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BROADCAST RADIATION: A SECOND LOOK

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ABSTRACT

As part of its program to determine the health and environmental effects of exposure to nonionizing radiation, the U.S. Environmental Protection Agency is gathering and analyzing information on sources which produce radiation levels in the environment. The question of broadcast stations as environmental sources of nonionizing radiation exposure has been previously addressed by the authors. This paper extends the results of the previous work. This investigation is developed around vertical radiation patterns and data supplied by the FCC on the heights of transmitting antennas above ground and above supporting structures, such as building roofs. In particular, power densities at roof and ground levels are calculated for areas very near FM broadcast installations using recent information on steep depression angle radiation from commonly used FM transmitting antennas. Associated field measurement data are also discussed and the overall implications of this analysis are examined in terms of present RF exposure standards and philosophy.

INTRODUCTION

The U.S. Environmental Protection Agency conducts a program to determine the health and environmental effects of exposure to nonionizing radiation. This program includes gathering and analyzing information on levels in the environment. In the initial phases of this program sources of electromagnetic energy were examined on a categorical basis in an attempt to identify those sources which provide the major contribution to ambient radiofrequency (RF) and microwave field intensities [1]. Source types with the highest effective radiated powers (ERP) were identified and became the subject of a subsequent analysis wherein satellite communication earth terminals ranked highest with high power search radars next on the list. On the basis of raw ERP alone, these sources are clearly the most potentially hazardous simply because of their high powers. But when analyzed on the basis of ground level power densities in their vicinity, these sources became less of a potential environmental problem than originally suspected because of the extremely directive antenna patterns employed. These super-power sources were then examined on an individual basis with respect to potential hazards should one be exposed in the main beam [2-4]. In general though it was found that the sources which contribute most to the environmental picture are the broadcast stations which are so predominant in this country. The term "environmental picture" is used to denote the average, ambient RF and microwave multiple source environment as opposed to the very intense levels associated with a specific source location. Table 1 gives the number of broadcast stations in the various services [5]. Broadcast sources are, of course, considerably lower powered than many satellite communications

Table 1. Broadcasting stations on air[A/]

513	VHF Commercial TV Stations
198	UHF Commercial TV Stations
711	Total Commercial TV Stations
95	VHF Noncommercial TV Stations
147	UHF Noncommercial TV Stations
242	Total Noncommercial TV Stations
953	Total TV Stations
4434	AM Radio Stations
2648	Commercial FM Stations
725	Noncommercial FM Stations
8760	Total Broadcasting Stations

[A/]As of the end of January 1975 taken from reference [5].

or radar stations but by their very nature they direct their emissions to the surrounding environment. Thus, on a practical basis, relatively high transmitter power and relatively low antenna gain are the two source factors which most influence population exposure in general. Table 2 summarizes some of the factors associated with non-broadcast emitters which lessen their environmental and/or general population impact.

Table 2. Non-broadcast source factors which lessen their environmental impact.

Source Type	Comments
Radar	Very narrow beam widths Antenna rotational duty factor
Satellite Communications	Very narrow beam width Orientation to sky
Land Mobile Communications	Low power Intermittent operation

Not only are more people exposed to radiation from broadcast stations than other types of sources but the dynamic range in exposure levels of various populations is very striking. A relative amplitude-frequency spectra for the FM broadcast band taken in Greenbank, West Virginia is compared with one collected in Washington, DC in Figure 1. The vertical axis of these figures is a logarithmic plot of the relative power density observed at these two locations. Thus, depending upon geographic location some individuals are routinely exposed to RF levels many orders of magnitude higher than others.

Figure. 1-A. Relative FM spectrum - Greenbank, WV

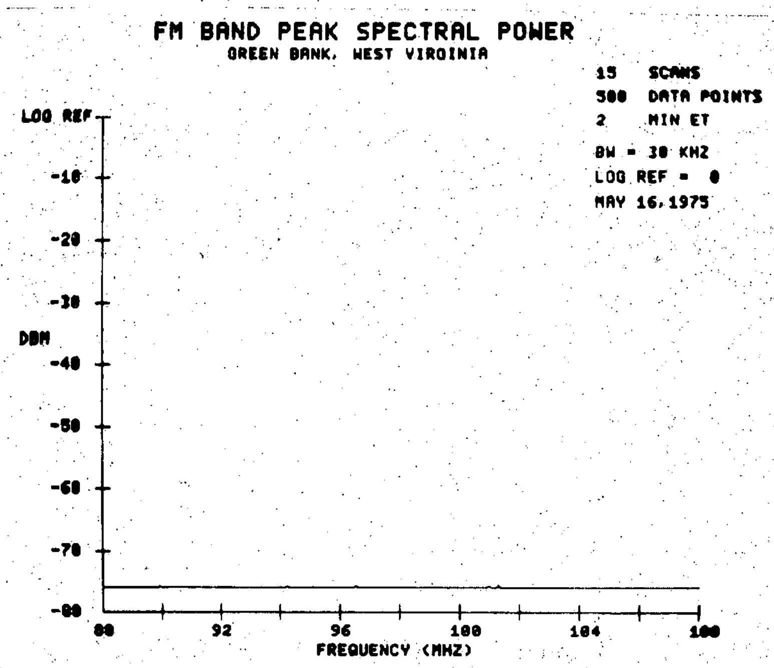
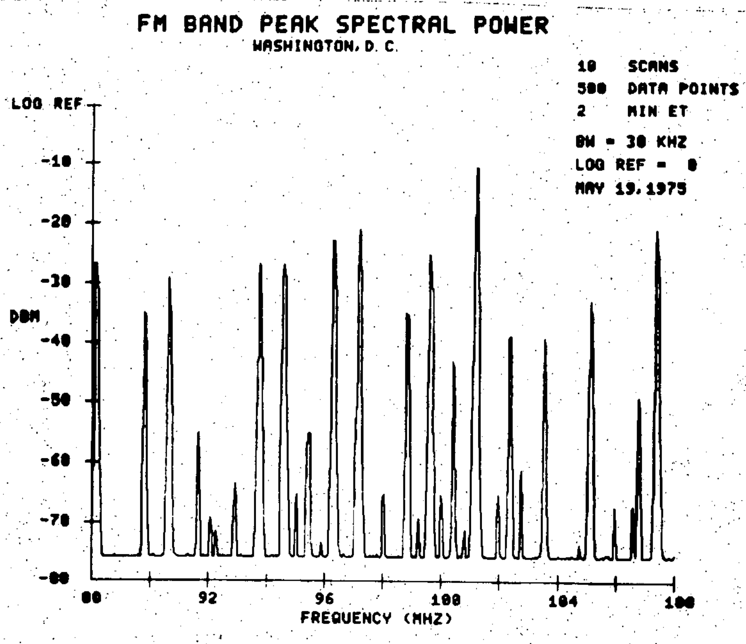


Figure 1-B. Relative FM spectrum - Washington, DC



The question of broadcast stations as environmental sources of nonionizing radiation exposure has been previously addressed [6]. This paper reviews some of the radiation properties of broadcast stations, extends the results of the previous work, and focuses on the identification of specific VHF broadcast sources which may produce practically observed power densities in the neighborhood of 1 mW/cm^2 or higher. Associated field measurement data are discussed and the overall implications of this study are examined in terms of present RF exposure standards and philosophy.

