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TECHNICAL BULLETIN

CONTROL OF HAZARDS TO HEALTH FROM MICROWAVE AND RADIO FREQUENCY RADIATION AND ULTRASOUND

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*** This publication supersedes TB MED 270, 6 December 1965.**

1. Introduction. Continuing developments in technology have resulted in increased utilization of electromagnetic energy in the radio frequency (RF) band of the electromagnetic spectrum. Particular growth has been seen in the upper portion of that band—above 100 megahertz (MHz)—the region referred to as the microwave band or region. It is customary among personnel speaking of the electromagnetic spectrum to divide the RF portion of the spectrum into the RF region (below 100 MHz) and the microwave region (above 100 MHz). That convention has been followed throughout this publication. The widespread utilization of this energy greatly increases the probability of personnel exposure to injurious intensities of radiation. In order to minimize unnecessary personnel exposure, a continuing program of evaluating sources, conditions of exposure, and potential hazards, and the development of control measures must be implemented. This publication has been prepared in the interest of expediting such measures.

2. Purpose. This bulletin provides guidelines for the protection of personnel from exposure to potentially hazardous levels of microwave and RF radiation, either directly to personnel or as a result of electromagnetic interference (EMI). A section also provides discussion on the use and control of ultrasound devices. Measures are outlined which should be used to reduce unnecessary exposure of personnel to such radiations and devices.

3. Definitions. An explanation of units of measurement is given in appendix A.

a. Antenna. A device employed as a means for radiating or receiving electromagnetic energy.

b. Antenna Beam (Beam, Main Beam). The major lobe of the antenna radiation pattern.

c. Antenna Gain (Relative). The ratio of the power gain of an antenna relative to a standard antenna. The relative gain may be in decibels or it may be numeric. The standard antenna is usually an isotropic antenna.

d. Antenna Pattern. A graph of antenna radiation intensity as a function of space coordinates.

e. Applicator. A device designed to conduct, transmit or transfer energy from a therapeutic product into human tissue. For ultrasound this energy would be acoustic energy and the applicator would contain one or more ultrasound transducers. For microwave or RF, this energy would be electromagnetic energy and the applicator may be referred to as a director.

f. Athermal Effect. (Nonthermal Effect.) Any effect of electromagnetic radiation absorption exclusive of the production of heat.

g. Attenuation. A general term used to denote a decrease in the power or energy density level of any electromagnetic or acoustic radiated field as it passes through an absorbing and/or scattering medium.

h. Average Power Output. The available transmitter power averaged over a modulation cycle (the power actually available to do the work). The average power is the peak power multiplied by the duty cycle. In continuous wave (CW) systems the average power is equal to the peak power since the duty cycle is one. In a pulsed system the average power is equal to peak power multiplied by the duty cycle.

i. Beam Width, Half Power. In a plane containing the main beam of the antenna the half power beam width is the angle between the two directions in that plane in which the radiation intensity is one-half the maximum value of the main beam intensity.

j. Bonding. An electrical union between two metallic structures, used to provide a low resistance path between them.

k. Conduction. The transmission through or by means of a substance or body capable of transmitting electricity, heat or sound.

l. CW System. A system designed to produce continuously successive oscillations of equal amplitude and wavelength.

m. Coupling. The transfer of radiating or propagating energy from one system or medium to another (air to water, radiator to air, etc.).

n. Decibel (dB). The unit used to express a power or voltage ratio with an arbitrarily defined reference level. The equation $n(dB) = 10 \log_{10} \left(\frac{P_1}{P_2}\right)$ expresses the decibel equal to 10 times the logarithm of a power ratio. The equation $n(dB) = 20 \log_{10} \left(\frac{V_1}{V_2}\right)$ expresses the decibel equal to 20 times the logarithm of a voltage ratio.

o. Denied Occupancy Area. Any accessible area in which the power density is 50 mW/cm^2 or greater.

p. Director (Diathermy). (See *Applicator.*) A device used to transfer microwave or RF energy from the diathermy unit to the patient. Transfers energy through a combination of coupling and radiation.

q. Dummy Load. Any device introduced into an RF or microwave system for the purpose of absorbing RF/microwave energy.

r. Duty Cycle. Ratio of "on time" to total exposure duration for a repetitively pulsed system. The product of the pulse duration and pulse repetition frequency.

s. Electromagnetic Compatibility. The capacity of electronic systems or devices to meet specified performance standards in a given electromagnetic environment.

