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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Requirements for an Effective National Nonionizing Radiation Measurement System

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Requirements for an Effective National Nonionizing Radiation Measurement System

Prepared in Response to a Recommendation by the Senate Committee on Commerce, Science, and Transportation

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ABBREVIATIONS

AM	-	Amplitude Modulated
ANSI	-	American National Standards Institute
BENER	-	Biological Effects of Nonionizing Electromagnetic Radiation
BRH	-	Bureau of Radiological Health
CAT	-	Computed Axial Tomography
CRCPD	-	Conference of Radiation Control Program Directors
CW	-	Continuous Wave
D.C.	-	Direct Current
DOE	-	Department of Energy
ELF	-	Extremely Low Frequency
EM	-	Electromagnetic
EMI	-	Electromagnetic Interference
EP	-	Engineering Problem
EPA	-	Environmental Protection Agency
EPRI	-	Electric Power Research Institute
FLN	-	Fundamental Limitation of Nature
GHz	-	Gigahertz = 10^9 hertz
H	-	High
Hz	-	Hertz - cycles per second
IEEE	-	Institute of Electrical and Electronics Engineers
ISM	-	Industrial, Scientific, and Medical
L	-	Low
LR	-	Long Range
M	-	Medium
MHz	-	Megahertz = 10^6 hertz
MR	-	Medium Range
N	-	No problem
NA	-	Not Applicable or Not Appropriate
NCRP	-	National Council on Radiation Protection and Measurements
NER	-	Nonionizing Electromagnetic Radiation
NIEHS	-	National Institute of Environmental Health Sciences
NIOSH	-	National Institute of Occupational Safety and Health
NMS	-	National Measurement System
NTIA	-	National Telecommunications and Information Administration
OSHA	-	Occupational Safety and Health Administration
OSTP	-	Office of Science and Technology Policy
SR	-	Short Range
TEM	-	Transverse Electromagnetic
U	-	Unknown
USNC/USRI	-	U.S. National Committee for the International Union of Radio Science
WISH	-	Workers Institute for Safety and Health
X	-	Treated Elsewhere

REQUIREMENTS FOR AN EFFECTIVE NATIONAL
NONIONIZING RADIATION MEASUREMENT PROGRAM

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The report provides a detailed assessment of the capabilities, limitations, and requirements of the National Nonionizing Radiation Measurement System. The priorities of these measurement requirements are assessed according to their ability to contribute (1) to the core competence of determining the electric and magnetic fields of a source or (2) to the associated capabilities for (a) generating and applying reference fields, (b) characterizing sources and reflectors, or (c) recording exposure histories. The report examines these measurement capabilities at all frequencies between dc and 300 GHz. These measurement requirements are reviewed in the context of the overall Federal Program for Nonionizing Electromagnetic Radiation Safety. The report concludes that the need to develop and improve instrumentation, measurement standards, calibration services, and standardized measurement techniques far outweighs the need to establish regional calibration laboratories at this time. The study was conducted with the assistance of the Conference of Radiation Control Program Directors in response to a recommendation by the U.S. Senate Committee on Commerce, Science, and Transportation.

Key words: calibration; dosimetry; electric fields; electromagnetic interference; exposure history; instruments; magnetic fields; nonionizing radiation; regional calibration laboratories; standards; techniques.

1. EXECUTIVE SUMMARY

The Report on Radiation Health & Safety published in December 1978 by the Senate Committee on Commerce, Science, and Transportation included the following recommendations:

> The National Bureau of Standards (NBS) should intensify its efforts to provide the physical measurement standards, calibration services, and standardized measurement techniques necessary for research and regulatory activities relating to nonionizing radiation.
>
> Additionally, NBS, in conjunction with the Conference of Radiation Control Program Directors, should prepare for the Committee on Commerce, Science, and Transportation a review of the need for an intermediate level of calibration

services, such as regional facilities to better couple NBS laboratories with State and industrial needs.

This document was prepared in response to those recommendations.

Based upon the findings of this study the National Bureau of Standards and the Conference of Radiation Control Program Directors (CRCPD) have concluded that for nonionizing electromagnetic radiation (NER) the need to develop and improve instrumentation, measurement standards, calibration services and standardized measurement techniques far outweighs the need to establish regional calibration laboratories at this time.

This conclusion rests upon several observations. First, NBS calibration services are not now experiencing excessive demands - principally due to a lack of regulatory pressure at either the Federal or State level and to the fact that there are not now a great number of instruments to be calibrated. (This situation may change in the future as regulatory agencies such as EPA and OSHA increase their radiation protection activities - see section 3.3.1.) A second reason is that there appear to be no unique targets of opportunity that might argue strongly for the establishment of such services.

The Conference of Radiation Control Program Directors believes that the principal barriers to its own efforts in assuring nonionizing radiation safety are the lack of (a) a general population exposure standard which its members can enforce, (b) enabling legislation at the State level which would give them authority to act, (c) inexpensive, commercially available field-survey instruments, and (d) adequately trained people (section 3.3.1).

The preparation of this report provided NBS with an opportunity to survey the current capabilities and deficiencies of the national measurement system (NMS) for nonionizing electromagnetic radiation (NER). The requirements which stem from these deficiencies were then reviewed (section 3.2) and priorities established (section 3.5). The detailed results of this review are presented in Tables 2 through 13. Some 84 specific, measurement-related requirements were identified. Slightly more than half were considered to have a high priority.

About 82 percent of the high-priority tasks identified in this study are already being addressed, either by NBS or by other organizations. Additionally, we learned that plans are already being developed to deal with nearly all of the remaining high-priority, measurement-related requirements.

2. INTRODUCTION

2.1 Purpose of Report

The Report on Radiation Health & Safety [1] published in December 1978 by the Senate Committee on Commerce, Science, and Transportation included the following recommendations:

> The National Bureau of Standards (NBS) should intensify its efforts to provide the physical measurement standards, calibration services, and standardized measurement techniques necessary for

research and regulatory activities relating to nonionizing radiation.

Additionally, NBS, in conjunction with the Conference of Radiation Control Program Directors, should prepare for the Committee on Commerce, Science, and Transportation a review of the need for an intermediate level of calibration services, such as regional facilities to better couple NBS laboratories with State and industrial needs.

This document was prepared in response to those recommendations. It presents the results of a study conducted by NBS, with the cooperation and assistance of the Conference of Radiation Control Program Directors, an organization of professional personnel who administer radiation protection programs in State and local governments.

To determine whether regional calibration facilities were needed at this time, the study first assessed the current capabilities and deficiencies of the national measurement system (NMS)[1] for nonionizing electromagnetic radiation (NER). The requirements which stem from these deficiencies were then reviewed and priorities established. This analysis and the conclusions which are drawn from it appear in sections 3 and 4 below. This review has proved to be particularly valuable to NBS both for assessing the adequacy of our current activities and for planning their future evolution.

2.2 Scope of the Report

For purposes of this report NER is defined as that portion of the electromagnetic spectrum extending from 0 hertz (cycles per second, Hz) to 300 GHz (3×10^{11} cycles per second). This portion of the spectrum includes both static (D.C.) and slowly varying electric and magnetic fields (e.g., those from high voltage transmission lines), as well as microwave and other radio frequencies. These radiations are called nonionizing because, in interacting with matter, they do not have sufficient energy to cause ionization, i.e., to separate electrons from atoms or simple molecules. Rather, their principal mechanisms of interaction are (a) ionic conduction (which results in an energy loss due to the electrical resonance of the medium), and (b) excitation of vibrational or rotational states of molecules. All of these mechanisms produce heat. This report provides a detailed assessment of the NMS requirements over the frequency range 0 - 300 GHz only.

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[1]The national measurement system consists of all of the activities and mechanisms -- intellectual and operational, technical and institutional -- used to provide physical measurement data to allow the creation of the objective, quantitative knowledge required by our society. For a complete discussion of this concept, see Structure and Functions of the National Measurement System by Raymond C. Sangster, NSBIR 75-949 (July, 1977), available from National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22151. Accession number PB 274-048, $10.

Ultraviolet, visible and infrared radiation are also forms of nonionizing electromagnetic radiation. However, even though the Conference of Radiation Control Directors has encountered a number of measurement problems in these areas, those problems will not receive a detailed examination in this report (see sections 3.3.5 and 3.3.6). There are three reasons for this. First, these subjects received little attention during the Committee's hearings in 1977. Second, they were not included in the deliberations of the ad hoc Working Group [2] established by the Office of Science and Technology Policy (OSTP) in 1978 or by the Interagency Task Force [3] on Biological Effects of Nonionizing Electromagnetic Radiation (BENER) formed in 1979 by the National Telecommunications and Information Administration (NTIA). And finally, the measurement problems which the States have experienced are directly related to the enforcement of regulations promulgated by the Bureau of Radiological Health (BRH). BRH is working directly with the States on these matters (see section 3.3). The basic measurement standards needed for these cooperative efforts are already available from NBS.

2.3 How This Report was Written

In gathering information for this report, NBS staff members participated in four meetings with members of the CRCPD. Several drafts have been reviewed by a task force of CRCPD members.[2] This final document reflects their suggestions and comments. Additionally, the NBS staff gathering data for this report have interviewed officials in at least seven Federal agencies with specific responsibilities in this area to determine their measurement and instrumentation needs.

In January of 1981, a draft of this report was submitted to 11 Federal agencies for review and comment. To the maximum extent practical, their suggestions have also been incorporated.

3. MEASUREMENT STRATEGY FOR NER HEALTH & SAFETY

3.1 Structure of the Measurement Problem

As it applies to issues of NER health and safety, the objective of the NBS program is

> To develop the theoretical and experimental basis for the measurements needed to predict or reduce the extent of interference from nonionizing electromagnetic radiation with electrotechnical or biological systems.