RADIATION PROPERTIES OF BROADCAST STATIONS

Amplitude modulation (AM) is employed in the AM standard broadcast band (535-1605 kHz). Stations range in power from 100 W to 50 kW and employ vertical monopole antennas. There exist 133 50 kW AM stations or about 3 percent of the total number of AM stations. These antennas, or phased arrays of monopoles, are used to propagate a vertically polarized groundwave signal in an omni-directional pattern. Generally the reason for a multiple tower array is to minimize radiation in some particular direction instead of enhancing the signal in a given direction. In this manner long distance interference protection is provided to distant stations operating on the same frequency. Because the earth acts as a ground plane for the vertical antennas used in AM radio transmission, ground conductivity plays an important role in determining the strength of the emitted signals. The greater the soil conductivity, the greater the signal strength at a given point for a fixed power. Ground conductivities found in the U.S. vary typically from 1 to 30 millimhos per meter [7]. Other factors that affect the intensity of an AM radio signal are the tower height (some heights are more effective than others in maximizing field strengths), the frequency of emission, the immediate terrain about the antenna site, and the actual power being transmitted.

Using a computer program developed by the Institute for Telecommunication Sciences [8], the ground level field strength near two different AM radio towers was computed and is plotted in Figure 2. These two curves represent the extremes in field strength for variations in ground conductivity, antenna tower height, and frequency. Each curve is computed for a transmitter output power of 50 kW and assumes that the power is totally delivered to the antenna without mismatch loss. The particular tower heights used were obtained by inspection of the official list of notified assignments of standard broadcast stations [9] and choosing actual indicated minimum and maximum tower heights according to the 50 kW stations operating on each of the two different frequencies. A maximum field strength of 22 V/m is obtained at 100 m from the 550 kHz case and decreases as approximately the inverse of the distance. Two qualifications need to be placed on these results: (a) the indicated field strength values are not valid at distances closer than 100 m due to near field effects and (b) it is possible that some particular station with an optimum tower height (5/8 λ) at its operating frequency and an excellent ground system might produce slightly higher field strengths - the two cases selected here are intended to be representative of typical extremes but not necessarily the absolute extremes. A field strength of 22 V/m is equivalent to 0.13 mW/cm^2 in free space.

As one approaches the monopole of an AM station the exposure must be computed on the basis of both the electric and magnetic fields and must include the induction and electric fields very near the surface of the antenna. It is of interest to determine the intense fields very near such antennas and this is accomplished by solving the field equations for the case of a monopole over a perfectly conducting ground plane [10]. In reality finite ground conductivity will affect the answers but for practical hazard analysis purposes the approximation is sufficiently accurate. Figure 3 is a plot of the electric and magnetic field strengths in the very near vicinity of a vertical monopole antenna driven with 50 kW of power with tower heights of 0.1 and 0.5 wavelengths.

Figure 2. Ground wave field strength for a 50 kW single monopole AM broadcast station.

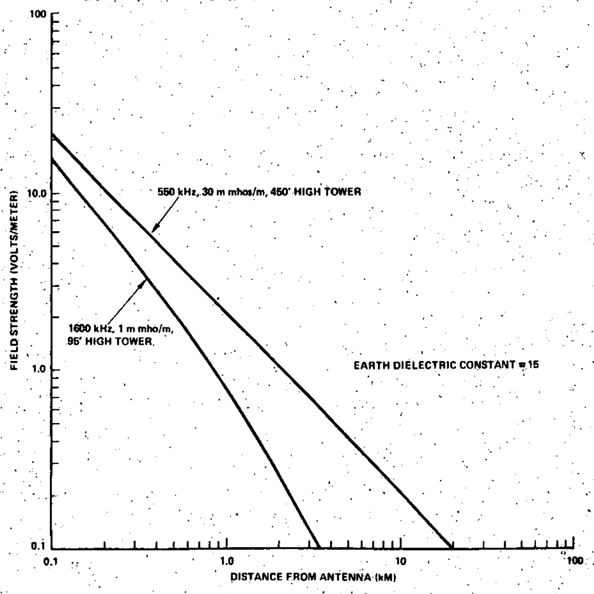
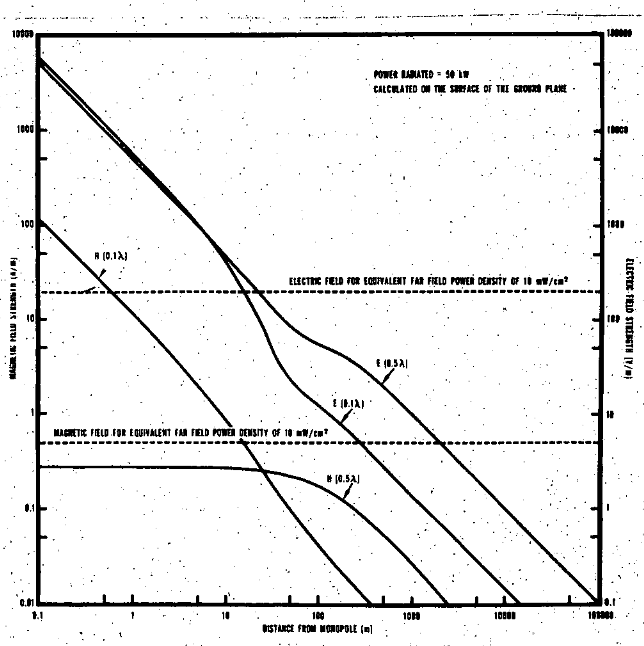


Figure 3. Electric and magnetic field strength for a monopole over perfect ground.



The two sets of curves represent the fields as calculated on the ground surface. The electric and magnetic field strengths which are equivalent, in the far field, to 10 mW/cm^2 are shown for reference. Through numerous calculations, depending on exact tower heights, it can be shown that these field intensity values represent the range of possible values for practically used standard broadcast towers. The strongest implication of these results is that field strengths very near and on the surface of such towers can reach extremely high values and may represent a hazardous condition for workers climbing them.

FM and TV stations operating in the VHF and UHF parts of the spectrum (see Table 3 for frequencies and authorized maximum powers) employ antennas which exhibit a uniform pattern in the azimuth but concentrate the power into a narrow vertical plane beam. An example of the vertical plane radiation pattern of a typical UHF-TV transmitting antenna is seen in Figure 4. Sometimes the antenna employs a certain degree of beam tilt to optimize the coverage in a particular locale. FM and TV antennas utilize the tower only as a supporting device; frequently a single tower may support several FM and/or TV transmitting antennas.

Table 3. Technical information relevant to FM and TV broadcasting.