t. EMI. Undesired electromagnetic energy in the environment or circuitry of electronic systems or devices which causes or can cause undesired response, malfunction, or degradation of system performance.

u. Electromagnetic Radiation (EMR). The propagation of energy in the form of varying electric and magnetic fields through free space at the speed of light.

v. Electromagnetic Susceptibility. The degree of sensitivity that electronic systems or devices have to EMI.

w. Energy. A quantity used to characterize the output of RF/microwave systems, generally measured in joules (1 joule equals 1 watt second). (Note—also called *radiant energy.*)

x. Far Field Region. That region of the radiated field of an antenna where the power density variation is inversely proportional to the square of the distance from the source (sometimes called the Fraunhofer region).

y. Field Strength. A measure of electric (E) or magnetic (H) field potential in an electromagnetic field. Usually expressed in volts per meter (V/m) or amperes per meter (A/m).

z. Grounding. The process of physically providing a metallic surface or wire with a low impedance path to reference or ground potential.

aa. Half Power Beam Width (HPBW). The HPBW is the angular width of the antenna radiation pattern between points where the power level has decreased to one-half of the maximum value.

ab. Hazard Evaluation Survey. Evaluation of the hazards to personnel in the vicinity of RF, microwave, or ultrasound transmitting sources.

ac. Hertz (Hz). The unit of frequency, equal to one cycle per second.

ad. Intermediate Field Region. That portion of the Fresnel region of an antenna where the power density is decreasing at a linear rate with distance.

ae. Isotropic Antenna. A hypothetical antenna radiation or receiving electromagnetic energy equally in all directions.

af. Limited Occupancy Area. Any accessible area in which the power density is in excess of 10 mW/cm^2 but less than 50 mW/cm^2.

ag. Maximum Permissible Exposure Level. The maximum power density or energy density level of EMR that an individual may be exposed to.

ah. Microwave Region. That portion of the electromagnetic spectrum which includes the frequency band from 100 MHz to 300 gigahertz (GHz) with corresponding wavelengths of 3 meters (m) to 1 millimeter (mm).

ai. Milliwatt (mW). A submultiple of the watt equal to one thousandth of a watt.

aj. Near Field Region, Radiating. That region of the radiated field of an antenna where the power density variation is not inversely proportional to the square of the distance from the source (sometimes called Fresnel region). In this region the power density increases irregularly with range to a maximum level, then decreases approximately at a linear rate to the onset of the far field region (see intermediate field region, far field region).

ak. Near Field Region, Reactive. The region of the field that immediately surrounds the antenna where the reactive field predominates. Usually considered to exist over a range less than or equal to $\lambda/2\pi$ from the antenna surface.

al. Power Density. The intensity of EMR present at a given point. Power density is the average power per unit area expressed as mW/cm^2. Power density and electric field strength are related by the following formula: $P_d = \frac{E^2}{3770}$ where E is given in V/m. Power density and magnetic field strength are related by the following formula: $P_d(\text{mW/cm}^2) = 37.7\ H^2$ where H is given in A/m.

NOTE: See appendix B for a conversion table between power density vs field strength.

am. Power, Peak. The maximum power amplitude produced in an individual pulse of energy (pulsed systems).

an. Pulse Duration. The amount of time that each output pulse or burst of energy is on. In radar systems a typical pulse duration is measured in microseconds (μs).

ao. Pulse Repetition Frequency (PRF). In pulsed systems, the number of output pulses per unit time.

ap. Pulsed System. A system designed to produce energy in short pulses or bursts, repeated at regular intervals (see pulse duration, duty factor, PRF).

aq. Radar. A system that radiates electromagnetic waves and processes the reflection of such waves from distant objects to determine their existence and position. RADAR is an acronym for "Radio Detection and Ranging."

ar. Radiation Intensity. The power radiated from an antenna per unit solid angle in a given direction.

as. RF Band. That portion of the electromagnetic spectrum that is useful for radio transmission. The current practical limits of RF are roughly 10 MHz to 300 GHz.

at. RF Region. A portion of the electromagnetic spectrum which, for the purpose of this publication, covers the frequency band from 10 MHz to 100 MHz with corresponding wavelengths of 30 m to 3 m.

au. Sonic Radiation. The generation and propagation of an oscillating pressure or stress, etc., in a medium.

av. Ultrasonics. The branch of science that deals with the phenomena of ultrasound.

aw. Ultrasound. Pertaining to sound or acoustic energy occurring at frequencies higher than 20,000 Hz.

