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AN ASSESSMENT OF ADVERSE HEALTH EFFECTS OF TELECOMMUNICATIONS TECHNOLOGY

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Introduction

What Do We Mean by Forecasting and Assessment?

Technological forecasting and technological assessments involve concepts and methodologies that are peculiar to a post-industrial society* such as exists in the United States of America and those few other countries who have reached the post-industrial society level.

Technological forecasting involves projecting possible future trends and events of a technological nature, either from extrapolation of past and present technology (exploratory forecasts) or from determining the future needs for new technology (normative forecasts). Technology assessment involves evaluating the deleterious and advantageous impact of the forecasted technology on society and the environment in both narrow and broad aspects.

The methods and data bases to perform these forecasts and assessments exist to a degree sufficient to provide, at least, a first order estimate of the direction of technological progress, and some reasonable estimate of the direction of the impact on society and the environment along with speculations on the magnitude of the impact of technological alternatives. The existence of such tools makes it almost mandatory that they be used by post-industrial nations to minimize future problems prior to their projected occurrence.

In the United States the problems associated with the impact of technological growth on society and the environment are receiving considerable attention. Congress has even initiated an Office of Technological Assessment which is not yet funded. This represents a major departure from previous Congressional action. Generally, Congress reacts to problems and does not work to alleviate them until the problems reach crisis proportions. This is understandable since many of the issues are extremely controversial such as population control, genetic control, Government regulation of land use, etc. Elected representatives want to avoid this controversy to the extent possible, since its discussion affects different blocks of voters on an emotional as well as a rational basis. Votes in future elections can be easily lost. This does not say that individual members of Congress are not concerned with these problems, but are often unwilling to become an advocate for solutions to the problem until the public has already made them issues for which a solution or position is expected.

The Judicial Branch cannot react until a legal case is made by the real existence of a problem, and then the judiciary are constrained by the Constitution and common law.

The Executive Branch has difficulties in addressing many of these problems because the controversial nature of the subjects makes even consideration of an effort to study them items for headlines. Should an agency even intimate that it might undertake a study on the possibilities of advantageous and disadvantageous results of genetic control, the headlines might read, "Government planning genetic control of nation."

However, the Office of Telecommunications Policy in the Executive Branch has recognized problems dealing with adverse effects of electromagnetic radiation through the formation of an expert committee, the Electromagnetic Radiation Management Advisory Council (ERMAC). As early as 1968 this Council recognized that "man-made radiation is relatively new as an environmental factor. Knowledge of its possible and biological consequences is limited and incomplete."[a] In 1972 ERMAC recommended a multiagency program be undertaken within the Federal Government to address this problem. Here is one area where the Executive Branch has acted.

The point is that Government is interested in these kinds of controversial problems, but cannot easily address them until the time becomes ripe in the public forum for acceptable discussion. Therefore, the early assessment of these types of problems must be approached by non-Government organizations in the public domain. Further, these organizations must be able to examine these activities, these controversial problems in a scientific and professional manner in which the validity of the methods and the manner of drawing conclusions is beyond question, although the results will be highly argumentative and speculative by the very nature of the activity.

To meet this responsibility the Institute of Electrical and Electronic Engineers has undertaken a forecast of electro-technology and what the impact of this technology may have on our society and the environment. This effort represents only one aspect of technology, but it is hoped that it can be replicated elsewhere. Such activities are under way in other areas, including the Engineers Joint Council. I would like to take this opportunity to describe briefly the IEEE program to undertake this forecast and assessment of electro-technology and to point out some of the problems that IEEE faces in getting this activity under way. Then I will attempt to identify some of the more controversial issues that must be faced and how these affect not only the United States but in some respects the whole world, as well as what can be learned from this activity.

IEEE Program in Forecasting and Assessment

There are four principal objectives of the IEEE Technology Forecast and Assessment (TF&A) Project. These are (1) to provide our members with information relevant to their own future career planning, (2) to indicate in which areas new initiatives need to be undertaken by the IEEE as an entity, (3) to establish the IEEE as a resource to which policy-makers may turn on questions of science and technology policy, and -- perhaps most important of all -- (4) by directly including the membership in the process of forecasting

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*Post-industrial society is used in the connotation of Herman Kahn in the sense that it is a society which is technologically developed to the extent that one must learn how to live with that technology.

and assessment to provide them with tools by which they can, as individuals, begin to assume their appropriate role as professionals in formulating policy related to their areas of expertise at every level of government.