Figure 1 illustrates the relationship between the four elements of the NBS strategy for achieving this objective. All of the measurement problems

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[2]Current members of the CRCPD task force include Mr. Charles Tedford (Arizona) Chairperson, Mrs. Susan Kent (Texas), and Dr. Francis Bradley (New York). Federal agency observers include Mr. Frank Tipton (OSHA), Mr. Norbert Hankin (EPA), Mr. William Herman (BRH) and Dr. Howard Clark (NBS). Mr. Joseph Thiel (Texas), a former member of the task force, also made significant contributions to the development of this document.

MEASUREMENT STRATEGY
FOR
NONIONIZING ELECTROMAGNETIC RADIATION
HEALTH & SAFETY

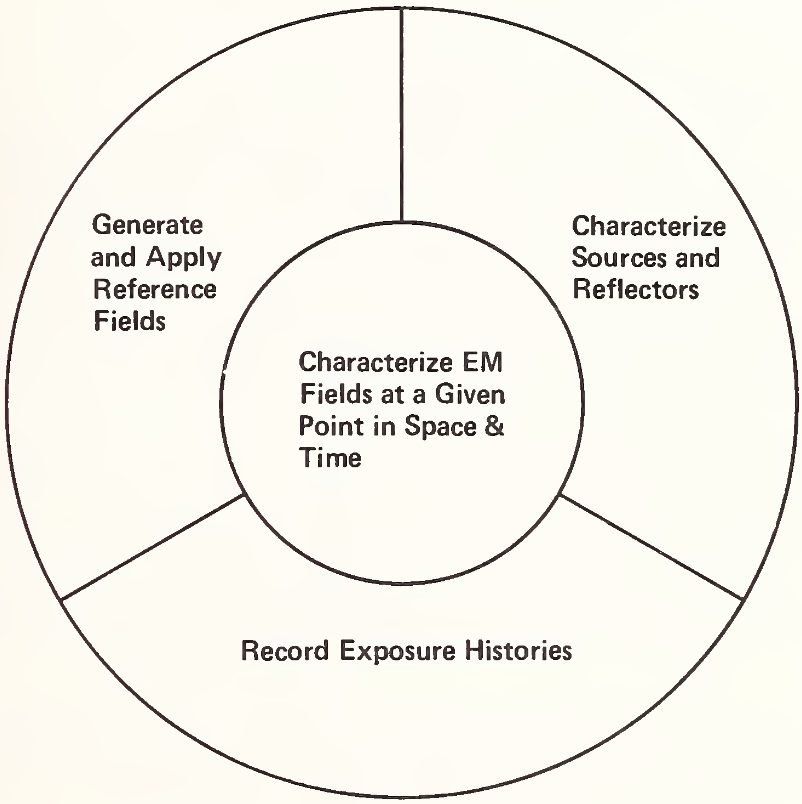

Figure 1

involving radiated electromagnetic fields, which the authors of this report have encountered, appear to fall under one of the four elements illustrated in that figure; i.e., they require efforts to:

I. Characterize the electromagnetic field at a given point in space and time;

II. Generate or apply reference fields;

III. Characterize radiation sources or objects that interact with radiation fields either by scattering, reflection or absorption; or

IV. Generate a recorded history of exposure to such fields.

The geometrical structure of Figure 1 emphasizes that the ability to characterize electromagnetic (EM) fields plays a central role in dealing with all such problems. Thus, it is impossible to apply a reference field, characterize a radiation source or record an exposure history without first developing the ability to characterize electromagnetic fields under the specific conditions that apply to the problem at hand. Elements II, III, and IV, however, are relatively independent of one another.

3.2 Analysis of Measurement Requirements

In order to assess the requirements of the national measurement system for NER, each of the four major objectives has been subdivided into logically independent pieces, e.g., measurement of magnetic field vs. electric field and measurements at radiofrequencies vs. extremely low frequencies (D.C. or 60 Hz). While it has not been possible to identify completely independent subgroups (a single TEM cell[3], for example, can be used to both generate and apply electric and magnetic fields), the division should assist the reader in focusing his attention upon more narrowly defined measurement requirements. A complete list of subheadings is given in Table 1.

It should be noted that objective I in Table 1 is labeled "Develop Ability to Characterize Electromagnetic Fields" whereas sub-elements I.A through I.D (and also II.A through II.G) refer either to electric or to magnetic fields but not to electromagnetic waves. The distinction is an important one and results from the fact that no instruments are yet available to directly measure the intensity of an electromagnetic field ($|\vec{E} \times \vec{H}|$) vs. independently measuring the intensity of the individual field components (E and H).

In the far field[4] of a radiation source, measuring either one of the components ($\vec{E}$ or $\vec{H}$) is entirely adequate. This is because, in the far field, knowledge of one component enables calculation of the other or of the power

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[3]A TEM cell is a special, expanded waveguide section that supports a transverse electromagnetic planewave.

[4]Far-field conditions apply when the source of radiation or any reflecting structures are sufficiently far away that the transmitted electromagnetic wave behaves like a plane wave. Under these conditions the electric and magnetic field vectors are perpendicular to one another and have a known ratio.

TABLE 1

MEASUREMENT STRATEGY
FOR
NONIONIZING ELECTROMAGNETIC RADIATION
HEALTH AND SAFETY

I. Develop Ability to Characterize Electromagnetic Fields

   A. Instruments and procedures for radiofrequency (RF) electric fields

   B. Instruments and procedures for RF magnetic fields

   C. Instruments and procedures for extremely low frequency (ELF) electric fields

   D. Instruments and procedures for ELF magnetic fields[5]

II. Develop Ability to Generate and Apply Reference Fields

   A. Equipment and procedures to generate uniform RF electric fields of known magnitude, direction, and phase

   B. Equipment and procedures for subjecting test objects to uniform RF electric fields of known magnitude

   C. Equipment and procedures to generate uniform RF magnetic fields of known magnitude

   D. Equipment and procedures for subjecting test objects to uniform RF magnetic fields of known magnitude

   E. Equipment and procedures for generating and applying ELF electric fields

   F. Equipment and procedures for generating and applying ELF magnetic fields[5]

III. Develop Ability to Characterize Sources and Reflectors

   A. Procedures to characterize radiation sources

   B. Instruments and procedures to collect and characterize RF radiation scattered from an object

   C. Explore interactions between electromagnetic (EM) waves and reflectors

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[5]The ability to measure, generate and apply extremely low frequency magnetic fields is very highly refined. Except for the case of personal dosimeters (treated in Table 13), we are aware of no measurement problems in this area - particularly as they might relate to issues of health and safety. These subjects will receive no further discussion in this report.

density $\vec{S} = |\vec{E} \times \vec{H}|$. However, in the near field[6] of a source (or under near-field-like conditions) $\vec{E}$ and $\vec{H}$ are not perpendicular to one another; nor do they necessarily have the same ratio as in the far-field case. Thus, until instruments have been developed which can simultaneously determine both $\vec{E}$ and $\vec{H}$, most work will focus on the measurement of either the electric field or the magnetic field independent of one another. While there is some uncertainty about the usefulness of measuring $(\vec{E} \times \vec{H})$ in any near-field situation, it is clearly desirable to simultaneously determine both $\vec{E}$ and $\vec{H}$ at the same point. The development of such instruments and the associated measurement techniques is, of course, one of the major thrusts of the NBS program.

Tables 2 - 13 form the core of this report. Except as noted, one table has been prepared for each of the subactivities identified in Table 1. These tables provide a current assessment of the capabilities and applications of NER measurement technologies as they exist today and as they relate to issues of radiation health and safety.

In developing these tables, the authors have attempted to provide as broad a view as possible; thus, we report on capabilities that are known to exist within U.S. industry, in foreign or academic laboratories, and in other Government agencies as well as those which exist at the National Bureau of Standards. We have attempted to exclude from consideration in this report any capabilities that do not have either a direct or closely related impact on health and safety. Thus, no attention is given to NBS expertise in characterizing the performance of antennas used, say, for satellite communications; but we have included the techniques for characterizing potential sources of electromagnetic interference (EMI), which may directly produce unsafe conditions, e.g., unintended detonation of explosives or disruption of medical services.

For each capability noted in Tables 2 - 13, the authors have attempted to identify any corresponding limitations. Thus, for example, a TEM cell of sufficient size cannot be reliably operated at frequencies much higher than 100 MHz -- an engineering problem (EP) that can probably be solved. Other kinds of limitations have also been noted. For example, no isotropic antenna will ever give information on the direction from which a signal is coming. This is a fundamental limitation of nature (FLN). If directional information is needed, another kind of instrument will have to be used.

All of the limitations thus identified lead naturally to new requirements, e.g., extending the frequency band over which a TEM cell can operate. These requirements have been classified either as:

(a) short range (SR) - something that is already being addressed, either at NBS or elsewhere;

(b) medium range (MR) - a problem that is not now being addressed, but one for which work could begin as soon as resources become available (either new resources or ones that become available as the short term goals are achieved);

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[6]Near-field conditions apply close to the source of radiation or to objects that modify the field of a distant source, e.g., by producing reflections.

(c) long range (LR) - a problem that will require a long time to solve (six years or more), or one for which definite plans do not yet exist; even if resources became available today, work could not begin to directly address such a problem.

Each of these requirements is followed by single letter (H, M, L, N or X) in parentheses. The letters give our assessment of the relative priority for each of these requirements: H = High; M = Medium; L = Low; N = No Problem, and X = Treated Elsewhere. These assessments, of course, were influenced by our discussions with personnel in other agencies, in U.S. industry and the States. Lowest priority was assigned to tasks (1) which would result in long-range, second or third order improvements in existing capabilities (e.g., T2, R5)[7]; (2) which cannot be approached until more fundamental (and, hence, more important) intermediate tasks are accomplished (e.g., achieving T6, R5 requires completing T6, R4); or (3) for which there is very little demand at this time (e.g., T7, R2). On the other hand, highest priority was assigned to (1) fundamental tasks at the core of the measurement strategy upon which other capabilities will depend (e.g., T2, R14); (2) measurement requirements which are needed to test for compliance with existing radiation protection standards (e.g., T2, R4); (3) tasks whose outcome will have broad and critical impact among researchers concerned with biological effects or equipment immunity (e.g., T5, R8); or (4) projects whose results are urgently needed to carry out an agency's mission (e.g., T4, R9).

