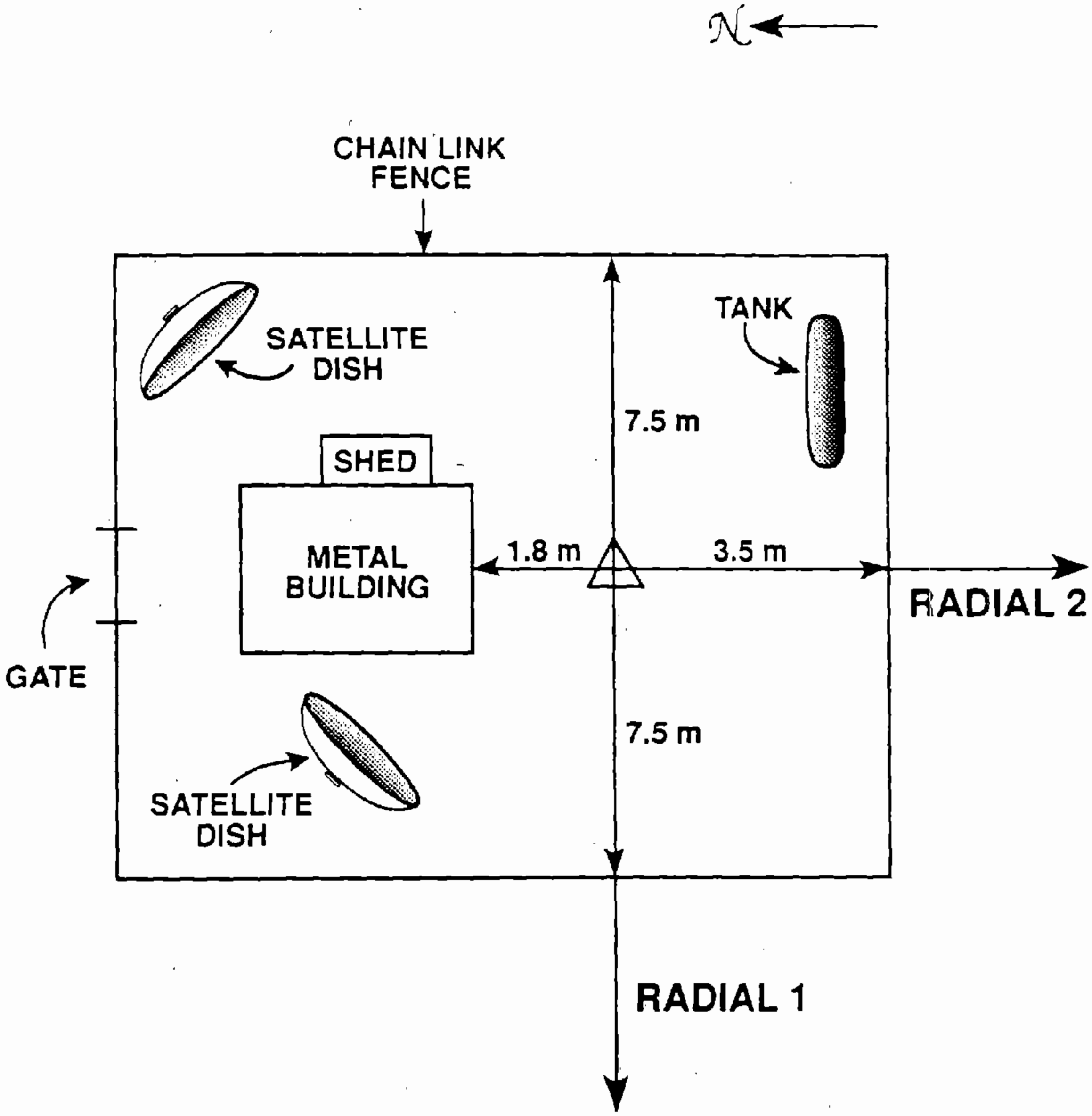



Figure 3. **DIAGRAM OF STATION B SITE (NOT TO SCALE)**

along Radial 2. Figures B-1 and B-2 show results of electric field measurements along these radials. Calculated values using the NEC model are also shown.

Good agreement between calculated and measured values for electric field strength is seen for distances beyond about 10 m. At closer distances measured values of electric field were less than predicted values by as much as 30 to 40 per cent.
Magnetic-field results are shown in Figures B-3 and B-4. The NEC model predicted magnetic fields greater than those measured at distances less than 4 meters from the tower and predicted magnetic fields less than those measured at distances between 6 and 50 meters from the tower. The maximum H-field reading was about 0.1 A/m (at 1 m).

## 5.3 STATION C

Station C is a directional station transmitting at 550 kHz from a two-tower array. Both towers are guyed, steel radiators of uniform cross-section and heights of 99.1 m (0.18 wavelength). The towers are series-excited and top-loaded with 30 feet of the guy wires of each tower. The two towers are separated by approximately 129 m. Input powers during the measurements were 4300 watts (Tower 1) and 625 watts (Tower 2). Only Tower 1 was modeled.

The ground system at the site consists of 120 buried copper radials that extend to the property line or to a common strap between the towers. Interspersed among these radials are 120 additional copper radials about 15 m long. The terrain and vegetation at the site are similar to that for Stations A and B. In fact, all three sites are within a few miles of each other.

Steel reinforced cinder-block walls 2.6 m high and 0.19 m thick surround each of the station C towers; also a small cinder-block building containing the matching network adjoins each enclosure. Tower 1 is near the center of a rectangle formed by the walls. The outside dimensions of this rectangle are 3.25 by 3.45 m. The enclosure surrounding Tower 2 is similar. An illustration of the site is shown in Figure 4.

Measurements were made in each of three directions extending from the base of Tower 1. "Radial 1" extended away from Tower 1 toward Tower 2 approximately toward the northeast. "Radial 2" was directed to the northwest away from Tower 1 and approximately perpendicular to Radial 1. "Radial 3" extended away from Tower 1 in a direction opposite to that of Radial 1.

The results of measurements made along these radials are shown in Figures C-1 through C-4 in Appendix C. In Figure C-1, an apparent effect of the block enclosure can be seen by the sharp drop in electric-field values along Radial 1 between the 1-meter

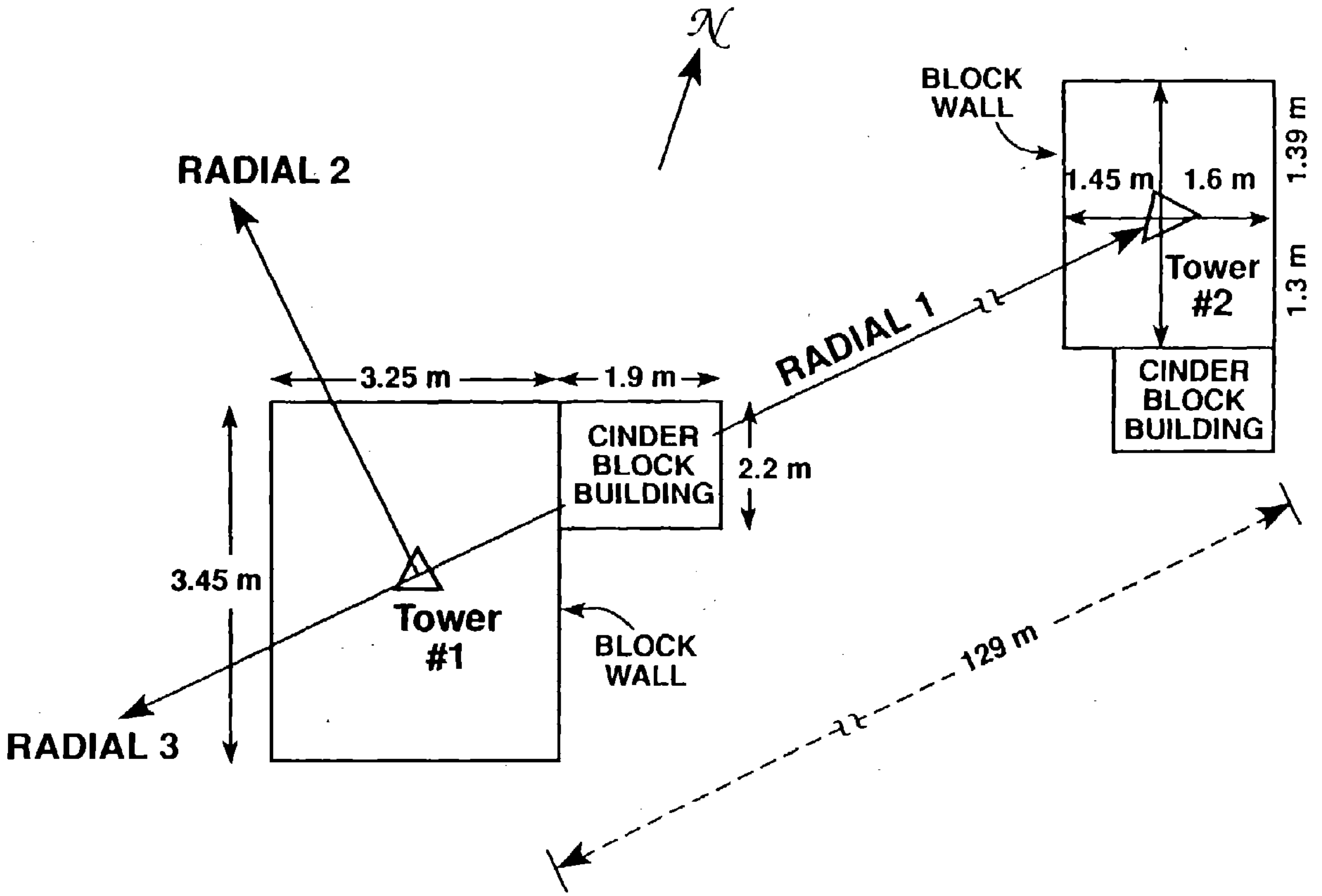



Figure 4. **DIAGRAM OF STATION C SITE (NOT TO SCALE)**

and 2-meter measurements. Both of these readings were made inside the enclosure. However, the 2-meter reading was made near the inside corner of the wall.

Both of these measurements include contributions from significant radial field components. Although the vertical field component predominated in the case of the 1-meter value, the radial component was greater than the vertical component at the 2-meter location. A significant (and predominant) radial field component was also measured along Radial 1 at the 4-meter point, just outside the block wall. However, at the 5-meter location the vertical component again became predominant.

In both Figures C-1 and C-2, predicted electric-field values were in fairly good agreement with measured values past a distance of about 5 m. Closer in, predicted values were higher than measured values (except at 1 m) for all three radial directions.

The effect of Tower 2 on electric field strength was not apparent along Radial 1 until past the mid-point between the two towers. A rise in field strength began to be detected at about 100 m and field strength continued to rise (not shown in Figure C-2), reaching a maximum value of about 27 V/m near the block wall surrounding Tower 2 (distance of 126 m from Tower 1). However, as the block wall was approached the value dropped to about 12 V/m just outside the enclosure, showing, an apparent perturbation caused by the wall. However, inside Tower 2's enclosure, a measurement of 152 V/m was obtained about 1 m from the tower.

Magnetic field strength results are shown in Figures C-3 and C-4. In Figure C-3 it can be seen that the NEC prediction for 1 m is higher than the measured value along Radial 1 (about 3 A/m versus 1.5 A/m). This is in contrast to the 1-meter electric-field value where the situation is reversed. The apparent perturbing effect of the block wall on the electric field, seen in Figure C-1, is not observed in Figure C-3, indicating that the magnetic field is not significantly influenced by the enclosure.

In general, with the exception of certain locations along Radial 1, predicted and measured values for the magnetic field are in reasonably good agreement. Closer to Tower 2 along Radial 1, past the mid-point between towers, magnetic field strength began to rise, reaching a maximum of about 1.3 A/m at a distance 1 m from Tower 2 (not shown in the figures). As with the Tower 1 enclosure, there was no apparent affect of Tower 2's block enclosure on the magnetic-field readings.

## 5.4 STATION D

Station D transmits from a single, guyed, uniform cross-section tower at 1440 kHz with 1000 watts of power. The height of Station D's tower is approximately 111 m (electrical height 0.53

wavelengths). The tower sits atop a 1-meter high concrete pedestal and 0.2-meter insulator, and is about 3.5 m from the corner of a small cinder-block transmitter building situated approximately to the east of the tower. A matching network in a metal enclosure is located immediately adjacent to the tower base. Both the building and the tower are enclosed by a chain-link fence approximately 2 m in height. The ground inside the fence is covered with loose gravel. The terrain surrounding the fenced in area is basically flat and dry with fairly dense scrub brush. The ground system consists of 120 radials, about 85 m long, interspaced with 120 additional radials, each about 15.2 m long. Figure 5 is a diagram of Station D's site.

Measurements were made in three directions from the tower base. Radials were designated as "Radial 1" (approximately north), a short "Radial 2" (approximately south), and "Radial 3" (perpendicular to these two and approximately west). None of these radials extended through the transmitter building. The chain-link fence is approximately 9.5 m from the tower along Radial 1, about 5.8 m from the tower along Radial 2, and about 2.7 m away along Radial 3. A vertical metal pipe, approximately 0.15 m in diameter, is located near the 4-meter point along Radial 1.

Measurement results and NEC predictions are shown in Figures D-1 through D-4 in Appendix D. With regard to the electric field, there was good agreement between measured and predicted values beyond 2 m but poor agreement in the immediate vicinity of the tower base (0-2 m). This was apparently due to the presence of locally perturbing objects. For example, the 1-meter reading along Radial 1 was made directly next to coupling loops used for tower lighting.

The effect of the chain-link fence on the electric field can also be seen. Along Radial 1, the fence was located between the 9 and 10 m, and the perturbing effect of the fence is evident in Figure D-2 at 10 m. The 15-meter reading was greater than the 10-meter reading that was made just outside the fence.

The 9-meter reading incorporated a predominant radial field component. Significant radial field components (i.e., at least 25% of the value of the vertical component) were also detected at all points up to and including the 4-meter measurements. At 3 m and 4 m along Radial 1 (near the pipe mentioned previously) the radial and vertical components were essentially of equal magnitude.

Tangential field components were also measured at a few locations near the tower base of Station D. Generally, tangential field components were negligible (under 3 V/m) except near locally perturbing objects. The maximum tangential component measured was at the 1-meter location along Radial 1, where a reading of

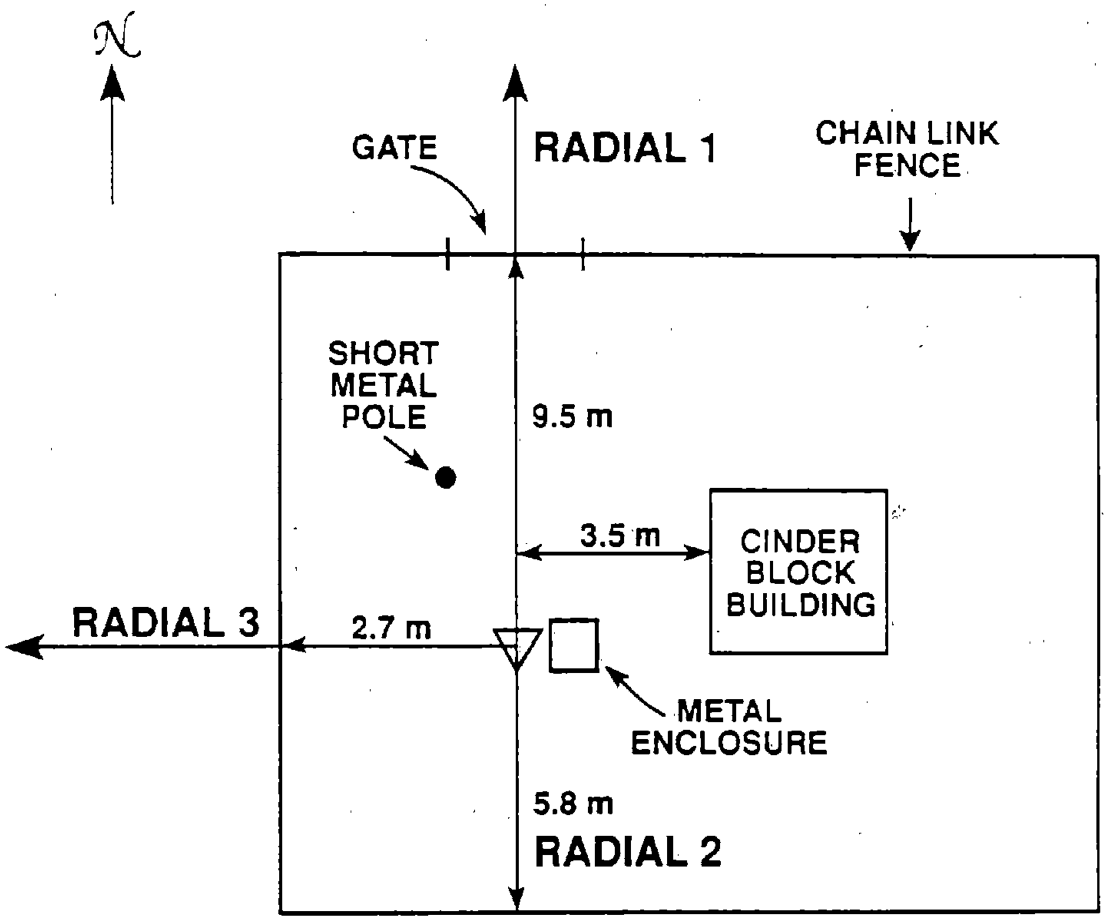



Figure 5. **DIAGRAM OF STATION D SITE (NOT TO SCALE)**

about 37 V/m was obtained (compared to a vertical component of 780 V/m and a radial component of 280 V/m).

Magnetic field measurements for Station D are plotted in Figures D-3 and D-4. There was very good agreement with the predicted values close-in to the tower as can be seen in Figure D-3. However, Figure D-4 shows that at distances beyond about 25 m, along Radials 1 and 3 (Radial 2 measurements only extended to 4 m), there was an increase in magnetic field readings. The NEC curve also increased after about 40 m. This result may seem counterintuitive. However, since these fields are determined essentially inside the antenna system (in the reactive near field) there is no reason why fields cannot increase with distance. This result may be related to the tower's height being close to one-half wavelength.

## 5.5 STATION E

The transmitting antenna used by Station E is a single, guyed, uniform cross-section tower approximately 57 m tall. The operating frequency is 1410 kHz, resulting in an electrical height of about 0.27 wavelength. Input power to the antenna was 4200 watts during the measurements. The surrounding terrain is flat and dry, consisting for the most part of loose soil with little vegetative growth outside of a few trees. The ground system for Station E consists of 120 equally spaced, buried copper radials, each about 46-52 m long, interspaced with 120 additional radials, each about 15.2 m in length.

Station E's tower is surrounded by a rectangular chain-link fence with wide metal strips interwoven diagonally through the links. The fence is about 1.5 m tall and there is about a 2-3 m clearance between the tower and fence. The tower sits atop a 0.25-meter high concrete pedestal with an additional 0.45 m in height provided by the insulator. A metal tuning box, also inside the fenced enclosure, is located about 0.5-1.0 m from the tower. An illustration of the site is shown in Figure 6.

Measurements were made in two directions from the tower base. "Radial 1" extended approximately north from the tower, and "Radial 2" was perpendicular to Radial 1 and in an eastward direction. Results are shown in Figures E-1 through E-4 in Appendix E.

Agreement between measured and predicted values was generally good for electric field values. The effect of the metallic fence on the electric field readings can be seen in Figure E-1, but the perturbation was not as great as was seen for other stations. The fence was located just inside the 4-meter point along Radial 1 and just outside the 2-meter point along Radial 2. Further out from the tower (Figure E-2) measured values tended to exceed predictions, but differences were generally not great.

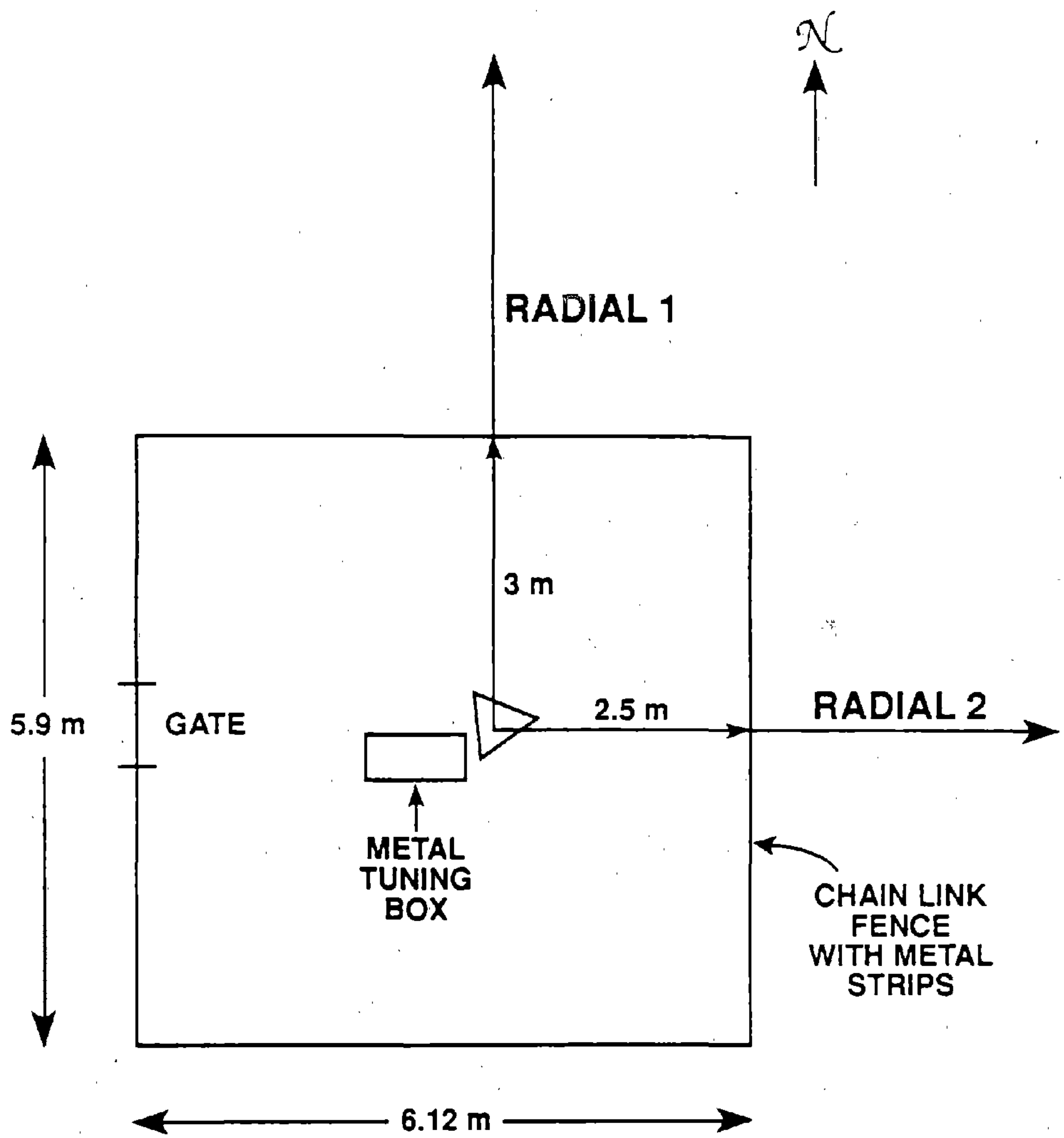



Figure 6. **DIAGRAM OF STATION E SITE (NOT TO SCALE)**

In the immediate vicinity of the tower base, radial electric field components were significant, as seen previously. Along Radial 1, the radial-field component at 1-meter was almost equal to the vertical-field component. There was also a small, but significant, tangential-field component that was about 10% of each of the other two components. The vertical-field component was predominant further out, but significant radial-field components (>25% of the vertical component) were detected along Radial 1 at the 2-meter, 4-meter, and 5-meter positions. Along Radial 2, a similar situation occurred except that the radial electric-field was actually greater than the vertical field until a distance 1 m past the fence (i.e., until the 4-meter reading). There were also notable tangential-field components at the 1-meter and 2-meter locations along Radial 2.

Excellent agreement between predicted and measured magnetic field values was obtained for Station E (Figures E-3 and E-4). As before, no perturbing effect due to metal fences was observed with respect to magnetic field strength.

## 5.6 STATION F

Station F was the only high-powered AM station surveyed during this study. This station transmits with an operating power of 50,000 watts at a frequency of 1070 kHz. The station format is "all news," making measurement of unmodulated field values easier due to the greater frequency of pauses in the modulation.

There are two towers on the site, a main antenna ("Tower 1") and an auxiliary antenna ("Tower 2"). Both are guyed, uniform cross-section, steel radiators. The towers are de-tuned (adjusted to a non-resonant condition) with respect to one another and are separated by a distance of about 105 m, with Tower 2 located to the northeast of Tower 1. The height of Tower 1 is about 150 m (0.53 electrical height). Tower 2 is slightly over 111 m (electrical height of 0.40). The ground system for Tower 1 consists of 240, 152-meter radials. A 15.2-meter radius ground screen is under Tower 1. Tower 2 also has a ground system consisting of 240, 152-meter radials. A 9.8 X 9.5 meter ground screen is under Tower 2. In the area between the two towers the radials meet at a common ground strap.

The land surrounding the two towers is flat and mostly covered with grass. The area is well maintained, since it is also used as public park land. Overhead power transmission lines are in the area but are at least several hundred meters from the closest tower. The ground was damp on the day measurements were made.

Tower 1 is surrounded by a relatively large cinder-block building that would have made close-in measurements difficult and not very useful. Therefore, it was decided to switch transmitting power over to Tower 2 and make all radial measurements relative to it. Tower 2 is in a more open area and there are fewer obstructions to interfere with the measurements.