Service	Frequency (MHz)	Maximum ERP (kW)
FM Radio	88-108	100 (may use 100 kW in both horizontal and vertical planes)
Low VHF-TV (Ch. 2-6)	54-88	100
High VHF-TV (Ch. 7-13)	174-216	316
UHF-TV	470-890	5000

Because of the collimation of a fairly narrow beam of radiation, these antennas exhibit gain over an isotropic radiator. This power gain is used to compute the effective radiated power (ERP) for the station since

$$ERP = P_t G \quad \text{where}$$

P_t = power input to antenna
G = gain of antenna

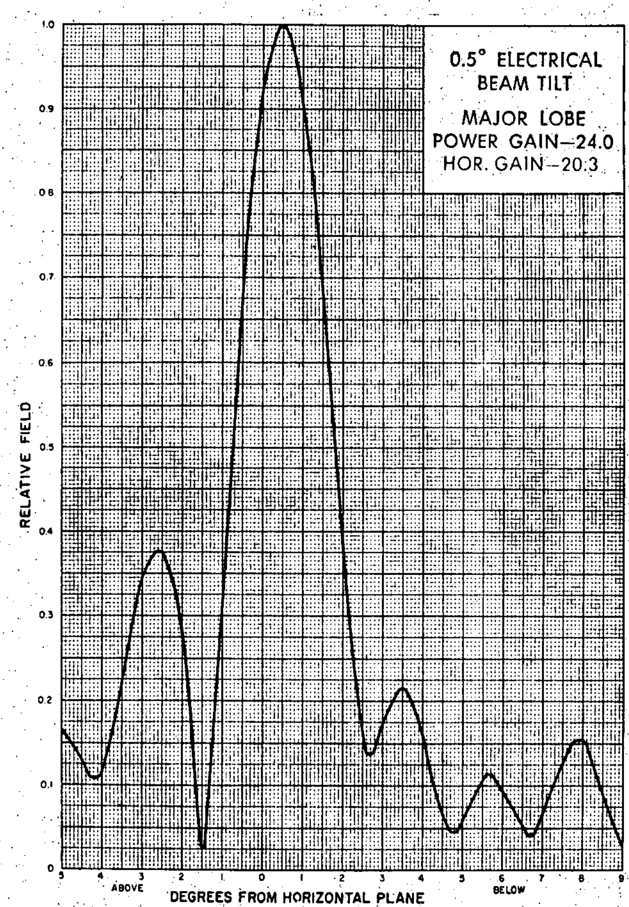
For computation of the field in the vicinity of such antennas, several relations hold for a hazards analysis. The electric field radiated from the antenna may be expressed by:

$$E(V/m) = \frac{2\sqrt{30\,P}}{R} \times F_\alpha \quad \text{where}$$

P = effective radiated power in watts in the main lobe of the antenna
R = distance from center of radiation of antenna in meters - usually taken as the physical center of the antenna - to the point in question
F_α = relative field factor for the desired depression angle from the horizontal of the antenna

F_α is that number which would be taken from a plot of the relative electric field strength for an antenna such as is given in Figure 4. The factor of two in this relation accounts for the reflection of the incident electric field which might occur due to surrounding objects. In the case of reflections the standing wave can double the value of the incident field. This factor is then a conservative way of making an estimate of the actual field.

Figure 4. Medium gain UHF antenna vertical radiation pattern.



Another useful relation is the free space expression for power density:

$$S(mW/cm^2) = \frac{P}{10\pi R^2} \quad \text{where}$$

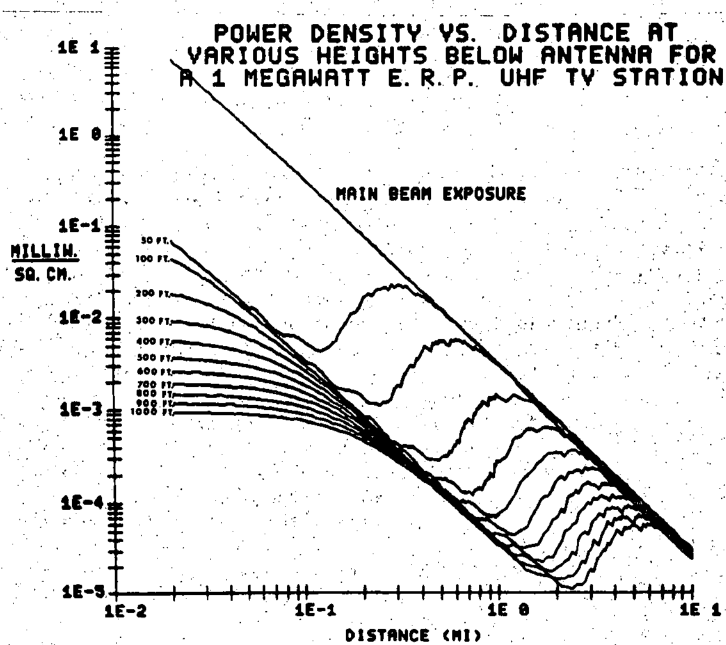
the terms are the same as previously defined. This relation comes directly from the expression for electric field strength since

$$S = \frac{E^2}{Z_o} \text{ where}$$

Z_o = intrinsic impedance of free space = $120\pi\ \Omega$

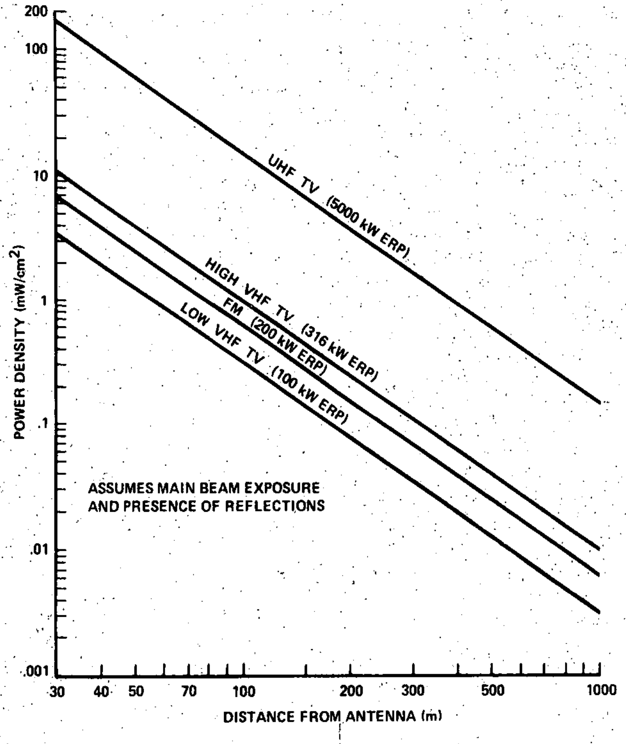
These relations have been used to compute the worst case values of expected power density at various heights above ground for an actual super-power UHF-TV station in Washington, DC [11]. Terrain elevation data along eight different radial directions from the station location were used in conjunction with the vertical radiation pattern of the actual antenna being used by the station. Figure 5 shows how the power density varies as a function of distance from a UHF transmitter and the distance below the center of radiation for the antenna. The computed curves are for a 1 MW ERP station and employ the radiation pattern characteristics of the actual station studied in Washington, DC. Main beam exposures could theoretically only exist in the case of a tall nearby building or other antenna mounting configuration which allowed individuals to "look into the antenna." Figure 6 gives the maximum worst case power densities produced in the main beam of FM, VHF-TV, and UHF-TV broadcasting stations. Maximum authorized ERP is used from Table 3 for each service and the computed power density assumes that reflections occur.

Figure 5. Power density for a VHF TV station.



FM and VHF-TV broadcast antennas exhibit broader beam widths in the vertical plane and in some instances less well controlled illumination of the array resulting in what are referred to as grating lobes [12]. Grating lobes are those radiation lobes which are directed straight above and below the antenna where it is not desired to radiate or waste power. Figure 7 illustrates

Figure 6. Maximum power density from FM and TV stations.