Finally, in Tables 2 - 13 we also identify the technical approach that is being used to address these problems and note who is working on them.

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[7](T2, R5) means Table 2, requirement 5.

TABLE 2

I. Ability to Characterize EM Fields

A. Develop Instruments & Procedures to Characterize RF (1 kHz to 300 GHz) Electric Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
Broadband E-field meters are commercially available to determine the time-averaged total electric field (CW and pulsed) present at a given point in space and time. Some meters have an isotropic response; others, give one or more of the x, y, and z components. Individual meters cover various parts of the frequency band between 500 kHz and 26 GHz and fields strengths from 1 V/m to 3,000 V/m.	To determine electric field levels (a) in general or occupational environments, (b) in facilities used to study the effects of such fields on electronics or biological systems and (c) in characterizing radiation sources and reflectors (or absorbers).	FLN-Broadband meters do not provide data on field strength at each frequency in the band.	(1) If multiple sources are present, such data may be helpful in identifying which sources make the strongest contributions to the total signal. (N)	Use a spectrum analyzer when such data are required.	Commercially available.
		FLN-Isotropic meters do not provide data on field strength vs. direction, i.e., they can not be used to determine the location of a source.	(2) Develop broadband directional antenna which can be used to distinguish between sources. (H) SR: 1 MHz - 6 GHz MR: 1 MHz - 26 GHz LR: 1 MHz - 40 GHz	 → TEM Horn → Undetermined → Undetermined	Short range tasks included in NBS program. NBS developing specific plans for medium and long range tasks.
		FLN-In far-field situations knowledge of electric field strength enables calculation of both the magnetic field strength and power density. This is not possible under near field or near-field like conditions where 75% of measurement problems are believed to occur.	(3) Develop prototype instruments & procedures to simultaneously measure E & H. (H) SR: 0.1 - 100 MHz MR: 10 - 1000 MHz LR: 25 - 1 MHz	Develop new probes (antennas) that will respond linearly to both E & H.	Feasibility study included in NBS program.
				Develop probe containing 3 orthogonal dipoles & 3 orthogonal current loops.	BRH pursuing this approach.
		EP-No meters cover full range of existing or proposed personnel exposure standards.	(4) SR: Extend upper frequency limit of high-precision, NBS E field meters to 5 GHz. (H)	Suppress the natural resonance of the receiving antennas.	NBS presently addressing this problem.
			(5) MR: 18 GHz. LR: 100 GHz. (L)	Uncertain.	NBS considering possible options.
		EP-Incomplete understanding of how such meters "add" electric fields arising from multiple sources and/or frequencies.	(6) MR: Develop such an understanding. (H)	Theoretical studies combined with experiments conducted in carefully controlled environments.	NBS is developing program plans.
		EP-Many instruments respond to signals outside their intended frequency band, e.g., to AM fields.	(7) SR: Instruments which have no out of band response or for which any response is well characterized. (H)	Determine extent of such responses. Then modify designs to eliminate, or, at least, inform customers.	Manufacturers responsibility. Some evaluations by BRH & NIOSH.

ABBREVIATIONS

NA = Not Applicable or Not Appropriate
FLN = Fundamental Limitation of Nature (i.e., no direct solution is possible without violating some law of nature)
EP = Engineering Problem (i.e., can probably be solved by some amount of additional work)
SR = Short Range
MR = Medium Range
LR = Long Range
U = Unknown
H = High
M = Medium
L = Low
N = No problem
X = Treated elsewhere

TABLE 2 (continued)

I. Ability to Characterize EM Fields

A. Develop Instruments and Procedures to Characterize RF (1 kHz to 300 GHz) Electric Fields

Capability	Applications	Limitations	Requirements	Technical Approach	Efforts
		EP-Minimum frequency (500 kHz) is not low enough.	(8) Low frequency limit should be extended to SR: 10 kHz (H) MR: 1 kHz (M)	Design new probes and circuitry capable of operating reliably over band.	NBS & NIOSH developing program plans.
Commercially available spectrum analyzers permit determination of electric field strength. Freq. Range: 1 kHz-22 GHz Sensitivity: microvolts/m to volts/m (antenna dependent).	Same as above. Knowledge of electric field intensity at specific frequencies is useful in determining the contribution of various radiation sources to the total field present.	EP-Systems are large and expensive. Performance highly dependent on characteristics of antenna in use.	(9) LR: Smaller and less expensive systems needed. Not a priority need at this time. (L)	NA	NA
		EP-Total system (antenna & instrumentation) must be jointly calibrated.	(10) MR: System calibration techniques are needed. (M)	Develop realistic calibration environment.	NBS developing specific program plans.
Miniature (3.0 mm diameter) isotropic electric field probes are now commercially available.	Determine electric field within test subjects.	EP-Present probes are 3 to 5 times larger than desired.	(11) SR: Develop isotropic probes of one half to one mm diameter. (M)	Unknown.	U of VA and NSF working on solution of this problem.
		EP-Probes are mounted on long, rigid cylinders and are not acceptable for use in unrestrained animals.	(12) LR: Design appropriate telemetry system. (M)	Unknown.	Unknown.
			(13) LR: Find alternative biophysical mechanisms which might indicate field strengths. (M)	Maintain an awareness of on-going research projects. Evaluate feasibility of adapting new discoveries.	A continuing part of the NBS program and other agency programs.
High-precision, experimental, laboratory-type systems are available to determine the intensity vs. time profile of rapidly varying radiated electric fields (pulsed and impulsive fields, e.g., 70 ps pulses).	Same as for broadband E-field meters. Specialized applications involve inverse scattering (i.e., determining the shape of an object by looking at the radiation reflected from it) and characterizing the EM pulses which accompany nuclear explosions.	EP-Existing systems are both large and expensive.	(14) MR: Inexpensive (<$1000) hand-held instruments for measuring pulsed and impulsive fields. (H)	Develop high speed microprocessor based broadband E-field meter.	NBS developing program plans.
		EP-Present antennas are not isotropic; in fact they must be shaped to match the wavefront.	(15) MR: Small, broad band, isotropic antennas. (H)	Unknown.	NBS developing program plans.

TABLE 3

I. Ability to Characterize EM Fields
B. Develop Instruments and Procedures to Characterize RF (1 kHz to 300 MHz) Magnetic Fields

Capability	Applications	Limitations	Requirements	Technical Approach	Efforts
Broadband, isotropic, magnetic field meters are commercially available for frequencies between 10 and 300 MHz with an accuracy of about 0.5 dB (6%).	To determine magnetic field levels (a) in general or occupational environments, (b) in facilities used to study the effects of such fields on electronics or biological systems and (c) in characterizing radiation sources and reflectors (or absorbers).	EP-Some meters measure magnetic field but read out in milliwatts per square centimeter, or in volts/meter.	(1) LR: Meters should read-out in units of the quantity to which they respond. (H)	Change dial face on the instrument.	Manufacturer's responsibility.
		EP-Low frequency limit does not include AM Broadcast band or induction heaters.	(2) SR: Minimum operating range .3 MHz - 100 MHz. (H)	Develop probe with three orthogonal loops and metering circuitry.	NBS & NIOSH involved.
		FLN-In far-field situations knowledge of magnetic field strength and power density. This is not possible under near-field or near-field like conditions where 75% of measurement problems are believed to occur.	(3) Develop prototype instruments and procedures to simultaneously measure E&H. (H) SR: 0.1 - 100 MHz MR: 10 - 1000 MHz LR: 25 MHz - 1 MHz	Develop new probes (antennas) that will respond linearly to both E&H.	Feasibility study included in NBS program.
				Develop probe containing 3 orthogonal dipoles and 3 orthogonal current loops.	BRH pursuing this approach.
		EP-Many instruments respond to signals outside their intended frequency band, e.q., to AM fields.	(4) SR: Instruments which have no out of band response or for which any response is well characterized. (H)	Determine extent of such responses. Then modify designs to eliminate, or, at least, inform customers.	Manufacturer's responsibility. Some evaluations by BRH & NIOSH.
Special laboratory equipment has been developed to provide single axis measurements of 0.5 dB (or 6%) accuracy over the frequency range of 10 MHz to 75 MHz at field strengths as high as 100 A/m. Special calibration techniques permit substantial improvements in accuracy and extension of the frequency range to at least 250 MHz.	As above.	EP-Instruments are large and expensive.	(5) SR: Need small portable meters designed for commercial production.* (M)	Apply modern techniques for miniaturization of electronic components. Design appropriate probes.	BRH, NBS & NIOSH involved.
		EP-Some instruments are not isotropic.	(6) MR: Meters should be isotropic to speed up data gathering and to improve accuracy.* (M)	Use probes with three orthogonal loops and associated metering circuitry. Allow for read out from each loop.	BRH, NBS & NIOSH involved.
		EP-Minimum frequency (10 MHz) is not low enough.	(7) MR: Low-freqency limit should be extended to 10 kHz in order to deal with VDT's. (H)	Design new probes and circuitry capable of operating reliably over this band.	BRH, NBS & NIOSH involved.

*One instrument of this sort (400 kHz - 150 MHz) was constructed for the Bureau of Radiological Health. It was described in a paper by Paul S. Ruggera entitled, "E- & H-Field Instrumentation and Calibration Below 500 MHz" presented at the USNC/URSI annual meeting in Boulder, Colorado, Oct. 20-23, 1975. No commercial probes for this design have ever been developed.