Tower 2 is surrounded by two separate chain-link fences, each 2-3m high. There is also a small cinder-block structure, about 3m on a side, next to the tower. The tower sits on a concrete pedestal about 2 m high with an additional 0.65 m provided by the insulator. The distance from Tower 2 to the inner chain-link fence is about 5.5-9.5 m, depending on direction. The outer chain-link fence is an additional 1.8 m beyond that. The closest wall of the block structure is about 1 meter from the tower, and much of the tower base is enclosed by a fiberglass shield. Station F's site is illustrated in Figure 7.

Before power was switched from Tower 1 to Tower 2, several measurements were made inside the cinder-block building surrounding Tower 1, since station personnel spend a significant amount of time inside this building, and it was desirable to record typical field-strength values. Ambient electric field strengths were generally found to be less than 10 volts/meter. This is not surprising in view of the fact that the building has copper mesh incorporated into the walls and roof. Higher electric-field readings could be obtained in certain locations very close to transmitter cabinets, but significant exposure to personnel is unlikely at those spots. Electric-field measurements made inside the small courtyard occupied by Tower 1, and surrounded by the building, were much higher (e.g., in excess of several hundred volts/meter approximately 1 meter from the tower). This location is rarely visited by personnel, and, if so, only for a short time.

After switching from Tower 1 to Tower 2, measurements were made in two directions. "Radial 1" was directed to the south away from Tower 2 and through the small block structure, although no measurements were made inside the structure itself. The first reading along Radial 1 was made between the inner chain-link fence and the wall of the structure farthest from the tower. This point was 7.5 m from the tower base. "Radial 2" extended to the west, perpendicular to Radial 1. This radial did not pass through the cinder-block structure, and the first measurement point was 2 m from the tower base.

Results of measurements made along the radials are shown in Figures F-1 through F-4 in Appendix F. It is obvious from Figure F-1 that electric-field values measured close-in were significantly less than those predicted from the NEC analysis. This could be due to perturbing effects of the small block structure and the metallic fencing or, possibly, to the relatively tall concrete pedestal upon which the tower rests (measurements were made 1-meter above ground; the pedestal height was 2 m, see cover photo), or to a combination of these factors. It was noted that

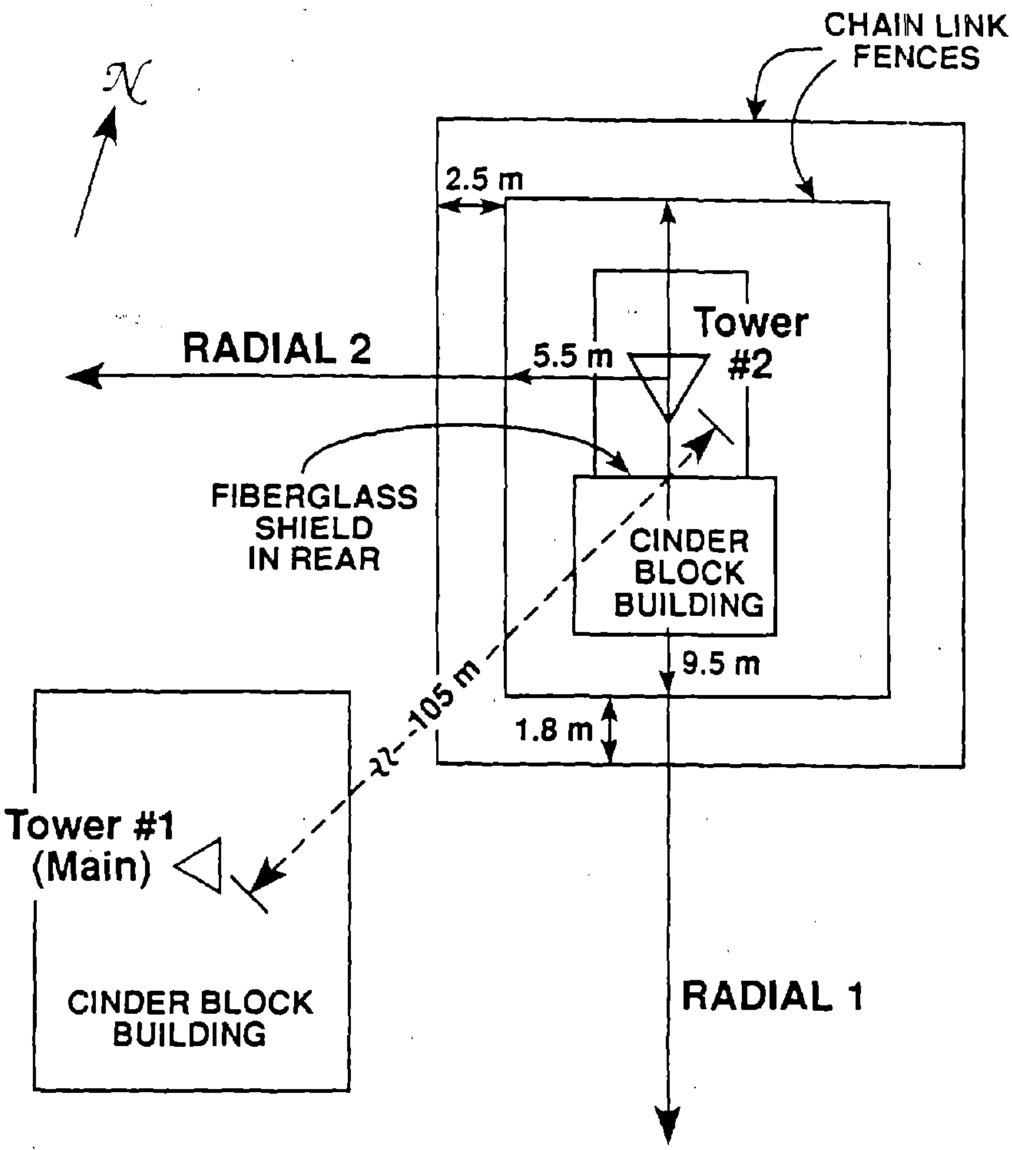



Figure 7. **DIAGRAM OF STATION F SITE (NOT TO SCALE)**

the radial component of the electric field close-in to the tower base constituted a less significant fraction of the total field than was observed at other towers surveyed with lower pedestals. The block structure also has copper mesh incorporated into its walls, making electric field perturbations even more likely.

The effect of the fencing on electric-field values can be seen clearly along Radial 1 in Figure F-2. The inner fence is located at about 9.5 m and the outer fence at 11.25 m. After the fences had been passed there was a steep increase in electric field strength that continued to about 15 m before leveling off and finally decreasing. However, even past the fences the measured field values continued to be somewhat less than those predicted. A similar pattern occurred along Radial 2, except the locations of the inner and outer fences were 5.5 m and 8 m, respectively. Radial field components were significant, with respect to the vertical components, close-in to the tower base and near the metal fences.

Figures F-3 and F-4 show that measured magnetic field values were also less than predicted. There was no noticeable effect of the metal fencing on the magnetic field readings.

Readings were also made of the <u>maximum</u> detectable field strength in any direction within 1-2 m of the base of Tower 2. The highest electric field reading obtained was 830 V/m, and the highest magnetic field strength reading was 1.6 A/m. Both of these readings were obtained at heights above 1 meter and relatively close to the top of the pedestal upon which the tower rests.

## 5.7 STATION G

Station G transmits at a frequency of 790 kHz and power of 5000 watts. The station is non-directional in the daytime, and directional at night. Two towers are used for nighttime transmission, but only one tower is used during the day. All measurements were made during the day when one tower ("Tower 1") was operational. The other tower ("Tower 2") is approximately 73.5 m from Tower 1 to the northwest.

Tower 1 is a uniform cross-section, guyed tower about 146 m high (electrical height of 0.39). It sits atop a 0.6-meter high concrete pedestal and 0.75-meter high insulator. Tower 2 is a tapered, self-supporting tower about 85 meter high (electrical height of 0.22 wavelengths). Tower 1 is located approximately at the center of a rectangular area enclosed by a chain-link fence about 1.5 m high. Dimensions of the fenced enclosure are about 15 m on a side. A steel-encased tuning box is located 1-2 m from the base of Tower 1. Figure 8 is a diagram of the site.

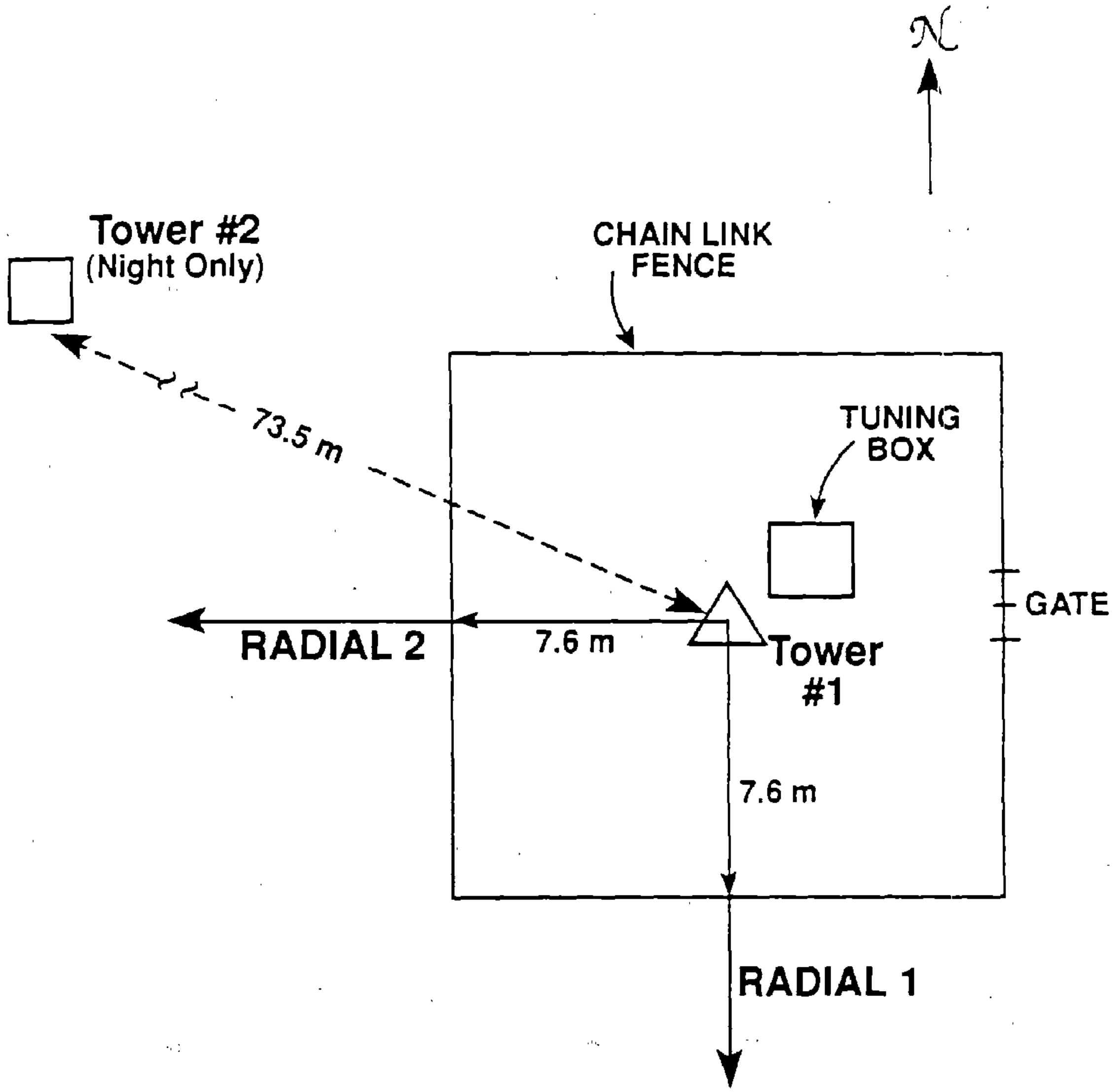



Figure 8. **DIAGRAM OF STATION G SITE (NOT TO SCALE)**

The ground system for Tower 1 consists of 120 equally-spaced, buried, copper radials extending to the edge of the property. The ground system for Tower 2 consists of 120 equally-spaced, buried copper radials extending about 91.5 m or to the edge of the property. There is a 15.2-meter square copper ground screen at the base of Tower 1 and a 10.7-meter square screen at the base of Tower 2. Both ground systems are connected to a common ground strap. The surrounding terrain is flat and dry with some scrub-type vegetation.

Measurements were made along two radials extending out from Tower 1. "Radial 1" extended to the south, and "Radial 2" extended to the west. Results are presented in Figures G-1 through G-4 in Appendix G.

With a few exceptions, there was very good agreement between measured and predicted values for electric field strength. From Figure G-1 it can be seen that there was some variation between predicted and measured values close-in (within 3 m) to the tower base. Also, in Figure G-2, lack of agreement was notable in the 10 to 15 m range, with actual values significantly less than predicted values. This anomaly could have been due to the perturbing effect of the chain-link fence that was located at about 7 to 8 m along each of the two radials. Although not shown in the figures, a peak electric-field reading of about 700 to 870 V/m was obtained within 2 m of the tower base near the antenna feed line.

With respect to magnetic field strength, Figure G-3 shows fairly good agreement between measured and predicted values close-in to the tower base. The only exception was the 1 m location where the NEC model over-predicted measured values. Figure G-4 shows that past the 10 m location the NEC model under-predicted the measured values.

## 5.8 STATION H

Station H was the only station where field strength measurements were made relative to a <u>self-supporting</u> tower. Station H is a non-directional station transmitting with 1000 watts, daytime, on a frequency of 1450 kHz. Although only the main tower was transmitting during the measurements, there is also a (de-tuned) auxiliary tower on the property about 63 m away from the main tower.

The main tower is a triangular, self-supporting, steel radiator approximately 70.1 m in height (electrical height of 0.34 wave-length). It rests atop three insulators (one per tower leg) 1.0 m above ground-level. The tower is located near the end of a paved (asphalt) parking lot, although the area immediately surrounding the tower is unpaved and enclosed by a chain-link fence that is approximately 2 m high. The overall dimensions of the fenced enclosure are about 6 by 7 m. A paved road surrounds the station lot, and one- or two-story buildings line most of the other side of this road. A tower used for microwave and land-mobile antennas is nearby, about 50 m to the west. The ground system consists of 120 equally-spaced, buried, copper radials 53.3 m in length plus an additional 120 interspaced radials 15.2 m in length.

The triangular base of the tower is approximately 3.5 m on a side, and the tower is situated cater-cornered inside the fenced enclosure. The tower tapers gradually from the base up to about the mid-point and is then uniform in cross-section to the top. Figure 9 shows a diagram of the Station H site.

Radial measurements were made in two directions, as shown in the Figure. "Radial 1" was directed to the south of the main tower, in the direction of the auxiliary tower, and "Radial 2" extended toward the north-northeast. Both radials extended over asphalt pavement. However, at the origin for the radials between the tower legs the lot was unpaved. A tuning box is also located under the tower legs. Results are presented in Figures H-1 through H-4 in Appendix H.

As can be seen in Figure H-1, there was not good agreement between measured and predicted electric-field values for distances within a few meters of the tower base. However, agreement was better beyond about 20 m (Figure H-2). This lack of agreement close-in was probably due to the difficulty in modeling a self-supporting tower such as this. The drop in measured electric field values between the 3 and 4 m points was likely due, at least in part, to the chain-link fence that is found at approximately 3-4 m along the radials. Although not plotted, a peak reading of about 300 V/m was found at the tower base under the tower legs.

Radial components were significant, but not predominant, up to about 5 m along Radial 2. However, the radial component along Radial 1 was predominant at the 3 and 4 m points on either side of the chain-link fence. Tangential components were measured at 2 m and 3 m and were also found to be significant components of the total field.

There was poor agreement close-in to the tower (less than 3 m) with respect to the magnetic field, as Figure H-3 shows. Better agreement occurs beyond 10 m (Figure H-4). The peak magnetic field measured (not plotted) was a value of about 0.4 A/m, obtained under the tower legs. A similar reading was made at 1 m along Radial 1.

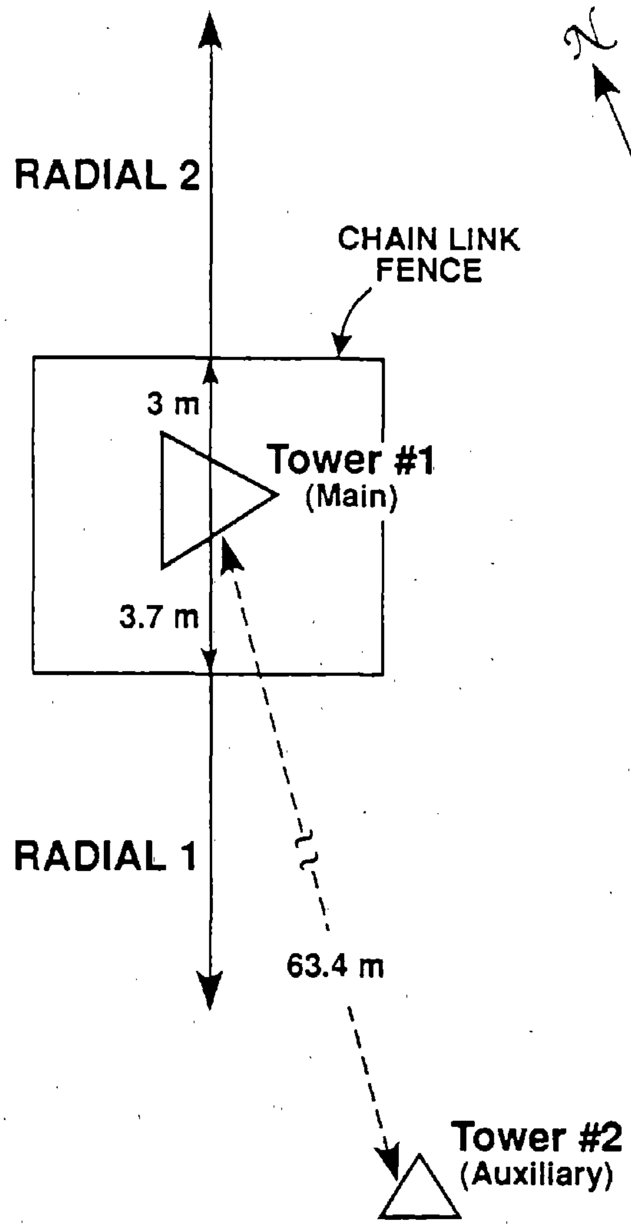



Figure 9. **DIAGRAM OF STATION H SITE (NOT TO SCALE)**

## 6. DISCUSSION AND CONCLUSIONS

The data collected during this study can be analyzed in a number of different ways. The following discussion covers various topics related to the analysis of electromagnetic fields near AM broadcast towers. Of particular interest is how the measurement data and the computer modeling techniques used in this study can help in more accurately predicting fields near AM towers.

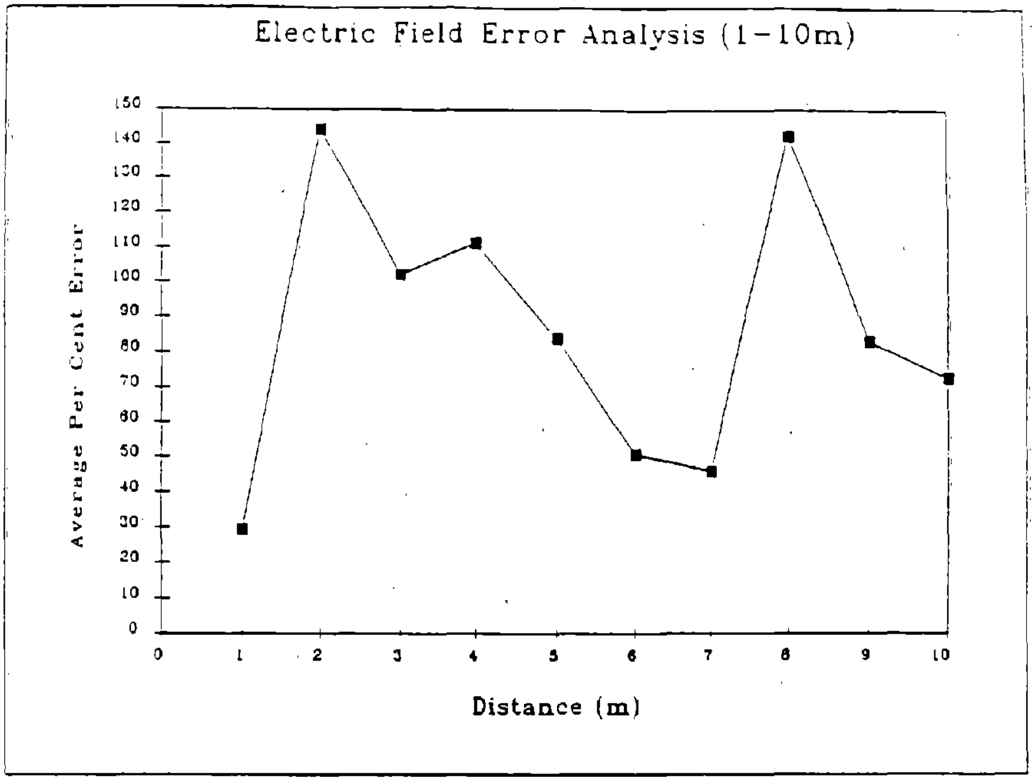
### 6.1 NEC MODELING AND AGREEMENT WITH MEASUREMENTS

Visual inspection of the figures in this report shows that, in general, agreement between measurement data and values predicted by computer modeling was better at larger distances from a tower than closer in to the tower. Unfortunately, the region close to the tower base is of greatest interest because this is where the highest field exposures can occur.

Figures 10 and 11 summarize data on the difference between measured and calculated fields versus distance for all the stations' data combined. To develop the graphs the average measured field value was first determined for each station at each distance by dividing the sum of measurements on different radials by the number of measurements. The absolute value of the difference between calculated NEC value and the average measured field divided by the average measured field times 100% gives the percentage error for each distance at each station. Finally, the average of these errors over all the stations was used to generate the plots of error versus distance. Generally, errors are largest for electric fields at distances less than 15 meters and largest for magnetic fields at distances less than 2 meters.

Two problems contribute to errors in calculating fields very close to the tower base. One is fundamental and is due to the approximations in modeling the base region of the tower. The second problem is incidental and is due to the presence of field perturbing objects near the tower base such as fences and tuning networks. If a fence is far away from the tower its perturbation of the fields is probably just as great but is unlikely to be seen in the data because measurements are not apt to be made near it.