ax. Ultrasound Transducer. An piezoelectric device used to convert electrical energy into ultrasound energy and ultrasound energy back into electrical energy.

ay. Unidirectional Applicator. An applicator designed to transmit energy in a direction along a single specified axis.

az. Watt (W). A unit of power defined as the rate of energy consumption or conversion when 1 joule of energy is consumed or converted per second.

ba. Wavelength (λ). The distance in the direction of propagation between two successive points of a periodic wave at which the wave has the same phase is termed one wavelength. The velocity of light (3×10^8 m/s) divided by frequency (in Hz) equals wavelength (in m). Wavelength is related to the velocity of propagation (v) of a wave and frequency (f) of the propagating wave by $\lambda = v/f$. Velocity of propagation is $v = c = 3 \times 10^8$ m/s for electromagnetic energy in a vacuum, $v = 1.5 \times 10^3$ m/s for ultrasound energy in water.

4. General Considerations.

a. Interaction of RF and Microwave Energy.

(1) Because of the low energy content of RF and microwave radiation it does not ionize materials and consequently is known as nonionizing radiation. Therefore, transfer of energy to a biological system must result in something other than molecular ionization, such as occurs with ionizing radiations (e.g., x-rays and gamma radiation). Since biological systems are primarily water, RF and microwave energy transfer to water molecules and dissolved ions and small molecules probably accounts for the majority of the absorption by these systems. Much of this can be explained by dipole rotation as dipolar molecules attempt to follow the alternating electric field. The electric field is attenuated by the biological system while the magnetic field essentially penetrates without attenuation, except for magnetically induced electric fields and currents. This may result in widely varying amplitudes of the electric and magnetic fields in different parts of the body.

(2) Absorption of RF and microwave energy generally results in heating of the absorbing medium. This has been well known for many years and is the concept utilized in the application of RF and microwave diathermy units for use in physical therapy. Heating in this manner adds to the normal metabolic heat load and requires compensating mechanisms to dissipate the added thermal burden and maintain homeostasis. As long as the additional thermal result is within the capability of the organism to dissipate, overall temperature increase will not occur or will be relatively small and manageable; however, if heat gain exceeds compensatory capability, the overall temperature may increase to deleterious levels. Significant amounts of absorbed RF energy could cause localized increase in body temperature with concurrent effects on other biochemical and physiological processes.

(3) Penetration of RF and microwave energy into a biological system is a function of frequency, therefore, biological effects would be expected to vary depending upon frequency of the incident radiation. A somewhat crude, but adequate, rule of thumb is that effective depth of penetration in a biological medium is one-tenth the free space wavelength. Thus, high frequency (short wavelength) microwave radiation exposure will result in predominant heating of superficial tissues. It must be noted that in the range of several hundred MHz to a few GHz, a combination of deep and superficial heating may be expected.

b. Biological Effects.

(1) A thermal burden may be expected to be the predominant effect of exposure to moderate and higher average power densities. The response to such an exposure can be expected to be similar to that from other thermal stress and will be a function of individual physiological and environmental (including clothing) factors. Few well-documented effects have been produced in

mammals which cannot be ascribed to hyperthermia. Local hyperthermic environments may be induced which would not necessarily be reflected in a significant increase in total body temperature. This situation could occur depending upon tissue, frequency, power density and amount of the body exposed. Energy deposition is not uniform throughout a biological system but is a function of the dielectric characteristics of each tissue since reflection and refraction of conducted waves are to be expected at each interface.

(2) The sensitivity of testes to hyperthermia is well known. Changes as a result of RF-induced hyperthermia are considered as no different than those resulting from the other thermal sources. Production of lenticular cataracts from acute exposures to microwaves is believed to require high-dose exposures while the probability of induction of microwave cataracts from long term, chronic exposures at low power densities is unknown and no mechanism for induction has been proposed. Several epidemiological studies comparing "microwave workers" with control populations have shown that there is no difference in aged-matched populations. Additionally, there is no evidence to indicate that alleged "microwave cataracts" can be identified ophthalmologically as different from cataracts induced by other means. The available evidence indicates that cataracts should not be a problem within Department of the Army with the current microwave exposure standards.