TABLE 4

I. Ability to Characterize EM Fields

C. Develop Instruments and Procedures to Characterize ELF Electric Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
60 Hz electric field meters are commercially available and measure field strengths from 1 V/m to over 100 kV/m. Probes have dipole design and measure one field component. Probes are electrically isolated from ground, battery operated, and are introduced into field with dielectric rod. Field measurements of of 5% or better are possible.	To measure the vertical electric field strength near ground level in vicinity of high voltage ac transmission lines. Vertical component is needed to calculate induction effects in objects close to the ground.	None	(1) None (N)	NA	NA
Carefully defined measurement and calibration procedures have been developed and standardized. Precision measurement seminars are presented regularly.	To determine electric fields produced by 60 cycle high voltage transmission lines.	None	(2) None (N)	NA	NA
Nonperturbing, miniature (1 cm diameter) high voltage electric field probes have been developed for laboratory applications. Measurement uncertainty is less than 2% over the 1 to 10 kV/m range. Probe senses two orthogonal field components.	Determine electric field in small animal exposure systems.	EP-Available systems are expensive. Not commerically available.	(3) LR-Small, self-contained, inexpensive, commercially available probes. (H)	To be determined by potential manufacturers.	No commercial development at this time.
Laboratory experiments have demonstrated the feasibility of detecting (to better than ±5%) the internal potential difference caused by exposing animal models to high strength electric fields (≈ 10 kV/m).	Ultimately, to determine the electric fields generated within animals and humans either by direct measurement or by confirmation of theoretical calculations.	EP-Only homogeneous saline models of simple geometry have been used.	(4) SR: Advance to more anthropomorphic shapes, inhomogeneous properties, and, finally, to live subjects. (M)	Apply techniques already developed for RF experiments.	Battelle's Pacific Northwest Laboratory (PNL) and U of Wash. using DOE funds.
		EP-Existing probes are too large for implanting in live animals.	(5) SR: Develop smaller probes. (H)	Apply standard printed circuit or microcircuit techniques.	Battelle's PNL and U of Wash. using DOE funds.
			(6) MR: Demonstrate that electrically induced fields can be distinguished from normal, internally generated fields. (M)	Unknown.	Battelle's PNL and U of Wash. using DOE funds.

TABLE 4 (continued)

I. Ability to Characterize EM Fields
C. Develop Instruments and Procedures to Characterize ELF Electric Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
DC electric field strength meters are commercially available for field measurements from 100 V/m to over 100 kV/m. Two types of probes currently in use are vibrating plate devices and rotating field mills (not readily available).*	Measurement of electric fields (1) in vicinity of dc transmission lines and (2) in apparatus to study field and ion effects in biological systems.	EP-Probes have been designed for space charge-free applications but may be employed in environments with large concentrations of of space charge, which can introduce errors.	(7) SR-Develop calibration procedures for relating instrument response to applied fields in the presence of space charge. (H)	Theoretical & experimental studies to understand and predict instrument response under these conditions. Establish limitations of probe response to fields with space charge.	NBS has ongoing DOE-sponsored program to develop apparatus for generation of dc fields with space charge (see Table II.A.) and to evaluate field measurement equipment. Related work is also underway at General Electric and Hydro-Quebec.
		EP-Measurements must be performed in ground plane to avoid systematic error.	(8) MR-Design instruments which are immune to self-charge, normally acquired when operating above the ground plane. (H)	Several alternatives have been identified. Now necessary to evaluate their performance under laboratory and field conditions. Split cylinder field mill is an example of such a device.	Work is underway at Hydro-Quebec. EPRI project at Westinghouse to develop above ground measurement instrumentation. NBS considering possible involvement.
Instruments are commercially available for measuring low-level ion charge densities. Some or all of these may be suitable for use near HVDC transmission lines.	Space charge (ions) near dc transmission lines produce ELF fields (due to effect of wind) which contribute significantly to total field. Measurements of charge densities near transmission lines and in apparatus used for studies of field and ion effects in biological systems are necessary to characterize the electrical environment.	The adequacy of commercially available instruments has not been evaluated since maximum charge densities encountered can be substantially higher than those for which instruments are designed.	(9) SR-Develop test methods to evaluate the range of ion densities over which the instruments will operate. (H)	Develop a laboratory system for generating predictable ion densities. Evaluate performance of instruments in such systems (See Table II.E).	DOE sponsoring NBS work on this project.

* High voltage dc transmission lines present a unique measurement problem since, at routine operating voltages, the lines are continuously in corona discharge. Ions produced by this corona discharge fall to the ground along the field lines and influence both the magnitude of the fields and the response of instruments placed in it. Measurements of dc fields and ion-related quantities such as ground current, ion density and net space charge are necessary to fully characterize the electrical environment. Information about ion mobilities and ion species will be needed if meaningful biological experiments involving dc fields in the presence of ions are to be carried out. Ozone will be generated; and aerosols, charged in the vicinity of the line, can be transported by winds to points significantly removed from the line.

TABLE 5

II. Ability to Generate and Apply Reference Fields

A. Develop Equipment and Procedures to Generate Well Characterized RF Electric Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
TEM cells, which generate uniform RF electric fields, are commercially available for frequencies between 0 and about 100 MHz. Electric fields within the cells are known to ±1 dB. Higher frequencies are possible, but only with an increase in uncertainty.	Used by NBS, private industry, the military & regulatory agencies to calibrate antennas and E-field meters.	FLN-Can not support circularly or arbitrarily polarized fields.	(1) Find alternate means to generate such fields. (H)	Explore use of mode-stirred reverberation chambers as well as anechoic chambers and open field test sites.	Included in current NBS program.
	Used by private industry, the military & others to evaluate the susceptibility of test objects to well characterized electric fields. (See II.B) Test objects may be electronic components and systems (including measurement tools) or biological subjects.	EP-High frequency limit near 100 MHz.	(2) SR: Extend upper frequency range by a factor of 2 to 10x. (H)	Conduct theoretical studies of how test probes perturb the field and experimental studies of ways to modify the chambers.	NBS program presently addressing this problem.
		FLN-Only two directions for wave propagation in TEM cells.	(3) SR: Develop alternative ways to calibrate probes in complex fields with multiple sources and directions. (H)	Explore use of mode-stirred reverberation chambers.	Included in current NBS program.
		FLN-Cannot generate useful pulsed fields in TEM cells.	(4) MR: Develop alternative ways to generate radar type pulses (i.e., CW fields switched on & off rapidly) and delta function pulses. (H)	Use anechoic chambers and open field test sites.	NBS developing specific program plans.
Shielded anechoic chambers are widely available for frequencies above 200 MHz. Any polarization direction can be achieved. Can generate impulsive (delta function) signals as short as 10 ns & simulated radar pulses (cw fields) rapidly switched on & off.	Same as TEM cells (See II.A above)	EP-Excessive reflections present at frequencies less than 200 MHz.	(5) Military needs anechoic chambers that operate down to 15 MHz. (M)	Longer absorbing cones and specialized materials.	DOD conducting experiments.
		EP-Electric field known only to ±2 dB.	(6) SR: Need E-fields accurate to ±1 dB for frequency ranges from 200 MHz - 18 GHz. (H) (7) LR: ±0.1 dB in 4-5 years. (L)	Theoretical calculations to better understand antenna field strengths and field patterns.	Addressed by current NBS program.
		EP-No competence with multiple frequency operation.	(8) MR: Develop expertise to generate at least 4 simultaneous cw signals. (H)	Theoretical calculations to better understand antenna field strengths, field patterns & mutual interactions.	NBS developing specific program plan.

TABLE 5 (continued)

II. Ability to Generate and Apply Reference Fields
A. Develop Equipment and Procedures to Generate Well Characterized RF Electric Fields

Capability	Application	Limitation	Requirements	Technical Approach	Efforts
Open field test sites scattered around the country operate at frequencies between 100 kHz and 400 MHz. Any single polarization direction can be achieved. Can generate delta function pulses of 150 ns duration and simulated radar pulses.	Same as TEM cells and anechoic chambers. Additionally, open field sites can be used as an independent check of results obtained both in TEM cells and anechoic chambers.	EP-Not useful in poor weather.	(9) MR: Construct a non-reflecting shelter. (M)	Inflatable Bubble.	NBS considering purchase.
		EP-Interference from external fields (30 dB increase in background levels over past 20 years).	(10) SR: Improve signal to noise ratio by 10 dB. (M)	Supply higher power to transmitter.	NBS considering purchase of new equipment.
			(11) LR: Quieter test site. (L)	Locate such a site.	NBS considering various alternatives.
		EP-Field strength accurate to 2 to 15 dB.	(12) SR: Improve accuracy to the 1-5 dB range. (H) (13) MR: Improve to 1 dB. (L)	Explore interactions between the transmitting and receiving systems and their surroundings.	NBS conducting theoretical studies.
		FLN-May temporarily interfere with other local users of the spectrum.	(14) Operate as quickly as possible and avoid those frequencies which are known to be in use. (H)	Same as ←	All users with test sites.
Laboratory spherical dipole radiators, which generate uniform electric field from 30 to 100 MHz.	Used for laboratory evaluation of test sites or chambers.	EP-Limited knowledge of its interaction with enclosures.	(15) SR: Precisely dependable radiation pattern and field strength. (H)	Theoretical study and evaluation.	NBS program presently addressing this problem.