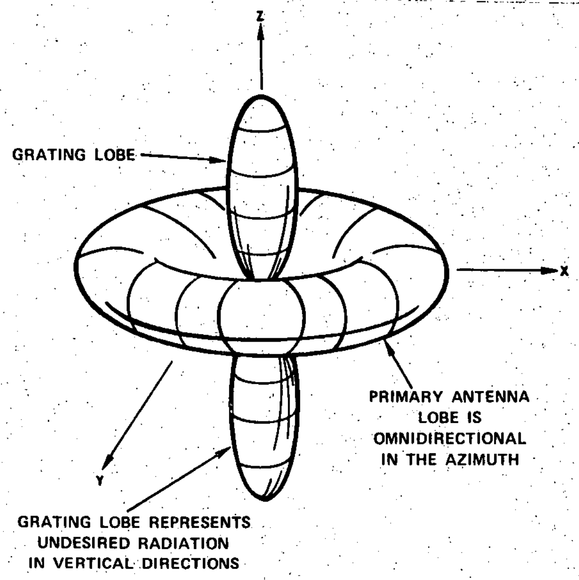


the existence of grating lobes. In the case of a broadcast antenna with a pronounced grating lobe, the electric field strength on the ground or at the base of the tower can be as intense as in the main lobe of the antenna at the same distance (a distance equal to the tower height) [13]. This interesting result is the basis for an analysis of FM stations to attempt identification of specific sites where unusually intense fields might be observed. This analysis will be discussed shortly.

HAZARD SURVEYS AT BROADCAST FREQUENCIES

Within the last few years a number of field measurement studies have been accomplished; some of these studies have been aimed at determining ambient RF levels a long distance away from broadcast sources while others have been directed toward assessing field levels in the immediate neighborhood of specific transmitting antennas. Two environmental studies, one in Las Vegas, Nevada and one in Washington, DC, have been performed to determine the relative intensities of stations operating in a number of broadcast bands [14,15]. These measurements provided some initial information on levels due to broadcast sources and demonstrated the difficulty of making accurate, broadband field intensity measurements. The results of the Washington study indicated that the principle component of the total power density observed, when monitored over the frequency range of 20 Hz to 10 GHz, was due to broadcast stations and nearby radar installations. The Las Vegas survey studied only broadcast stations in the VHF spectrum (54-220 MHz). Maximum power density observed in Las Vegas was 0.8 $\mu W/cm^2$ at one monitoring point and this was due in large part to one TV station and two FM stations. A total integrated value of power density of

Figure 7. Visualization of grating lobes of an FM transmitting antenna.



0.4 $\mu W/cm^2$ was recorded as the largest value in the Washington, DC survey. More recent measurements in the Washington area using more accurately calibrated equipment indicate that much higher ambient levels can be expected [16]. As an example of the type of general environmental surveys being performed presently by EPA, Figure 8 shows the field strengths in the FM and low VHF-TV bands. These measurements utilize antennas designed to respond to all polarization components of the impinging waves and make use of computer automated data corrections which incorporate all system correction factors necessary such as for the antennas. These graphical outputs were obtained at Sibley Hospital in Washington and when converted to equivalent power density plots represent a total of 0.4 $\mu W/cm^2$ in these two bands alone. This compares with a value of 0.007 $\mu W/cm^2$ measured at the same location in the previous Washington, DC survey [15] which was reportedly due to contributions throughout the entire spectrum.

Another interesting study concerns the measurement of RF field strengths at the University of California Medical Center in San Francisco [17]. This study was prompted by the construction of a nearby major broadcast tower which now supports the transmitting antennas for several television and FM stations. Personnel in the hospital were worried about possible interference from the new tower with medical instrumentation and particularly cardiac pacemakers. Measurements were made both before and after installation of the new tower to assess the impact which the more closely situated stations would have. Maximum observed field strengths of 1.4 V/m were found after the new tower was placed in operation, and this value was from an FM station. A report by personnel of the hospital [18] indicates that their Office of Environmental Health and Safety has established an inside the hospital standard which requires that the field strength must not exceed 1 V/m average or 1.5 V/m peak. These two studies

Figure 8-A. FM band field strengths in Washington, DC

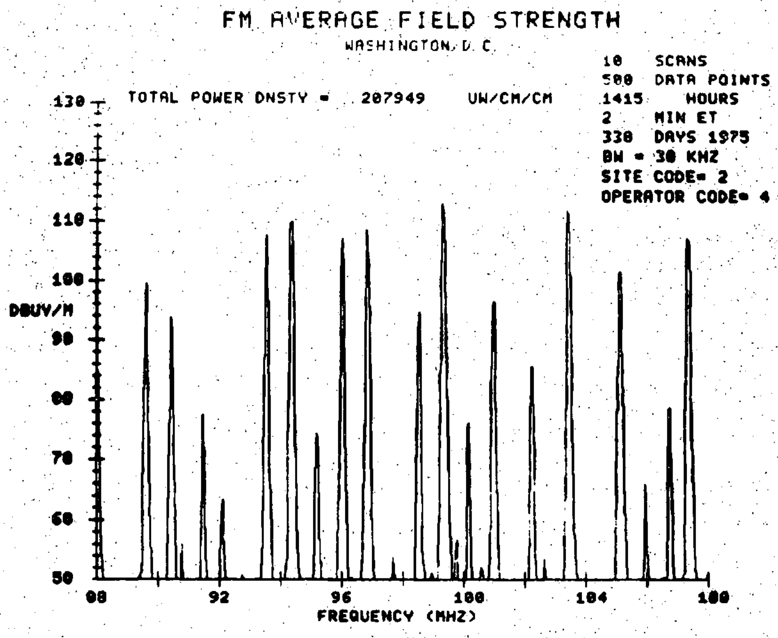
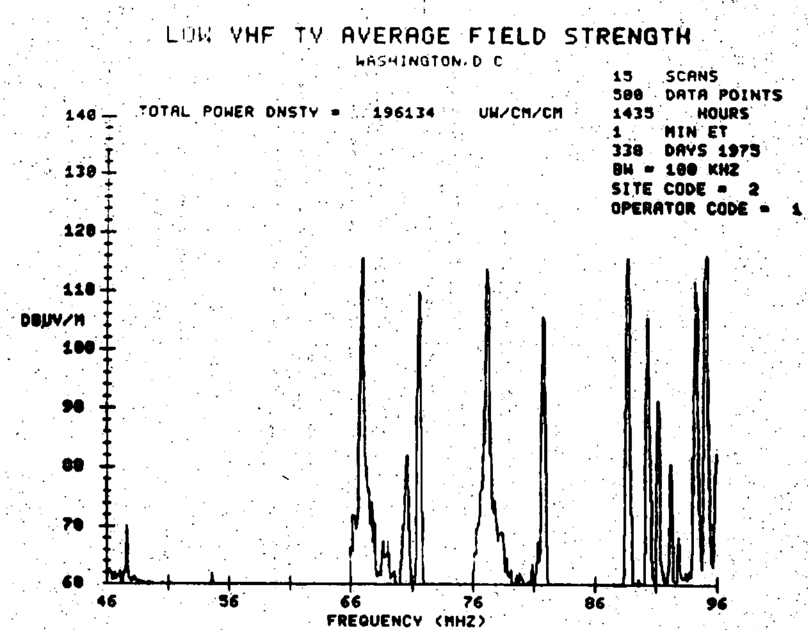


Figure 8-B. Low VHF TV field strengths in Washington, DC



suggest that the effects of RF interference to critical life support devices may be as important as the direct thermalizing effects in tissue from intense RF fields. Though cardiac pacers have been greatly improved with respect to RF interference susceptibilities in the past few years, this problem may still exist for some time in the close proximity of high power broadcast stations [19].