(3) Considerable biological effects research is currently being conducted or planned to further evaluate effects of pulsed fields with high peak powers. Although little is known, the possibility of effects not attributable to hyperthermic situations must be investigated. At this time, there is no scientific evidence of effects which may be deleterious within published exposure guidelines. Pulsed fields have been well known to produce the so-called "microwave hearing" phenomenon—a buzzing or clicking sound which is apparently a function of the PRF. The mechanism and biological effects of this phenomenon currently are under study.

c. RF and Microwave Field Characteristics. Propagating electromagnetic energy is always accompanied by E and H force fields which are varying sinusoidally with time and space. A measurement of the intensity of these fields will characterize the total amount of electromagnetic energy that is available. There are certain conditions of propagation where a measurement of either the E or H field component adequately indicates the energy level present. This is not always the case, however, and it becomes necessary at the lower frequencies to measure both the E and H field components of the propagating electromagnetic wave to fully characterize the energy present. Some factors that help to determine which measurement conditions suffice are discussed in the following paragraphs.

(1) There are essentially two propagation modes for electromagnetic energy: conduction and radiation. In the RF and microwave frequency range, there is no boundary line that separates these two modes. In fact, an antenna can be viewed as a device for transforming between the conduction and radiation propagation modes. Electromagnetic energy that is propagating along a transmission line has extensive E and H fields in the space around and between the conductors. These fields are associated with the voltage between the conductors and the current flowing in them. Typical examples of such lines are 60 Hz high voltage lines (one wire to ground); RF diathermy feed lines; and television antenna transmission line. It is possible to extract or couple energy from such a transmission line if the appropriate coupling mechanism is used, for example, an automobile antenna under a 60 Hz power line couples energy from that line. In order to characterize the energy at a point in space, closer to a transmission line, which might be coupled to another line or object, it is necessary to measure both the E and H fields at the point of interest.

(2) In a radiation propagation mode, the energy available at a point in space may generally be determined according to the following:

(a) In the far field region, a measure of either the E or H field intensity will establish the energy available. Most instrumentation used for personnel hazard evaluation indicates the radiated intensity in terms of power per unit area (power density) usually in mW/cm^2. In these radiating regions, a standard factor is available for converting mW/cm^2 to E field strength (v/m). That conversion factor is indicated in paragraph 3 under power density.

(b) In the near field reactive region, the conditions described for the conduction mode of electromagnetic wave propagation apply and both the E and H fields must be measured to determine the actual power density that is present. Paragraph 3 establishes the approximate range limit for the near field reactive region at $\lambda/2\pi$. At 10 MHz that range is about 5 m. Consequently both E and H field measurements would be necessary to accurately determine power density with 2 to 5 m of most RF diathermy or within 5 m of most high frequency (HF) (2-30 MHz) radio transmitters. Equipment for accurately measuring these fields has been developed recently and is becoming available.

5. Medical Surveillance. In consideration of possible biological effects from exposure to RF and microwave radiation levels in excess of permissible exposure limits, a specific preplacement and termination eye examination will be performed as required by AR 40-583, Control of Potential Hazards to Health from Microwave and Radio Frequency Radiation, for potentially exposed personnel, both military and civilian. The preplacement and termination examinations should consist of a physical examination which as a minimum consists of a comprehensive eye examination, including evaluation of media and fundus with an ophthalmoscope, slit-lamp examination of the lens with pupil widely dilated, and determination of best visual acuity for far and near vision. Following the preplacement examination, the individual should be included in the routine occupational vision program which includes screening examinations by orthorater and other available screening equipment at least biennially. Additional ophthalmoscope and/or slit-lamp examinations will be performed if indicated by abnormal findings obtained in the screening examinations. Investigations of known or suspected exposures in excess of applicable radiation standards will be performed as required by AR 40-583.

6. System Analysis and Hazard Evaluation. The US Army inventory of RF and microwave generating systems is divided among one broad and two narrow equipment categories for maximum simplicity in the respective radiation control programs. The two narrow categories include industrial heating and microwave food processing, and RF and microwave diathermy systems. These categories are essentially closed systems in which the electromagnetic energy is contained within a closed environment (industrial heaters and ovens) or one with the least possible extraneous radiation (diathermy). A third very broad category of equipment includes all other RF and microwave systems, such as radar, communications systems, and other electronic devices. Equipment in this category is generally designed for free space transmission of energy. Analysis and measurement of systems, particularly in the third category, and associated hazard evaluations, are complex and usually result in recommendations for carefully structured hazard control programs. Guidelines for system analysis, hazard evaluation, and basic control programs are presented here.