TABLE 6

II. Ability to Generate and Apply Reference Fields

B. Equipment and Procedures for Subjecting Test Objects to Well Characterized RF Electric Fields

Capability	Applications	Limitations	Requirements	Technical Approach	Efforts
TEM cells (see II.A above).	Used by private industry, the military & others to evaluate the susceptibility of test objects to well characterized electric fields. Test objects may be electronic components and systems (including measurement tools) or biological subjects.	Same as II.A. Additionally, however: (FLN)-Volume of test object should not be more than 1/3 the height of the TEM cell (no computers, trucks, airplanes, or resonant antennas).	(1) SR: Use alternate means to generate reference fields for exposing large objects. (H)	Anechoic chambers or open field test sites.	See other entries in this table.
		EP-Influence of test object on imposed field not fully understood.	(2) SR: Determine magnitude of errors introduced by these interactions. (H)	Theoretical and experimental studies of electric fields with and without test object.	Included in current NBS program (contract to University of Colorado).
Anechoic chambers and open field test sites. (See II.A above).	Same as TEM cells above.	EP-Reliable test facilities are not available. However, a few facilities exist to accomodate large systems.	(3) SR: Need adequately characterized testing methods. (H)	Theoretical and experimental studies.	NBS and private industry.
Mode stirred and mode tuned reverberation chambers are currently being evaluated to determine their suitability for generating omnidirectional electromagnetic fields (i.e., time averaged intensity is the same at all points on surface of test object). Devices operable for frequencies between 200 MHz and 20 GHz.	Determine the susceptibility of electronic or biological test subjects to interference caused by electromagnetic fields. Avoids the need to conduct a series of measurements with test objects in different orientations. Systems are especially well suited for measuring shielding effectiveness.	EP-Lack of knowledge regarding the way in which the test object modifies the properties of the chamber.	(4) SR: Ability to understand and predict the ways in which field strengths and field patterns are affected by the introduction of various test objects. (How much interaction between the object and the field can be tolerated?) (H)	Theoretical and experimental studies of predicted and measured field patterns and intensities.	NBS and private industry (supported by Navy).
		EP-For mode tuned cavities coupled to automatic data analysis systems accuracy is between 3 and 10 dB depending upon frequency. For less expensive, mode stirred cavities there is an additional 4 dB uncertainty.	(5) LR: Achieve minimum uncertainty of <3 dB. (L)	Theoretical and experimental studies needed.	NBS developing specific program plans.

TABLE 6 (continued)

II. Ability to Generate and Apply Reference Fields

B. Equipment and Procedures for Subjecting Test Objects to Well Characterized RF Electric Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
A variety of standardized test procedures have been developed to...(see next column).	Evaluate the susceptibility of electronic devices or systems to externally applied fields.	EP-Not all of the test procedures are compatible. Thus, it is possible to pass one standardized test while failing another. And it may be impossible to design any device that could pass all such tests. (Example - MIL. STD. 461/462 and 1377)	(6) LR: Wherever possible, achieve uniformity of test methods across industrial and national boundaries. (H)	Continued participation in national and international standards writing committees.	NBS actively involved.
"Standardized" small-animal, transmission line exposure systems are available on a semi-commercial basis. Systems feature a screened, cylindrical wave-guide cavity which supports circularly polarized electric and magnetic fields, by measuring the power incident upon, reflected from and transmitted through such cells, one can determine the energy absorbed by the animal.	Systems are used for exposing unrestrained animals over long periods of time (months).	EP-To what extent is exposure in one of these systems different from exposure in a TEM cell, an anechoic chamber or an open field situation.	(7) LR: Protocol for each method of exposure to describe uniformity of practice. (H)	Evaluation would probably require careful measurement of electrical parameters as well as comparison of the dose-response behavior of a particular biological effect as studied in various kinds of exposure systems.	None underway or planned.
		EP-Strengths of electric and magnetic fields have a fixed ratio.	(8) SR: Arbitrarily variable magnitudes for electric and magnetic fields. (N)	For short-term studies with high intensity fields use synthesizers already developed by NBS. See Table 8.	NIOSH and Air Force are using these NBS produced devices.
Electronic near field synthesizers have been developed to produce fairly "pure" high-level electric or magnetic fields.	See Item 2 in Table II.D for details.				

TABLE 7

II. Ability to Generate and Apply Reference Fields

C. Develop Equipment and Procedures to Generate Well Characterized R.F. Magnetic Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Effort
Wire loops, whether isolated, packed tightly together, stretched out along a single axis (solenoid) or packed in two clusters along such an axis (Helmholtz coils) provide alternate means for generating well characterized predictable rf magnetic fields.	Calibrating field sensors and assessing the effect that such fields might have on electronic or biological systems placed therein.	FLN-It is difficult to contain such fields leading to potential interference with other users.	(1) SR: Conduct your own business without interfering with another's use of the same frequency. (N)	Work with small volumes which can be shielded, ISM frequencies or low power and minimum on time.	Included in current NBS program.
TEM cells, which generate uniform RF magnetic fields, are commercially available for frequencies between 0 and about 100 MHz. Magnetic fields within such cells are known to ±1 dB.	As above.	EP-Most cells are made of aluminum and do not adequately contain magnetic fields at frequencies less than 10 to 20 kHz.	(2) LR: Develop TEM cells capable of containing magnetic fields. (L)	Construct such cells of high permeability metals.	None underway or planned.

TABLE 8

II. Ability to Generate and Apply Reference Fields
D. Develop Instruments and Procedures for Subjecting Test Objects to Well Characterized RF Magnetic Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Effort
TEM cells, which generate uniform RF electric fields, are commercially available for frequencies between 0 and about 100 MHz. Electric fields within the cells are known to ±1 dB.	Assessing the effect of magnetic fields on electronic or biological test items.	FLN- Magnetic fields produced in a TEM cell are accompanied by a proportionately large electric field.	(1) SR: Ability to arbitrarily determine the relative magnitude of the electric and magnetic fields to which the sample is exposed. (N)	Use special electromagnetic near field synthesizers in which E & H can be arbitrarily established.	Designed by NBS for other agency sponsors.
Laboratory-quality electromagnetic near-field synthesizers have been developed to produce fairly "pure", high-level electric (to 10,000 V/m) and magnetic (to 100 A/m) fields in the 10 to 100 MHz frequency range. Device permits direct measurement of power absorbed by biological specimens placed in the synthesizer.	To determine the relative hazards of intense electric, magnetic, and electromagnetic fields by independently studying their effects on laboratory animals.	EP- Very narrow frequency range.	(2) LR: Extend the upper frequency limit by a factor of 10. (M)	Uncertain.	None underway or planned.

TABLE 9

II. Ability to Generate and Apply Reference Fields

E. Equipment and Procedures for Generating and Applying ELF Electric Fields

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
Parallel plate systems for generating uniform 60-Hz electric fields are readily fabricated. Facilities at NBS and elsewhere are readily capable of generating fields up to 100 kV/m or more with 1% uniformity.	Simulation of 60 Hz electric fields from high voltage ac transmission lines near ground level. Calibration of instrumentation and biological studies of field effects in plants and animals.	None	(1) None (N)	NA	NA
A Parallel-plate system is available at NBS for generating calculable static (D.C.) electric fields over the range of 6 kV/m to 20 kV/m with current densities up to 6 A/m^2. Field strengths are known to better than 5%.	Simulation of electric environment at ground level under high voltage D.C. (HVDC) transmission lines. Calibration of field measuring instrumentation. Similar systems may be developed at other institutions for bio-effects research.	EP-Physical mechanisms which determine the mobility of ions are not fully understood.	(2) SR-Theoretical models be developed to predict the behavior of practical apparatus for the generation of an electric field with space charge. (H)	Collect experimental data on the mobility of space charge in laboratory systems.	Included in NBS program.
A unique airflow system with a corona discharge ion source has been developed at NBS to produce steady state ion densities up to 10^6 ions/cm^3.	Evaluation of ion measuring instruments for densities up to 10^6 ions/cm^3.	Reproducibility and uniformity of space charge have not been fully determined. Control of ion densities over wide range of values is not available. Interaction of system air flow with aspiration instruments may cause systematic errors.	(3) Space charge needs to be smooth and spatially uniform. Ion densities should be controllable over the range expected near HVDC transmission lines and must be known absolutely. Determine interaction between instruments and air flow system. (H)	Construct low speed air flow facility and evaluate flow characteristics. Evaluate corona ion sources in air flow system for producing space charge with characteristics suitable for evaluating ion measuring instruments. Then, determine absolute calibration techniques for calibrating ion measuring instruments.	NBS has ongoing program with DOE.

TABLE 10

III. Ability to Characterize Sources and Reflectors

A. Develop Instruments and Procedures to Characterize Radiation Sources

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
TEM cells, anechoic chambers and open field test sites described in section II can be used with the tools described in section I to characterize the electromagnetic fields produced by various electronic products.	To assess the test object's potential for interfering with other systems (electronic or biological).	Addressed in Sections I and II.	(1) Addressed in Sections I and II. (X)	Addressed in Sections I and II.	Addressed in sections I and II.
Specialized and sophisticated instruments are now commercially available to evaluate leakage from microwave ovens and medical diathermy equipment.	To test compliance with existing microwave oven and proposed microwave diathermy regulations.	EP-Instruments measure electric field but report power density.	(2) LR: Meters should readout in units of the quantity to which they respond. (H)	Change dial face on the instrument.	Manufacturer's responsibility.
Simple, inexpensive consumer oriented probes are commercially available for use with microwave ovens.	To indicate whether ovens leak more than preset amount.	BRH has reported that such probes do not provide accurate or reliable indicators of safety.	(3) Simple, inexpensive accurate & reliable testing devices from commercial sources. (H)	NA	Commerical manufacturers are attempting to improve present devices.
At least eight different national and international organizations have developed "standardized procedures" for measuring the radiation fields associated with potential sources of EMI.	Results of such tests are used (a) to predict whether one device might interfere with the operation of another (b) to determine whether the device meets minimum leakage standards as required prior to sale or operation.	EP- Lack of reliable measurement methods in determining the emission from impulsive devices.	(4) LR: Measurement methods for arbitrary emission sources, e.g., internal combustion, computer, etc. (M)	Develop theoretical and experimental approaches to statistically distributed EM emissions.	None underway or planned.
		EP- Some of the procedures permit widely variable results for the same source thereby making it difficult to compare data from one source with those from another.	(5) MR: Measurement procedures which produce a unique result. (H)	Refine or discard present procedures.	NBS working with standards committees to help achieve this goal.
		EP-Measurement results from different techniques are difficult if not impossible to correlate.	(6) MR: Measurement procedures whose results can easily be compared with one another. (H)	Refine and unify present procedures to the extent possible.	As above.