An investigation of a new proposed broadcast antenna installation in Minneapolis has been made to determine if radiation levels on the roof of the building supporting the tower will exceed the OSHA regulation of 10 mW/cm^2 [20]. Using as a guide a previous study made at the Shell Plaza in Houston [21] from which eight FM radio stations transmit, the expected power density on the building in Minneapolis was predicted to be 5.9 mW/cm^2 if four stations are used or 9.1 mW/cm^2 if five stations operate. The Shell Plaza study, supported by field measurements, found that levels approaching 5.6 mW/cm^2 could occur on that building. A similar analysis performed for the new Sears building in Chicago which supports a number of major television and FM stations determined that exposure levels were in the 4-5 mW/cm^2 range at the point of maximum intensity [22].

The question of broadcast radiation from a hazard point of view has been raised by the Hawaiian State Senate which has passed a resolution asking for a formal examination of this question from the Hawaiian State Department of Health [23]. An impetus for this resolution was the denial of an application for a building permit for a new high rise building which would be located immediately adjacent to a broadcast tower which is the single most powerful source of broadcast power, ERP wise, in Honolulu [24]. EPA has assisted the State of Hawaii in this endeavor [25]. In a previous broadcast situation in Hawaii, the strong fields produced by an AM standard broadcast station induced high RF currents and voltages in nearby cranes used in ship loading operations at an adjacent pier [26]. A subsequent study was performed to quantitate the induced field effects and to investigate possible remedial measures [27].

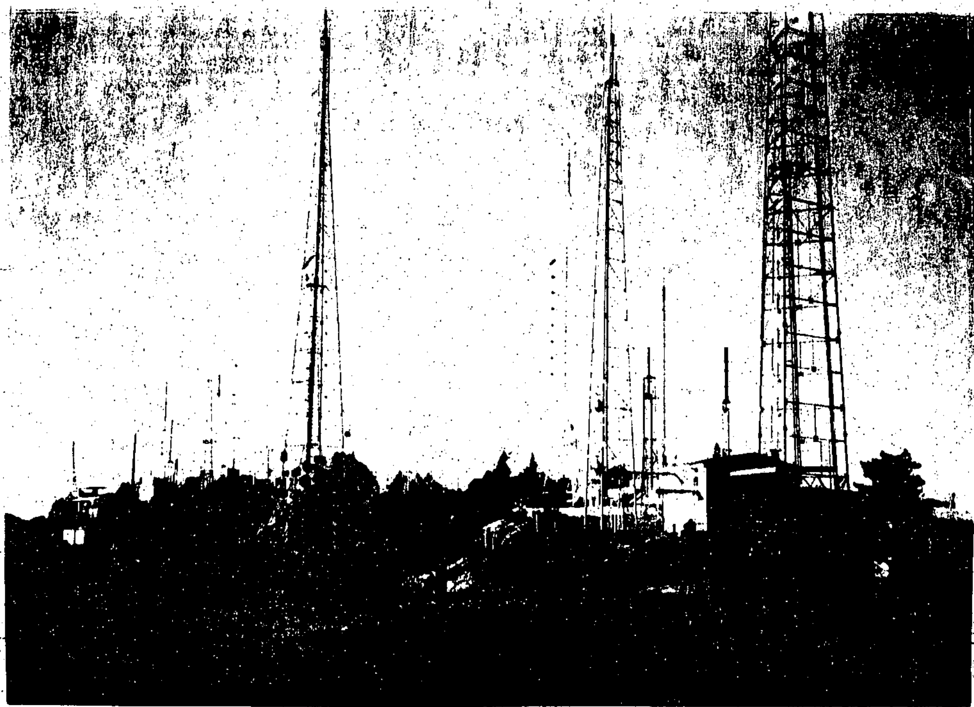
Recently a very interesting exposure situation has been identified at Mt. Wilson near Los Angeles in California. Mt. Wilson is the site of probably more FM radio and television broadcast stations than any where else in the nation. At the request of the Los Angeles County Health Department, EPA is presently assessing the possible levels of RF radiation which exist at the base of the many towers on this mountain top. At one particular location, a post office is situated in the midst of 27 different radio and TV stations located on different towers. Figure 9 illustrates the Mt. Wilson broadcast complex.

Because of the unique setting of this large broadcast installation, most of the towers are relatively low to the ground since they are on a mountain top to begin with, EPA will be conducting a series of field measurements at Mt. Wilson in the near future to determine actual exposure levels and to investigate various instrumentation approaches applicable in a multiple source, intense field environment.

IDENTIFICATION OF HIGH INTENSITY FM TRANSMITTER SITES

The foregoing examples of hazard surveys at various broadcast installations point out that broadcast stations are a major source of RF exposure in the environment and if the circumstances are right, environmentally significant exposures may occur. Significant is defined as any exposure which is in the range of 1 to 10 mW/cm^2, 1 mW/cm^2 being a tenth of the current accepted occupational guide for exposure in this country. It is of interest to determine what segment of the population may be routinely exposed to significant levels of RF energy, if any, before a decision is made as to the necessity of creating an

Figure 9. Broadcast tower complex on Mt. Wilson near Los Angeles.



environmental standard for RF exposure that would be applicable to the general population. Prompted by the outcome of some of these past broadcast radiation hazard surveys and the observation of relatively intense grating lobes from FM radio transmitting installations [28] we decided to study the population of FM radio stations in this country. The intention was to identify specific FM transmitting sites where the RF exposure levels might be relatively high, at least in the significant range. These sites then, could serve as locations to make careful field intensity measurements for the purpose of validating the calculational procedures used in identifying them.

The first step in this analysis was to obtain the required technical information on all FM radio stations in the nation. A list of all FM stations was obtained directly from the FCC which contains in addition to the usual technical specifications for the stations the height of the antenna above the tower base and the height of the antenna above ground. This information is very difficult to obtain without individually contacting each station of interest and unfortunately is not available on a computer automated data base. From this listing of some 3,000 stations a sorting criteria was established to select out those stations which appeared to be interesting from a high level exposure viewpoint. If the following conditions were met by a station it was placed in a new list for subsequent analysis:

(a) the actual transmitter power had to exceed 100 W

(b) either the antenna height above ground or the tower base had to be less than 100 feet.

Using this criteria 326 stations were found that qualified for further analysis. In this procedure, there exists the possibility that a maximum authorized power station might be situated just over 100 feet in height and be missed. During the sort process, therefore, some judgment was used to include in a few instances stations that were slightly over the 100 foot limit if they were high power outlets.

Each station which met the sorting criteria was then analyzed for the maximum possible power density which could exist at the base of its tower. This power density might be on a roof top, if the station was situated on a building, or on the ground. Power density calculations were performed using the simple free space relation previously discussed and includes the possibility of reflections which would enhance the field intensity and assumes that the grating lobe field is as substantial as the main beam. In the case of stations utilizing dual polarization, only the ERP in the horizontal plane was used in the computation. This procedure was assumed reasonable since previous measurement results seemed related to the power in one polarization plane only [13]. A final cross check for current operation power was made by referring to another commonly available source of broadcast station information before ranking the results [5]. Table 4 is a list showing the results of this analysis with the stations listed in order of decreasing computed power density. This list reveals that the maximum computed power density is about 21 mW/cm^2 for a roof top location in Oklahoma City. Power densities decrease fairly rapidly to the range of 1-2 mW/cm^2. This list shows only the first 24 stations; it was determined that 86 stations could potentially produce a power density of 1 mW/cm^2 or higher. This represents 3 percent of all FM stations in the country. The predominate number of the higher exposure values calculated are for roof top installations. Sixty-one of these 86 stations were roof mounted. Table 5 provides a summary of the data found in Table 4.