The project is intended to provide both knowledge, recognized as speculative but preferable to neglect, and human resources, developed by exposure of substantial numbers of IEEE members to TF&A methodology. Provided it is continually updated, the knowledge of TF&A results will be valuable to individuals, to IEEE Committees, to industry, to all levels of government and to the community-at-large. The human resources can provide the catalyst for extension of TF&A to sectors of the community unlikely to undertake such studies on their own initiative. The TF&A Committee and Dr. William D. Rowe, Chairman of the Committee, call for the support of those who favor extension of rationality in the conduct of human affairs.

The project is organized under a TF&A Administrative Committee, which reports to the Vice Chairman of IEEE Technical Activities Board. Its funds come from a member's dues supplement paid only by members from the United States and aimed at supporting projects of a professional nature only of prime interest to United States members. The TF&A Administrative Committee interacts directly with the representatives named by the Groups and Societies, for training, advising, reviewing and encouraging G/S activities. An Interdisciplinary Coordination Committee is responsible for specific tasks of interfacial coordination among G/S, geographically focussed task teams, societal goals and exploratory vs normative forecasting.

Current activities involve 29 of the 31 G/S and a couple of geographically focussed teams. A full time staff manager manages the project under the direction of the volunteer, professional members of the TF&A Administrative Committee in order to capitalize on the enthusiasm generated in the G/S representatives at training sessions and to generate sufficient momentum for the project to be self-sustaining at an effective level. When completed as planned, the final current forecast and assessment for electro-technology will be available at the Bicentennial Intercon in 1976.

The Nature of an Assessment of Telecommunications

In order to make a forecast of the technological growth and the development of new technology in the telecommunications field and then to make an assessment of the impact of that technology on society involves consideration of a large number of diverse factors. Some of those that are involved with the development of the technology consider the increase in transmission band width, the ease of obtaining point to point communication, the quality of the information presentation, and the information content and interpretation of the transmitted messages. These factors which are basically technical must be combined with the economic factors and the demand for different kinds of information transfer to project the technological development.

The assessment of the impact of this technology on society also involves a number of factors, some of them technical. The technical factors involve energy requirements and frequency spectrum saturation and allocation, as well as the problems of interference and interference patterns. The societal impacts involve the beneficial and adverse effects of instant communication to large populations at very low cost. Much has been written in this area with the idea of the cabled community with instantaneous transmission to all individuals on a selected basis. It has been postulated that this type of communication net could eliminate much of our need for transportation and could even change patterns of urbanization. The extent to which changes of this type are advantageous or deleterious is the type of difficult question that must be addressed by this kind of an assessment.

Another type of adverse effect that may occur involves the health effects of exposure to electromagnetic radiation. We know in advance that health effects are deleterious and the question that must be addressed is what level of health risk is society willing to accept for the benefits of this type of communication. This problem of health effects from electromagnetic radiation provides a good example for illustrating the problem of developing an assessment in the telecommunications area. The remainder of this paper will attempt to provide an assessment of the adverse health effects of telecommunications technology.

Nature of Health Effects

The effects due to exposure to nonionizing electromagnetic radiation are separable into two categories, thermal effects and nonthermal effects. Thermal effects arise from the heat produced when electromagnetic energy is absorbed and converted into heat energy. The phenomenon has beneficial applications in diathermy, microwave cooking, and industrial heating processes. If improperly used, there can also be harmful side effects such as heat stress, cataract formation, and testicular degeneration.[2,3] Nonthermal effects arise from the direct interaction of electromagnetic radiation on a molecular or macroscopic level without intermediate conversion to heat. Well documented examples include field evoked force effects such as molecular orientation[4] and microwave hearing, i.e., detection of the repetition rate of certain pulsed sources as audible noise.[5,6]

Since thermal hazards are recognized, the nonthermal effects of interest from a health viewpoint are those that occur at exposure levels which do not produce detectable or significant heating. These low-level nonthermal effects fall into two categories, direct health effects and interference effects. The direct health effects are the behavioral, neurological, and physiological reactions reported principally by investigators in the U.S.S.R., Czechoslovakia, and Poland.[7,8] Considerable controversy exists about the existence of some of these direct low-level nonthermal health effects and whether effects such as microwave hearing represent a hazard.