TABLE 10 (continued)

III. Ability to Characterize Sources and Reflectors
A. Develop Instruments and Procedures to Characterize Radiation Sources

Capabilities	Applications	Limitations	Requirements	Technical Approach	Efforts
U.S. and French researchers have developed passive experimental measurement systems to collect microwave radiation generated by internal body organs. Active systems also irradiate specific organs *in vivo* with microwaves for the purpose of heating.	Data are used to produce thermographic images which reveal the outline, position and temperature of hot spots such as tumors.	EP-Resolution limited to about 1 cm in any plane perpendicular to line of sight.	(7) MR: Ability to locate tumors of 1 mm size. (H) LR: Tumors of <1 mm.	Smaller detectors better coupled to the body and more precisely located.	Some academic and industrial researchers. NIH and NASA providing funds. NBS considering possible role.
		EP-Most temperature measurements are relative and have uncertainties 0.1°C; some require insertion of a thermistor into the subject.	(8) MR: National Cancer Institute needs temperatures to better than 0.1°C by non-invasive techniques. (H)	Theoretical and experimental studies to explore the use of multiple receivers and/or multiple frequencies and/or phased array detectors in variable positions.	NBS considering possible roles.
		EP-Systems work best with homogeneous regions of body; they have no ability to resolve features along the line of sight. Thus, thermograms are two dimensional. It is difficult to distinguish between a warm source near skin & a hot source (stronger signal) deeper in the body.	(9) MR: Three dimensional images comparable to "CAT" scans are needed to define temperature profile. (H)	As above.	As above.

TABLE 11

III. Ability to Characterize Sources and Reflectors

B. Instruments and Procedures to Collect and Characterize RF Radiation Scattered from an Object

Capabilities	Applications	Limitations	Requirements	Technical Approach	Effort
Experimental systems developed by Army medical researchers use microwaves for generating images of body organs.	Noninvasively construct visual images through various planes of internal organs and determine the energy deposited by an external field at any site in the organ.	EP-Resolution is about 2 mm X 3 mm perpendicular to the "line of sight" and 9 mm along that axis. Data acquisition requires about 4-1/2 hours. Technique applicable to excised organs only.	(1) MR: Refine system to provide resolution to the 0.1 mm range with data collection times less than 1 minute for organs in vivo. (H)	Inverse scattering techniques involving phased array sources & detectors immersed with the sample in a liquid dielectric bath.	US Army pursuing this.
		EP-Present system utilizes fixed geometry between source and receiver.	(2) MR: Ability to rotate source & detector to any angle so that data can be displayed for any plane in the subject. (M)	Develop capability to conduct "CAT" scans as used in x-ray imaging systems.	US Army pursuing this.
Researchers at U.S. & Canadian institutions have developed experimental laboratory systems for measuring the amplitude and phase of electromagnetic waves reflected from specific internal organs.	Evaluation of reflected signals permits determining the absolute quantity of liquid in lungs, as well as monitoring respiration and blood flow. EKG's can be generated without making physical contact with the patient.	EP-Most measurements are experimental and qualitative due to a lack of information on (1) the dielectric properties of living tissue and (2) the nature of the interaction between radiofrequency radiation and living tissue.	(3) MR: Improved knowledge of complex permittivity of living tissue and a detailed understanding of the interactions between electromagnetic radiation and biological systems. (H)	Use demonstrably accurate measurement techniques to characterize the electronic properties of small volumes of living tissue. Develop theoretic models to describe and predict tissue/field interactions.	Univ. of Georgia, Univ. Univ. of Pennsylvania, the Ministry of Health & Welfare in Canada, the University of Utah, Wayne State University and the Bureau of Radiological Health are leaders in this field.
		EP-Inability to produce high resolution images of internal or excised organs using radiofrequency radiation.	(4) MR: Improved imaging techniques. (H)	Explore the use of phased array transmitting and receiving antennas, holography, etc.	U.S. Army is principal sponsor of this work.
		EP-Clinical significance of various changes in detected signals is not yet well understood.	(5) MR: Knowledge of what kind of physiological changes are correlated with the observed "symptoms" i.e., departures from normally encountered parameters. (H)	Biomedical research.	Government research in agencies concerned with health.

TABLE 12

III. Ability to Characterize Sources and Reflectors
C. Explore Mechanisms of Interaction between EM Waves, Reflectors or Absorbers

Capabilities	Applications	Limitations	Requirements	Technical Approach	Effort
Generalized formulas describing the behavior of electromagnetic waves at boundaries between regions with different electrical properties have been known since the days of Kirchhoff (1880's), and exact solutions to simple and idealized boundary value problems are well known. Some progress has been made in defining the shape of an object by collecting the scattered radiation (see tables 10 and 11).	These formulas may be used to predict the manner in which simple, homogeneous bodies perturb an incident electromagnetic wave. Thus, for example, it is possible to predict the rate of energy disposition per unit mass at various points within uniform prolate spheroidal models of monkeys or men. Similarly, one can calculate the penetration of such fields into planar models having several layers of tissue with different properties (skin, fat, muscle, etc.). Knowledge of internal fields and dielectric properties enable calculation of heating patterns in the body. In common radar applications, one can accurately determine the speed and distance of a reflecting object. Analysis of various shielding designs is another application.	EP-It is not yet possible to accurately predict (or to confirm by measurement) the magnitude or other related features of electromagnetic waves at specific points within real bodies. For example, what electromagnetic fields will be generated (1) at various points within a room whose walls have known electrical properties when it is subjected to several electromagnetic waves, having different frequencies, polarizations and modulation parameters and coming from different directions, or (2) at the membrane of a red blood cell located somewhere in a human body.	(1) SR: More sophisticated models and computing methods must be developed and confirmed both for living subjects and inanimate objects. (H)	Further refinement of existing models; the the development of new, faster and more powerful computing techniques, and basic research to better understand the detailed nature of the interactions.	Most of the work on this problem is being handled by academic institutions under contract to various Federal agencies (including NBS).
			(2) SR: There must be a better understanding of the detailed interactions between incident fields and the cells, membranes and molecules that make up living tissue. (H)	As above.	Most of the work on this problem is being handled by academic institutions under contract to various Federal agencies.
		EP-It is not yet possible to relate characteristics of radiofrequency images of excised organs with specific disease states.	(3) MR: Biomedical research to correlate features of radiofrequency images with disease states of the organs in order to permit (in the long range) diagnosis of medical problems <u>in vivo</u>. (M)	Obtain radiofrequency images of organs known to have specific pathological characteristics and correlate irregularities of the images with specific disease states.	None yet.
		EP-Interactions between pulsed waves and biological systems are not well understood.	(4) MR: Improved methods for exposing subjects to well characterized EM pulses and for evaluating the results. (M)	Develop instruments mentioned in requirements 13 & 14 of Table 2.	NBS developing program plans.
				Theoretical investigation of the mechanisms of interaction.	U.S. Army and academic scientists involved.

TABLE 13

IV. Ability to Record Exposure Histories

Capabilities	Applications	Limitations	Requirements	Technical Approach	Effort
Sophisticated, limited-edition, measurement systems have been designed, built and tested to continuously monitor and record the intensity of electric and magnetic fields at a fixed measurement site. Present systems are isotropic and cover the frequency range from 10 kHz to 18 GHz.	Current systems provide a continuous record of field intensities in the neighborhood of stored weapons systems. Special circuitry initiates protective actions if exposure exceeds preset levels which vary with frequency. Similar systems could be useful in collecting information for epidemiological studies.	EP-Current systems are large and costly. Not commercially available. Won't give adequate details for generating individual exposure histories.	(1) MR: Smaller, portable systems (about the size of a cigarette pack) are needed for personal use. Should respond to electric fields in the 2 MHz to 23 GHz range and magnetic fields in the the range 2-300 MHz. Sensitivity of 6 to 434-V/m for electric fields and 0.016 to 1.15 A/m for magnetic fields. Personal dosimeters require an alarm to alert the wearer of excessive exposure. Find means for dealing with the effect of interactions between the wearer's body, the incident field, and the dosimeter. (H)	Develop miniaturized sensors as well as information storage, processing, and retrieval systems. Conduct theoretical evaluation of cited interaction mechanisms so that data may be used for medical evaluations.	Included in current NBS program (supported by US Navy).
Personal dosimeters accurate to about ±10% have been developed to record the time integral of exposure to ELF electric fields over as many as nine separate intensity ranges - e.g., 0 to 5 kV/m, 35 to 40 kV/m, and greater than 40 kV/m. By splitting up the field strengths in this fashion, the devices are able to distinguish between long exposure to low-level fields and short exposure to high field intensities.	To generate a data base indicating the amount of time that workers have spent in electric fields of varying strengths. By assuming that the surface current density induced in the wearer's body is proportional to the applied field, such exposure measurements can be related to a more biologically significant parameter - exposure - to alternating currents.	Laboratory prototypes not yet fully evaluated.	(2) SR: Determine immunity to EMI and physical abuse. (H)	Laboratory and field tests to simulate extreme extreme use conditions.	Academic and industrial institutions in U.S., Canada, & Japan. Some OOE funding.
		Commercial models not yet available.	(3) MR: Commercial availability. (M)	Responsibility of private enterprise system.	Unknown.
Prototype personal dosimeters have been developed to record the time integral of exposure to 3 orthogonal components of magnetic induction, their time rate of change, the peak field within a preset time frame, and the number of times that a preset threshold level is exceeded. An audible alarm warns the wearer if a preset maximum field strength is exceeded. Batteries last 4 weeks w/o recharging.	To generate personal exposure histories useful in medical or legal assessments and to warn wearer of potentially dangerous environments.	EP-Performance not thoroughly evaluated. Devices are not commercially available.	(4) SR: Test and report performance. Make design details available to possible producers. (H)	Laboratory and field tests required.	Lawrence Berkeley Labs involved (supported by Dept. of Energy).

3.3 Other Considerations

For describing the capabilities and requirements of the national NER measurement system, the preceding tables tell only part of the story. While giving detailed information on tools and techniques that are already in place, though often performing in only a limited fashion, the tables say little about some subjects that are of specific interest both to the States and to Federal agencies as well - such as enabling legislation, active enforcement programs, standards to be enforced, equipment, or the trained people to do the job. It is important, for instance, to assure that people who may be provided with good quality instruments are also carefully instructed in what the instrument will and will not do. These individuals also need to know how to compare the results of a measurement with the applicable standard in order to account for the duty cycle of the equipment which is generating the field, its frequency, and other considerations. The tables also give little attention to those needs for which not even a limited capability has yet been developed -- items such as measurement quality assurance programs or the capability for dealing with conducted EMI. (See 3.3.4, below.)