The antenna tower as a field source may be fundamentally viewed as a series of radiofrequency current elements. Fields due to current elements decrease with the inverse cube of the distance. Because of this, at points where some elements are much closer than others, those close elements dominate the field. This implies that at locations close to the tower base only the base region is the field source, whereas at greater distances the entire tower is the source. Since the base region is the most poorly modeled part of the tower, large errors are seen when



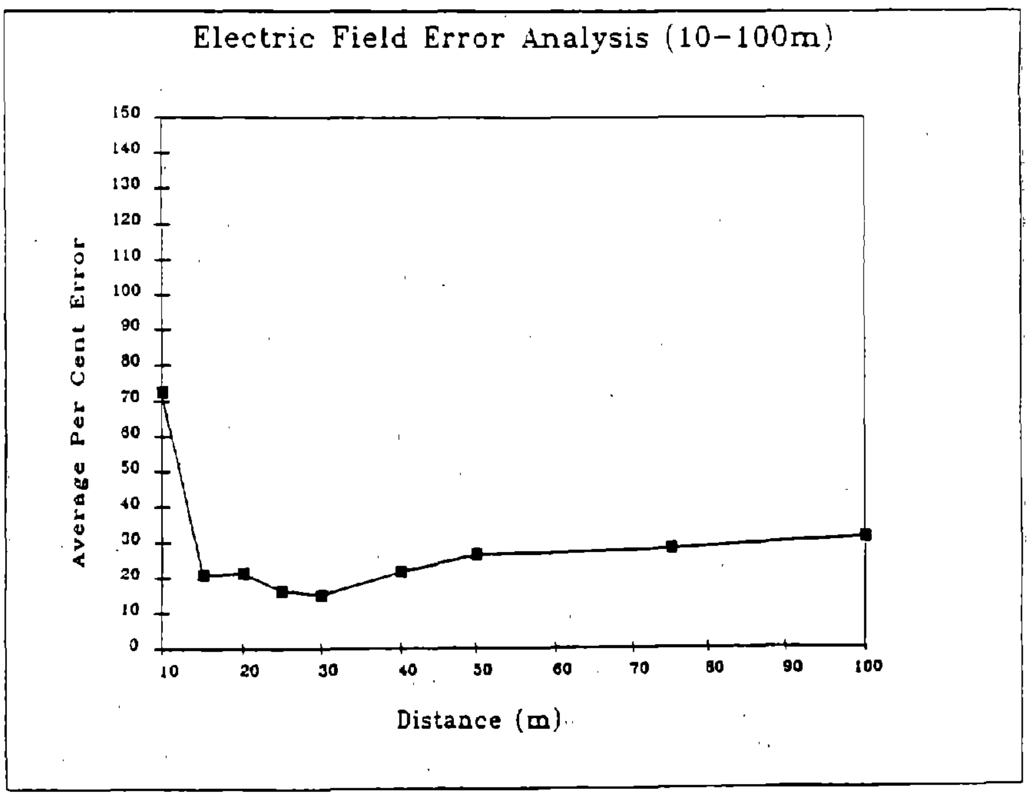
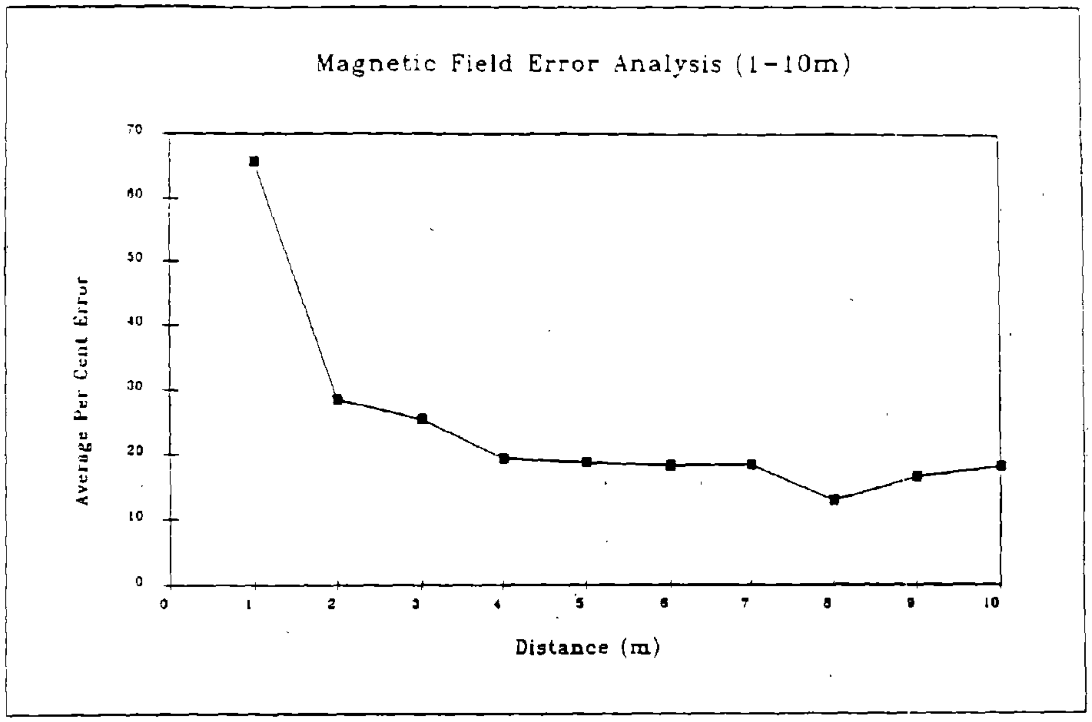




Figure 10. Electric Field Error Analysis



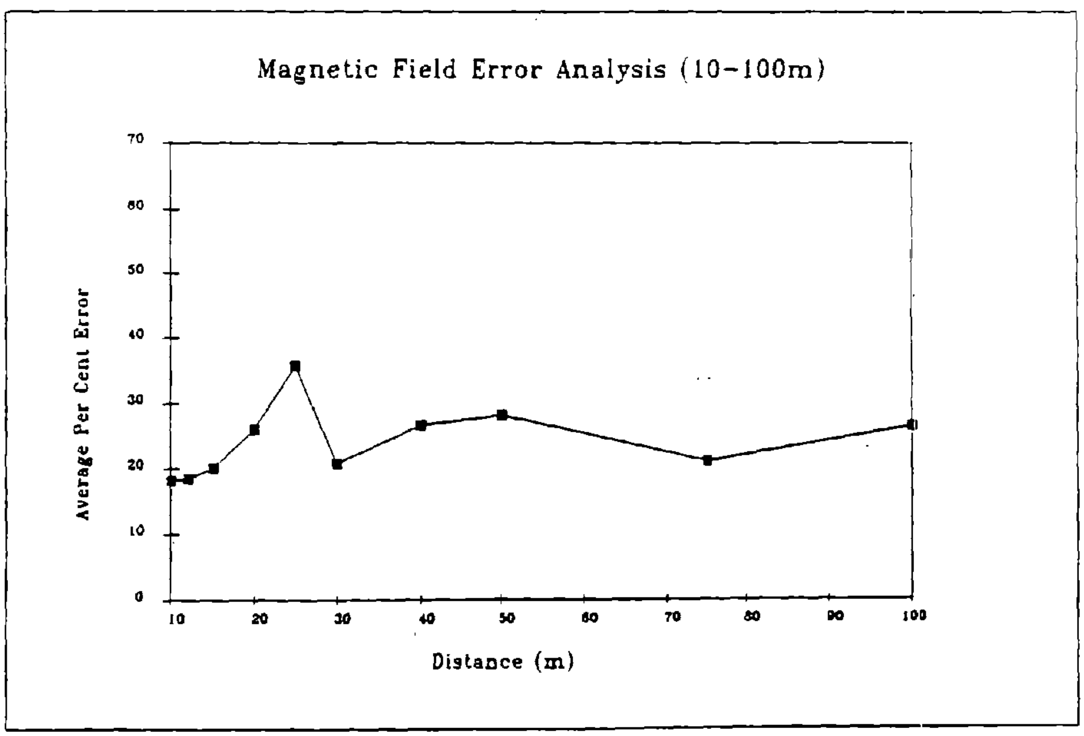




Figure 11. Magnetic Field Error Analysis

approaching the base, especially when the scale of measurements is small compared to the size of the tower base as for station F.

Detailed modeling of the base region is not practical using NEC. The NEC rules on wire diameter and length are restrictive for this application. The effort to match calculated impedances to the measured base impedance was intended to better approximate the known voltage to current ratio at the base at the expense of accurately modeling the height of the tower. The correct base impedance was assumed to lead to better modeling of fields near the base, while small changes in tower height would only affect fields further away and of less interest. This approach was only partially successful. It has also been suggested that a capacitance be added across the feed point to better model the electrical effects of the detailed base geometry; this has not been attempted here. Other possibilities with NEC include modeling fences as vertical wire segments and modeling guy wires.

## 6.2 QUASI-STATIC MODELING OF CLOSE-IN FIELD STRENGTH

The immediate base region, nearby conductive fences and other field perturbing objects close to the tower base are small compared to the wavelength at AM frequencies. This implies that a quasi-static approximation could be used to determine fields near the tower base. Qualitatively, at least, the effect of conductive fences on electric fields can be understood using electrostatic reasoning. A metal fence may be considered an equipotential surface at ground potential. At large distances from the tower the fence perturbs the horizontal equipotential surfaces such that the electric field is normal to the fence surface, decreases on both sides of the fence, and increases above the fence. A fence close to a tower brings ground potential closer to the high potential tower and increases electric fields between the tower and fence but shields regions outside the fence. This has the practical result that conductive fences of adequate height around a tower should reduce electric fields outside the fence, but may increase occupational exposure inside the fence, as well as disturb the tower impedance by increasing the capacitance between the tower and ground. This result is consistent with measurements in this study.

A quasi-static approach to magnetic fields assumes that fields are due to electric currents or magnetized material and the speed of propagation is not considered. For the case of a conductive fence surrounding a tower the eddy currents induced in the fence are probably small because the magnetic fields are circumferential around the tower and generally tangential to the fence surface. If the fence is also magnetic these effects are assumed to be localized and secondary to the eddy current effects. In either case the effect of fencing on magnetic fields would be small and this is consistent with the results of the study.

Simple quasi-static approximations can be used to estimate fields close to the tower base. Since for AM stations the complex impedance (primarily a function of electrical height) and power are measured at the feed point, the current and voltage at the tower base can be easily calculated. The current is given by the square root of the power divided by the real part of the impedance, $I=\sqrt{P}/Re(Z)$. The voltage is given by the current multiplied by the magnitude of the impedance. The voltage can be divided by the distance between a surface on the tower (above the insulator) and a grounded surface (below the insulator) to estimate the average electric field between those two points. This approach was used to calculate electric fields close to (mostly at 1 m) the eight stations in this study. The distance chosen to divide the voltage is somewhat arbitrary, it was chosen to be the distance from the bottom of the radiator to the ground beneath the measurement point. This distance is calculated by adding the pedestal height to the insulator length, squaring this number, adding the square of the horizontal distance from the center of the tower to the measurement point and taking the square root of this quantity. The results of these calculations are shown in Table 4. The average electric field measured and the value calculated by NEC are shown for comparison. It is not clear that the NEC calculations are "better" than this simple quasi-static estimate at close-in locations. At least, the quasi-static numbers are always greater than the average measured values.

Similarly, the magnetic field can be estimated near the base by dividing the current by the circumference of a circle around the tower at the distance of interest. At the 1 m distance the circumference is 6.28 m and at the 2 m distance the circumference is 12.6 m. The results of this calculation are shown in Table 5. The average magnetic field measured and the value calculated by NEC are shown for comparison. The quasi-static values are essentially the same as the NEC values except for the self-supporting tower H, where only the quasi-static number is in good agreement with measurement.

These results show that the quasi-static approach needs to be explored further. It should be emphasized that quasi-static methods must fail at large distances from the tower. However, detailed quasi-static modeling by computer of the base region including perturbing objects may be able to calculate close-in fields with high accuracy. In any case, measurement is probably the only economical approach to accurately determine fields near the base of AM towers.

### 6.3 FACTORS AFFECTING CLOSE-IN FIELD STRENGTH

The question of whether the electric or magnetic fields predominate near a tower base is important if only one of the fields is known. In this case, simple rules based on electrical height

TABLE 4. QUASI-STATIC ELECTRIC FIELD RESULTS

| Station | Base Voltage (V) | Base to Ground Distance (m) | Quasi-Static Electric Field (V/m) | NEC Electric Field (V/m) | Average Measured Electric Field (V/m) |
|---|---|---|---|---|---|
| A | 475 | 1.43 | 332 | 109 | 109 |
| B | 956 | 1.46 | 655 | 348 | 271 |
| C | 964 | 1.66 | 581 | 89 | 200 |
| D | 938 | 1.56 | 601 | 262 | 500 |
| E | 1061 | 1.22 | 870 | 333 | 311 |
| F | 6179 | 3.32 | 1861 | 3289 | 491 |
| G | 1978 | 2.03 | 974 | 739 | 499 |
| H | 550 | 1.41 | 390 | 125 | 95 |

NOTES: Calculations and measurements are at 1 meter except for Station G at 1.5 m and Station F at 2 m. Average measured field is the average of values obtained along one or more radials.



TABLE 5. QUASI-STATIC MAGNETIC FIELD RESULTS

| Station | Base Current (A) | Quasi-Static Magnetic Field (A/m) | NEC Magnetic Field (A/m) | Average Measured Magnetic Field (A/m) |
|---|---|---|---|---|
| A | 4.50 | 0.716 | 0.68 | 0.22 |
| B | 1.23 | 0.196 | 0.18 | 0.10 |
| C | 13.9 | 2.21 | 2.2 | 1.5 |
| D | 3.58 | 0.570 | 0.55 | 0.53 |
| E | 7.72 | 1.23 | 1.23 | 1.17 |
| F | 15.9 | 1.27 | 0.88 | 0.51 |
| G | 2.73 | 0.434 | 0.43 | 0.32 |
| H | 1.91 | 0.304 | 0.04 | 0.31 |

NOTES: Calculations and measurements are at 1 meter except for Station F at 2 m. Average measured field is the average of values obtained along one or more radials.

that determine whether the ratio of electric to magnetic fields is high or low relative to the free space value of 377 ohms would be useful. The magnetic field is expected to be most significant near the base of towers with heights close to one-quarter wavelength since a current maximum exists at or near the base of the tower. On the other hand, the electric field should predominate in the immediate vicinity of the base of towers with heights close to one-half wavelength since a voltage maximum would exist at or near the tower base.

This relationship can be examined among the eight stations that were the subjects of this study. In Table 6, average values of electric and magnetic field strength (measured at one meter, unless otherwise noted) are given for the various stations in order of increasing electrical height. Electrical height ranged from 0.18 to 0.53 wavelength. As expected, with increasing electrical heights in this range there is a general qualitative trend toward a higher electric field strength and lower magnetic field strength near the tower base. This can be seen in the last column in the table where ratios are given for values of E and H (field impedance).

This observation is supported by the results of a recent study of electromagnetic fields near quarter-wavelength AM towers done for the FCC by R. A. Tell Associates [6]. Tell's results indicated that magnetic fields are more likely to exceed safety limits (in which electric and magnetic fields are related at the free space ratio as in the ANSI C95.1 - 1982 RF protection guides) than electric fields close-in to quarter-wavelength towers.

Another means of analyzing the data is to compare measurements from different stations according to their operating frequency and electrical height. These comparisons are useful for illustrating certain patterns that can be detected from the data. Table 7 shows measurement data from five stations arranged in four categories. Field-strength readings (normalized) are listed for four representative distances as averaged from the two or three radials measured with respect to each station. Note magnetic field units are mA/m.

Data listed under category (1) (similar frequency and different electrical height) show, as expected, relatively greater magnetic field values near the quarter-wave towers (Stations A and E) than near the towers with electrical heights closer to one-half wavelength (Stations B and D).

Category (2) in Table 7 compares data from stations with similar electrical height but different frequencies. There is some difference in electric field readings close-in, but at greater distances relatively little difference is seen.

TABLE 6. ELECTRIC AND MAGNETIC FIELD STRENGTH AS A FUNCTION OF ELECTRICAL HEIGHT

(Measured in the immediate vicinity of each tower base)

| STATION | ELEC HT | POWER (kW) | AVG E (V/m) | AVG H (A/m) | E* (V/m) | H* (A/m) | E/H (ohms) |
|---|---|---|---|---|---|---|---|
| C | 0.18 | 4.3 | 200 | 1.5 | 96 | 0.72 | 133 |
| A | 0.25 | 1.0 | 109 | 0.22 | 109 | 0.22 | 495 |
| E | 0.27 | 4.2 | 311 | 1.17 | 152 | 0.57 | 266 |
| H | 0.34 | 1.0 | 95 | 0.31 | 95 | 0.31 | 306 |
| G | 0.39 | 5.0 | 499 (1.5 m) | 0.32 | 223 | 0.14 | 1559 |
| F | 0.40 | 50.0 | 491 (2 m) | 0.51 (2 m) | 69 | 0.07 | 963 |
| B | 0.42 | 1.0 | 271 | 0.10 | 271 | 0.10 | 2710 |
| D | 0.53 | 1.0 | 500 | 0.53 | 500 | 0.53 | 943 |

NOTES:

(1) AVG E and AVG H values are averages obtained along the various radials at 1 m (unless otherwise noted) from each respective tower.

(2) E* and H* are normalized to 1.0 kilowatt of power.

Category (3) repeats the data from (1) but for a different comparison, similar frequency and similar electrical height. Quarter-wave towers (Stations A and E) with similar frequencies should show generally consistent field values along the measured radials. However, some differences are noted, particularly for close-in electric field readings. With respect to the half-wave towers (Stations B and D) there is some discrepancy in the close-in magnetic field data, but otherwise differences were not very great.

In category (4) of Table 7, stations with different frequency and different electrical height are compared (A and E versus G). Significant differences in relative field readings can be seen, with the magnetic field predominating close-in for the quarter-wave towers and the electric field predominating close-in in the case of the relatively low-frequency, half-wave tower.

TABLE 7. COMPARISON OF DATA FROM STATIONS ACCORDING TO FREQUENCY AND ELECTRICAL HEIGHT

| STATION | AVG E-FIELD (V/m) | | | | AVG H-FIELD (mA/m) | | | |
|---|---|---|---|---|---|---|---|---|
| | 3m | 5m | 10m | 25m | 3m | 5m | 10m | 25m |
| (1) Similar frequency, different electrical height: | | | | | | | | |
| E*(1410 kHz, 0.27) | 23.9 | 16.8 | 11.3 | 7.0 | 208 | 134 | 68.5 | 31.3 |
| B (1410 kHz, 0.42) | 59.2 | 25.0 | 15.8 | 7.2 | 48.4 | 32.6 | 21.7 | 15.6 |
| A (1350 kHz, 0.25) | 10.5 | 8.1 | 6.4 | 5.4 | 185 | 130 | 74.4 | 27.2 |
| D (1440 kHz, 0.53) | 60.6 | 32.7 | 15.6 | 8.2 | 176 | 99.0 | 34.8 | 3.48 |
| (2) Different frequency, similar electrical height: | | | | | | | | |
| G* (790 kHz, 0.39) | 94.4 | 49.6 | 15.4 | 7.3 | 72.8 | 48.9 | 29.0 | 15.3 |
| B (1410 kHz, 0.42) | 59.2 | 25.0 | 15.8 | 7.2 | 48.4 | 32.6 | 21.7 | 15.6 |
| (3) Similar frequency, similar electrical height: | | | | | | | | |
| A (1350 kHz, 0.25) | 10.5 | 8.1 | 6.4 | 5.4 | 185 | 130 | 74.4 | 27.2 |
| E*(1410 kHz, 0.27) | 23.9 | 16.8 | 11.3 | 7.0 | 208 | 134 | 68.5 | 31.3 |
| B (1410 kHz, 0.42) | 59.2 | 25.0 | 15.8 | 7.2 | 48.4 | 32.6 | 21.7 | 15.6 |
| D (1440 kHz, 0.53) | 60.6 | 32.7 | 15.6 | 8.2 | 176 | 99.0 | 34.8 | 3.48 |
| (4) Different frequency, different electrical height: | | | | | | | | |
| A (1350 kHz, 0.25) | 10.5 | 8.1 | 6.4 | 5.4 | 185 | 130 | 74.4 | 27.2 |
| E*(1410 kHz, 0.27) | 23.9 | 16.8 | 11.3 | 7.0 | 208 | 134 | 68.5 | 31.3 |
| G* (790 kHz, 0.39) | 94.4 | 49.6 | 15.4 | 7.3 | 72.8 | 48.9 | 29.0 | 15.3 |

* = data normalized for 1.0 kilowatt power

Although most of the stations participating in this study operate at 1 kilowatt of power, a few operate at higher power levels. It is instructive to compare data from the 1 kilowatt stations with data from the higher powered stations. For example, field strength measurements from a 1 kilowatt station may be useful for predicting the magnitude of electric and magnetic fields near a higher powered station with a similar frequency and electrical height. This could be accomplished by multiplying measured values from the 1 kilowatt station by the square root of the power of the high power station.

TABLE 8. COMPARISON OF MEASURED FIELD STRENGTH BETWEEN STATIONS WITH DIFFERENT OPERATING POWERS

| | | Distance from tower* | | | |
|---|---|---|---|---|---|
| | | 2m | 5m | 10m | 50m |
| **STATION B** | | | | | |
| 1.0 kW, 1410 kHz, | E-FIELD(V/m): | 105 | 25 | 16 | 4 |
| 0.42 λ | H-FIELD(A/m): | .059 | .033 | .024 | .012 |
| **STATION D** | | | | | |
| 1.0 kW, 1440 kHz, | E-FIELD(V/m): | 124 | 33 | 16 | 3 |
| 0.53 λ | H-FIELD(A/m): | .296 | .099 | .035 | .010 |
| **AVERAGE FOR B AND D:** | E-FIELD(V/m): | 115 | 29 | 16 | 4 |
| | H-FIELD(A/m): | .178 | .066 | .030 | .011 |
| **STATION G** | | | | | |
| 5.0 kW | E-FIELD(V/m): | 361 | 111 | 34 | 9 |
| 790 kHz | AVG(B&D)*$\sqrt{5}$(V/m): | 257 | 65 | 36 | 9 |
| 0.39 λ | | | | | |
| | H-FIELD(A/m): | .291 | .114 | .069 | .025 |
| | AVG(B&D)*$\sqrt{5}$(A/m): | .398 | .148 | .067 | .025 |
| **STATION F** | | | | | |
| 50.0 kW | E-FIELD(V/m): | 436 | 169 | 44 | 26 |
| 1070 kHz | AVG(B&D)*$\sqrt{50}$(V/m): | 813 | 205 | 113 | 28 |
| 0.40 λ | | | | | |
| | H-FIELD(A/m): | .505 | .293 | .207 | .075 |
| | AVG(B&D)*$\sqrt{50}$(A/m): | 1.259 | .467 | .212 | .078 |

*NOTE: Actual field strength values were taken from the measured data from Stations B, D, F, and G at the indicated distances along 1, 2, or 3 radials, depending on the station. An average reading was used if 2 or 3 radials were measured.

To test this proposition, Table 8 was constructed. This table shows a comparison of data from Stations B and D (both 1 kilowatt of power with similar frequencies and electrical heights) with actual and "expected" field strength values from Station G (5 kilowatts) and Station F (50 kilowatts). Stations G and F both have elctrical heights that are not very different from Stations B and D, but the frequencies are not similar. The "expected" field strength values for Stations G and F were obtained by multiplying average values from Stations B and D by the square root of 5 or 50, as appropriate. Field strength comparisons were made at 2, 5, 10, and 50 meters along the radials measured from each tower base.

An interesting observation from Table 8 is the generally good agreement between measured data and the extrapolated, 1-kilowatt values beyond 10 m from a tower. However, agreement was not so good within 10 m, illustrating the variability of measurements very close-in to a tower base. In the case of Station G, expected E-field values were exceeded by actual values within 10 m while H-field values were lower than might be expected. On the other hand, actual E and H values from Station F within 10 m were lower than those that might be expected from the data for the 1-kilowatt stations.

## 6.4 PERTURBATION OF FIELDS DUE TO OBJECTS NEAR A TOWER BASE

Our results show that conductive objects close to the base of an AM tower can have a significant effect on the electric field strength in the immediate vicinity. Chain-link fences, in particular, had a noticeable effect on electric field strength. Measurements made on either side of chain-link fences near towers showed an attenuation in the total electric field. The vertical component of the electric field was particularly reduced near these fences, while radial field components tended to be enhanced relative to values farther away from the fence. This is consistent with an electrostatic model of the fence as an equipotential surface held to ground potential. We did not obtain data on electric field strength directly above the fences. However, a significant enhancement would be expected.

As discussed by Tell [6], this effect of chain-link fencing is due to the tendency of electric field lines to terminate on metallic fences which are at a lower (ground) potential. This results in a lower value for the total electric field near the fence than would be found if the fence were not present. Tell also found that in cases where wooden fences surround tower bases there was virtually no perturbation in the electric field.

A good example of the effect of metallic fences was observed at Station F. Station F is a relatively powerful AM station, transmitting at 50 kilowatts, and we had expected to find significantly higher close-in field strengths. However, the two chain-link fences that surround the tower base apparently were the primary cause of our results showing values considerably lower than predicted. Only when we measured very close to the tower base (about 1 meter) and substantially within the fenced area did we obtain higher readings that were closer to those that would be expected.

Chain-link fences are not the only objects that can affect field strength. At other station locations we found that any large metallic object can alter electric field readings, particularly if such objects are relatively close to the tower base. As for magnetic field readings, they can be affected by the presence of nearby tuning coils or inductive loops. However, as also noted by Tell [6], magnetic field readings are generally more stable and less susceptible to the local field perturbations seen for electric fields.

## 6.5 VARIATION OF FIELDS ALONG DIFFERENT RADIALS

A comparison of measured values obtained at the same distance from a tower base, but in different radial directions, also suggests the perturbing effect of the environment in the immediate vicinity of the tower. In general, there appeared to be better agreement from radial to radial farther out from a tower's base than closer in, at least for electric field measurements. In an attempt to illustrate this, Table 9 was constructed using data from four single-tower stations. The table gives field strength values obtained at the same distances along radials from each tower. At distances beyond 10 m the differences tend to be less, in general, than the differences closer in. This table shows that the direction in which measurements are made can make a difference in readings close-in to a tower. Differences tend to be more noticeable for electric field readings than for magnetic field readings. This may be related to the electric field readings being more susceptible to perturbation by conductive objects near the tower base that may be encountered along one radial but not along others.

Tell made similar observations in his study [6]. He obtained variations in field strength readings at fixed distances around AM towers as a function of direction from the tower. As Tell pointed out, this implies that field strength measurements along a <u>single</u> radial may not be representative of maximum exposure levels. Along with field perturbation by conductive objects and tuning structures, Tell suggested that disturbances in a tower's ground system may be a factor in explaining the differences in readings. Tell proposed that measurements to show compliance with safety limits be made along the perimeter of controlled areas near AM towers in order to be certain of locating maximum field levels.

TABLE 9. VARIATION OF FIELD STRENGTH VALUES AS A FUNCTION OF RADIAL DIRECTION FROM SINGLE AM TOWERS*

| | Station | No. Radials | DISTANCE ALONG RADIAL (m) 2 | 3 | 5 | 10 | 25 | 50 |
|---|---|---|---|---|---|---|---|---|
| E FIELD: (V/m) | A | 3 | 15.9 | 13.6 | 10.5 | 7.4 | 5.5 | 4.9 |
| | | | --- | 8.3 | 5.6 | 6.0 | 6.0 | 5.3 |
| | | | --- | 9.6 | 8.2 | 5.8 | 4.7 | 4.5 |
| | B | 2 | 107.1 | 62.3 | 27.0 | 13.9 | 7.2 | 3.9 |
| | | | 102.9 | 56.2 | 23.1 | 17.7 | 7.2 | 4.1 |
| | D | 3 | 124.7 | 73.5 | 28.6 | 8.7 | 7.5 | 3.4 |
| | | | 133.1 | 34.6 | 36.9 | 22.6 | 8.9 | 3.0 |
| | | | 114.4 | 73.8 | --- | --- | --- | --- |
| | E | 2 | 124.6 | --- | 31.4 | 22.6 | 13.8 | 11.9 |
| | | | 164.4 | 49.0 | 37.5 | 23.6 | 14.8 | 9.9 |
| H FIELD: (A/m) | A | 3 | 0.23 | 0.18 | 0.13 | 0.07 | 0.03 | 0.02 |
| | | | --- | 0.23 | 0.14 | 0.07 | 0.03 | 0.02 |
| | | | --- | 0.14 | 0.12 | 0.07 | 0.02 | 0.02 |
| | B | 2 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 |
| | | | 0.06 | 0.05 | 0.03 | 0.02 | 0.02 | 0.01 |
| | D | 3 | 0.28 | 0.16 | 0.10 | 0.03 | 0.01 | 0.01 |
| | | | 0.31 | --- | 0.09 | 0.04 | 0.01 | 0.01 |
| | | | 0.27 | 0.18 | --- | --- | --- | --- |
| | E | 2 | 0.56 | --- | 0.27 | 0.14 | 0.06 | 0.03 |
| | | | 0.68 | 0.42 | 0.28 | 0.14 | 0.07 | 0.03 |

* At the indicated distances from a tower's base, measured values are listed for each of the respective radials. Values have been rounded off.