Table 4. FM station analysis.

Call	Location	ERP (kW)	Antenna Heights Struct/Gnd (Ft)	Power Density (mW/cm^2) Structure	Ground	Freq. (MHz)
KAFG	Oklahoma City, OK	100	40/301	21.414	0.3782	102.7
KFNB	Oklahoma City, OK	100	40/457	21.414	0.1641	101.9
WFMR	Milwaukee, WI	39	35/330	10.908	0.1227	96.5
KCMW	Warrenburg, MO	100	60/100	9.517	3.426	90.9
WQFM	Milwaukee, WI	50	44/279	8.849	0.2201	
WFUV	New York, NY	50	45/199	8.460	0.4326	90.7
WJR	Detroit, MI	50	54/486	5.875	0.0725	96.3
WOMA	Tallahasse, FL	51	55/149	5.777	0.7871	94.9
WTMI	Miami, FL	60	60/409	5.710	0.1229	93.1
KPRI	San Diego, CA	50	55/135	5.663	0.9400	106.5
KSRN	Reno, NV	25	40/40	5.354		104.5
WBYU	New Orleans, LA	100	80/513	5.354	0.1302	95.7
WQRS	Detroit, MI	50	58/516	5.093	0.0643	105.1
KEZQ	Little Rock, AR	60	66/310	4.719	0.2139	94.1
KYKR, KCAW	Port Arthur, TX	25	44/204	4.424	0.2058	93.3
KEZK	St. Louis, MO	63	70/347	4.405	0.1793	102.5
KRAB	Seattle, WA	45	60/60	4.283		107.7
WMTQ	Mt. Washington, NH	48	62/62	4.278		94.9
KITT	San Diego, CA	120 H, 31 V*	100/320	4.112	0.4015	105.3
KRWG	Las Cruces, NM	100	--/92		4.048	90.7
WPRB	Princeton, NJ	17	38/154	4.034	0.2456	103.3
KTBA	Broken Arrow, OK	3	16/174	4.015	0.0340	92.1
WFYR	Chicago, IL	50	69/549	3.598	0.0568	103.5

*Effective radiated power in horizontal and vertical planes.

Table 5. Statistical summary of FM data.

Power Density Range	Number of Stations	Percent of Those >1
1.0 - 1.99	36	41.9
2.0 - 2.99	21	24.4
3.0 - 3.99	7	8.1
4.0 - 4.99	8	9.3
5.0 - 5.99	7	8.1
6.0 - 6.99	0	
7.0 - 7.99	0	
8.0 - 8.99	2	2.3
9.0 - 9.99	1	1.2
10.0 - 10.99	1	1.2
------------	--	
21.0 - 21.99	2	2.3

Total number of FM stations = 3373 = 100%.
No. of Stations which met "pull-out" criteria = 326 = 9.7%.
No. of stations which have power densities >1.0 = 86 = 2.6%.
No. of above power densities measured from a roof = 61 = 70.9%.

A number of qualifications must be indicated concerning these results. The indicated antenna heights as obtained from the FCC are in reality the heights to the very top of the supporting structure rather than to the center of radiation for each antenna. In some instances this is in fact to the top of the antenna but in others it may be a significant distance beyond the point on the tower where the antenna is mounted. In the cases where the antenna is actually lower to the tower base than shown in the FCC data, the calculated power density will be under-estimated. Another factor is the accuracy of the data base as supplied by the FCC; it was found by checking with a few stations at random that some errors in antenna heights exist in the FCC listing. Additionally there were 78 stations which had insufficient antenna height information to determine if they should be included with the stations for which power densities were computed. This factor, of course, could place other stations in Table 4 which are not presently there. Finally the computation of power density used in this analysis is a simplification of the problem in that it does not use measured vertical radiation pattern data for each station's antenna nor does it use any method of correction for near-field gain effects when the computation is for a distance in the near field. Another very important factor is the proximity of the nearest radiating element with respect to the ground or the roof. The local fields in the immediate vicinity of a radiating element can be extremely intense and these estimates do not take into account this possibility since we have no data on such element locations. All of these factors can obviously modify the order of the listing in Table 4, the actual stations and power densities found therein, and, of course, can account for differences between those power densities calculated and the exposure which would be measured in the field. Nevertheless, this analysis can provide a guide to locations where relatively intense fields will be found and measurement locations useful for verifying analytical methods of predicting exposures.

A similar sorting was performed for TV stations in the U.S. using both a special list provided by the FCC and other sources [29]. From the available data it was not possible to determine if a given TV tower was located on a building or on the ground; additionally the significance of grating lobes on TV antennas is assumed to be far less than in the case of FM antennas. Thus a listing was produced of all stations with antenna heights above ground of 100 feet or less. This list, Table 6, is produced in order of increasing tower heights and indicates those stations with short towers where ground level field intensities will be relatively high.

Table 6. TV station analysis.

Call	Location	ERP (kW)	Antenna Heights Struct/Gnd (Ft)	Channel
NEW	Salinas, California	23.48	29	7
WVPT	Staunton, Virginia	87.1	46	51
KMEB	Wailuku, Hawaii	31.6	47.3	10
KVRW	Rawlins, Wyoming	12.6	57	11
KTIE	Oxnard, California	20	59	63
WOLE	Aquadilla, Pureto Rico	17.8	60	12
KMAU	Wailuku, Hawaii	14.1	60	3
KYUS	Miles City, Montana	10.2	65	3
KINY	Juneau, Alaska	0.24	69	8
KAIL	Fresno, California	355	69.5	53
KMVI	Wailuku, Hawaii	27.5	70	12
KEKO	Elko, Nevada	26.3	71	10
KAII	Wailuku, Hawaii	29.8	75	7
KYVE	Yakima, Washington	19.1	78	47
WNNE	Plattsburgh, New York	525	79	57
KWRB	Riverton, Wyoming	58.9	79	10
WSVI	Christiansted, Virgin Islands	58.5	80	8
KBSC	Corona, California	457	82	52
KBGL	Pocatello, Idaho	66.1	87	10
KTVR	LaGrande, Oregon	12.2	87	13
KSL	Salt Lake City, Utah	33.9	90	5
KTEH	San Jose, California	95	92	54
KORL	Reno, Nevada	17.4	92	4
WLBZ	Bangor, Maine	51.3	95.5	2
KBYU	Provo, Utah	49	96	11
KEET	Eureka, California	66.1	97	13
KBLL	Helena, Montana	0.973	97	12
KBSA	Guasti, California	219	98	46
KIXE	Redding, California	115	99	9
NEW	Reno, Nevada	31.05	100	5
WETK	Burlington, Vermont	251	100.4	33
WBBJ	Jackson, Tennessee	295	109	7
KEYC	Mankato, Minnesota	316	116	12

The next phase of this study is to document by a set of careful field measurements the actual field intensities at the base of a number of the previously discussed FM and TV transmitter sites. These field measurements will examine the applicability of various measurement techniques including: (a) the use of tuned dipoles and narrow band tuneable receivers, (b) electrically short probes using broadband diode detection, and (c) commercially available RF hazard survey instrumentation. The comparison of electrically short probes with more conventionally used half-wave dipoles is important to define conditions under which the larger antennas may give erroneously low results due to complex standing wave configurations.