3.3.1 Radiation Control

Several recent documents [1], [2], [3], [4], [5], [6] and [7] have pointed out that the United States has no mandatory, Federally enforced, general population exposure standard for NER at this time. One consequence of this situation is that while more than 20 States have passed enabling legislation, which will permit them to exercise control over NER exposure, only six are known to have active programs. The city of Portland, Oregon, and the State of Texas are the only public bodies in the U.S. to currently impose a population exposure limit (100 $\mu W/cm^2$ and 10 mW/cm^2, respectively).

The CRCPD considers this lack of a general population exposure standard, which the States can enforce, to be one of the principal barriers in its own efforts to assure nonionizing radiation safety. It should be added, however, that EPA is currently developing Federal guides for controlling radio-wave and microwave exposure in areas accessible to the public. Additionally, EPA is distributing RF/microwave survey meters to its Regional Offices.

While there are no Federal standards which control environmental exposure to NER, OSHA is taking steps to more vigorously enforce its 10 mW/cm^2 occupational exposure limit. It has, for instance, recently trained personnel from all 10 Federal Regions in performing RF/microwave inspections. OSHA is also providing these offices with the measurement instruments needed to enforce that standard.

In addition to these regulatory efforts, the training branch of the AFL/CIO, the Workers Institute for Safety and Health (WISH), is sponsoring a series of four symposia during 1980 and 1981 in which it will train safety officers from local unions within the AFL/CIO in matters of safety and health concerning RF/microwave and laser radiation.

These actions by EPA, OSHA and WISH are expected to generate an increased demand for measurement equipment and for the calibration services needed to support it.

The CRCPD cites the lack of (a) adequate funding for State radiation control programs, (b) inexpensive, commercially-available, field-survey instruments, and (c) trained personnel in State enforcement programs as three of the major deficiencies in the current national radiation control effort. While the efforts of EPA, OSHA and WISH will add significantly to the number of trained and well-equipped personnel, none of these are expected to reside in State facilities.

3.3.2 Measurement Quality Assurance

As noted in the preceding tables, NBS has the capability of generating standard electric and magnetic fields which can be used for instrument calibrations. This service is available to any organization - Governmental or private, large or small - that needs reference to highly accurate or precise measurements. However, as noted by Ries and Anson in an earlier study of the national NER measurement system [8], "Most of the measuring instruments used in this country are never calibrated by NBS or any other standards laboratory. At best, they have been calibrated toward the end of the production line on which they were manufactured. Often, they are not calibrated at all during manufacture, and their accuracy depends upon the precision of the manufacturing process and upon their basic good design. Obviously, instruments that are never seen by a standards laboratory carry the entire burden of measurement adequacy for whatever purposes they are used."

This situation is not necessarily unsatisfactory. Ries and Anson point out, "Optimally, the production line calibrations or manufacturing processes can be traced in some meaningful fashion back to basic standards as maintained by NBS or as embodied in fundamental scientific processes, definitions, or phenomena."

In any case, NBS does not have the ability to calibrate all or even a modest fraction of all the instruments used in this country. Nor would such calibration necessarily assure any improvements in accuracy. A perfectly calibrated instrument may not be able to survive the trip home. (How could the user even tell whether it had been jolted out of adjustment?) Furthermore, how could NBS be certain that the instrument was used properly after it left the site? Clearly, there is a need to provide users with a means for checking the operation of their instrument in its normal surroundings. If deficiencies were noted, the instrument could be returned to the manufacturer for repair and recalibration.

One approach to solving this problem would be the establishment of regional calibration laboratories. If such facilities were available, a customer could personally and carefully transport his instrument to and from the facility and check its operation. Alternatively, it might be possible to develop small, rugged, inexpensive transfer standards that could be sold or loaned to the customer for use on his own site. Such standards would permit simple and frequent checks of the users' entire measurement process.

This latter procedure, known formally as a Measurement Assurance Program, has already been instituted by NBS for nine other quantities. The possibility of developing a Measurement Assurance Program for radiated EM fields is currently under consideration.

3.3.3 Calibration Workload

NBS is not at this time experiencing excessive demands for its calibration services. There are four reasons for this. First, the services are quite costly; for example, it may cost $3,000 to $5,000 to fully calibrate a $2,000 instrument. A user is more likely to send his instrument to the manufacturer, who will recalibrate it at a lower cost, though usually at only a few specific frequencies.

A second reason for the low demand is the lack of pressure on users to demonstrate that their measurements are accurate. Thus, since there has been no legal requirement to demonstrate compliance with a mandatory personnel exposure standard, few people feel the need to demonstrate any level of accuracy beyond that claimed by the manufacturer. However, if EPA, OHSA, and WISH continue to intensify their efforts (see 3.3.1 above), there is likely to be an increasing need to make measurements whose accuracy is traceable (through some calibration chain) to national standards.

Third, some services are available elsewhere at no cost. For example, each year the Bureau of Radiological Health calibrates about 500 instruments at one or two frequencies for those organizations which are responsible for enforcing the BRH microwave oven standard. However, they do not provide such calibrations for industrial or academic institutions, except where needed to determine compliance with the microwave oven performance standard.

A fourth reason for the low demand is that NBS has not routinely listed such a service in its own catalog of calibration activities - Special Publication 250. This is because the calibration techniques were not yet fully developed. Automation of the calibration system, together with a detailed error analysis, should be completed by the end of FY 81. Calibrations can then be provided on a routine basis rather than by special contract.

State regulators are understandably reluctant to rely on private industry for the calibration of those instruments which will then be used to assess the industry's compliance with the regulations. Thus, they have encouraged NBS to take whatever action may be needed (e.g., automation) to bring down the cost of its calibrations. If Measurement Assurance Programs were available in the NER area, the State regulator could easily and routinely check the performance of his instrument before and after a thorough calibration by the manufacturer or independent laboratory.

3.3.4 Conducted Electromagnetic Interference

It is widely recognized that the performance of many electronic devices can be significantly degraded by exposure to radiated electromagnetic fields. For example, reception in the A.M. radio band (0.5 - 1.6 MHz) becomes extremely noisy during electrical storms, and two-way radios need to be turned off in blasting zones.

There is yet another major source of EMI - specifically, interference which reaches electronic equipment through its power cables or data lines. This is called "conducted EMI" and may result in a significant deterioration of the equipment's performance. Conducted EMI can have severe impact on health and safety - especially if it affects medical devices.

Although the National Bureau of Standards does not now have any ongoing work that addresses this important problem, various options for starting this work are being considered. Possible approaches include reprogramming from current activities and acquiring other agency support.

3.3.5 Lasers

One of the most difficult high priority problems facing State radiation control program directors is the enforcement of FDA regulations[8] relating to the use of laser beams for artistic/entertainment displays for rock concerts, art exhibits, and discotheques. Lasers used in these applications usually employ a high power argon or krypton or mixed gas laser with beam deflecting optics [9]. The Bureau of Radiological Health has noted, "Exposure of the public to hazardous levels of laser radiation is now occurring in widely separated locations and applications. In several instances the levels of optical radiations exceed, manyfold, those levels known to be capable of producing permanent eye damage." [12].

Under the BRH regulations, "It is required that the manufacturer of a laser light show meet all of the requirements of the laser performance standard and laser light show guidelines. Calculations, measurements or their combination of the accessible laser radiation must be made and presented to the Bureau of Radiological Health for review before the laser light show is presented." [9]

Compliance with such regulations is not only possible but also highly desirable. And while it will certainly provide some measure of safety, the State radiation control program directors feel that the use of radiation monitors during the actual performance would provide an even better assurance of safety. However, actual measurements of the pulse intensity of a moving laser beam are extremely difficult to make in practice. The BRH is working on this problem and has already developed some prototype instruments. While field tests have not yet commenced, some companies have already expressed an interest in commercial development of the final product [10].

3.3.6 Ultraviolet Radiation

Another important and current measurement problem faced by the State radiation control program directors relates to protecting the public from excessive exposure to man-made ultraviolet radiation. The two principal sources of exposure are damaged, high-intensity, mercury vapor lamps (used in gyms, department stores, banks, parking lots) and tanning booths now available throughout the country at special "tanning clinics."

The high-intensity lamp problem has also been addressed by BRH, which has issued standards (effective March 7, 1980) relating to their manufacture. Lamps produced in compliance with the standard either have a built-in device that extinguishes the light within 15 minutes if the outer globe is broken, or will bear detailed warnings about possible hazards and preferred methods of installation and use. This is more a problem of maintenance than of measurement.

There is a need, however, for new, portable, inexpensive instruments to measure the spectral irradiance inside tanning booths or other environments.

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[8]21 CFR 1030.10, January 1976 and as amended November 28, 1978. Also, FDA Compliance Policy Guides. "Applicability of Laser Product Performance Standard to Laser Light Shows (21 CFR 1040.10(s) and 1040.11(c)" (November 23, 1977). "Interim Enforcement Policy for Certain Laser Light Shows and Displays (2) CFR 1040.10 and 1040.11)" (February 21, 1978).

The Bureau of Radiological Health has developed such a hazard meter and has submitted it to NBS for evaluation. If the instrument is found to be satisfactory, BRH will make the plans available to potential manufacturers.

3.4 Addressing Measurement Problems

In this section of the report, we shall briefly identify the roles of the various Federal agencies in addressing measurement problems involving NER. A more complete discussion of the specific responsibilities will be found in [3] and [6].