## 6.6 AGREEMENT WITH VALUES GIVEN IN FCC BULLETIN 65

One of the reasons for this study was an attempt to determine the accuracy of some of the predicted values for AM electromagnetic fields given in the FCC's OST Bulletin No. 65 [1]. Table 1 on page 49 of this bulletin gives distances at which fields from AM stations are predicted to fall below various field strengths. That table is reproduced here as Table 10. It should be kept in mind that the values given in this table were based on NEC computer models and represent "worst-case" situations. They were intended to apply to any station, regardless of the tower height or frequency. Therefore, it was expected that in most cases the values in the table would be conservative. The results of this study generally confirmed that assumption.

Table 10 may be used to obtain distances necessary for compliance with the exposure guidelines of the American National Standards Institute (ANSI) that are used by the FCC for purposes of evaluating RF radiation in the environment (7). According to Table 10, all of the stations in this survey should be candidates for exceeding the ANSI guidelines at various distances from their respective tower bases. In fact, however, we found that only at Stations D and F did we obtain readings that actually exceeded the ANSI limits.

In Table 11, values from Table 10 are compared with actual distances where the indicated electric and magnetic field strengths were measured or were interpolated from our data. The measured distances given in the table represent the maximum distance observed from among the two or three radials surveyed for each station. For simplicity, distances obtained from our data were rounded to the next highest whole number.

From Table 11 it can be seen that the recommended distances from Table 10 are generally conservative with regard to the eight stations studied. An exception occurred with regard to Station C where the magnetic field distance at 0.06 A/m exceeded the recommended distance. However, this reading was obtained on a radial between two active towers, and there may have been a significant contribution from the second tower to the magnetic field reading at the measurement location.

Tell also observed that the values in Bulletin 65 tend to be conservative. His report included a table similar to Table 11 for the four stations he surveyed. In no case was a recommended distance exceeded by the measured distance for a given field strength level.

Even though our results and those of Tell illustrate the conservative nature of the values given in Bulletin 65, it should be emphasized again that those values were meant to represent "worst-case" approximations and were intended to apply to any

TABLE 10. (From OST Bulletin No. 65)
DISTANCES (IN METERS) AT WHICH FIELDS FROM AM STATIONS
ARE PREDICTED TO FALL BELOW VARIOUS FIELD STRENGTHS
(*See notes below)

| Electric Field Strength (V/m) | Magnetic Field Strength (A/m) | Transmitter Power (kW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 50.00 | 25.00 | 10.00 | 5.00 | 2.50 | 1.00 | 0.50 | 0.25 | 0.10 |
| 25 | 0.06 | 109 | 83 | 60 | 47 | 37 | 27 | 22 | 18 | 13 |
| 50 | 0.13 | 65 | 51 | 37 | 29 | 23 | 18 | 14 | 11 | 8 |
| 75 | 0.19 | 49 | 38 | 28 | 23 | 18 | 13 | 11 | 8 | 6 |
| 100 | 0.25 | 40 | 31 | 23 | 19 | 15 | 11 | 9 | 7 | 5 |
| 150 | 0.38 | 30 | 24 | 18 | 15 | 11 | 8 | 6 | 5 | 4 |
| 200 | 0.50 | 25 | 20 | 15 | 12 | 9 | 7 | 5 | 4 | 3 |
| 300 | 0.75 | 20 | 16 | 11 | 9 | 7 | 5 | 4 | 3 | <2 |
| 400 | 1.00 | 16 | 13 | 9 | 7 | 6 | 4 | 3 | <2 | <2 |
| 500 | 1.25 | 14 | 11 | 8 | 6 | 5 | 3 | 3 | <2 | <2 |
| 632 (ANSI) | 1.58 (ANSI) | 12 | 9 | 7 | 5 | 4 | 3 | <2 | <2 | <2 |
| 750 | 1.88 | 11 | 8 | 6 | 5 | 4 | 3 | <2 | <2 | <2 |
| 1000 | 2.50 | 9 | 7 | 5 | 4 | 3 | <2 | <2 | <2 | <2 |

*Notes: (1) This table can be used for any AM frequency or electrical height.
(2) The entries in this table apply to both electric field strength and the corresponding magnetic field strength (assuming impedance of free-space equals 400 ohms).

TABLE 11. COMPARISON OF RECOMMENDED AND MEASURED DISTANCES FOR FIELD STRENGTHS USING VALUES FROM OST BULLETIN 65 AND DATA COLLECTED IN THIS STUDY

(Order of entries is: OST 65 distance/E-field distance/H-field distance)

| E (V/m) | H (A/m) | STATION A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 0.06 | 27/3/12 | 27/7/3 | 44/9/65 | 27/7/8 | 44/10/29 | 109/55/100 | 47/17/12 | 27/6/7 |
| 50 | 0.13 | 18/3/6 | 18/4/- | 27/2/23 | 18/4/5 | 27/4/12 | 65/25/22 | 29/9/5 | 18/4/4 |
| 75 | 0.19 | 13/2/4 | 13/3/- | 22/2/16 | 13/4/4 | 21/4/9 | 49/15/12 | 23/7/3 | 13/3/3 |
| 100 | 0.25 | 11/2/3 | 11/3/- | 18/2/12 | 11/3/3 | 18/3/6 | 40/9/10 | 19/6/2 | 11/-/2 |
| 150 | 0.38 | 8/-/- | 8/2/- | 14/2/10 | 8/2/2 | 14/3/4 | 30/5/4 | 15/5/- | 8/-/2 |
| 200 | 0.50 | 7/-/- | 7/2/- | 11/1/8 | 7/2/2 | 11/2/3 | 25/5/2 | 12/4/- | 7/-/- |
| 300 | 0.75 | 5/-/- | 5/-/- | 8/-/6 | 5/2/- | 8/2/2 | 20/4/- | 9/3/- | 5/-/- |
| 400 | 1.00 | 4/-/- | 4/-/- | 7/-/4 | 4/2/- | 7/-/2 | 16/3/- | 7/3/- | 4/-/- |
| 500 | 1.25 | 3/-/- | 3/-/- | 6/-/3 | 3/2/- | 6/-/2 | 14/2/- | 6/2/- | 3/-/- |
| 632 | 1.58 | 3/-/- | 3/-/- | 5/-/- | 3/2/- | 5/-/- | 12/-/- | 5/-/- | 3/-/- |
| 750 | 1.88 | 3/-/- | 3/-/- | 5/-/- | 3/2/- | 5/-/- | 11/-/- | 5/-/- | 3/-/- |
| 1000 | 2.5 | <2/-/- | <2/-/- | 4/-/- | <2/-/- | 4/-/- | 9/-/- | 4/-/- | 2/-/- |

NOTES: (1) Entries from survey data have been rounded to next highest whole number.
(2) Dash indicates that a field strength of that magnitude was not measured at that station.

station, regardless of electrical height or frequency. It should also be noted that the recommendations in Bulletin 65 did not take into account the perturbing effect of conductive objects such as metal fencing on localized field values. For example, our results and Tell's results show that chain-link fencing may significantly reduce close-in field readings from those that would be expected if a fence were not present. Another point that should be made is that we only measured along a few selected radials. It is apparent that there can be significant variation from radial to radial, particularly if conductive objects are encountered along the radial.

## 6.7 RELATED STUDIES

The results of Tell's study should be considered along with our results to obtain a better understanding of the electromagnetic field environment in the immediate vicinity of AM broadcast towers. In that connection, a few other observations made by Tell should be mentioned.

Tell's study investigated directional tower arrays as well as a non-directional tower. He found that for both the non-directional tower and directional arrays RF fields near quarter-wavelength towers were directly related to the base current in the tower under investigation.

For towers in arrays, the influence of other towers in the array was found to be minimal with respect to compliance with the ANSI guidelines. Tell also observed that "non-driven" towers in a directional array exhibited strong electric fields but essentially no magnetic fields. He suggested that this was due to the process of "floating" the non-driven tower by disconnecting it at the base.

Tell also investigated "contact currents" measured at guy wires and at a chain-link fence near AM towers. He found that such currents can exceed the 100 milliampere level on guy wires and can result in localized RF burns if these objects are touched.

In another field study conducted by the FCC and the U.S. Environmental Protection Agency (8) we measured body currents induced in an individual climbing a transmitting AM tower. In that study, induced body current of up to 110 milliamperes was measured, and the magnitude of the current appeared to be correlated with the radial component of the local electric field. Such currents may be more relevant to the question of exposure of tower personnel, since body current may be more closely related to absorption of RF energy than field strength [9].

## 7. SUMMARY

(1) A survey was made of electric and magnetic field strength at distances within 100 m of the transmitting towers of eight AM broadcast stations. These measurements were made along various radial directions from the towers. The purpose of the survey was to acquire data that can be used to more accurately assess the potential for human exposure to high radiofrequency fields near these towers.

(2) Using the Numerical Electromagnetic Code (NEC), models have been developed for AM towers of varying electrical height and operating frequencies. The models predict electric and magnetic field strength values at locations relatively close to a tower's base. However, it is difficult to predict the effects of conductive objects such as metallic fencing on electric field strength.

(3) Measurements generally yielded results in good agreement with the NEC model for distances greater than several meters from a tower's base. The agreement was generally not as good closer in to the tower base.

(4) The NEC modeling technique developed for calculating near fields from AM towers involves representing a given tower as "three wires" and adjusting the tower height to match impedances. Further work on numerical modeling may be useful.

(5) Electrical height of an AM tower is important in determining whether the electric field or the magnetic field will predominate close-in to the base of the tower.

(6) Measurement data near AM towers showed that significant effects on electric field strength can result from conductive objects such as chain-link fencing. Metallic fences tend to reduce electric field strength on either side of the fence.

(7) Field strength values near single, non-directional AM towers may differ when measured at the same distance but in different directions from the tower.

(8) Results of this study tend to confirm that the values given in the FCC's Bulletin No. 65 are generally conservative with regard to recommended minimum distances for compliance with various field-strength limits.

## REFERENCES


1. "Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Radiation." Federal Communications Commission, OST Bulletin No. 65, October 1985. Copies may be purchased from the National Technical Information Service (NTIS), (800) 336-4700. Order number is: PB 86-127081. A limited number of copies are also available from the FCC at (202) 653-8169.

2. Cleveland, R.F., Jr., and E.D. Mantiply, "Estimating Human Exposure Near AM Broadcast Towers: Comparison of Theoretical and Measured Electromagnetic Fields." In Eleventh Annual Meeting Abstracts, Bioelectromagnetics Society, Tucson, AZ, June 18-22, 1989, p. 77.

3. Mantiply, Edwin D., "An Automated TEM Cell Calibration System." EPA 520/1-84-024, U.S. Environmental Protection Agency, Las Vegas, NV, October 1984.

4. Mantiply, E.D., and N.N. Hankin, "Radiofrequency Radiation Survey in the McFarland California Area." EPA 520/6-89/022, U.S. Environmental Protection Agency, Las Vegas, NV, September 1989.

5. Burke, G.J. and A.J. Poggio, "The Numerical Electromagnetic Engineering Design System (NEEDS)." Version 1.0, February 1988. Distributed by The Applied Computational EM Society.

6. Tell, R.A., "Electric and Magnetic Fields and Contact Currents Near AM Standard Broadcast Radio Stations," August 1989. Prepared for the Federal Communications Commission by Richard Tell Associates, Inc., Las Vegas, NV. Copies may be purchased from the National Technical Information Service (NTIS), (800) 336-4700. Order number is: PB 89-234850.

7. "American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz." ANSI C95.1 - 1982. Copyright 1982 by the Institute of Electrical and Electronics Engineers, Inc. Copies may be obtained from the American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018. These guidelines are also discussed in Reference 1.

8. "Radiofrequency Electromagnetic Fields and Induced Currents in the Spokane, Washington Area," April 1988, U.S. Environmental Protection Agency, Report No. EPA/520/6-88/008. Copies may be purchased from the National Technical Information Service (NTIS), (800) 336-4700. Order number is: PB 88-244819/AS.

9. Tell, R.A., "An Investigation of RF Induced Hot Spots and their Significance Relative to Determining Compliance with the ANSI Radiofrequency Protection Guide," July 1989. Prepared for the National Association of Broadcasters (NAB), Washington, DC 20036. Copies available from NAB: (202) 429-5346.

# APPENDIX A
# STATION A GRAPHS

Figure A-1: Station A Electric Fields (0-10m)

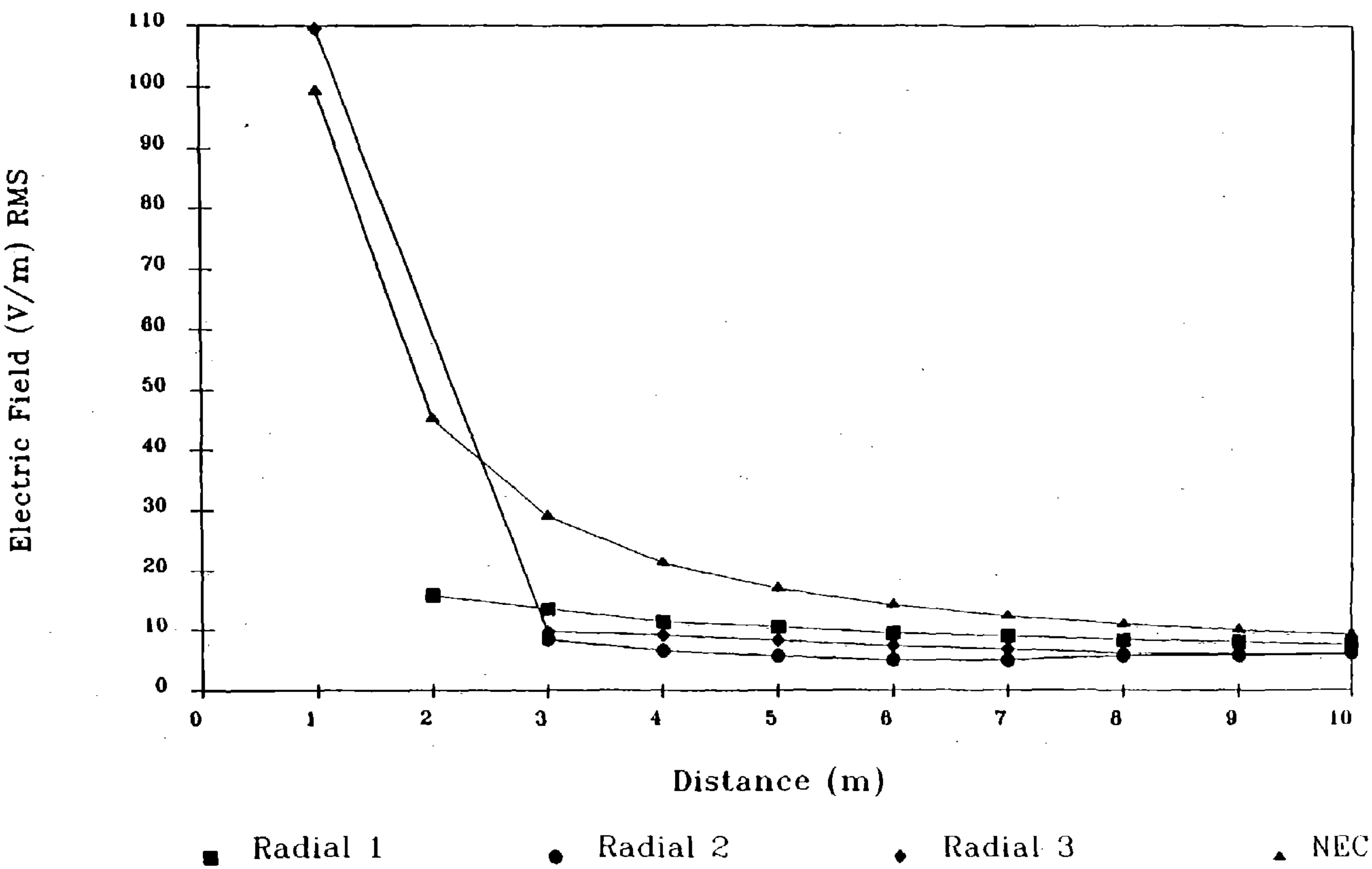


Figure A-2: Station A Electric Fields (10–100m)

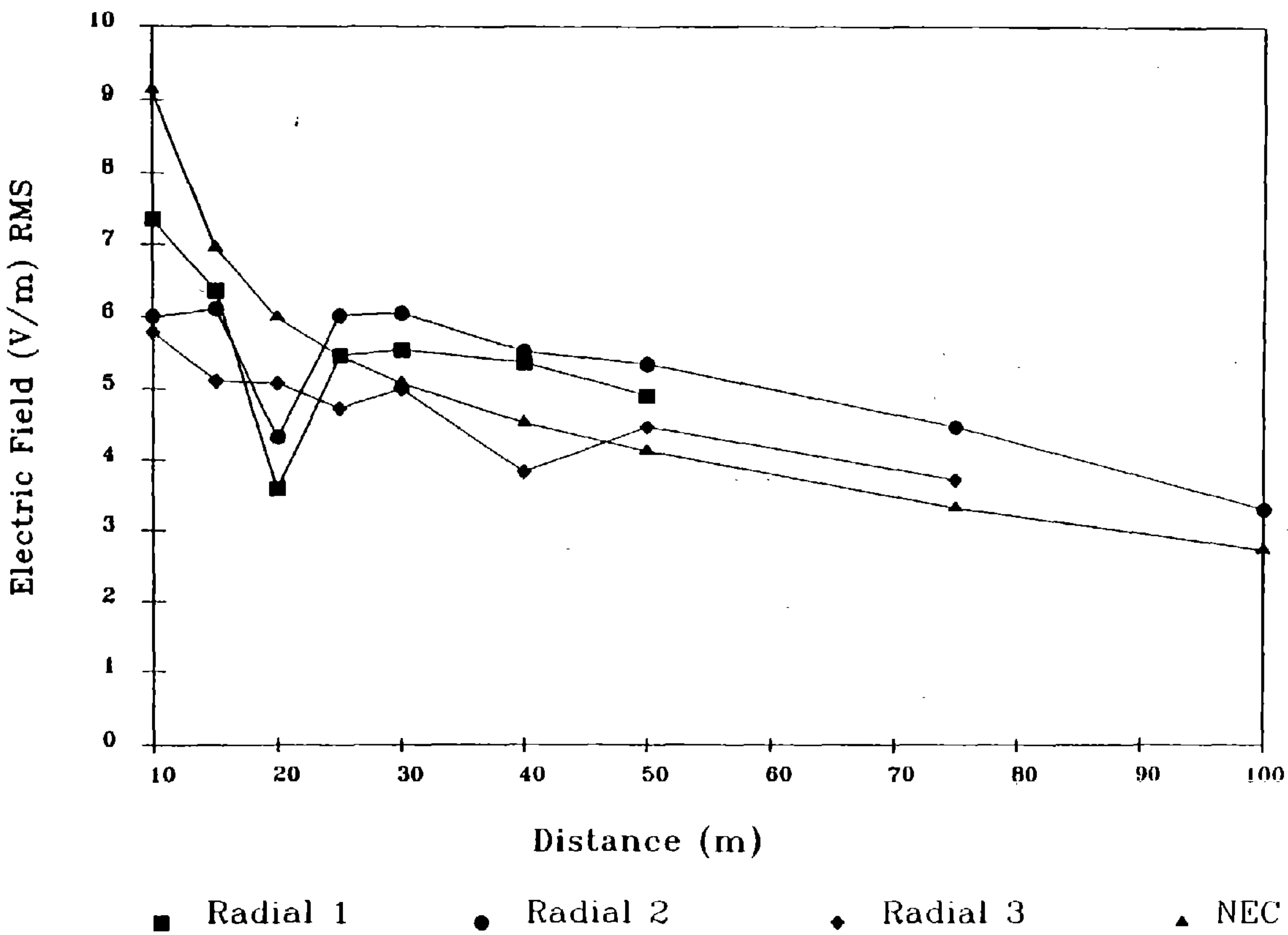


Figure A-3: Station A Magnetic Fields (0-10m)

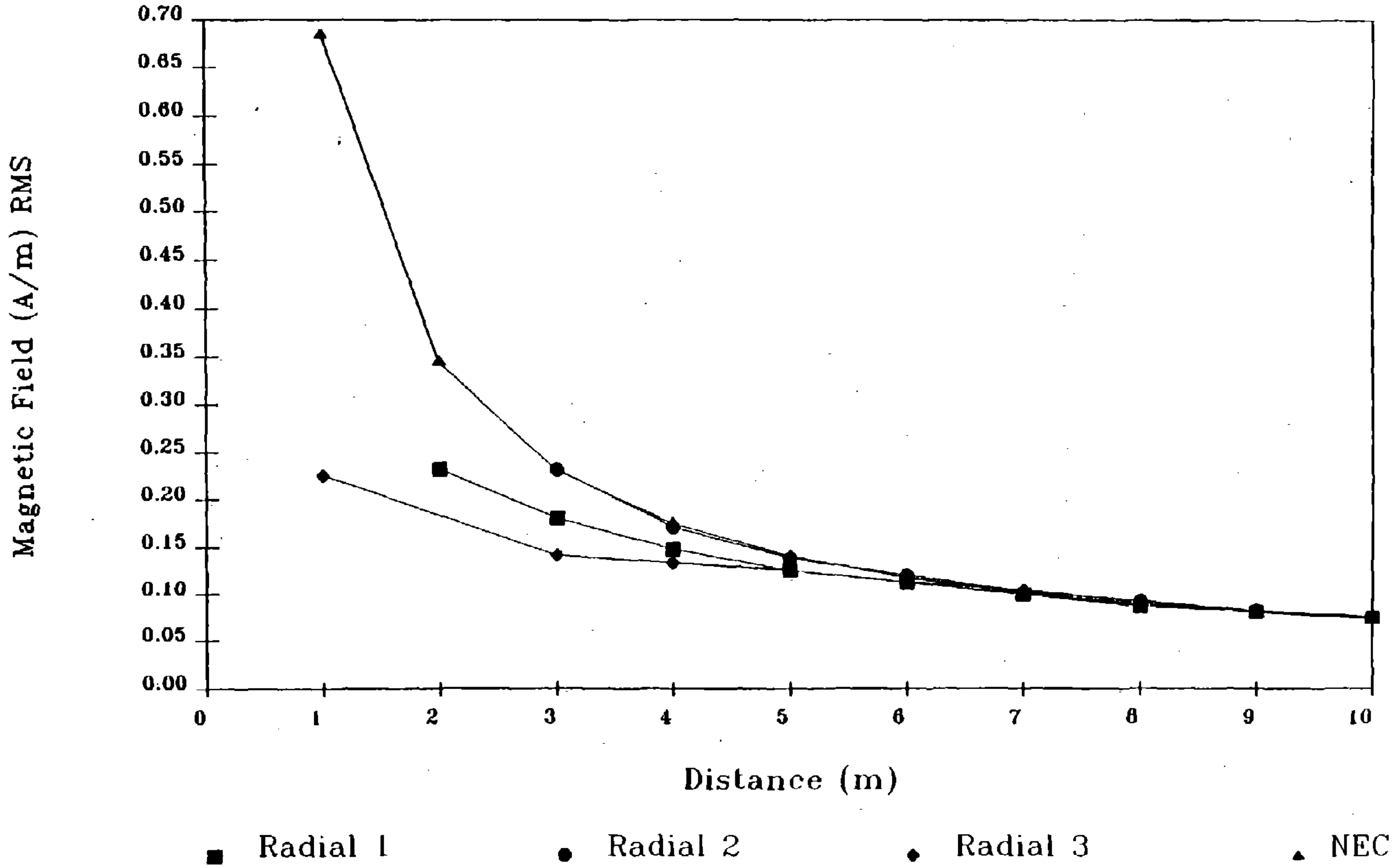
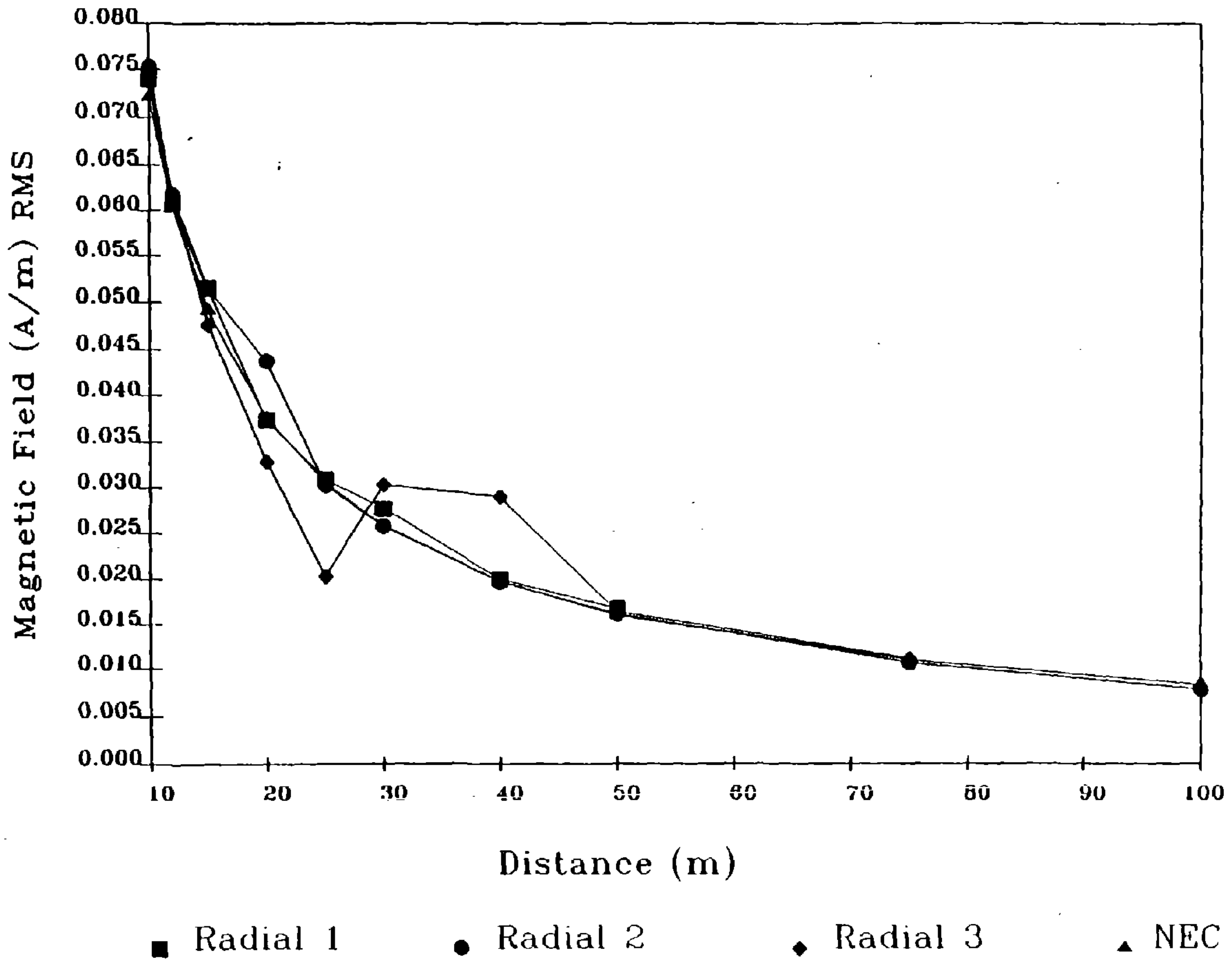