Interference effects include interference with life support systems such as cardiac pacemakers and telemetering equipment in hospitals, interference with critical communications such as aircraft guidance and communication, and interference with other devices ranging from electrocardiographs to home television receivers.[9,10,11]

In the U.S., guidelines or standards for exposure to nonionizing electromagnetic radiation are based on the premise that any direct effect on health is due to the heat that is generated when the radiation is absorbed. The Occupational Safety and Health Administration (OSHA) has adopted the American National Standards Institute C95.4 standard of 10 mW/cm^2 for the frequency range 10 MHz to 100 GHz as a consensus standard for occupational exposure.[12] More restrictive levels, 1 to 5 mW/cm^2, have been set by the Department of Health, Education, and Welfare over the frequency range 890 MHz to 6 GHz as emission limits for electronic products (microwave ovens) where neither the source nor the environment is subject to knowledgeable control.[13] Except for the product performance standard for microwave ovens, there is currently no Federal guideline or standard for nonoccupational exposure to electromagnetic radiation.

Based principally on the results of human clinical studies and occupational hygiene surveys, considerably lower exposure guidelines are used in the U.S.S.R., Czechoslovakia, and Poland for frequencies between 300 MHz and 300 GHz. The reported effects are generally reversible neurological and physiological reactions, i.e., the effect vanishes when or shortly after exposure to the field stops. For exposure periods lasting the entire workday, the standard is 0.01 mW/cm^2 in the U.S.S.R. and Czechoslovakia[14,15] and up to 0.2 mW/cm^2 in Poland.[16] For shorter exposure periods, higher values are allowed -- 1 mW/cm^2 for 15-20 minutes in the U.S.S.R. and up to 10 mW/cm^2 in Poland for individuals without health contraindications. The standard for nonoccupational exposure is .01 mW/cm^2 in Czechoslovakia and Poland[15,16] and .001 mW/cm^2 in the U.S.S.R.[14]

Considerable effort is being expended to determine the existence and health implications of exposure to nonionizing radiation at levels below 10 mW/cm^2. In 1968, the Office of Telecommunications formed the Electromagnetic Radiation Management Advisory Council (ERMAC) to recommend measures to investigate and mitigate undesirable side effects of electromagnetic radiation. After conducting a comprehensive review, the Council recommended a multiagency research effort to generate pertinent and dependable data for scientific evaluation of biological hazards.[17] The program recommends an expenditure of $63 million over a period of 5 years. The major participants are the Department of Defense, the Department of Health, Education, and Welfare, and the Environmental Protection Agency, which together account for about 85% of the recommended effort. The recommended funding level in Fiscal Year 1974 for all Federal agencies is $10.6 million, and it is estimated that actual expenditures will be about $6 million.[18] With the emphasis on research now being placed on effects that occur at exposure levels below 10 mW/cm^2, it is important to determine the actual levels of electromagnetic radiation in the environment. The information is needed to interpret effects in terms of actual exposure and to determine the magnitude of the problem if significant effects are discovered, say at levels below 1 mW/cm^2.

The Environment

Present Environment and Its Uncertainties

There are two distinct components to nonionizing electromagnetic radiation encountered in the environment. One is the relatively high radiation level from high power sources such as some radars and satellite communications stations where the power density in the useful beam can exceed that thought to be safe for human occupancy even outside the boundary of the facility, i.e., a thermal problem. The other is the general environmental level which results from the superposition of the fields from many sources. This level may be high or low depending on the location and the types of sources contributing to the exposure, but is generally low, i.e., except in unique situations, a nonthermal problem.

Of the two problems, thermal and nonthermal, the thermal is easier to resolve. If we assume that exposure to industrial and medical sources can be controlled by good industrial hygiene and that exposure to consumer products such as microwave ovens can be controlled by good design and product emission standards, then the number of sources capable of producing environmental levels of 1 to 10 mW/cm^2 is limited. In 1971, there were 223 nonpulsed emitters with an average effective radiated power (ERP) of one megawatt or greater and 375 pulsed emitters with a peak ERP of ten gigawatts or greater.[19] A one megawatt ERP source can produce a power density of 1 mW/cm^2 at a distance of .05 miles and 1 μW/cm^2 at about 2 miles from the source. The characteristics of the 20 most powerful nonpulsed and 20 most powerful pulsed sources are summarized in Tables 1 and 2.