3.4.1 Population Exposure

The job of determining population exposure to radiofrequency and microwave radiation rests primarily with the regulatory agencies. EPA, for example, has been conducting a vigorous program to determine the magnitude and extent of environmental exposure to NER. Similarly, OSHA, BRH, NIOSH and (in special circumstances) EPA have developed a cooperative program to determine the magnitude and extent of occupational exposure to NER. Their efforts are coordinated by the Radiofrequency and Microwave Committee of the Interagency Regulatory Liaison Group. Exposure resulting from consumer and medical applications of NER is being addressed by the BRH. The Armed Services also collect information regarding the exposure of their personnel to NER. Both DOE and EPA have programs for measuring and calculating population exposure to 60 Hz electric and magnetic fields. DOE is also measuring exposure levels for DC fields.

In response to this growing interest in and need for reliable measurements of radiofrequency radiation exposure, EPA's Office of Radiation Programs - Las Vegas Facility - conducted a three day Radiofrequency Measurements Workshop in November of 1980. It was attended by about 35 representatives of nearly 20 different organizations (mostly Federal agencies). The workshop was organized to provide a forum for the exchange of information, measurement experiences, and problems. The participants agreed upon two recommendations:

1. That a group, such as the American National Standards Institute (ANSI), should set the following standards for broad band RF survey instruments: a) minimum, uniform reporting requirements of performance characteristics for existing instruments; b) minimum testing procedures for evaluating instrument performance, and c) performance characteristics for future instruments.

2. That standardized measurement techniques be developed based on: a) existing instrumentation; b) applicable safety standards, and c) specific exposure situations.

A complete report on the conclusions reached by workshop participants is scheduled to be published at an early date.

3.4.2 Dosimetry

Measurements play a crucial role in the Government's effort to determine the relationship between incident and absorbed electromagnetic radiation, including the distribution of local electric and magnetic fields, or absorbed energy, within exposed individuals or experimental subjects. Reliable quantitative measurements of absorbed dose are needed in order to develop a basis for defining dose equivalency and for making interspecies comparisons or extrapolations based on the use of quantitative scaling factors. Reliable data on absorbed dose are also of importance in connection with research on mechanisms of field interactions at the cell and tissue levels. Current status is addressed in Tables 2, 4, 6, 8, 11, 12 and 13.

Numerous Federal agencies (including all three military services, NIOSH, NIEHS, EPA, DOE and BRH) are involved in either conducting or sponsoring research to determine the energy absorbed from an electromagnetic field. The reader's attention is particularly directed to the Radiofrequency Radiation Dosimetry Handbook, prepared by the Departments of Electrical Engineering and Bioengineering at the University of Utah for the U.S. Air Force School of Aerospace Medicine, Brooks Air Force Base, Texas 78235 (Report Numbers SAM-TR-76-35, SAM-TR-78-22 and SAM-TR-80-32).

3.4.3 Biological Consequences of NER Exposure

As with dosimetry, there are numerous Federal agencies involved in determining (a) what biological effects can be caused by exposure to NER, (b) what relationships exist between the observed biological effects and the relative NER parameters (e.g., power density, field strength, absorbed dose, frequency, and modulation), and (c) what is the health or biological significance of any such effects. Physical measurements will play a critical role in understanding the causal connections between radiation exposure and the resulting biological effects. As noted by the BENER Task Force, "The lack of adequate tools such as EM field probes, EM field simulators, dosimeters, calibration and exposure systems, and standardized measurement techniques has been one of the major deterrents to progress in this field." [3]

Access to state-of-the-art instrumentation is a matter of concern to many laboratory scientists. The problem is that advanced instruments or exposure systems designed to solve the measurement problems of one organization may never become commercially available for use in other facilities. It is incumbent upon agencies like NBS, who develop such devices, to fully document and publish the results of all work which might lead to the development of marketable products. The recent commercialization of the NBS isotropic electric field meter is a notable example of success in this area.

3.4.4 Cooperation and Coordination

Since about 1971, the National Telecommunications and Information Administration or its predecessor, the Office of Telecommunications Policy, has provided a forum for the exchange of information among all of those Federal agencies which have responsibilities relating to NER health and safety. In addition to the interactions provided through this mechanism, the National Bureau of Standards has had a long history of direct contacts with most of these Federal agencies. In some cases, NBS is called upon to solve specific measurement problems, e.g., to develop a small-animal exposure system for the U.S. Air Force [11] which would provide for independently generating high-level electric and magnetic fields in the frequency range 10 to 30 MHz. In other cases, memoranda of understanding are developed in order to define the responsibilities of the specific agencies.

An informal agreement between EPA and NBS, for example, states, "EPA has a responsibility for performing the field measurements for EM environments, for evaluating the potential impact of these environments, and for providing guidance with respect to adherence to establish[ed] standards." On the other hand, "The National Bureau of Standards recognizes its responsibility in developing measurement techniques, standardized testing methods, instrumentation, and prototype devices for the measurement of EM fields..." Further, it is agreed, "NBS will refer all future requests for field measurements of the EM environment to the EPA for appropriate action."

Staff participation on standards writing committees such as those of ANSI, IEEE and NCRP also provide an excellent opportunity for exchanging information relating to current activities or measurement system needs.

As a result of these formal mechanisms as well as other, informal contacts between staff members of the various agencies, the BENER Task Force concluded that there was "a good match between the kinds of work needed and projects already underway and no unnecessary duplication or unrecognized needs. Thus, the ongoing program provides an excellent base for expansion."

3.5 Priorities and Time Scales

Some 84 different requirements were spelled out in Tables 2 - 13. Approximately

61 percent of the requirements were considered to have high priority,

21 percent of the requirements were considered to have medium priority, and

9 percent of the requirements were considered to have low priority.

The remaining items presented no measurement problems.

Among the 51 requirements that were considered to have a high priority, 82 percent are now being addressed either by NBS or by another laboratory; 18 percent are not yet covered.

Of the 26 high priority requirements which are already included in the NBS program

- 25 percent are expected to be completed within one year. Examples include:
    - the development of a directional, broadband antenna for use in the 1 MHz to 6 GHz frequency band (T2, R2);
    - extending the upper limit of the NBS-developed electric field meter from 1 GHz to 4 GHz (T2, R4); and
    - completing a theoretical model to predict the behavior of practical approaches for generating an ELF electric field with space charge (T9, R2).
- 25 percent are expected to be completed within three years. Examples include:
    - reducing to 1 dB the uncertainty in the magnitude of the EM fields within the Bureau's anechoic chamber (T5, R6);
    - validation of source-emission test methods (T10, R5); and
    - devising test methods to evaluate the range over which ion density meters will operate acceptably (T4, R9).

- 15 percent are expected to be completed within five years. Examples include:

  - the development of a directional, broadband antenna for use in the 1 MHz to 40 GHz frequency band (T2, R2);
  - the development of a field probe that will simultaneously measure both electric and magnetic fields (T2, R3); and
  - the development of a personal dosimeter (T13, R1).

Those topics with the greatest number of unmet needs include:

- Characterizing RF Electric Fields (Table 2), and
- Generating RF Electric Fields (Table 5).

Of all the requirements identified in Tables 2 - 13 which remain to be addressed, the three which we consider to be of the very highest priority are the development of:

- an EM field probe that will simultaneously measure both electric and magnetic fields (T2, R3);
- prototype hand-held instruments for measuring the intensity vs. time profile of pulsed and impulsive fields (T2, R13); and
- expertise needed to generate at least four simultaneous, well-characterized, CW, EM fields (T5, R8).

These items will clearly become a part of the NBS program as current activities are brought to a conclusion.

Aside from these top priority requirements, however, there remains the major question of how to deal with conducted EMI discussed in section 3.3. As noted there, NBS does not now have any ongoing work that addresses this important problem. An effort is being made, however, to find some means for building the "critical mass" of resources that will permit a meaningful start on this problem. Reprogramming from current activities and seeking other agency support are among the various options now being considered.

4. CONCLUSION

This examination of the capabilities and limitations of the national measurement system for NER health and safety has demonstrated that while a number of high priority tasks remain to be completed (e.g., validation of emission test methods) and still others to be even initiated (e.g., the development of electric field intensity meters for pulsed and impulsive sources), there exists a strong foundation upon which future developments can be based. Of the 84 recognized tasks that remain to be completed more than half were judged to have a high priority, but 82 percent of these tasks were already being addressed either by NBS or another institution.

The study noted that the United States has no mandatory, federally enforced, general population exposure standard at this time. Additionally, while it is generally recognized that States play a critical role in the regulatory process, only a handful of States have active NER protection programs, and only two public bodies (the city of Portland, Oregon and the State of Texas) have adopted their own population exposure standards. This lack of strong regulatory pressure, combined with other factors cited in the report (section 3.3.3), has served to limit the demand for NBS calibration services in the NER area. This situation may change in the future if regulatory agencies such as EPA and OSHA continue to increase their radiation protection activities.

Attention was drawn to the fact that numerous other Federal agencies play a key role in assuring NER health and safety. These agencies often work together for the solution of common problems (e.g., the EPA workshop cited in section 3.4.1) or to plan future activities (e.g., the BENER Task Force). These interactions help to keep NBS informed of present and future measurement needs as they arise.

In view of these considerations, it appears at this time that there is not sufficient demand for present or additional NER calibration services to justify the establishment of regional calibration laboratories; nor are there any unique opportunities that argue strongly for the establishment of such services. However, as Federal, State and other radiation control programs are further strengthened, the need for regional facilities will again need to be assessed.

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The report provides a detailed assessment of the capabilities, limitations, and requirements of the National Nonionizing Radiation Measurement System. The priorities of these measurement requirements are assessed according to their ability to contribute (1) to the core competence of determining the electric and magnetic fields of a source or (2) to the associated capabilities for (a) generating and applying reference fields, (b) characterizing sources and reflectors, or (c) recording exposure histories. The report examines these measurement capabilities at all frequencies between dc and 300 GHz. These measurement requirements are reviewed in the context of the overall Federal Program for Nonionizing Electromagnetic Radiation Safety. The report concludes that the need to develop and improve instrumentation, measurement standards, calibration services and standardized measurement techniques far outweighs the need to establish regional calibration laboratories at this time. The study was conducted with the assistance of the Conference of Radiation Control Program Directors, Inc. in response to a recommendation by the Senate Committee on Commerce, Science, and Transportation.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)
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