Figure A-4: Station A Magnetic Fields (10-100m)



# APPENDIX B
# STATION B GRAPHS

Figure B-1: Station B Electric Fields (0-10m)

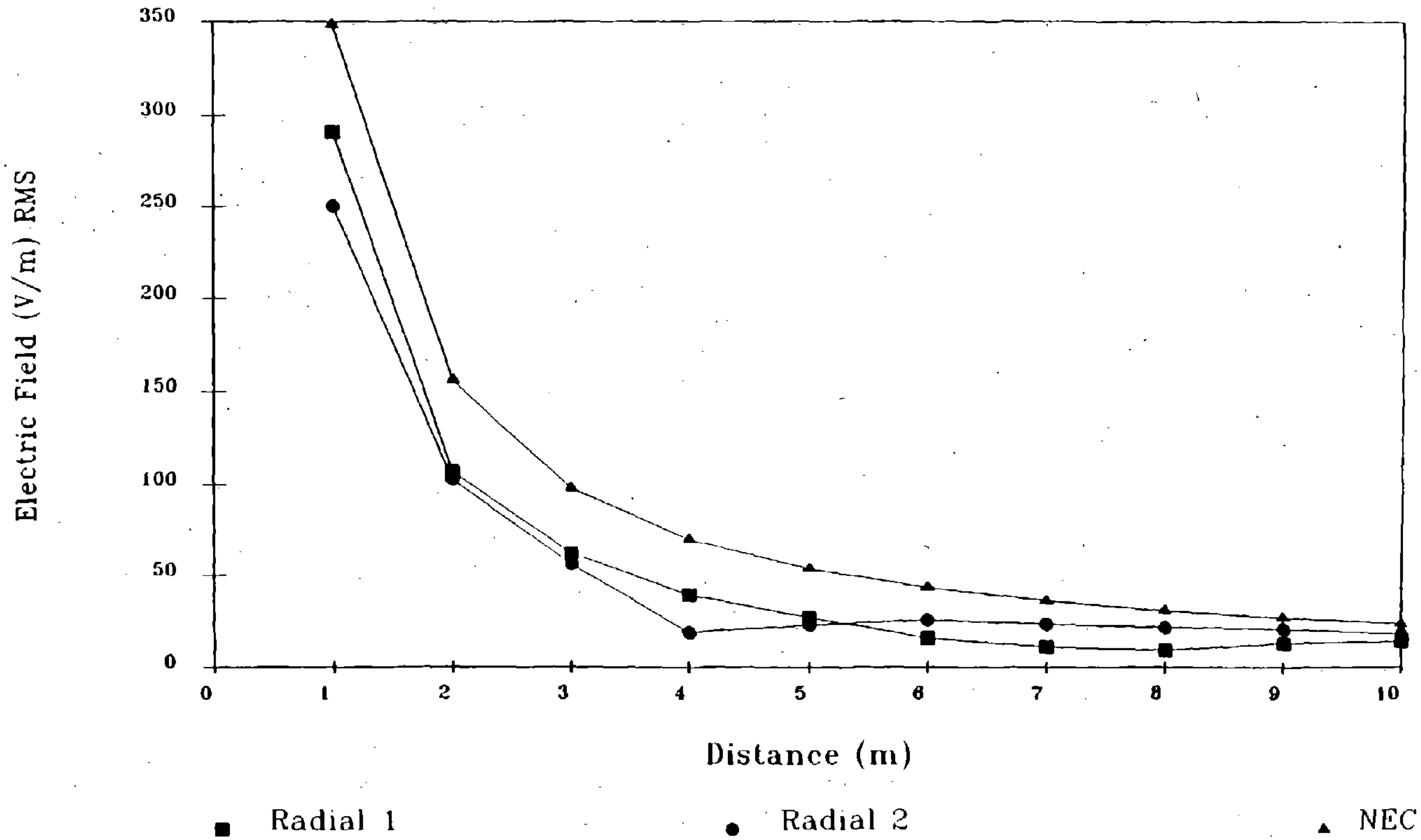


Figure B-2: Station B Electric Fields (10-100m)

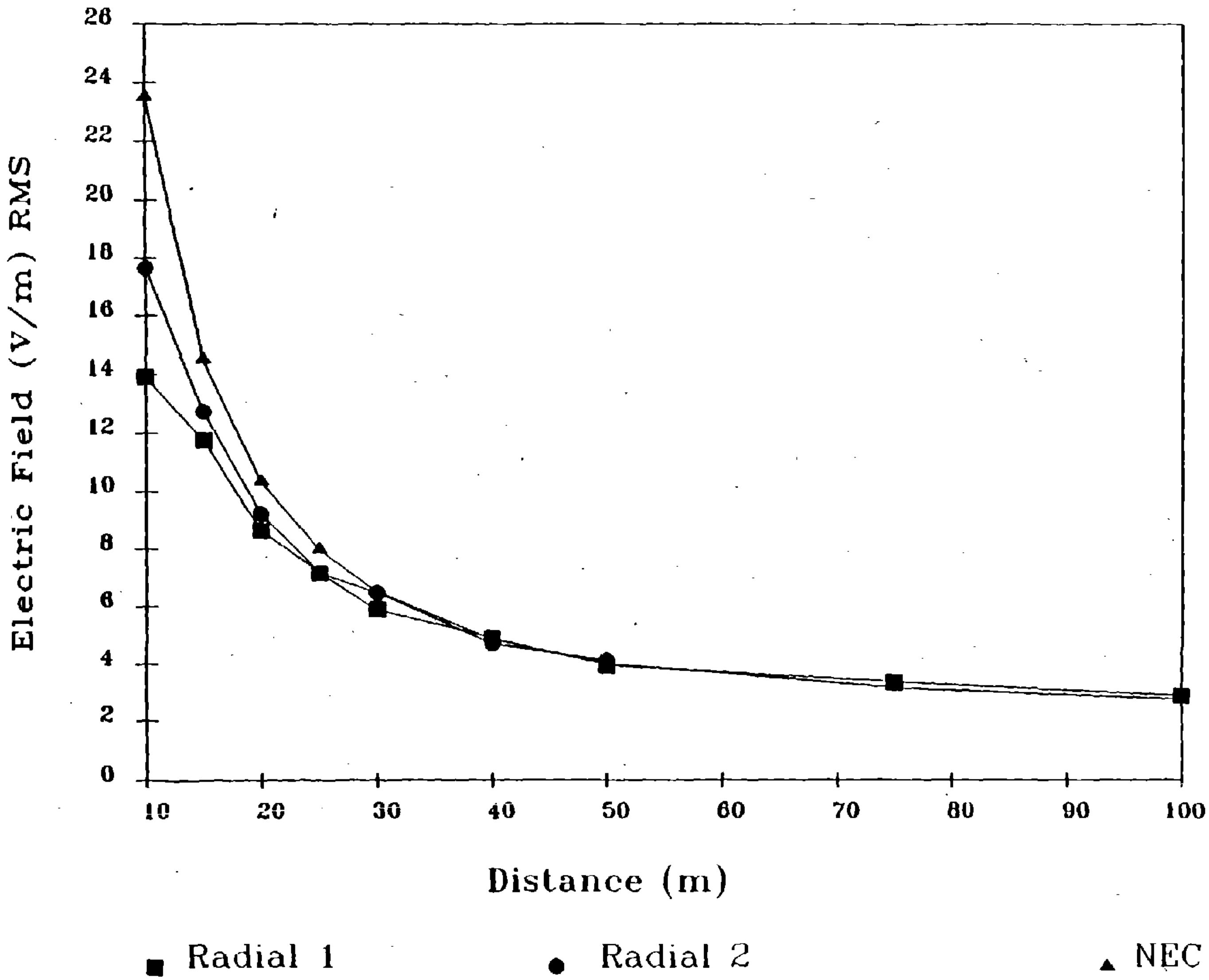


Figure B-3: Station B Magnetic Fields (0-10m)

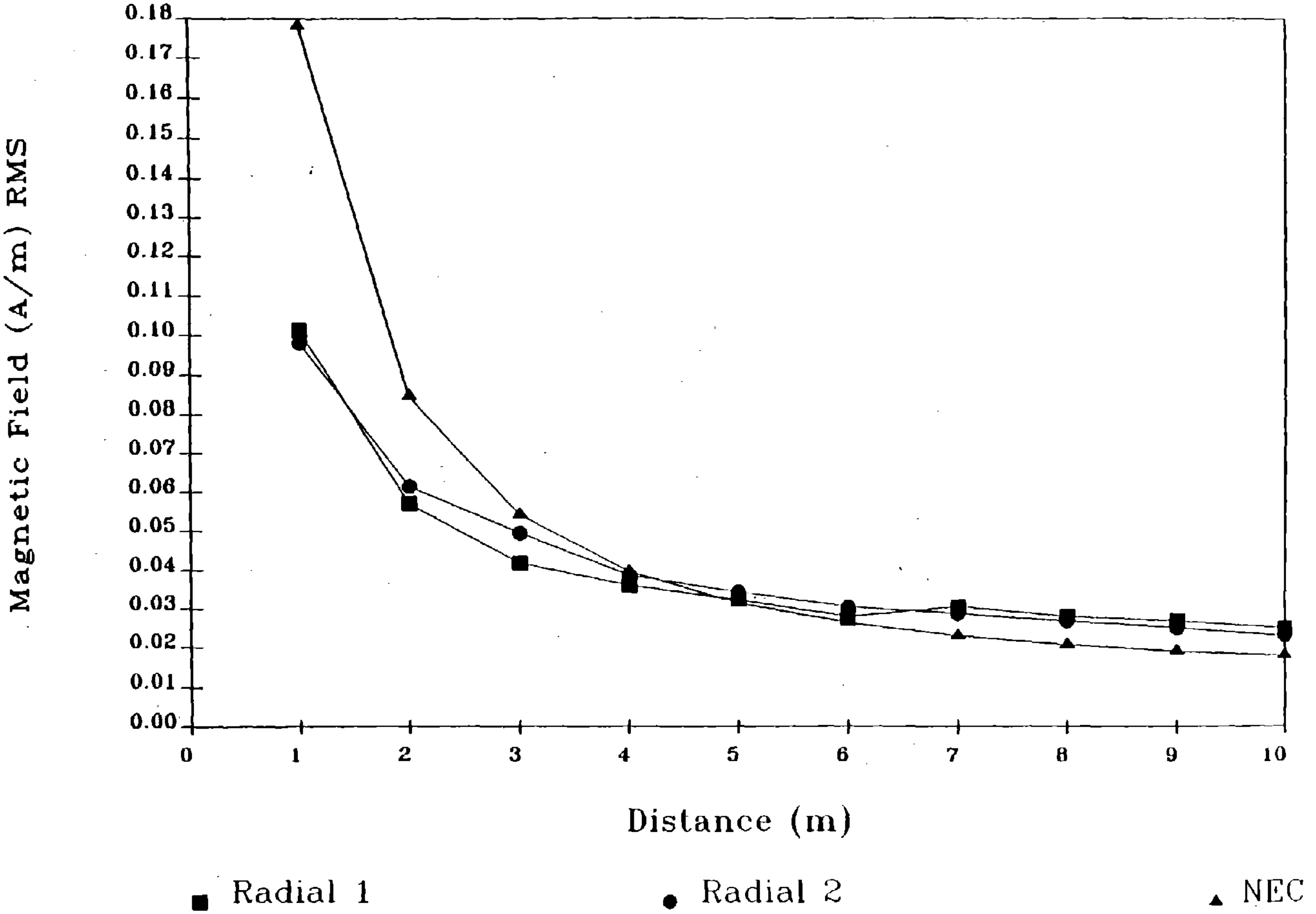
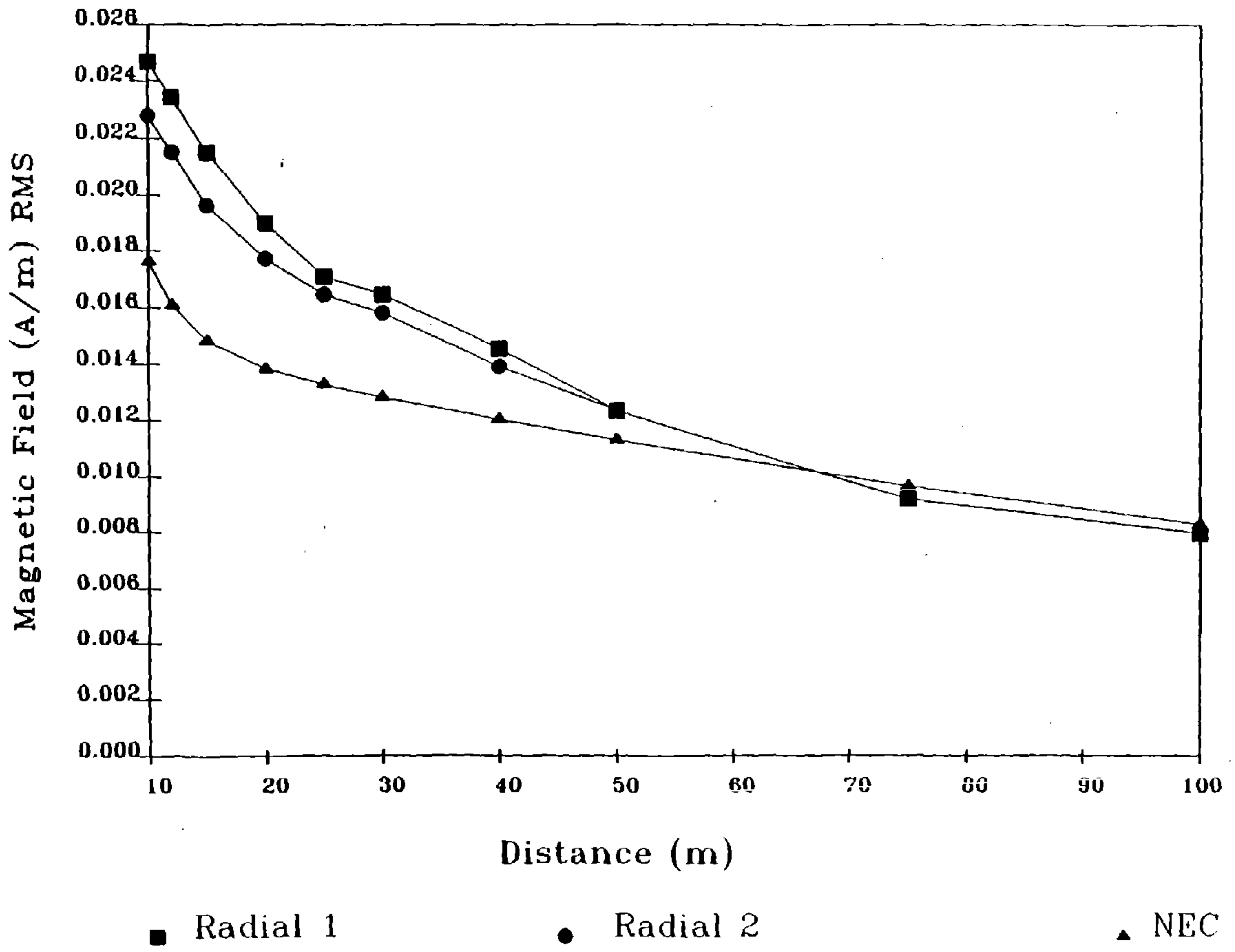


Figure B-4: Station B Magnetic Fields (10-100m)



APPENDIX C
STATION C GRAPHS

Figure C-1: Station C Electric Fields (0-10m)

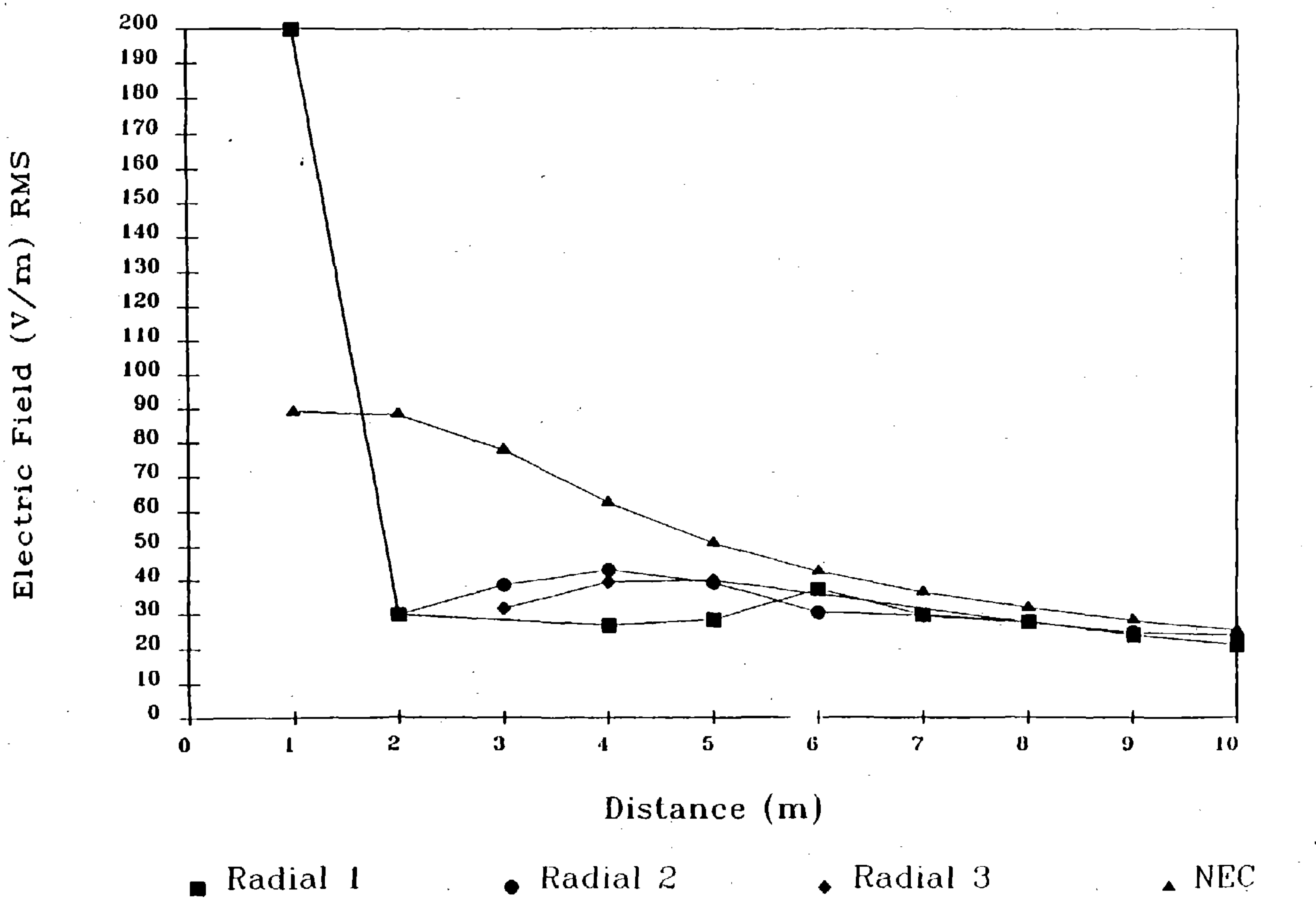





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Figure C-2: Station C Electric Fields (10–100m)

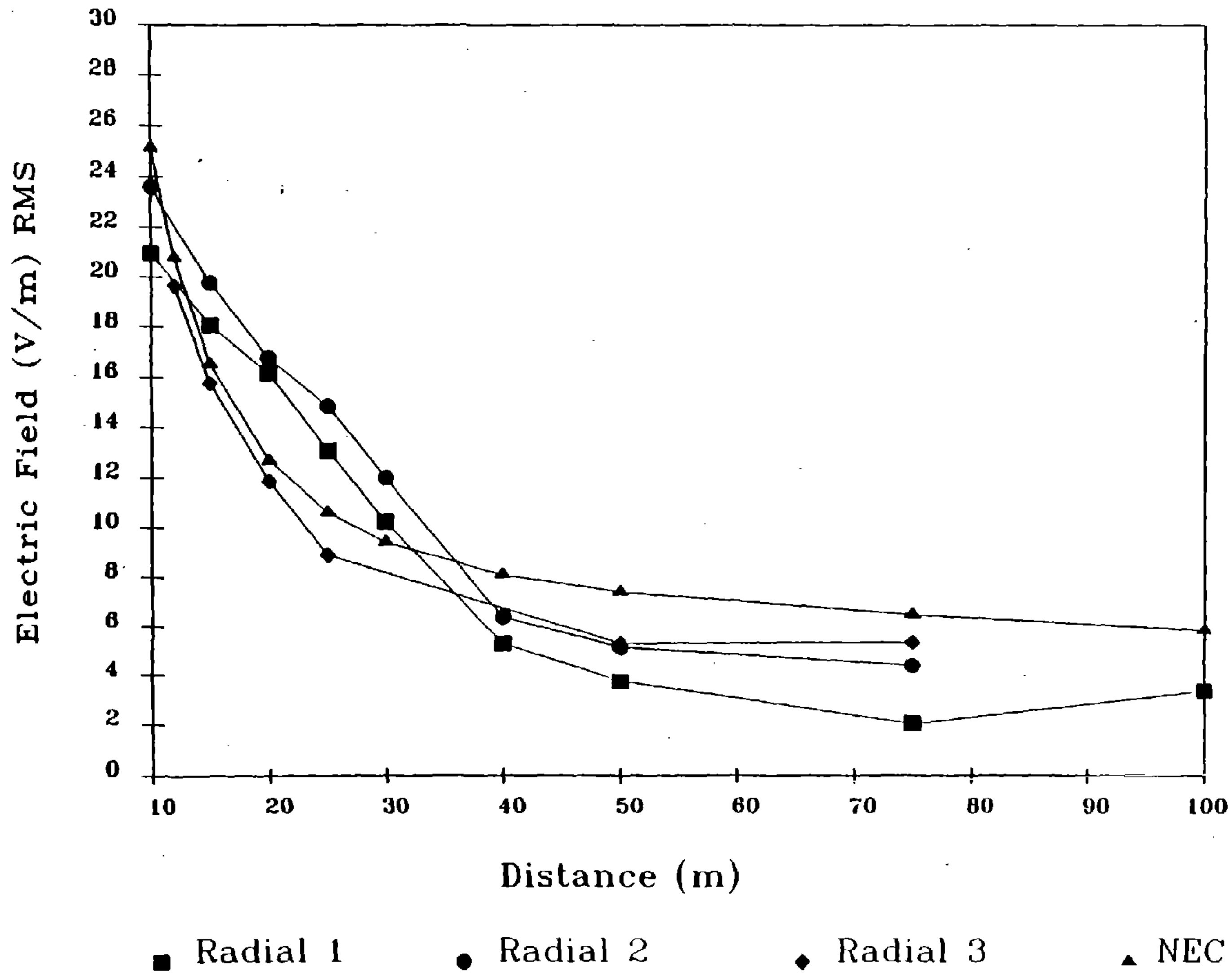


Figure C-3: Station C Magnetic Fields (0-10m)