Table 1

Source Parameters for Top 20 Nonpulsed Emitters

Rank	Frequency (MHz)	Average ERP (GW)
1	7748	31.6
2	8004	20.0
3	7985	20.0
4	5925	11.3
5	5925	7.9
6	5925	7.9
7	5925	7.9
8	5925	7.9
9	5925	7.9
10	5925	7.9
11	217	6.4
12	5985	6.4
13	7997	5.0
14	7990	5.0
15	7990	5.0
16	7986	5.0
17	7990	5.0
18	7986	5.0
19	7986	5.0
20	8004	5.0

The potential of these high power sources for causing thermal exposure problems is directly related to the probability of being illuminated by the beam and the duration of illumination. Both the satellite communication stations and radar installations use very directive antennas to achieve these extremely high effective radiated powers. Thus, the probability of being illuminated by a beam at any given time is quite small. Many of the sources are remotely located and almost all are surrounded by an exclusion area which further limits the probability of exposure. Site surveys are done for many sources to delineate operational procedures which will prevent the inadvertent exposure of occupied areas. Some sources are mechanically or electrically equipped to limit the pointing directions of antennas or to reduce or shut off power when occupied areas are scanned. Also, there is the rotational factor of many radars which further reduces the chances of prolonged exposure. Nevertheless, a careful analysis of high power sources is required to determine the adequacy of operational procedures and adherence thereto and to determine the unique exposure situations that might be encountered when radar beams are intentionally swept near the ground for navigational purposes or when satellite communications antennas may be depressed near the horizon for prolonged periods of time.

Table 2

Source Parameters for Top 20 Pulsed Emitters

Rank	Frequency (MHz)	Average ERP	Peak ERP
1	7840	840 MW	2.8 TW
2	2850	605 MW	2.2 TW
3	9378	640 MW	1.0 TW
4	2820	608 MW	0.95 TW
5	2840	608 MW	0.95 TW
6	5400	25.2 MW	0.63 TW
7	5555	94.3 MW	0.59 TW
8	5840	20.8 MW	0.52 TW
9	2900	115 MW	0.35 TW
10	1295	9.6 GW	0.32 TW
11	5400	149 MW	99.8 GW
12	5400	147 MW	99.8 GW
13	5480	12.7 MW	79.2 GW
14	5490	8.7 MW	47.5 GW
15	5600	8.7 MW	47.5 GW
16	3100	---	39.8 GW
17	2700	---	39.8 GW
18	2700	---	39.8 GW
19	2730	---	39.7 GW
20	2700	23.6 MW	35.4 GW

The nonthermal problem is considerably more complex and the complexity increases as the level considered to produce effects decreases. For a single source, it is a relatively easy task to determine the potential exposure level but another much more difficult task to map a truly reliable, calculated exposure pattern into a population distribution in the source's area. Reasons for this difficulty lie in the nonavailability or difficulty in obtaining accurate source antenna information and analytical solutions to complex environments filled with buildings, power lines, and other obstacles, and the highly dynamic nature of man-made RF levels.[19] The situation is confounded even more when multiple sources are considered. Also, at locations remote from a powerful source, an individual's exposure may be due principally to his close proximity to a relatively low power source which is not included in available source inventories. As a result of these factors, an attempt to map the total exposure levels in a given geographical area from the characteristics of sources which exist in that area will be an approximation to the real situation. There is simply not enough information on actual environmental levels to test how good the approximation for calculated multisource environments might be. Much of the available data is on man-made noise in particular frequency bands and does not include intentional signals in the analysis.[20,21] Two studies have attempted to provide integrated power density levels over a broad range of frequencies. A maximum value of 0.813 $\mu W/cm^2$ for the frequency range 54 to 220 MHz has been reported for Las Vegas, Nevada,[22] and a maximum value approaching 100 $\mu W/cm^2$ (+ or - 15 dB) for the frequency range up to 10 GHz has been reported for the Washington, D.C., area.[23] Whether or not this wide range of values is typical of differences in urban environments remains to be determined. It is expected that the highest levels will be encountered in urban areas because the density of sources corresponds roughly to the population density.[24]

Problem of Forecasting Future Without Data on Present Environment

There are a number of indicators that might be used to predict the future growth in environmental levels of electromagnetic radiation. The factory sales of electronics increased from about $3 billion in 1950 to $23 billion in 1968 and it is estimated that the net worth of electronic equipment today is $50 billion.[25] The number of television broadcast stations has increased from 6 in 1945 to 847 in 1969 and the number of radio stations increased from 930 to 6,442 over the same period.[26] Predictions through 1982 have been made on the number of households in the U.S., growth of the wired city (CATV), microwave frequency authorizations, land mobile licensed transmitters, FCC authorized transmitters and stations, and other factors which may be related directly or indirectly to the future growth of environmental levels.[27] However, without data on actual levels in the environment, these indicators cannot be used in more than a general way to forecast future environmental levels.