BIOLOGICAL CONSIDERATIONS

There has been considerable controversy within the past few years over the wide range which exists between RF exposure standards in the USSR and in this country. To date this controversy still exists but steps toward its resolution have been taken by U.S. scientists who are attempting to replicate some of the

Russian biological effects research. Other guides or standards for RF exposure exist and several of these are outlined in Table 7. The most striking feature of this table is the 1 V/m limit in the Soviet Union for the frequency range of 30-50 MHz [30]. This field strength is equivalent to a free space power density of 0.27 $\mu W/cm^2$ as compared to the OSHA [31] or ANSI [32] limits of 10 mW/cm^2 which are defined for individuals occupationally exposed. The low exposure limits, for the general population in the USSR, if applied in this country, would be exceeded for a substantial fraction of the U.S. population where field strengths of this magnitude routinely exist and have so for years. It is even questionable whether such low limits can be practically complied with even in the USSR.

Table 7. Some RF/microwave exposure standards.

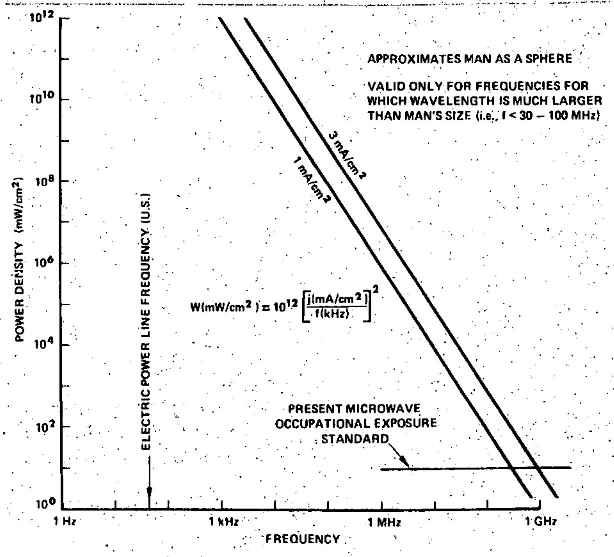
Standard	Applicable Frequency Range	Limits and Comments	
OSHA	10 MHz - 100 GHz	10 mW/cm^2 for periods >0.1 hour 1 $mW\text{-}hr/cm^2$ during any 0.1 hour period	
ANSI	10 MHz - 100 GHZ	Same as OSHA but includes other specifications for field as 40,000 V^2/m^2 or 0.25 A^2/m^2	
BRH	915, 2450	5 mW/cm^2 at any point two inches from surface of microwave oven during life time	
USAF	300 MHz - 300 GHz	$T = 6{,}000/W^2$ where T is time of exposure permitted and W is power density in mW/cm^2	
	10 kHz - 10 MHz	50 mW/cm^2 for periods >6 min 18,000 $mW\text{-}sec/cm^2$ for periods <6 min 100 kV/m peak pulse, 1 pulse/minute	
USSR		Occupational Groups	The Population
	Medium Waves	50 V/m	10 V/m
	100 kHz - 3 MHz	5 V/m	Not Established
	3 - 30 MHz	20 V/m	4 V/m
	30 - 50 MHz	10 V/m	1 V/m
	50 - 300 MHz	5 V/m	Not Established
	0.3 - 300 GHZ	10 $\mu W/cm^2$	1 $\mu W/cm^2$

The ANSI standard allows for exposures in excess of 10 mW/cm^2 when the duration of the exposure is sufficiently short. One possible shortcoming of this standard is the allowance of very intense exposures for these short time periods. A modification of the ANSI standard by the U.S. Army and Air Force [33] limits maximum exposure under any conditions to 100 mW/cm^2 regardless of how short an exposure time is involved. A proposed regulation for RF exposure in the State of Texas [34] is patterned after the ANSI standard.

Generally the degree of thermal hazard from RF exposure decreases with frequency. However, to date, standards in this country do not take this into consideration. There have been suggestions that a much higher limit should be used for frequencies below 30 MHz by at least two different organizations [35, 36]. The Admiralty Surface Weapons Establishment of the U.K. has adopted an unofficial guide of 1,000 V/m below 30 MHz and this level has been chosen on the basis of phantom dielectric heating and analytic studies which show a decreased heating effect. The U.S. Air Force has suggested the use of 50 mW/cm^2 at frequencies below 10 MHz from their own animal studies which indicate negligible thermal damage at this level and frequency range [36].

Based on simple electric field coupling alone, safe current-density values were projected by Schwan [37] which indicated that incident power densities on the order of 10^6 times that considered safe at 1 GHz (10 mW/cm^2) would be required at 1 MHz to produce the equivalent power deposition in a spherical model of man and that the concept of current density might be a better choice of a hazard parameter, especially for the lower frequencies. A current density of 3 mA/cm^2 is used as corresponding to an incident flux of 10 mW/cm^2 in the microwave spectrum and is equivalent to the thermal load in the body imposed by the basal metabolic rate. Schwan's relation between incident power density and frequency for current densities of 1 and 3 mA/cm^2 are plotted in Figure 10. The 3 mA/cm^2 figure is compatible with the fairly extensive data on electrical hazards of low frequency currents.

Figure 10. Power density as a function of frequency for current densities of 1 and 3 mA/cm^2.

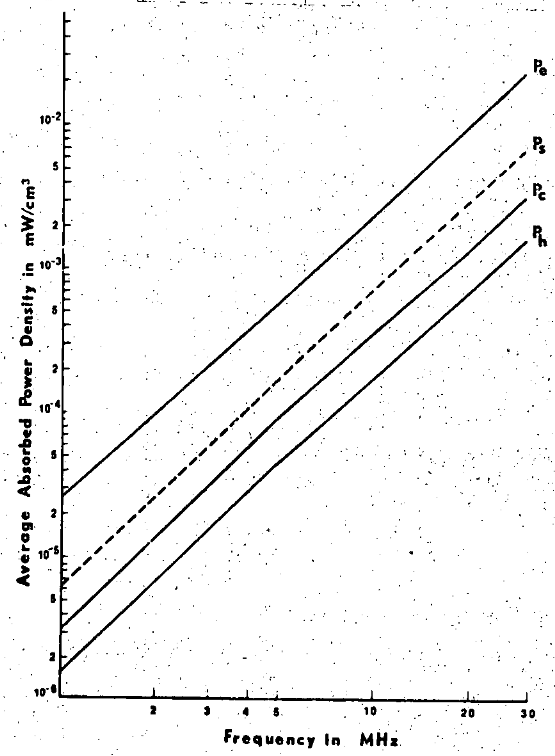


Numerous studies have been performed to determine the relative absorption cross section of man in different frequency ranges. Notably, the early studies concerned with radar hazards examined planar tissue slabs [38] and spheres [39] and showed that lossy dielectric absorbers could absorb up to several times the product of the incident power density and geometric shadow cross section of the sphere in the frequency range of 400-10,000 MHz. Subsequent thermographic analyses determined the distribution of the absorbed microwave radiation in spheres [40,41].