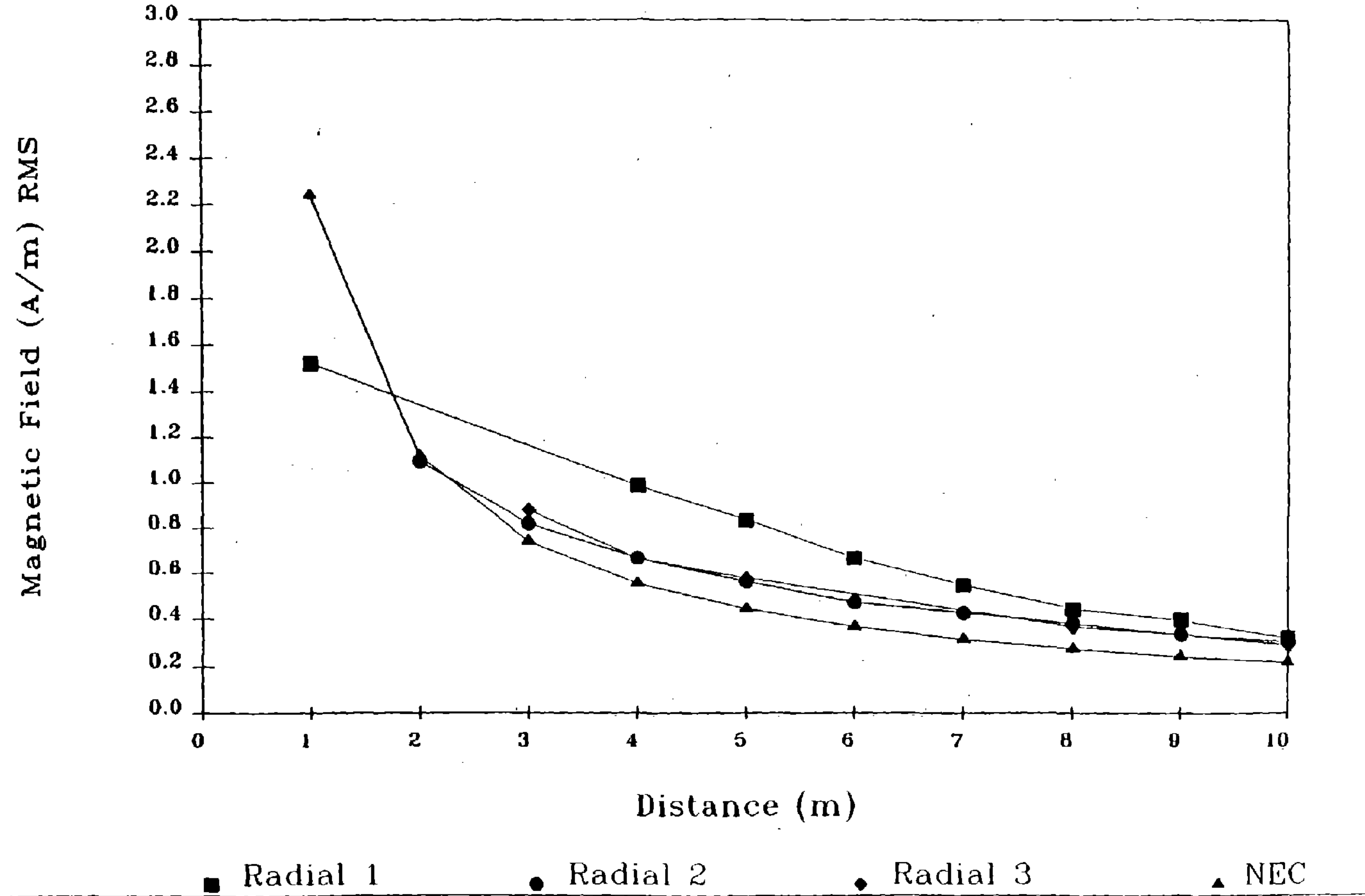
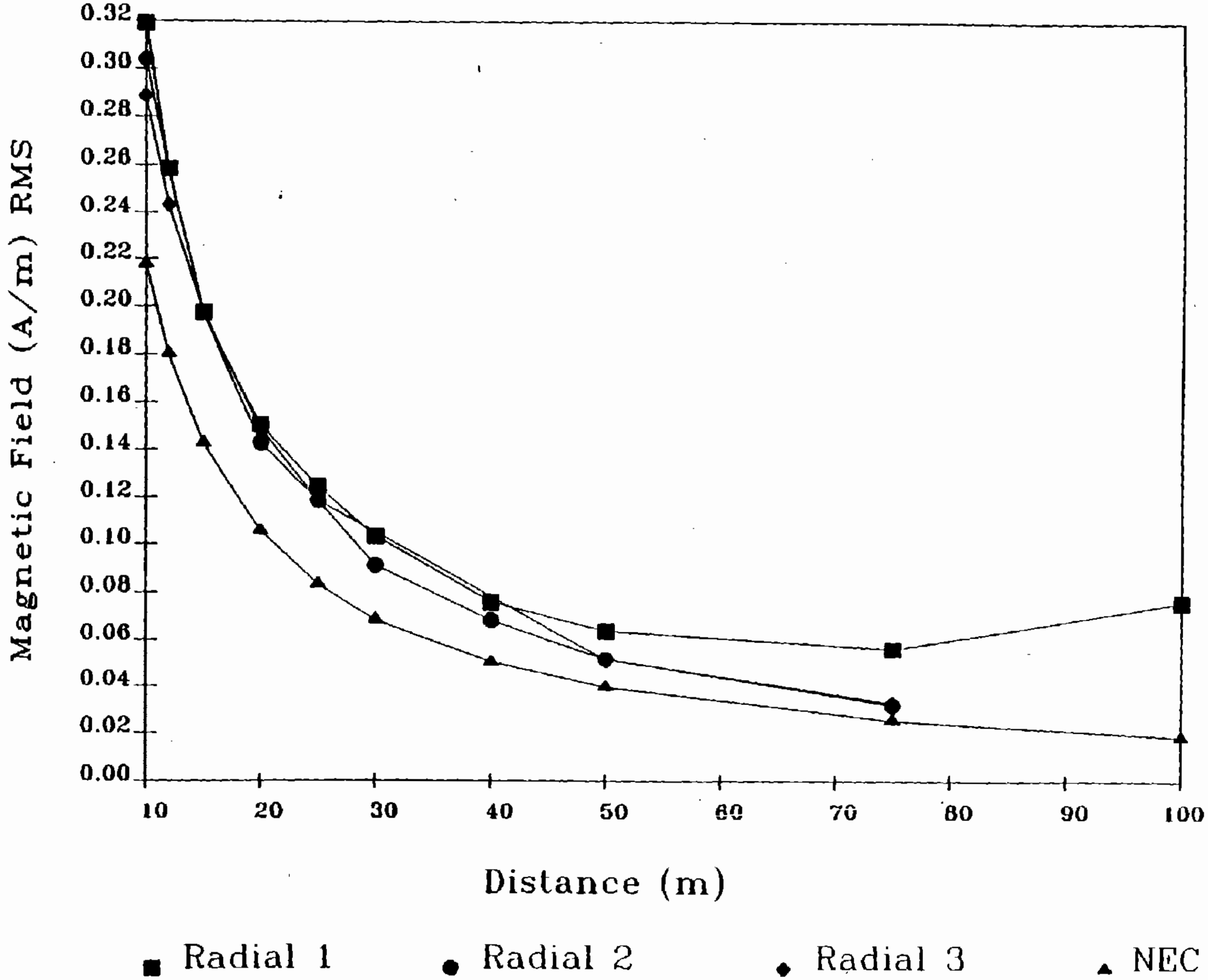


Figure C-4: Station C Magnetic Fields (10-100m)



# APPENDIX D
# STATION D GRAPHS

Figure D-1: Station D Electric Fields (0-10m)

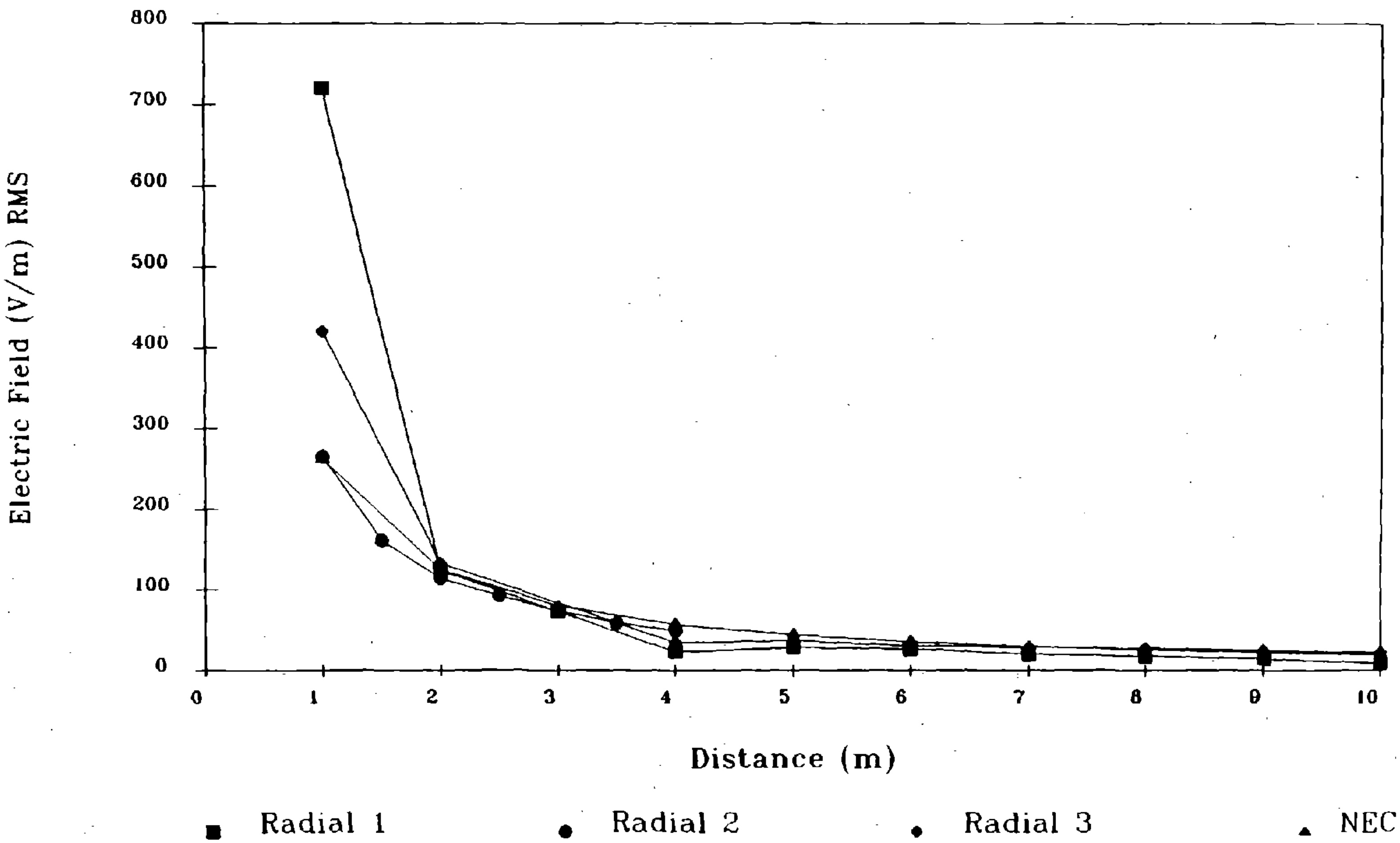


Figure D-2: Station D Electric Fields (10–100m)

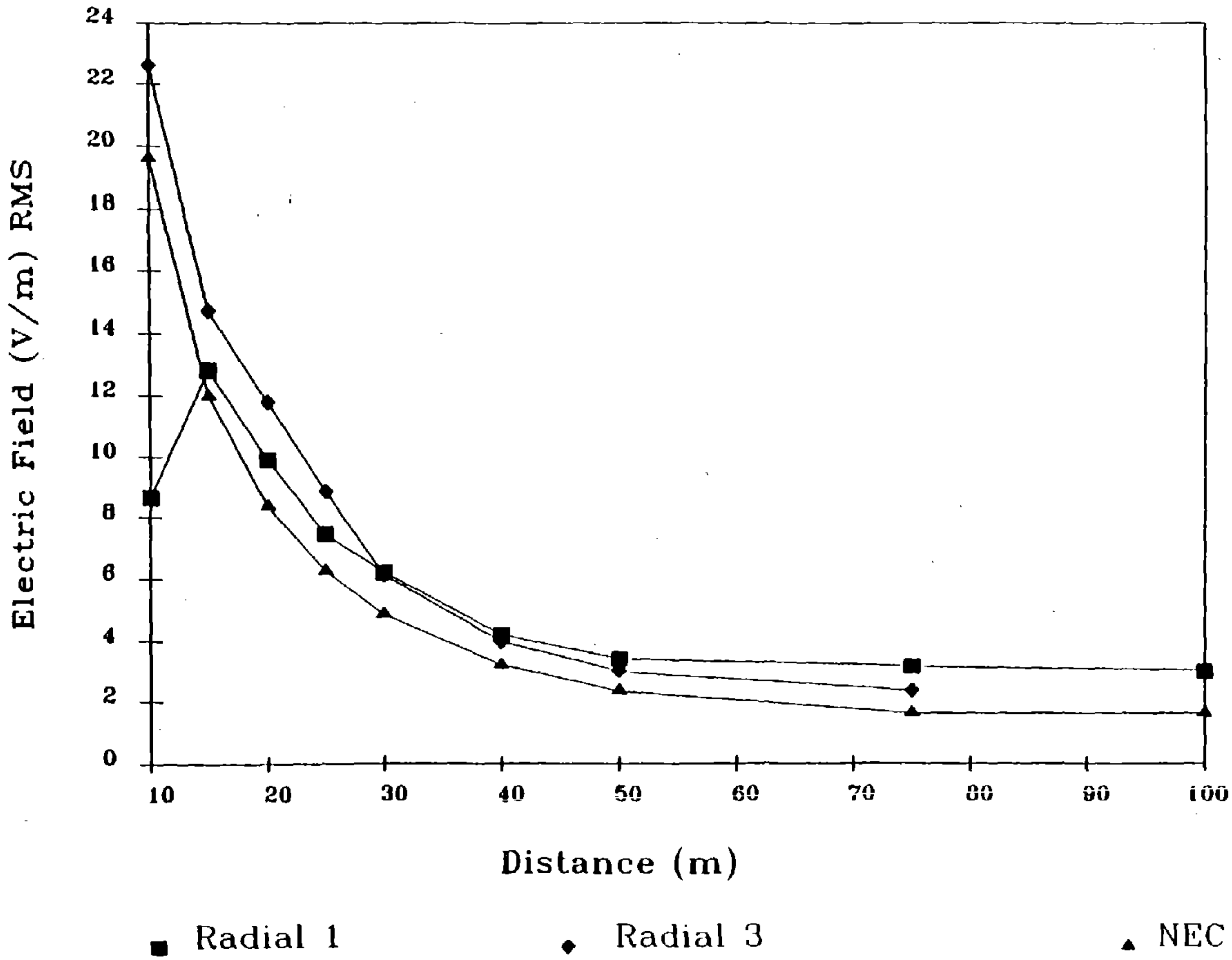


Figure D-3: Station D Magnetic Fields (0-10m)

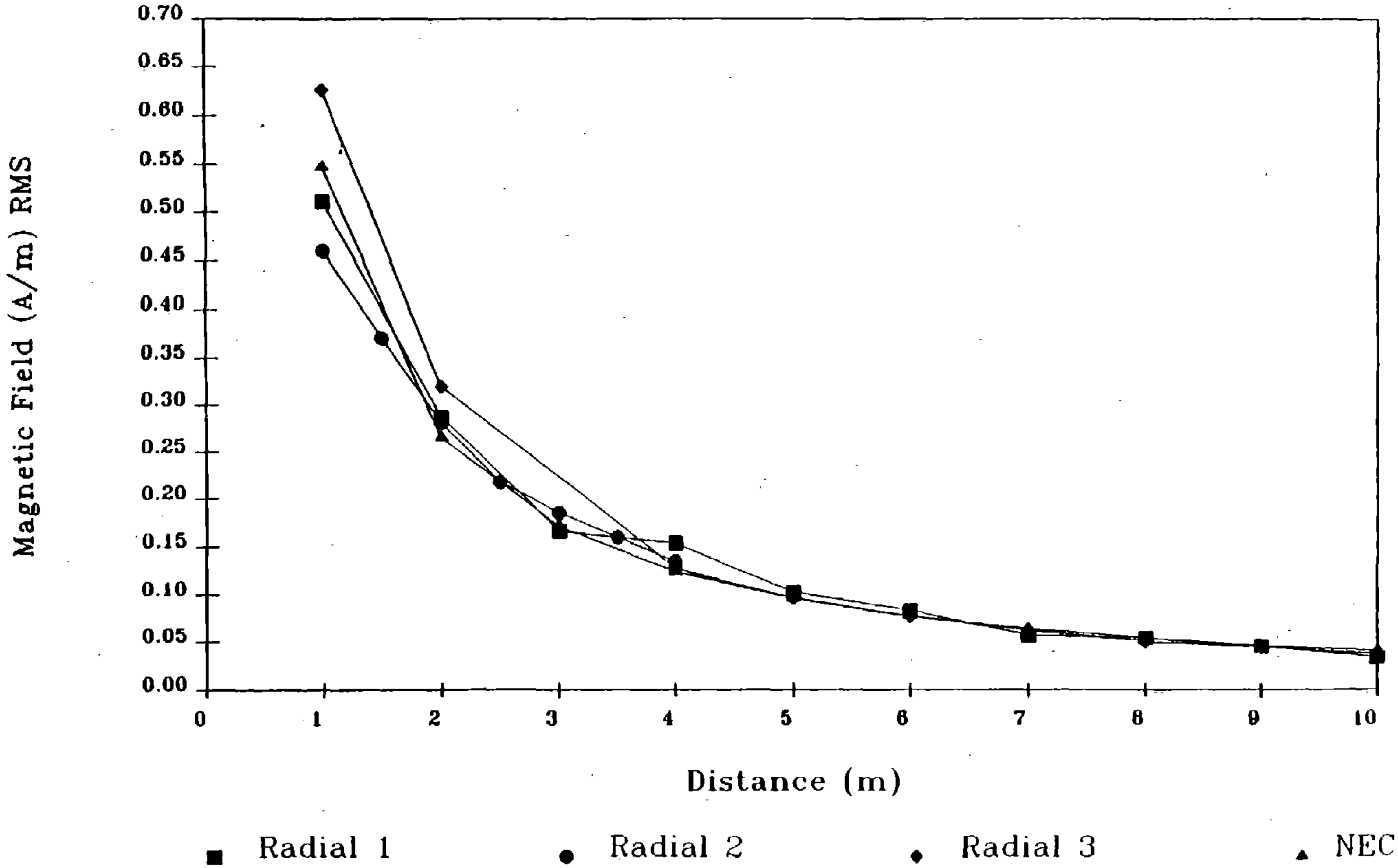
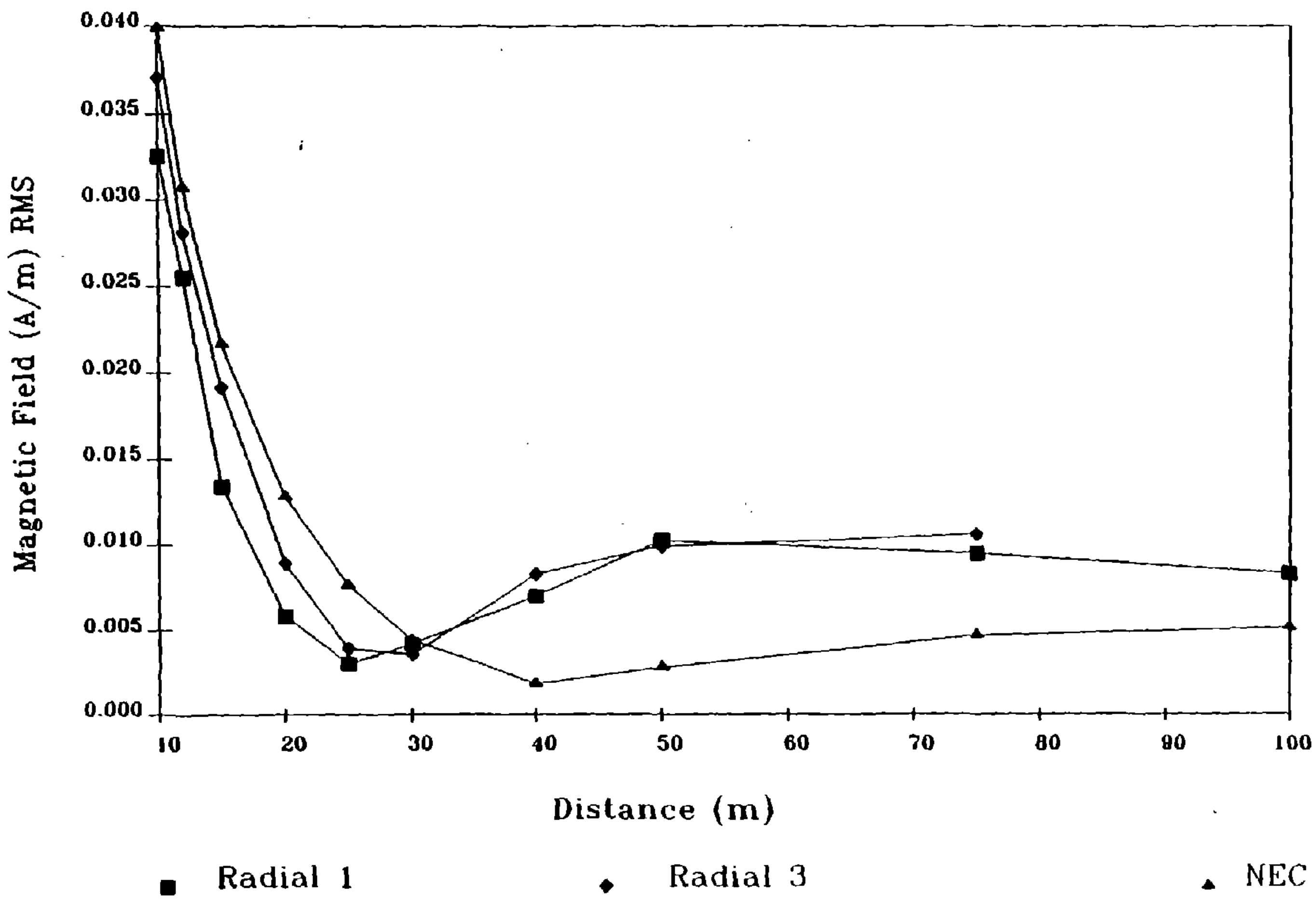


Figure D-4: Station D Magnetic Fields (10-100m)



# APPENDIX E
# STATION E GRAPHS

Figure E-1: Station E Electric Fields (0-10m)

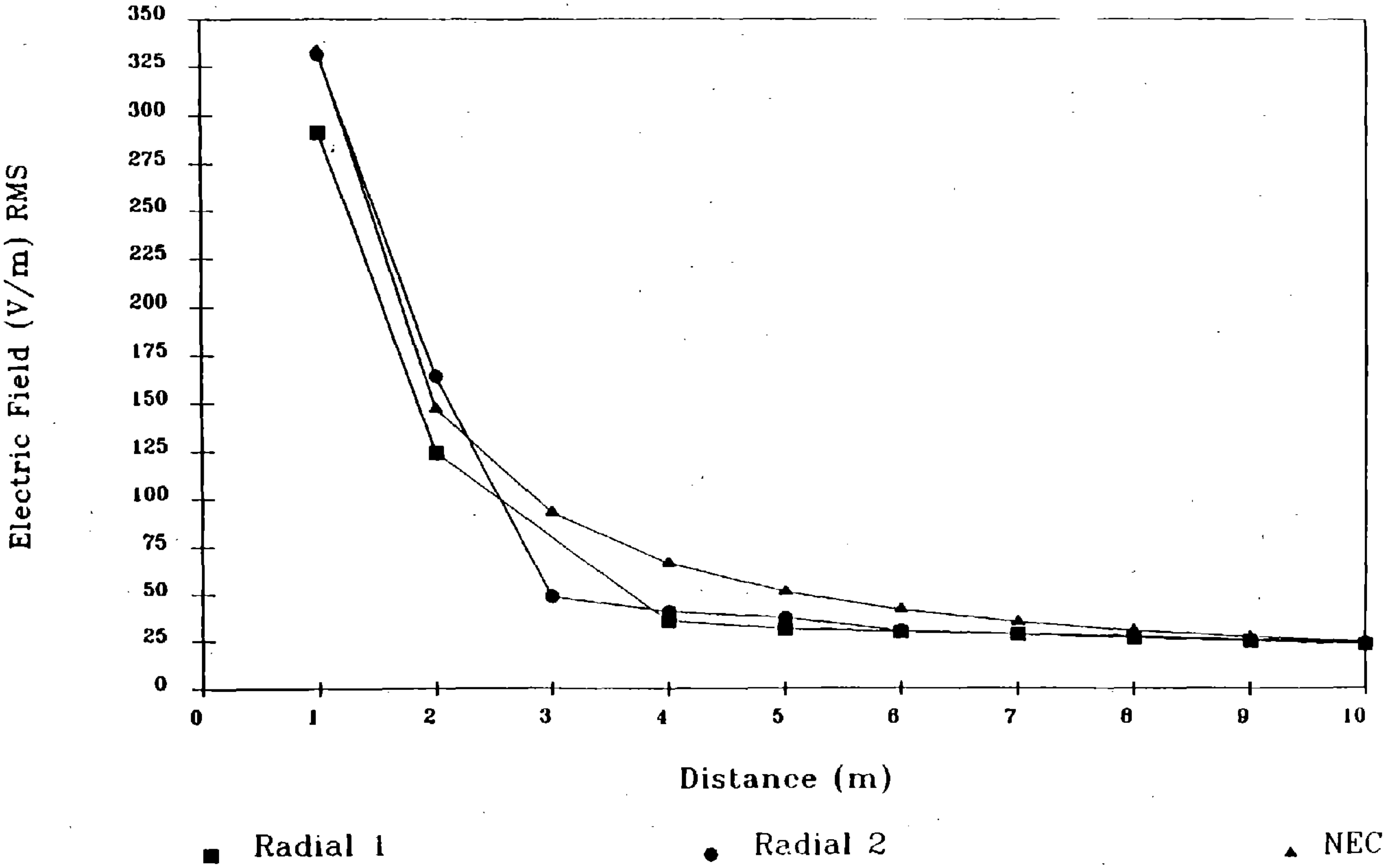


Figure E-2: Station E Electric Fields (10-100m)