Source Inventories

One way to gain an appreciation of the scope of the potential environmental nonionizing electromagnetic radiation problem is to examine the number of sources capable of producing power densities of interest as distance from the source is increased. Figures 1 through 4 show the number of sources capable of producing 10, 1, 0.1, and .01 mW/cm^2 respectively at various distance intervals from the source. The upper and lower limits of the range correspond to the occupational exposure standards in the U.S. and U.S.S.R., respectively. The source inventory data was provided by the Electromagnetic Compatibility Analysis Center.[28] The analysis is based on a transmitter environment of 56,000 transmitters within the continental U.S., Alaska, and Hawaii, having an average ERP greater than 40 dBm (10 watts). The transmitter environment used for the source inventory includes deployed military equipment, frequency authorizations of all U.S. Government agencies, common carrier microwave equipment, and all FCC-licensed equipment except that in the Amateur Bands, Citizens Band, and Aircraft and Ship Services and 459,000 land mobile records. The omission of the lower powered sources should not effect the distributions at appreciable distances from the sources. However, at distances close to the source, the values in Figures 3 and 4 should be viewed as a minimum estimate of the number of sources capable of producing a power density of 0.1 mW/cm^2 and 0.01 mW/cm^2, respectively. For the distance interval between 31.7 and 100 meters, there are 2,366 sources capable of producing a power density of 10 mW/cm^2, 5,099 which can produce 1 mW/cm^2, 16,174 which can produce 0.1 mW/cm^2, and 30,102 which can produce 0.01 mW/cm^2. Thus, as one moves from thermal to nonthermal considerations, the number of sources of concern increases by a factor of 13 or more.

Measurements Program

Good data on actual environmental levels of nonionizing electromagnetic radiation in both urban and rural areas is required in order to use the results of biological effects research to predict risks and also to provide baseline data for interpretation of growth rate indicators. It appears that the most direct method of predicting environmental levels is to predict the number and types of sources in a given area and then calculate the contribution of each source from the pertinent source parameters. We have already indicated the difficulties inherent in such an approach. More sophisticated modeling which takes into account variations in terrain and ground clutter may yield the required result. However, a large investment in sophisticated modeling should not be made until data is available to test the "goodness" of the model.

In order to obtain the required data on environmental levels, the Environmental Protection Agency has started an environmental nonionizing radiation measurements program. The program is being developed in two phases. The near-term effort is concentrated on field studies of selected high power sources using for the most part wide band, relatively high level, frequency integrative devices. Concurrently, the capability to measure and analyze the multisource general environment is being established for the frequency range from 10 kHz to 10 GHz. The measurement system consists of several different antenna arrays to cover the required frequency range, a commercially available spectrum analyzer, and a small minicomputer which controls the spectrum analyzer and processes and analyzes the amplitude data. The measurements system will be installed in a mobile van and should be fully operational by June 1974.

Interrelationship of Health Effects Research and Environmental Measurements

The requirements placed on an environmental measurements program are a strong function of the power density level which is demonstrated to produce an effect. It is anticipated that there will be sufficient information from current and planned research to make a judgment on the severity of nonthermal effects within the next few years. Based on this research and other factors, guidelines will be developed, if required, to protect public health and the environment. One question that needs to be answered in the nonthermal effects area is whether interference effects ought to be controlled, i.e., does there need to be a trade off between allowed environmental levels and the level where a particular device is required to reject interfering signals.

In this context, it is interesting to examine the impact on a measurements program of the selection of particular levels as environmental exposure guidelines. For predictive purposes, we have examined three possible power density levels: 1, 0.1, and 0.01 mW/cm^2. The highest level, 1 mW/cm^2, is a factor of ten below the current U.S. guideline for occupational exposure and the lowest level, 0.01 mW/cm^2, is the guideline used for nonoccupational exposure in Czechoslovakia and Poland, and is the lowest level where we have reasonably reliable data on the number of sources that need to be considered.