a. Microwave Food Processing Systems. Use of microwave energy for cooking applications has been gaining in popularity for a number of years. Microwave cooking systems use the interaction between the permanent electric dipole moment of water molecules and the electric field component of the incident microwave energy. The molecules of a material (principally water, in food), when subject to an electric field, will try to rotate and align with the direction of the applied field. Since the electric field changes polarity at a very rapid rate (typically 2450 or 915 million times per second) depending on the operating frequency of the system (2450 MHz or 915 MHz), heat is generated due to mechanical friction between the molecules. As this heat is conducted through the material, the cooking process is achieved. Practical applications of these heating systems include conventional and conveyor microwave ovens. The conventional ovens are widely used in food vending areas, cafeterias, quick order kitchens and mobile kitchens in hospitals. The conveyor ovens are used sparingly in large commercial kitchens. Personnel hazards from these ovens may arise whenever the microwave radiation leakage levels become excessive. The excessive levels typically are caused by degeneration of the door seals, faulty interlocks, and damaged or misaligned doors. One cause of door seal degeneration is food particle accumulation around the electronic seal allowing arcing to occur, which in turn causes actual physical damage to the door and oven cavity interface. Interlock failures can occur in several ways. A typical problem in the field involves misadjusted interlocks which allow the oven to operate with the door partially open. Another problem occurs when interlocks malfunction or are bypassed (electrically or mechanically), thereby rendering them ineffective. Microwave oven malfunctions involving interlocks should be regarded as a most serious problem as such failures, more than others, result in a high potential for exposing personnel to hazardous levels of microwave radiation. Door damage or misalignment can occur from unnecessary abuse by the user. Other frequently encountered causes of microwave radiation leakage from ovens include missing hardware and misplaced or damaged panels and shields.

(1) *Oven Surveillance Guidelines.* Microwave oven hazard assessment is accomplished by a comprehensive survey consisting of two parts, a visual inspection and radiation measurements, in accordance with the standards outlined in Public Law 90-602, Radiation Control for Health and Safety Act of 1968, and Title 21, Code of Federal Regulations, Chapter 1, Subchapter J, Part 1030, Performance Standards for Microwave and Radio Frequency Emitting Products. AR 40-44, Control of Potential Hazards to Health from Microwave Cooking Ovens and Other Microwave/Radio Frequency (RF) Food Service Devices, further defines the requirements for the survey.

(a) Visual inspection. A visual inspection is always performed first during a survey. If properly conducted, it provides information on the overall condition of the oven prior to the radiation measurements. Even though the exact amount of leakage from a microwave cooking oven cannot be conclusively determined without suitable instrumentation, the visual inspection can alert the surveyer to possible radiation problems. Particular emphasis should be placed on visual inspection of the door since nearly all instances of leakage occur there. The following visual checks should be made to discover:

—Loose or bent door hinges and screws missing from the hinges.

—Sprung, warped, or misaligned doors.

—Faulty interlocks. For example, oven should not be operable with door open or slightly ajar.

—Damaged oven.

—Worn, missing, or damaged seals around the door or viewing area.

—Pitting and burnt spots around the periphery of the door closure area, usually caused by arcing as a result of grease buildup around the door or by attempts to cook with metal foil or cans.

—Whether adequate instructions and warning signs to oven users as specified by public law and Army regulations are properly posted. Because frequent changes in the area of signs and instructions have been experienced in the past, appropriate regulations should be checked regularly.

(b) Microwave radiation leakage measurements. Determination of the microwave radiation leakage level is accomplished by using appropriate instrumentation to take measurements around the oven, while the oven is operating under typical load conditions. The load consists of a specified amount of water, the quantity of which is determined by the RF power output of the oven. This procedure approximates the water content of normal amounts of food cooked in that particular oven. Waterloads to be used for the various RF power levels during the leakage measurements are as follows:

1000 W or less	100 ml ± 5 ml
1000 to 2000 W	200 ml ± 15 ml
2000 to 3000 W	500 ml ± 20 ml
3000 to 6000 W	1 liter ± 35 ml
6000 W or more	1.5 liter ± 45 ml

If the power of a home-type oven is not known, 100 milliliters (ml) should be used as the water load.

(c) If acceptance testing is performed on ovens, the test must conform to the requirements of Public Law 90-602 referenced in paragraph 6a(1).

(d) Any oven found to be leaking 5 mW/cm^2 or greater at a distance of 5 cm or more shall immediately be removed from service. A comprehensive survey must be conducted prior to placing a repaired oven back in service.