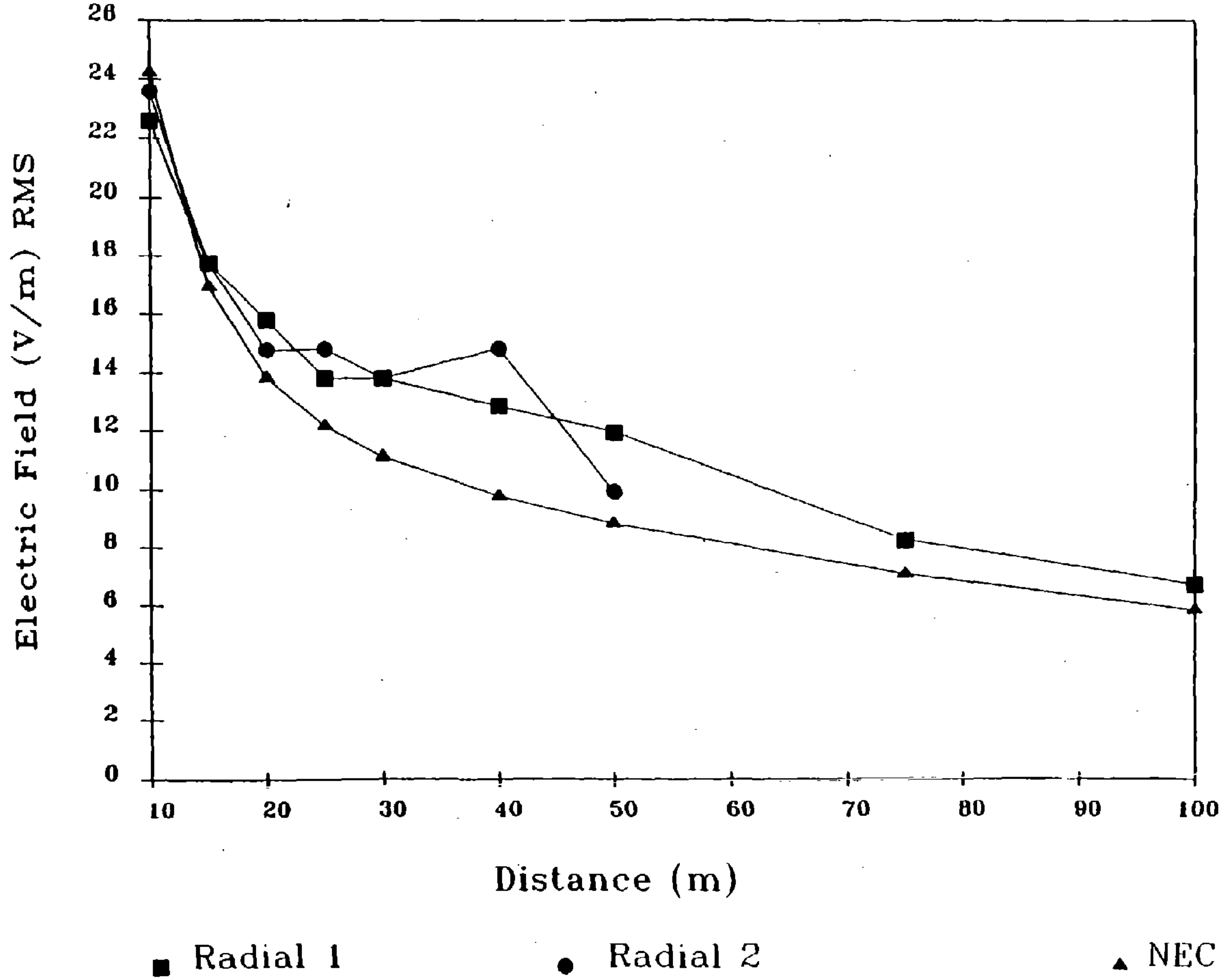


Figure E-3: Station E Magnetic Fields (0-10m)

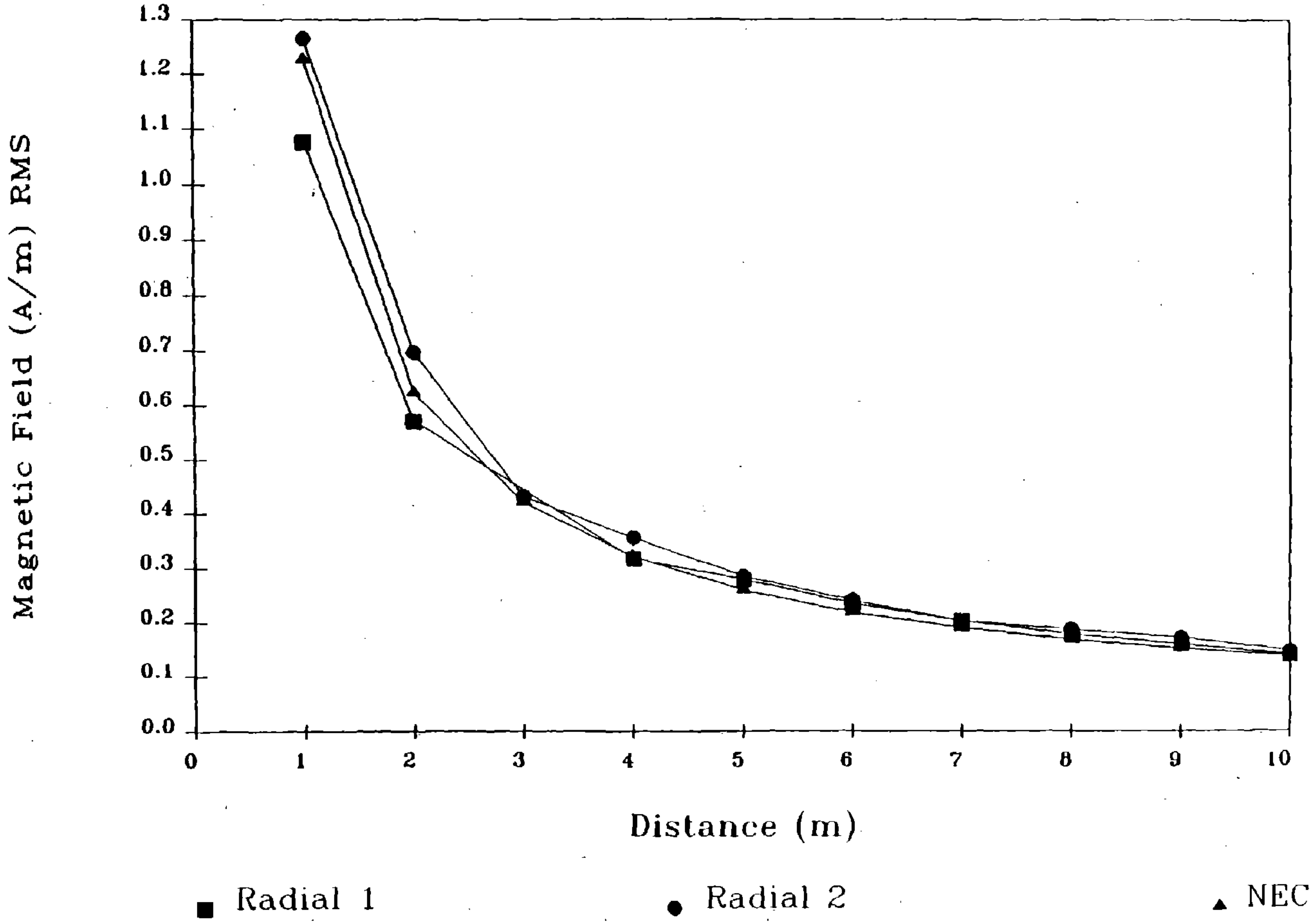
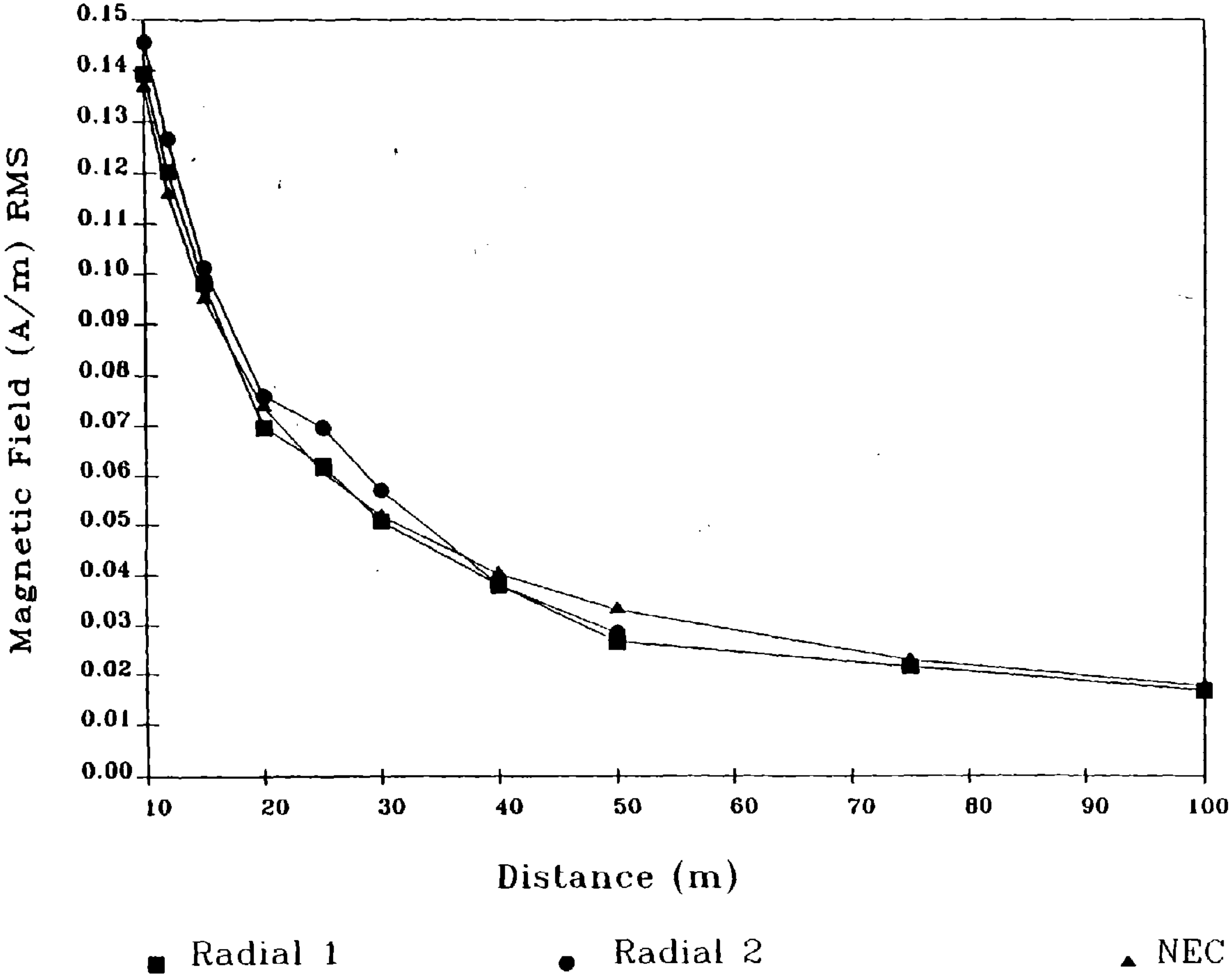


Figure E-4: Station E Magnetic Fields (10-100m)



# APPENDIX F
# STATION F GRAPHS

Figure F-1: Station F Electric Fields (0-10m)

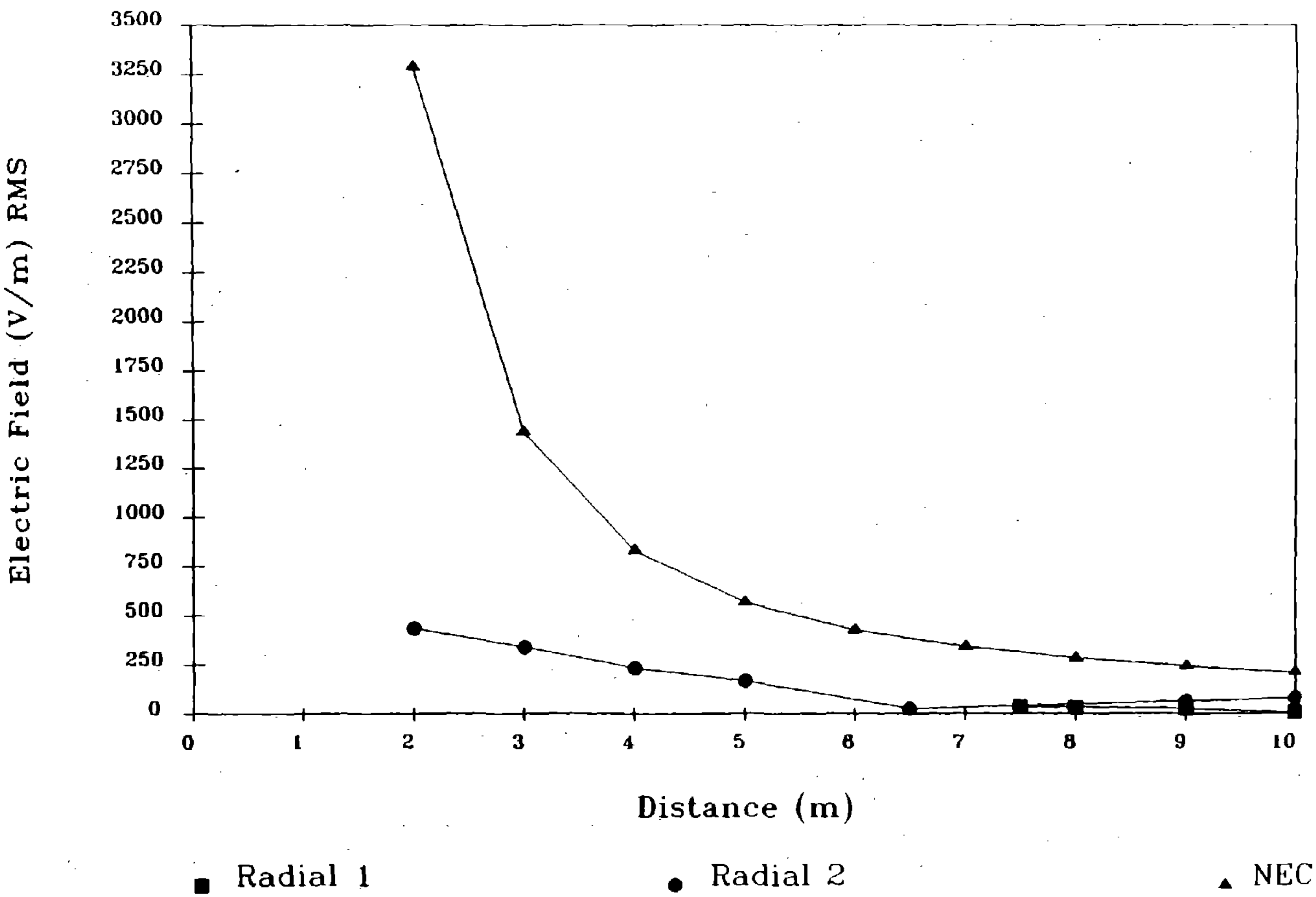





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Figure F-2: Station F Electric Fields (10-100m)

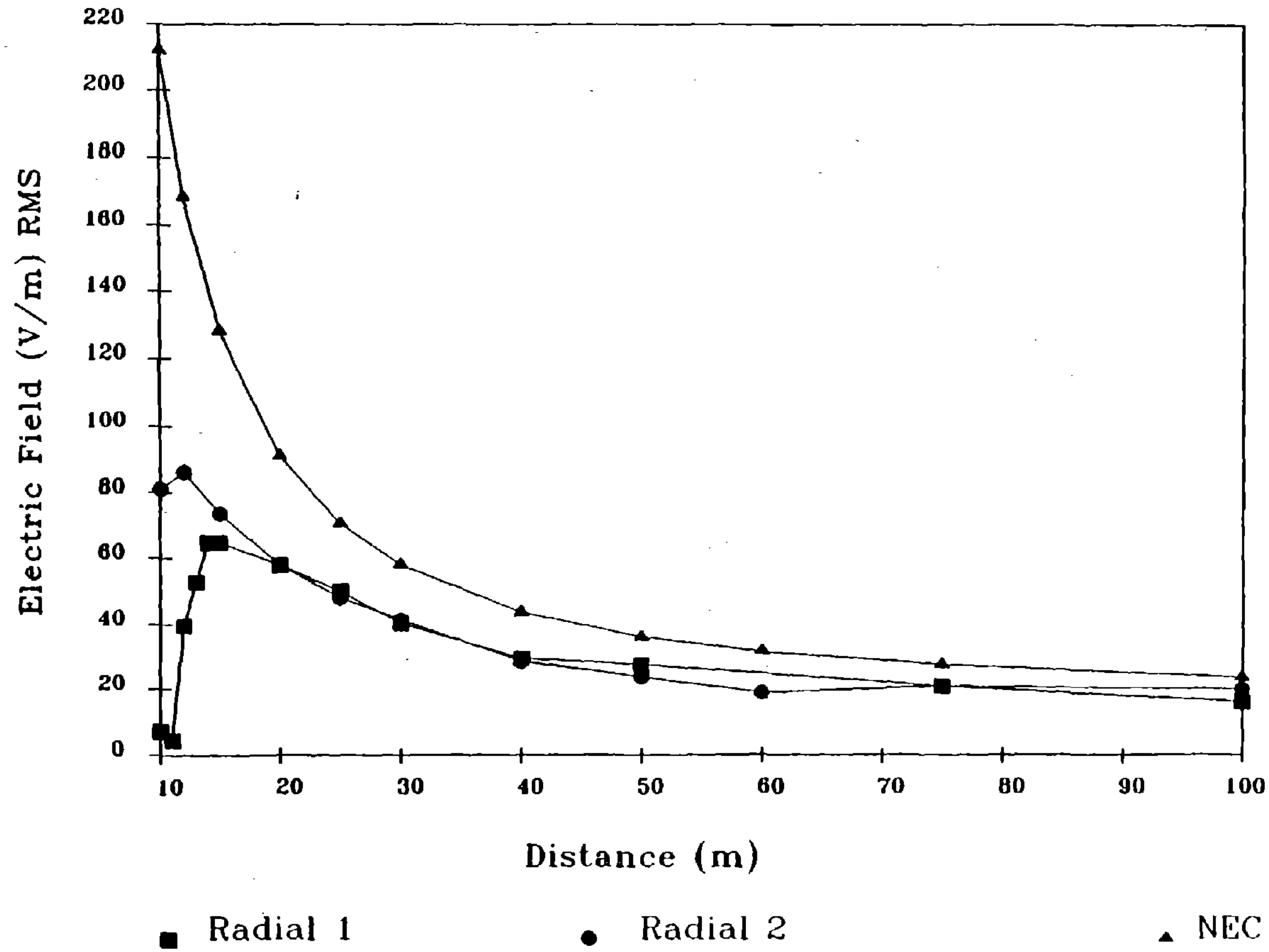


Figure F-3: Station F Magnetic Fields (0-10m)

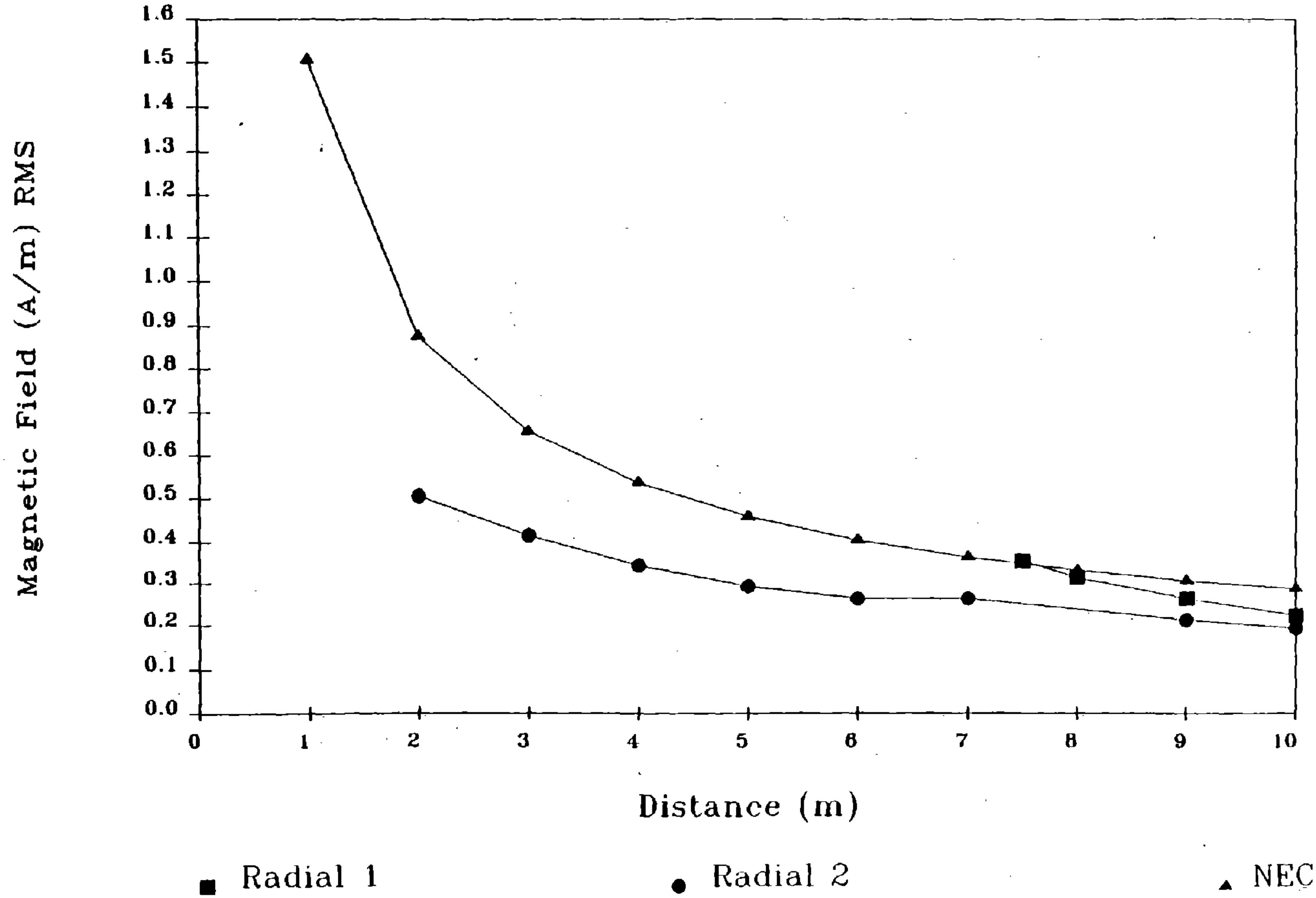
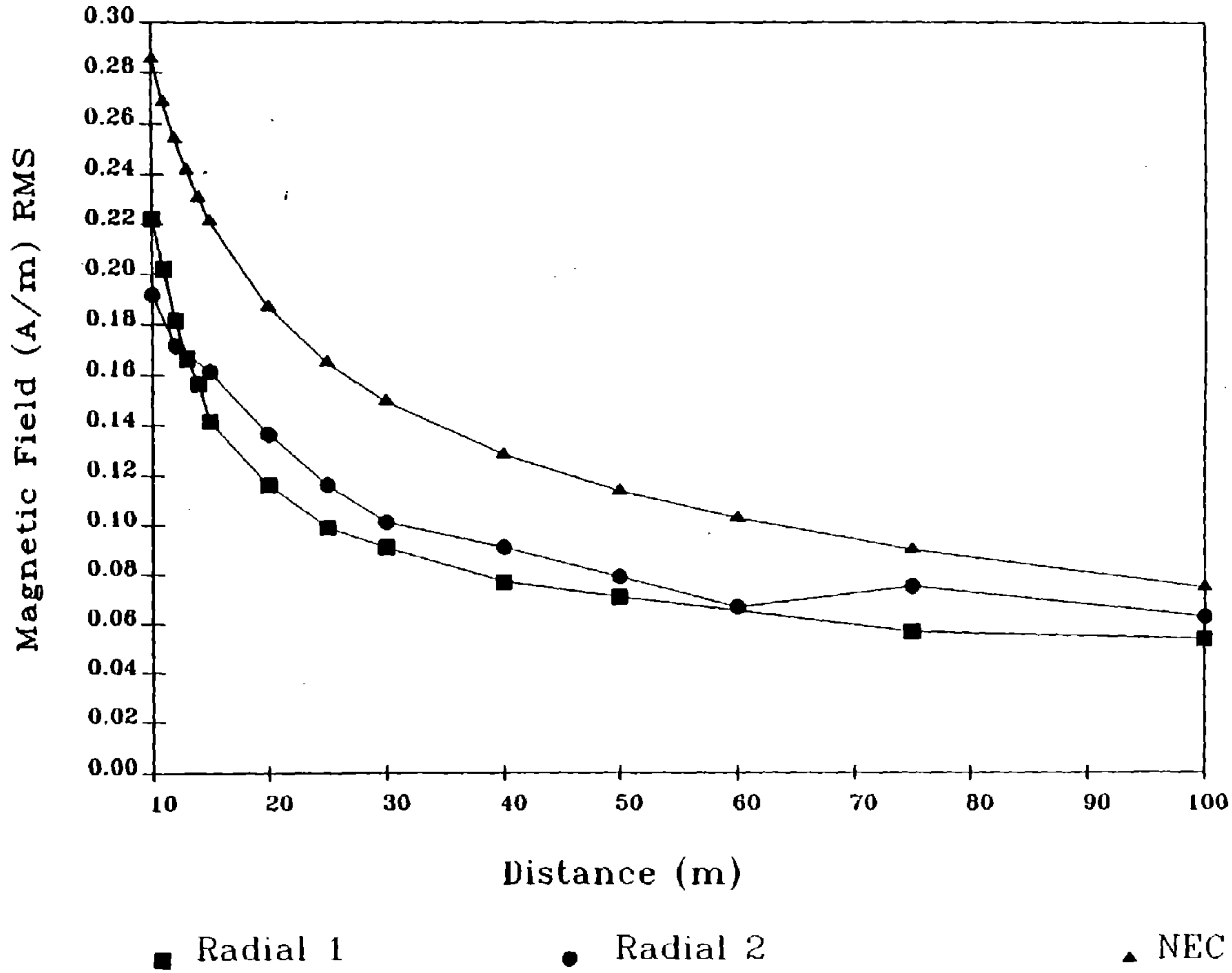
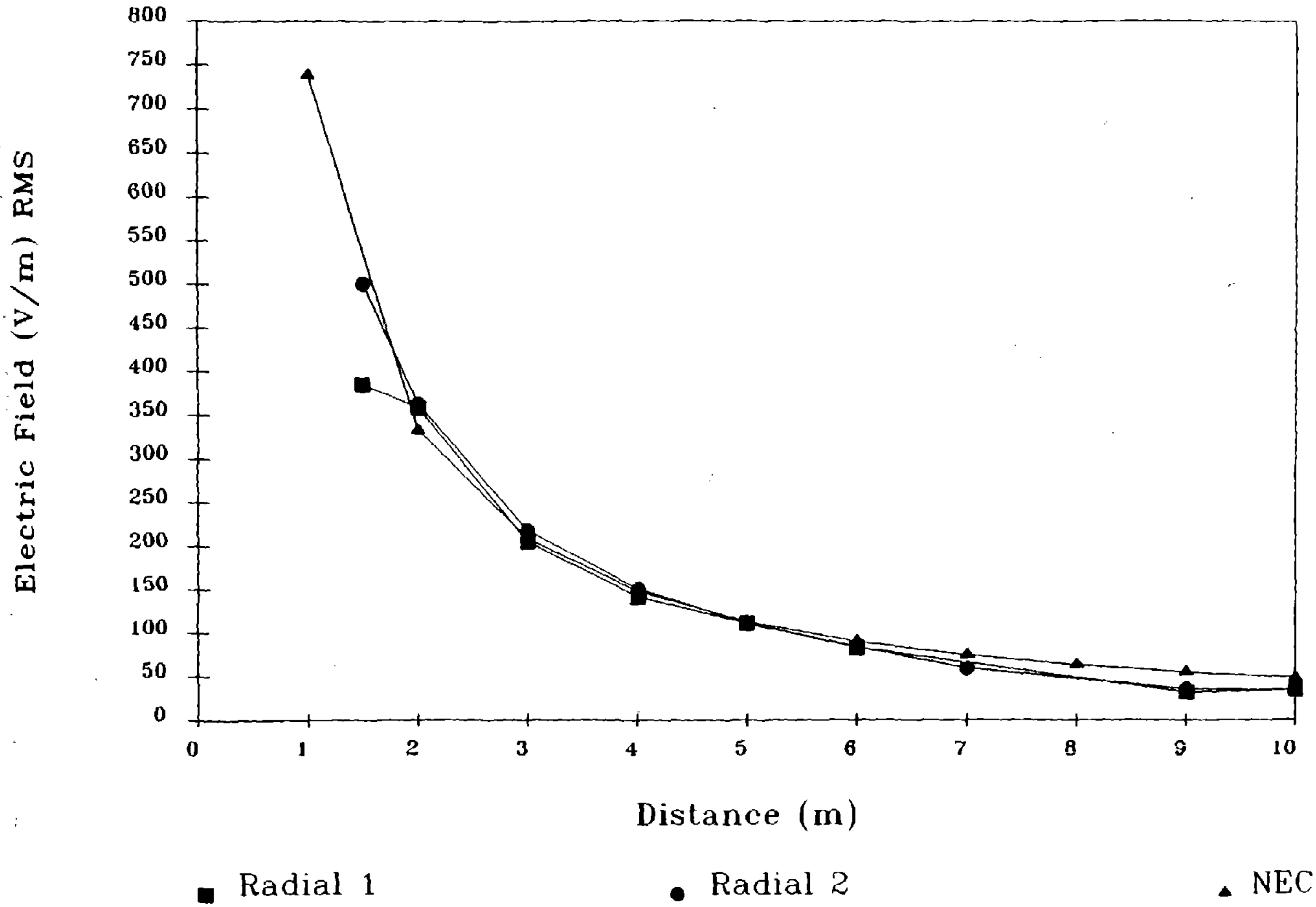