Environmental levels of 1 mW/cm^2, except in unique exposure situations, should be produced only in the vicinity of relatively high power sources. Most of these sources can be located and classified according to type from existing source inventories. Relatively simple procedures can be used to identify the installation of new sources. Field studies on specific types will define their hazard potential and provide the basic information required to make decisions on what controls are needed.

At a level of 0.1 mW/cm^2, measurements of general environmental levels in areas of high source density are required to augment the data on specific high power sources. Reasonable estimates of the size of the population at risk can then be made by combining the environmental data with source inventories.

At a level of 0.01 mW/cm^2 or below, the number of contributing sources becomes so large that the emphasis must shift from problem definition to the verification, under field conditions, of predictive models for calculating exposure levels. Extensive statistical modeling would be required to incorporate such factors as the large number of land mobile transmitters and other low-powered sources.

Most of the current research on the biological effects of nonionizing radiation bears directly or indirectly on the existence of effects occurring at levels of 10 mW/cm^2 or below and on a determination of the health implications of observed effects. A careful distinction must be drawn between an effect and an adverse health effect. Though it may be several years before definitive results are available, enough information now exists to begin an assessment of the impact of low-level effects and to identify areas where additional information needs to be obtained while the effects problem is being resolved. If effects are not demonstrated at levels below 1 mW/cm^2, then the problem reduces to assuring ourselves that the limited number of sources which can now produce environmental levels of this magnitude and new sources are operated in a way that keeps the exposure of people below this level. If effects are demonstrated below 1 mW/cm^2, then the scope of the problem increases significantly. In addition to determining the existing environment, models for predicting environmental levels from source inventories or growth rate indicators must be developed to provide the basic data to assess the future impact of electro-technology.

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Figure 1. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater Than 10 mW/cm^2, as a Function of Distance

Figure 2. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater Than 1.0 mW/cm^2, as a Function of Distance

Figure 3. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater Than 0.1 mW/cm^2, as a Function of Distance

Figure 4. Cumulative Distribution of Emitters in the United States Capable of Producing a Power Density Equal to or Greater Than 0.01 mW/cm^2, as a Function of Distance