(2) *Instrumentation.* The only currently recommended instrument for Army microwave oven surveys is the Narda 8200 Electromagnetic Leakage Monitor (NSN 6665-00-526-0432). This is a handheld instrument with a removable probe designed to detect microwave radiation at the 2450 MHz oven frequency. Two probes are available for the system, each covering a different measurement range:

Model 8221	0-20 mW/cm^2
Model 8223	10-100 mW/cm^2

The recommended system for an oven surveillance program includes two Model 8221 probes, since this affords the correct measurement range plus a backup probe in the event of a failure. Purchase of the Model 8223 probe is discouraged since the addition of this probe does not enhance the oven program. The instrument is used by holding the probe at right angles to the area to be measured (along the door seal and window area), while slowly scanning these points to determine the maximum level of radiation. An important point to emphasize with regard to the Narda 8200 system is that it can be used *only* at the 2450 MHz microwave oven frequency. It cannot be used for radiation monitoring of systems operating at other frequencies; such as RF diathermies, radars, and communications systems.

(3) *Microwave Oven Control Program.* The microwave oven radiation protection program is

detailed in AR 40-44. This regulation explains the responsibilities, policies, and procedures for establishing and maintaining an effective microwave oven radiation protection program. The following are considered minimum requirements:

(a) Clean oven daily.

(b) Perform visual inspection at least monthly.

(c) Perform comprehensive survey of oven at least every 6 months.

(d) Do not operate the oven empty.

(e) Do not stack ovens. Maintain a minimum distance of 60 cm (2 feet) between ovens.

(f) Maintenance personnel should not operate the oven with cover removed.

(g) Perform continuity check of all safety interlocks whenever an oven is removed from service for maintenance and prior to being placed back into service.

(h) Perform comprehensive survey of all ovens removed from service for maintenance prior to ovens being placed back into service.

(i) Maintain a current comprehensive inventory of installation microwave ovens.

(j) Provide comprehensive survey results to the US Army Environmental Hygiene Agency (USAEHA) for analysis and evaluation.

b. RF and Microwave Industrial Heating Systems. RF and microwave energy sources are often employed for rapid, carefully controlled heating of various materials during industrial processes (manufacturing, tempering, testing, etc.). Systems designed for these purposes usually involve very high average power levels, applied inside enclosures. Typically such enclosures are sealed against radiation leakage and are interlocked to prevent operation with the sealed enclosures open. Many controls which are recommended for microwave food processing equipment are useful for industrial heating systems; however, such controls may not be applied casually. Different kinds and levels of control are required depending on equipment parameters, operator training level, and operational environment. Generally a radiation protection program will be required for industrial heating equipment including an overall system analysis and hazard evaluation similar to that for radar and communications equipment.

c. RF and Microwave Diathermy. Physical therapy clinics at many Army installations use RF and microwave diathermy which utilize the heating effect of electromagnetic energy. The recommended control program for these units involves visual inspection to insure that the timing devices are operating satisfactorily and that the directors or radiating elements and transmission lines have not been damaged. Routine radiation level measurements are made on all such diathermy devices as part of the USAEHA mission services in support of AR 40-583. All directors (applicators) are also tested at this time for power distribution and relative efficiency. The purpose of RF and microwave measurements of diathermy devices is to determine as far as possible the energy distribution outside of the local area for which the treatment has been prescribed. Elements of a diathermy control program including a basic standing operating procedure (SOP) recommended for the RF and microwave diathermy user are presented below.

(1) A general recommendation for insuring safe use of RF/microwave diathermy units is to exercise extreme caution in the use of these units, so as not to inadvertently expose the eyes of either personnel administering the treatment or the patient to RF/microwave radiation. The following procedures should be observed:

(a) All applications of RF/microwave radiation to personnel should be performed only at the request of the attending physician or physical therapist.

(b) The suggested percentage of power setting should be maintained.

(c) The duration and areas of exposure, as outlined by the physician or physical therapist should not be exceeded and should be administered by qualified personnel only.

(d) All applications to the facial area should be avoided.

(e) The diathermy unit should be secured when not in use.

(f) The power setting control should be checked prior to operation to determine any looseness in the control knob position.

(g) The timing mechanism should be checked prior to each application to ascertain that the unit does cut off at the end of the preset time of exposure.

(2) A general diathermy operating procedure should be to:

(a) Make the patient ready and comfortable.

(b) Place the applicator/director in the vicinity of the area to be irradiated.

(c) Set all controls necessary for warmup and operation of the diathermy unit.