Figure F-4: Station F Magnetic Fields (10-100m)



# APPENDIX G
# STATION G GRAPHS

# Figure G-1: Station G Electric Fields (0-10m)




G-1

Figure G-2: Station G Electric Fields (10-75m)

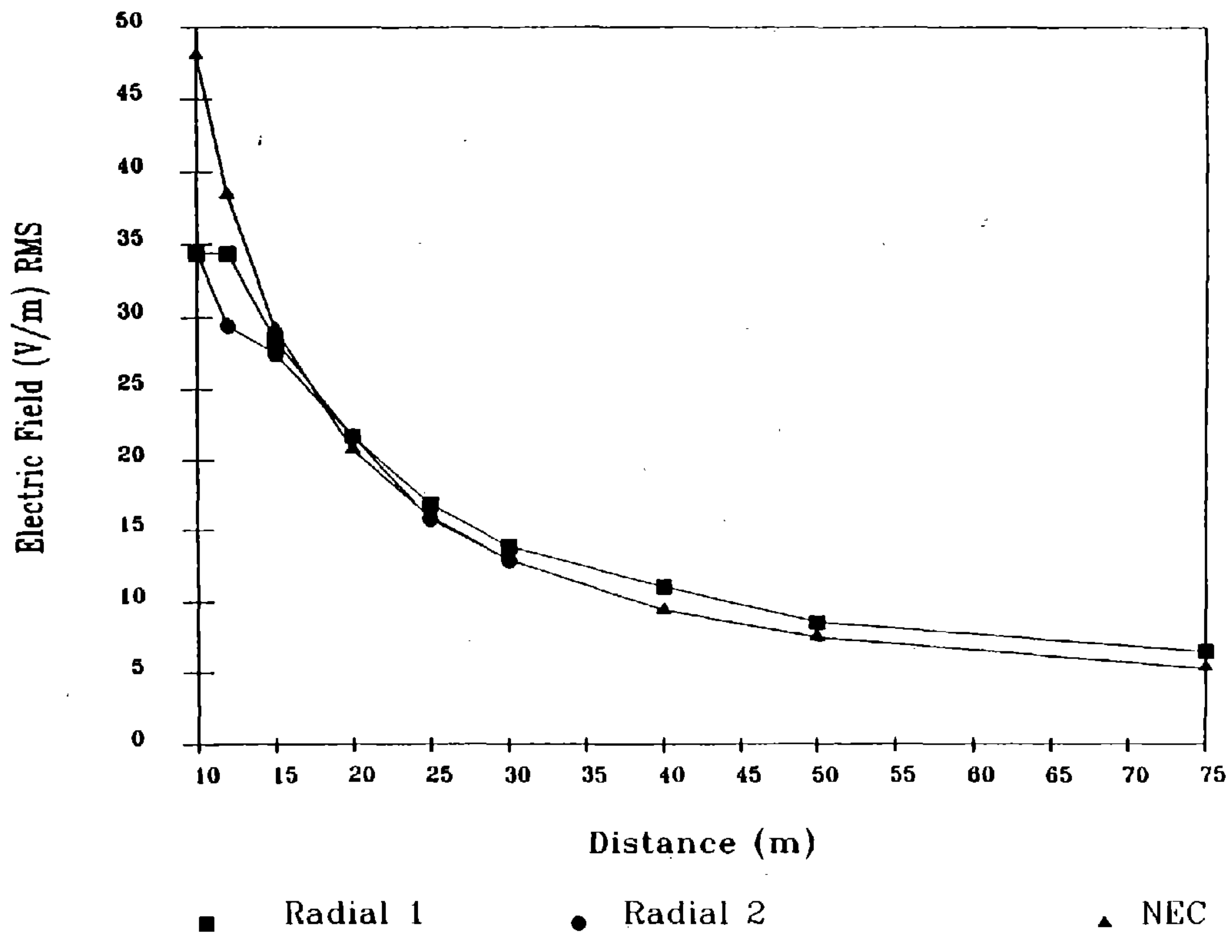


Figure G-3: Station G Magnetic Fields (0-10m)

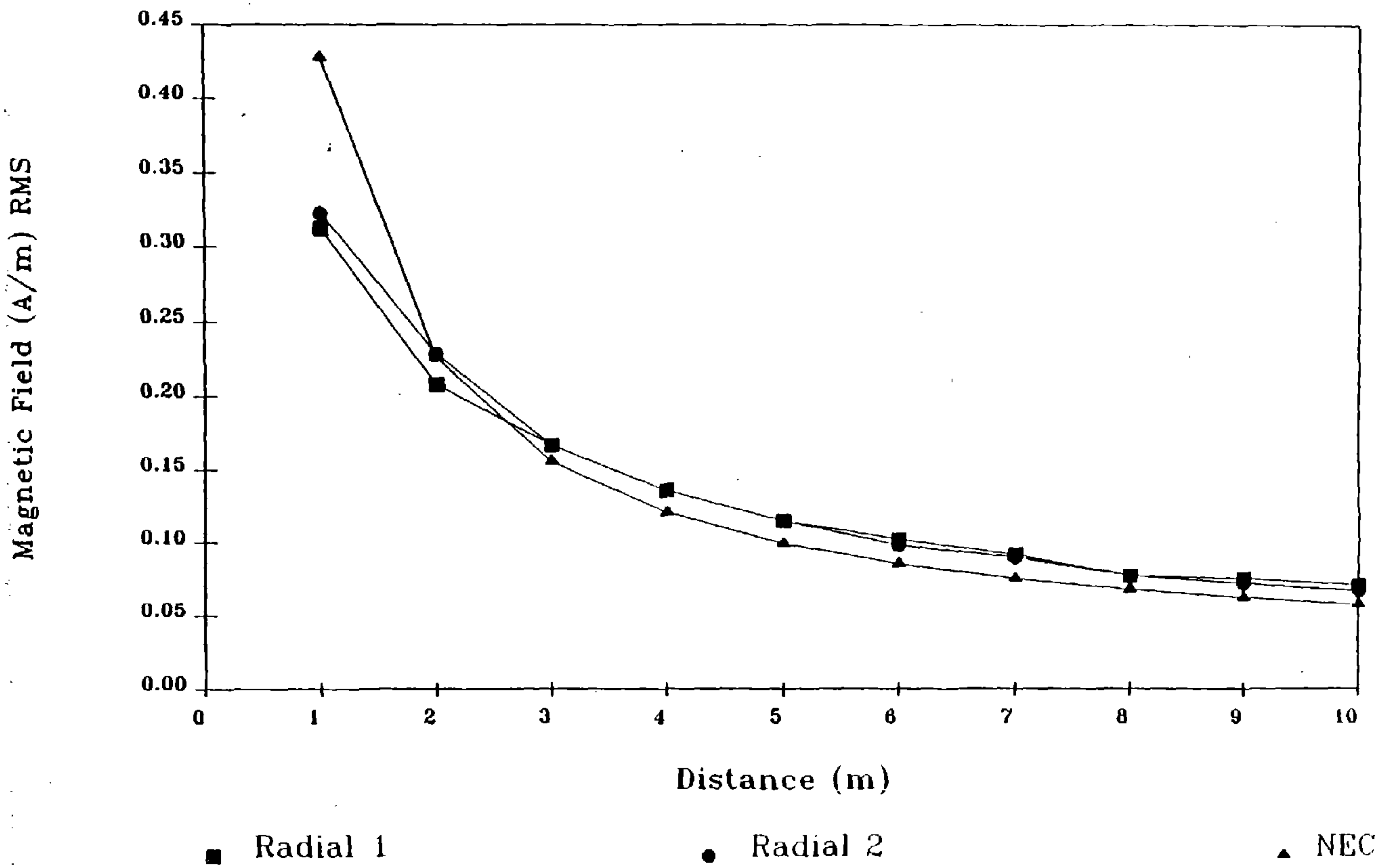
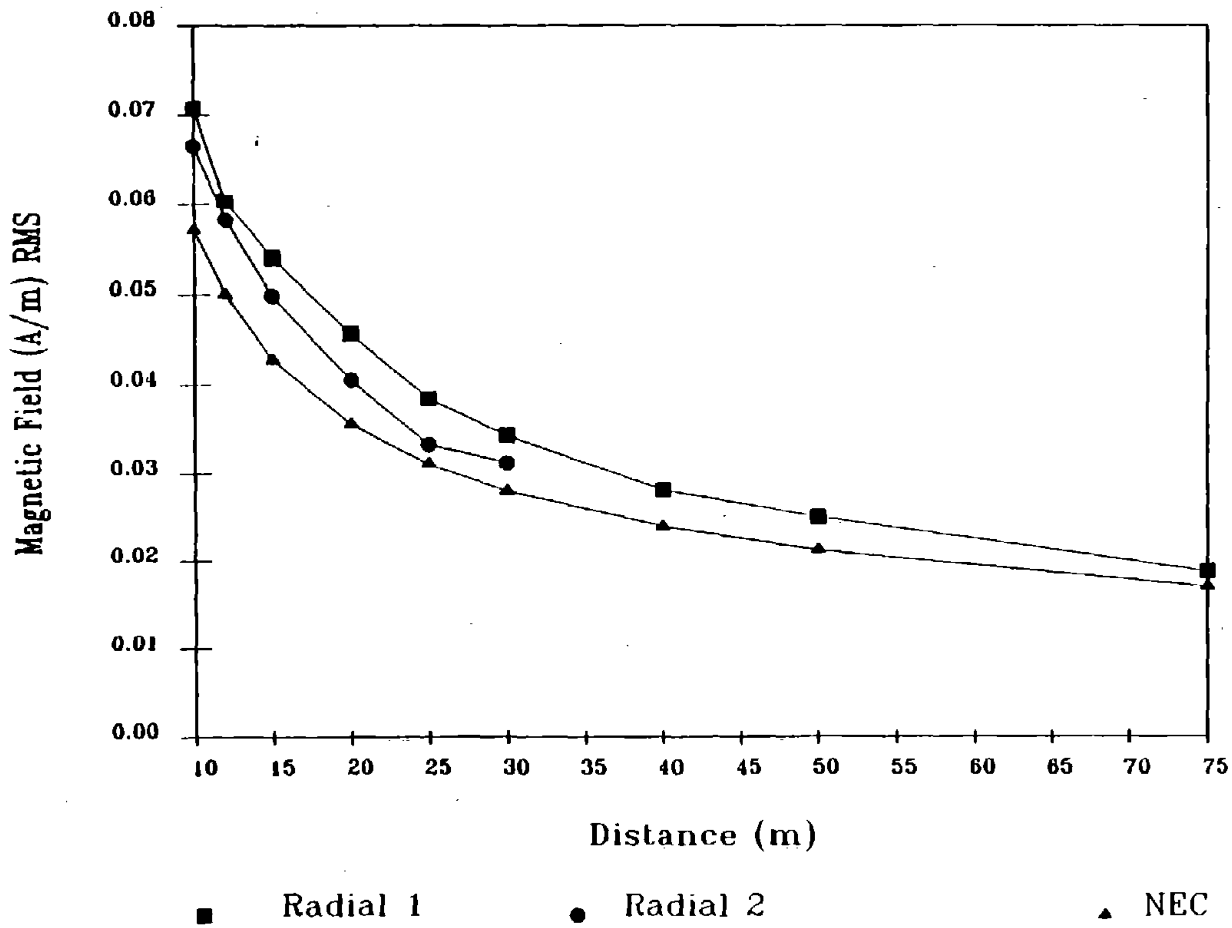


Figure G-4: Station G Magnetic Fields (10-75m)



APPENDIX H
STATION H GRAPHS

Figure H-1: Station H Electric Fields (0-10m)

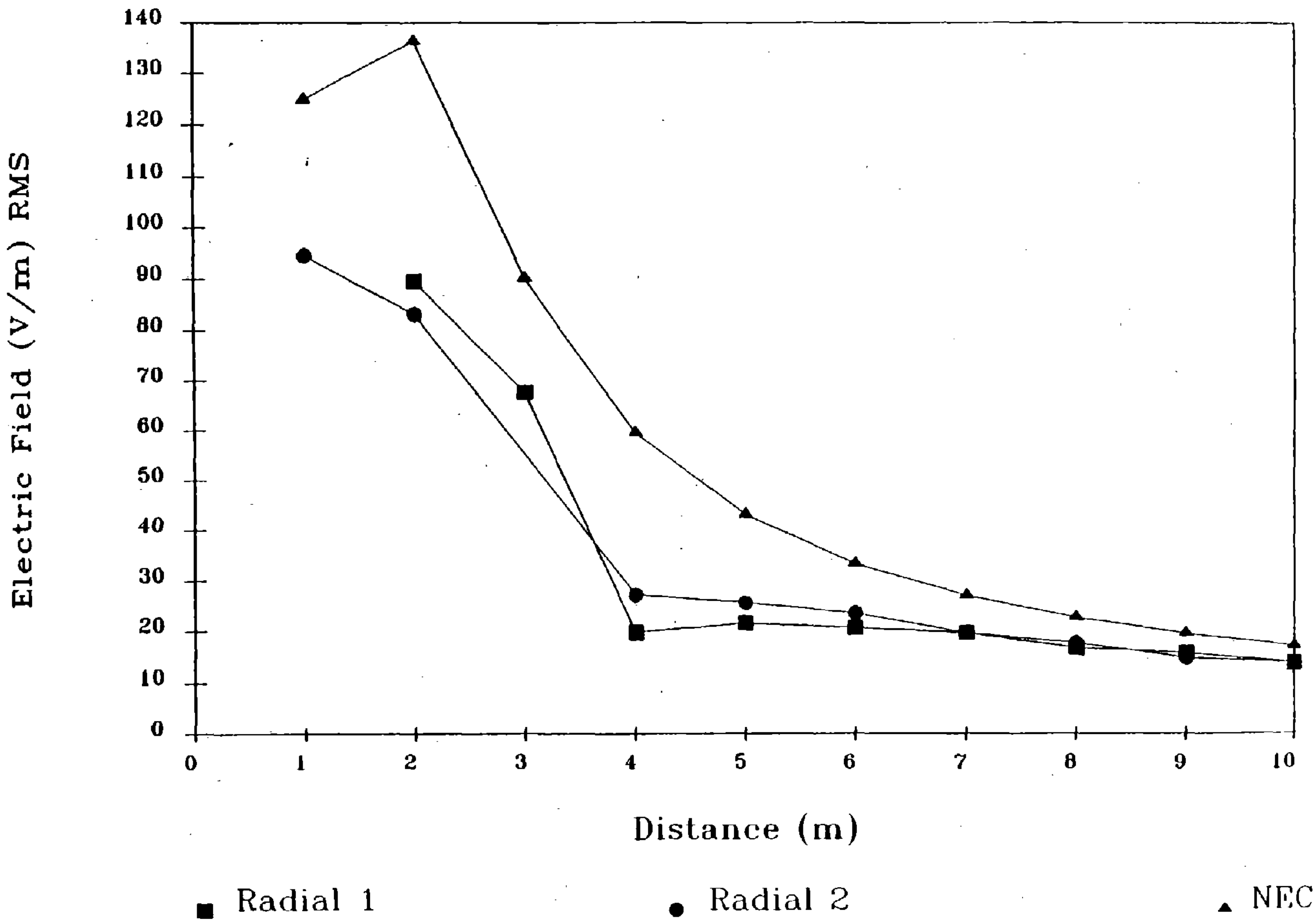
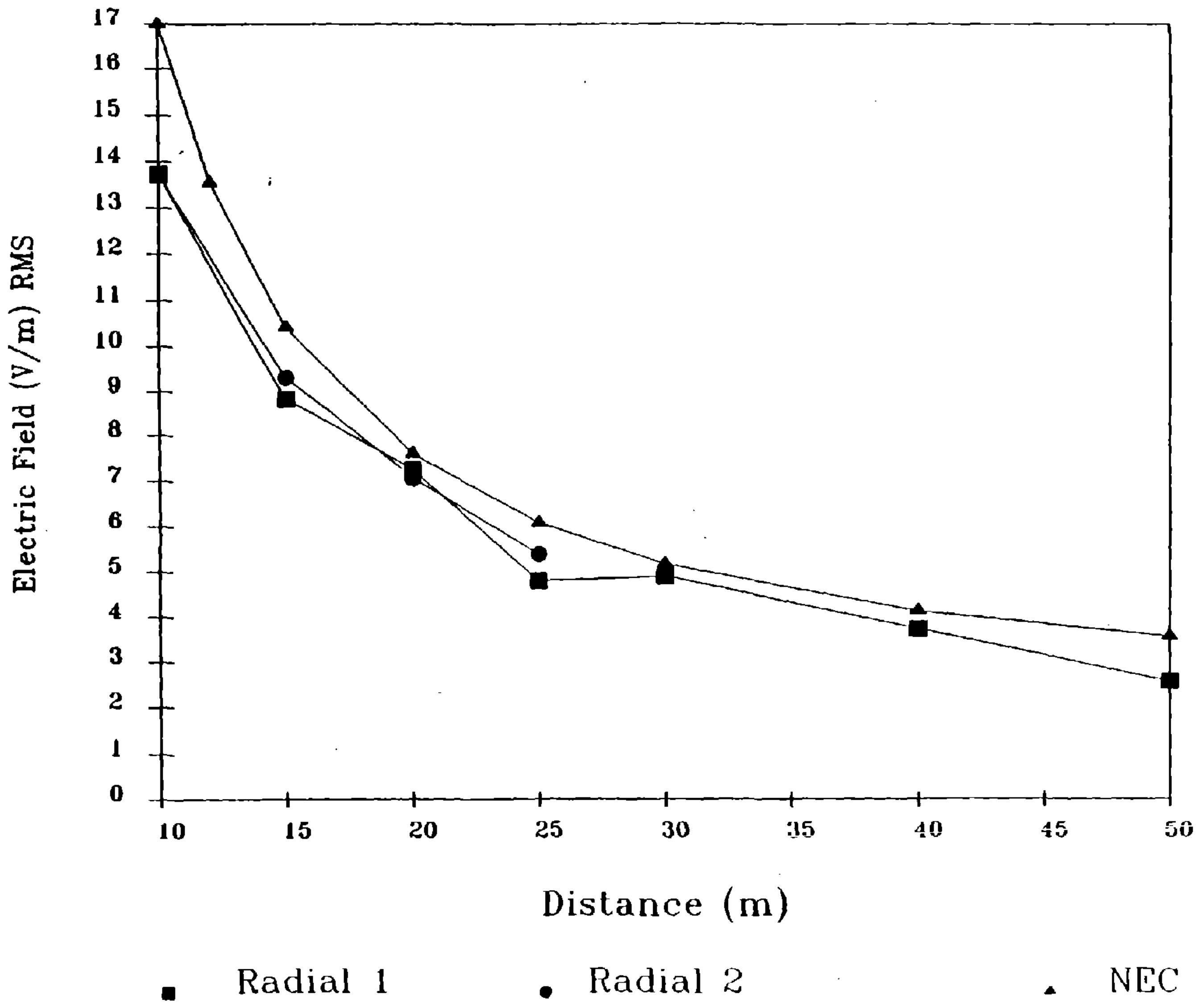


Figure H-2: Station H Electric Fields (10-50m)



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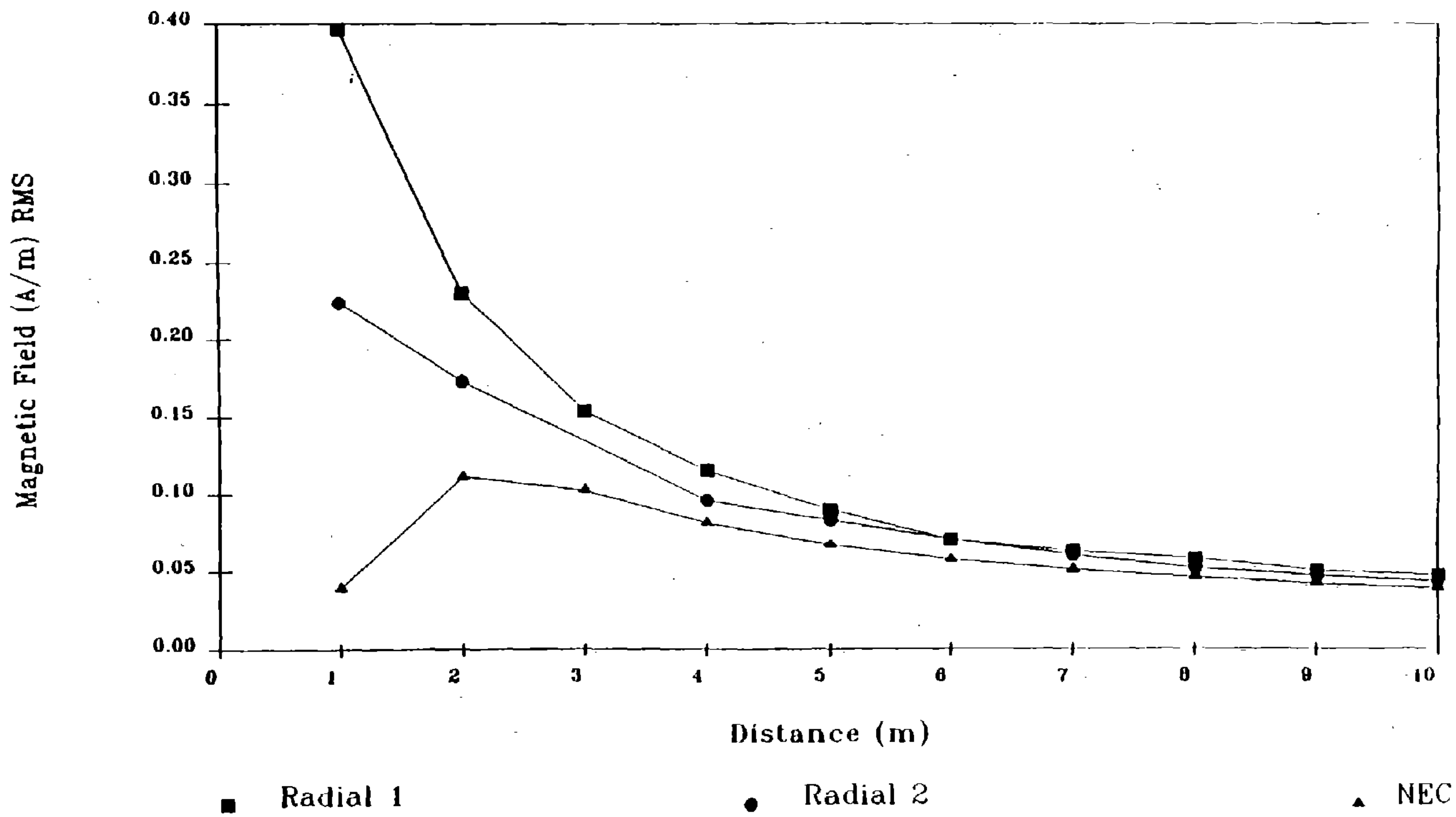

Figure H-4: Station H Magnetic Fields (10-50m)