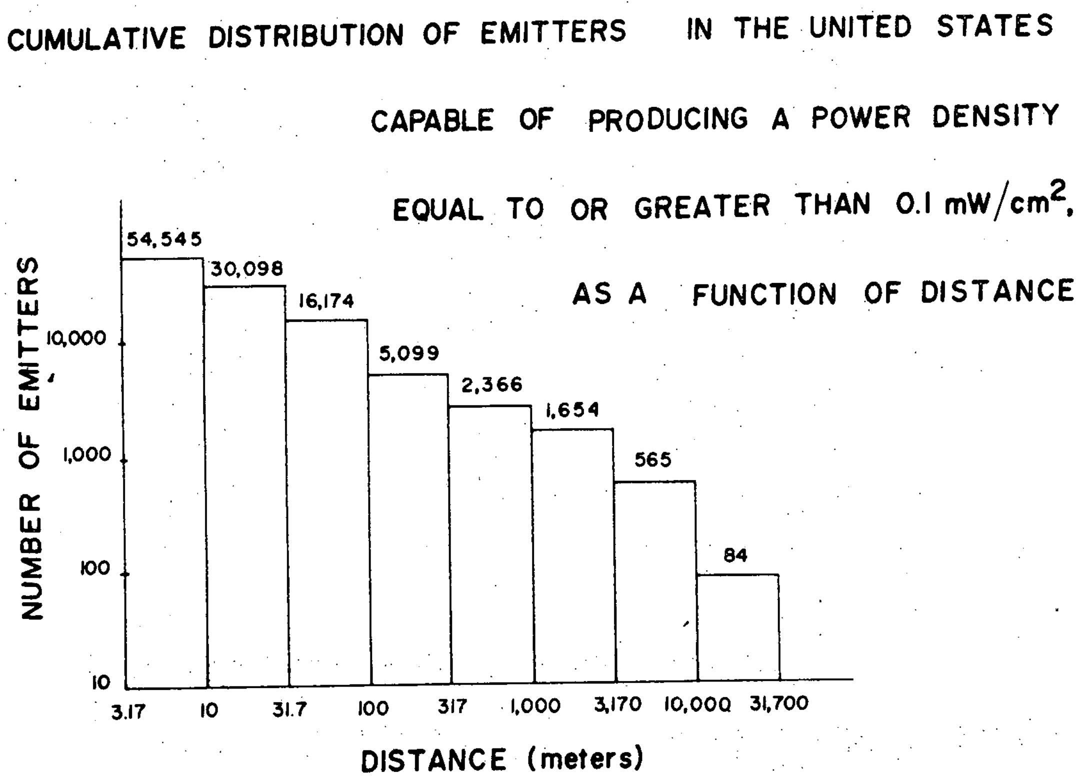

FIGURE 1

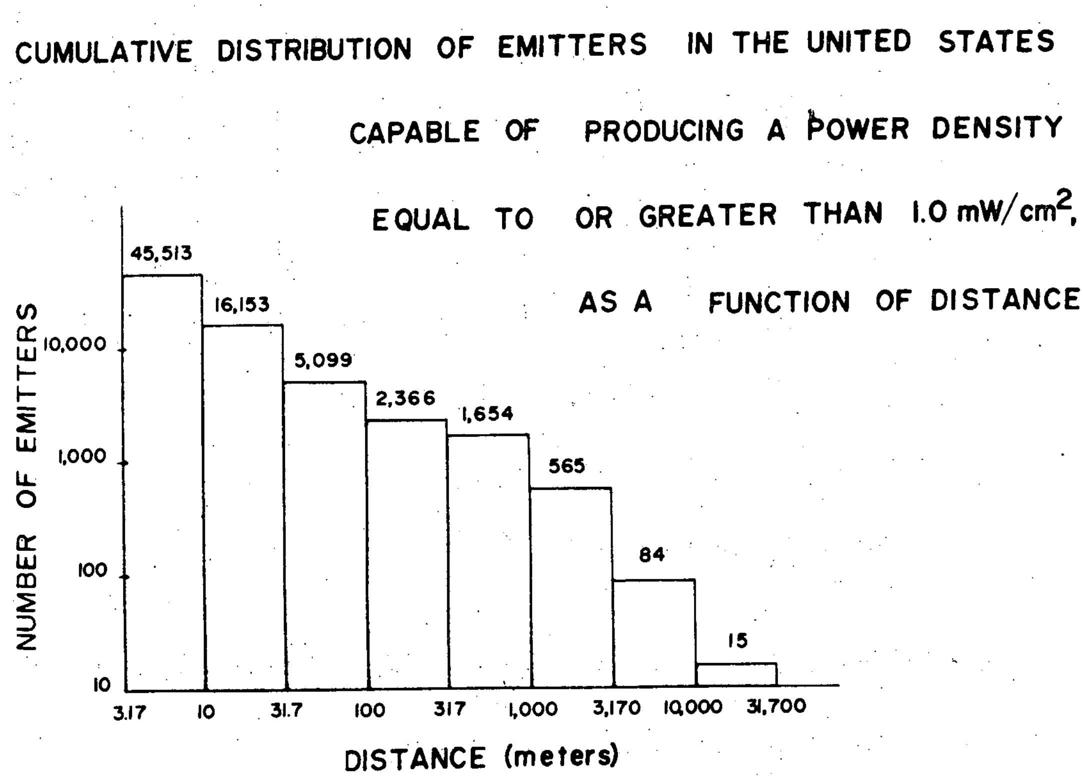

FIGURE 2