(d) Be certain that patients in adjacent beds or areas will not be exposed.

(e) Be certain pacemaker patients are not in the vicinity of the unit.

(f) Apply RF power.

(g) Check settings and position of director.

(h) Caution patient not to place face in field of radiated energy from director.

(i) Post pacemaker warning signs of the type shown in figure 1 only while the equipment is in operation. A suggested instruction for insertion in the lower triangle of the sign is shown in figure 1.

(j) Do not treat patients on objects which are grounded or use beds, couches, tables, or chairs with steel springs or inner-spring mattresses, because sufficient heat may be generated to ignite the mattress or other cushioning material.

(3) Calibrate the diathermy units in accordance with the manufacturer's guidelines. Where no guidelines are provided, local SOPs establish the calibration schedule.

d. Radar, Communication and Related Systems.

(1) Before any hazard evaluation can be attempted, certain basic information concerning

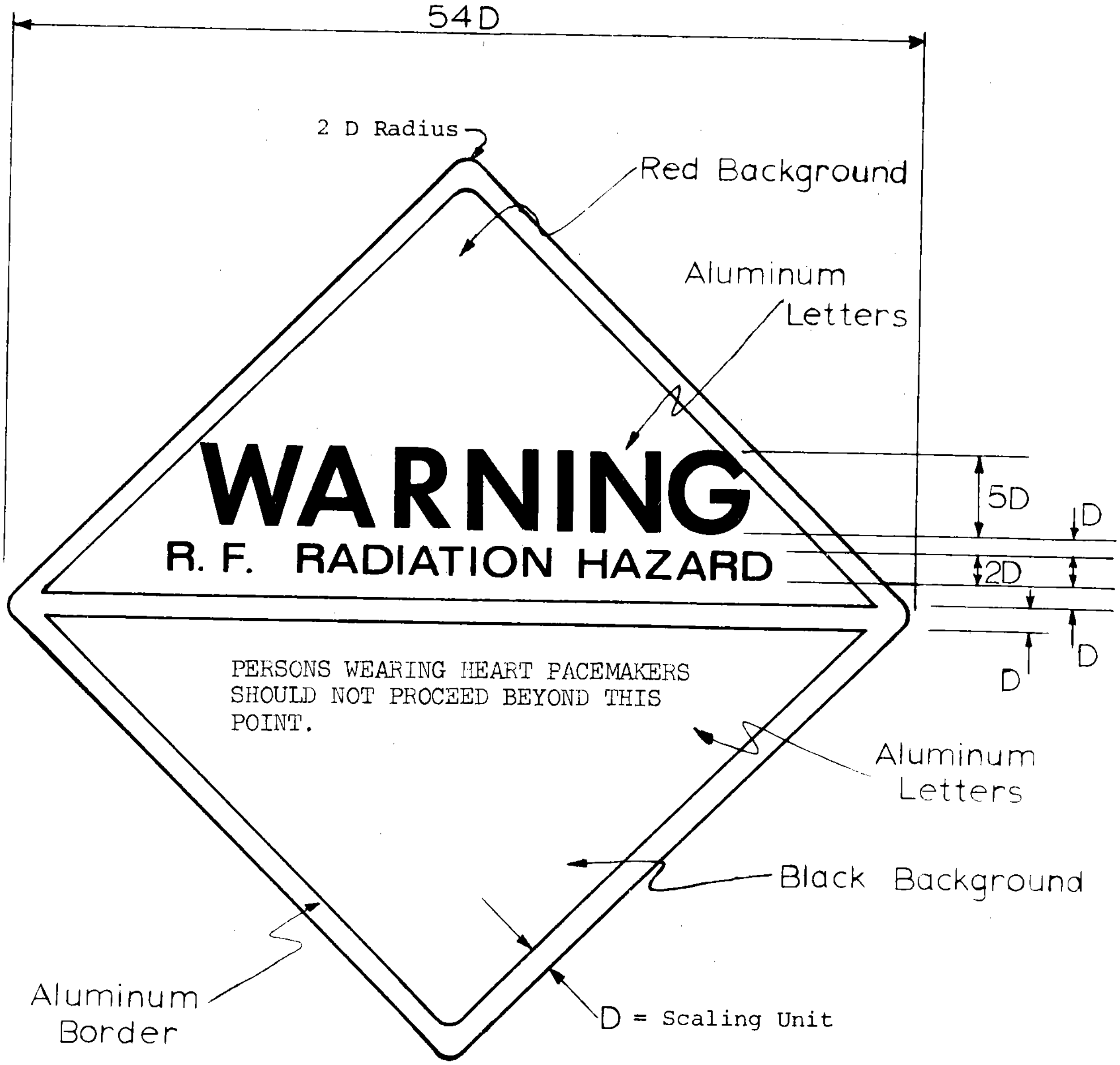

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Figure 1. Pacemaker WARNING sign.

each system must be known. The required information for several types of microwave devices, such as radar and communications systems, are listed below.