A more careful analysis of relative absorption characteristics of man at lower frequencies has shown the importance of considering both electric and magnetic coupling effects in spheres [42]. Figure 11 from Lin's work, illustrates the variation of absorbed power density (mW/cm^3=total power absorbed/volume) for a man-equivalent sphere model in the frequency range of 1 MHz to 10

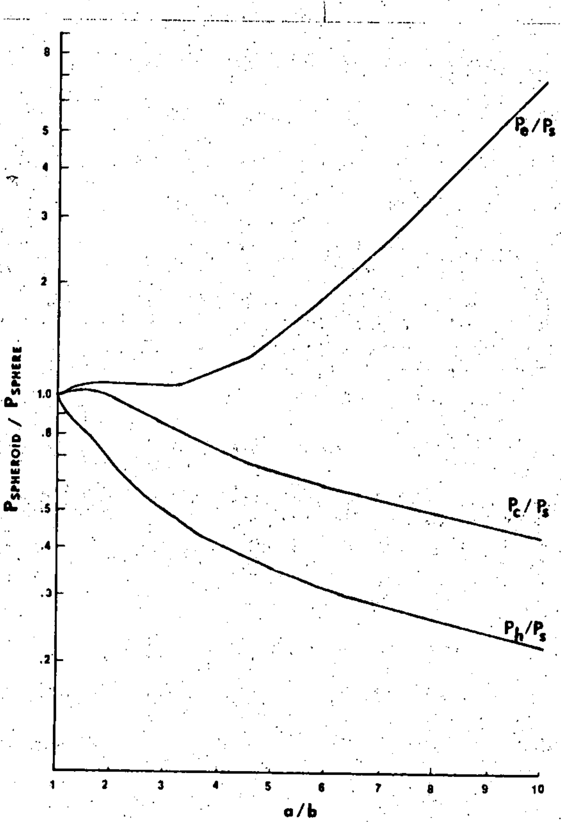
An extension of spherical analysis has been accomplished for a more suitable model of man in the form of a prolate spheroid, exposed to a plane wave field [43]. This work showed the very significant effect of orientation of the model to the incident field in the HF band (3-30 MHz). Maximum power absorption is obtained when the major (long) axis of the prolate spheroid is polarized with the incident electric field. This occurs because of maximum electric coupling and maximum magnetic coupling since more magnetic flux is intercepted by the cross section. A factor of ten difference can exist in the total absorbed power density (mW/cm^3) depending on whether the spheroid is polarized with the electric or magnetic field. Figure 12 is reproduced from the work of Durney at al. [43] which illustrates this phenomenon where the aspect ratio (ratio of length of major axis to minor axis) of the spheroid approximates that of man. Again the principle power absorbed is due to the incident magnetic field. The curve of average absorbed power density for electric polarization is highest since the spheroid is aligned for optimum electric field coupling and optimum magnetic field coupling (the body of the spheroid intercepts more magnetic field flux lines). Figure 13 from Durney et al. [43] also illustrates the interesting effect of the aspect ratio for the spheroid where the absorbed power is normalized by dividing it by the power absorbed in a sphere of equal

Figure 12. Average absorbed power density by a muscle prolate for each of the three polarizations, electric (P_e), magnetic (P_h), and cross (P_c), and for a sphere (P_s) with an incident power density of 1 mW/cm^3, a = 1 m, a/b = 7.73, volume 0.07 m^3 (taken with permission from Durney et al. [43]).



volume. This curve provides significant insight to the problem of extrapolating the results of animal bio-effect research to man where the aspect ratio may be totally different than that of man. Experimental studies have documented this polarization dependence in the microwave range [44]. In this study frequency ranges of 40-55 MHz and 135-165 MHz which are near the FM and VHF TV broadcast region were suggested as being important frequencies for human absorption; this study is based on an extrapolation of data obtained for prolate spheroids in a transmission line configuration [45]. At the lower frequencies the importance of quantifying the magnetic field is again emphasized for hazard evaluations.

Figure 13. Total absorbed power of a 0.07 m^3 muscle prolate spheroid normalized to that of a muscle sphere of equal volume for each of the polarizations as a function of the ratio of the major axis to the minor axis of the spheroid at 10 MHz (taken with permission from Durney et al. [43]).



Thermographic studies at lower frequencies have been performed using scaling techniques to investigate the absorption properties of humans in the HF range [46] using scaled down phantom models. Maximum absorption has been observed to occur at frequencies for which the human body is approximately $\lambda/2$ in length in free space configurations and at frequencies for which the body is

$\lambda/4$ when on a ground plane. The observed resonance effect in this study is in contrast with another study which has shown a relative flat, frequency independent characteristic of the body in the frequency range of 30-80 MHz [47].

These studies, in general, have treated the case of plane wave irradiation and further study is required to assess the absorption properties of man in near field conditions where-in the electric and magnetic fields are not in time phase; these are the conditions which exist very near the AM standard broadcast towers for example.

Certainly an environmental exposure standard should not exceed the occupational standard and perhaps should be lower. The occupational guide [29,30] implies that the health conditions of the worker are known, that the actual exposure can be controlled, and the daily exposure is limited to approximately eight hours. None of these conditions apply when dealing with the uncontrolled exposure of the public at large. This suggests that a general environmental limit of 10 mW/cm^2 applied to large population groups may not be prudent. On the other hand, it is not clear at what point a lowered exposure would satisfactorily compensate for the uncontrolled aspects of general population exposure. Any environmental standard should incorporate the flexibility necessary for upwards or downwards adjustment to take into account unique exposure situations.

Careful examination is being given to the range between 1 and 10 mW/cm^2 in an attempt to define an acceptable exposure level for large population groups under uncontrolled exposure conditions. The closest scrutiny is being given to the lower end of the range. This does not preclude the promulgation of even lower levels should later biological data indicate that standards should be set below the indicated range. Due consideration must be given to frequency range and duration of exposure. The strongest factors to be considered in choosing environmental exposure criteria are the protection afforded, the means of providing for control, and the economic impact on both the user of the source and the consumer of source related services.

Values which lie within the indicated range, especially at the lower end, would generally provide for a less hostile electromagnetic compatibility environment for many sensitive medical devices, would provide an additional safety factor of up to 10 for direct (thermal) biological effects, and would limit radiofrequency interference to consumer electronic devices.

CONCLUSIONS

Broadcast stations are significant sources of RF exposure in the environment; they represent the major portion of exposure from all source categories, including radar, when viewed in a macro-environment context and can, under special circumstances, produce significant exposure levels on a specific source basis or in the micro-environment. The levels of exposure associated with broadcast stations in either situation exhibit a wide dynamic range depending on location and local source density but are generally not considered to represent a hazard. Specialized exposure circumstances, however, can imply relatively intense power densities and these situations should and are being investigated to determine the real extent of possible hazards.

Several specific conclusions are drawn:

a) Because personnel routinely work on energized broadcast towers, the currents and local fields on such towers should be investigated further to determine actual exposure and absorbed dose data. This consideration applies to AM and VHF or UHF installations.

b) Significant ground or roof level power densities (1 mW/cm^2 or greater) from FM and TV stations may be more prevalent than previously thought; however, accurate field measurements to better validate this possibility are indicated.

c) Careful consideration should be given to work on towers or buildings immediately adjacent to high power broadcast stations, especially UHF-TV.

d) More definitive data on the relative absorption cross section of man is needed in the frequency range of 50 to 400 MHz. This data would help to establish a better perspective on RF hazards at lower frequencies than most available data and would be helpful in determining the applicability of presently used exposure guides.

e) At present no environmental standard exists for RF or microwave exposure. Careful examination is being given to the range between 1 and 10 mW/cm^2. The actual choice of a level will be based on the results of current effects research, the protection afforded by the chosen level, control methodology, and economic impact.

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