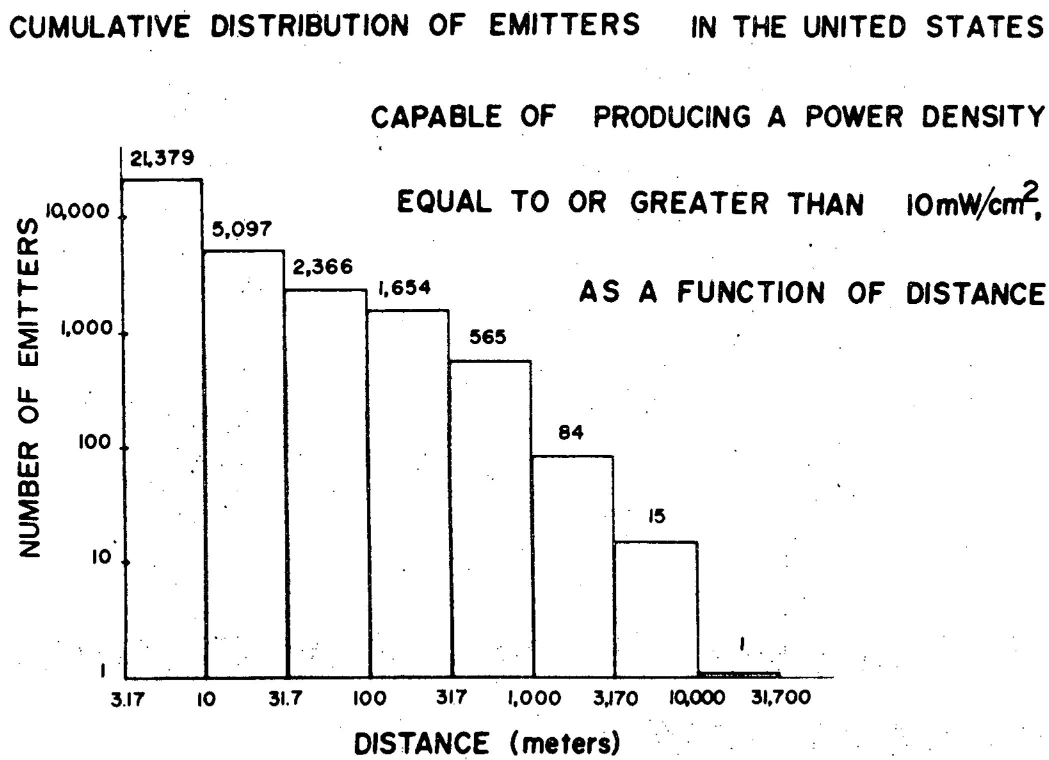

FIGURE 3

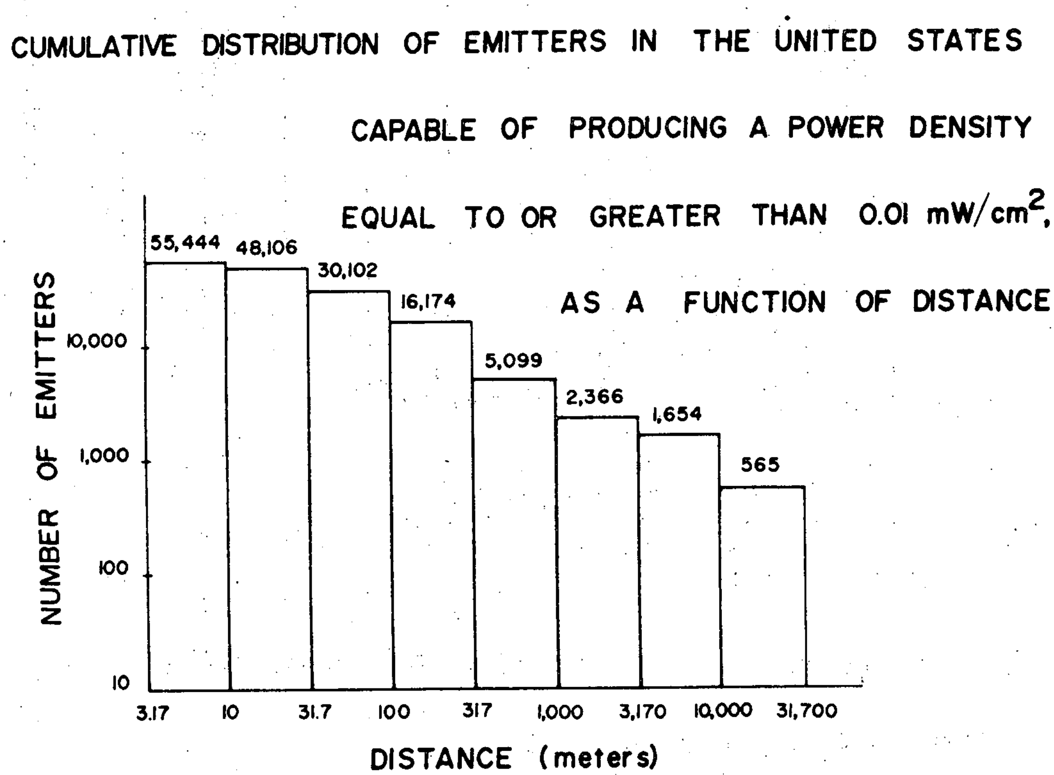

FIGURE 4