(a) Identification of the system to be evaluated, and the operating characteristics, such as peak or average transmitter power, PRF or rate, duty cycle, frequency, antenna dimensions, antenna gain, antenna type, and polarization of the transmitted wave.

(b) The power density level along the antenna's main radiated beam axis at any distance from the antenna surface. This information can be obtained from USAEHA (see para 13 of this document).

(c) The height of the antenna centerline above ground, as well as antenna azimuth and elevation angles of operation. This information is required to construct a beam height diagram appropriate for the system under evaluation.

(d) The site configuration as well as terrain variations, to include the location of all structures, such as buildings, towers, other radar or communication systems, etc., which could be occupied by personnel and possibly irradiated by the system under evaluation.

(e) The location of all access routes to the site under evaluation including helicopter approach paths which may be in the path of the radiated beam.

(f) The procedures followed by personnel during all phases of operation of the system. Maintenance and test procedures as well as operational procedures should be included. Usually an SOP implemented at the local command level would contain this information.

(2) The information collected during the Radiation Hazard Analysis forms the basis for evaluating the personnel hazard (actual or potential) from a given RF or microwave system. The following paragraphs describe the hazard evaluation approach for RF/microwave radar, communication and related systems. The hazard evaluation points out the area where certain prohibitive or near prohibitive radiation levels exist.

(a) When the azimuth and elevation angles at which the antenna can be oriented are known, it is possible to determine the extent of areas exposed to the beam. Using the approximate antenna height and minimum beam elevation angle, a beam height diagram can be constructed. A simple calculation will then reveal the beam height above the ground surface at any distance from the antenna. Particular attention must be given to terrain features. If the position of the beam is such that it is inaccessible to personnel at all times, no potentially hazardous condition exists. If it is possible for personnel to be exposed to the beam, further hazard evaluation is required.

(b) When conditions are such that personnel can be exposed to the beam, it is necessary that incident power densities be known. As distances from the antenna to areas of exposure are known from the previous beam-position analysis, it remains only to determine the power densities corresponding to these distances. This information is initially obtained by analysis and then verified by measurement.

(c) When the beams from two or more radar sets overlap, the power density existing in the area of intersection can be considered as the sum of the individual power densities.

(d) When the power density at the area of exposure is less than 10 mW/cm^2, no potential hazard exists. However, should the power density be in excess of 10 mW/cm^2, a potentially hazardous condition does exist. Area designations and hazard classifications corresponding to various ranges of power densities are given in table 1.

Table 1. Area Designations and Hazard Classifications

POWER DENSITY	AREA DESIGNATION
Below 10 mW/cm^2	Unlimited occupancy
10 mW/cm^2–50 mW/cm^2	Limited occupancy
Above 50 mW/cm^2	Denied occupancy

(e) When a transmitting antenna whose maximum power density has been determined to be less than 10 mW/cm^2 is directed toward an area where ground reflections or reflections from other structures could exist, precautions must be taken because the power density level in that area could well exceed the 10 mW/cm^2 level. The area could then be considered as a potentially hazardous area and must be treated as such.

(f) Under conditions where the antenna is continuously rotating, the stationary power density level may be reduced to an average scanning power density by the use of the equation below. It may be used for reducing stationary power densities only in the antenna pattern far field region. This reduction factor is not generally applicable, without modification, to sector scanning antennas. *Reduction of power densities from nonscanning intensities in excess of 50 mW/cm^2 is not permitted.* Reduction to an average scanning power density level could lead to an area around a radiating source being declared safe for personnel occupancy. However, should the antenna stop scanning but continue radiating, hazardous levels of radiation should be assumed to be present within such an area. It should be noted that the rotation rate of the antenna does not enter into the equation. If the antenna has a fast rotation rate the exposure time would be far shorter durations but more frequent than slow rotation rates. At slow rotation rates the exposure time would be long but so would the time between exposures.

$$W = W_0 \frac{1.5\,(\mathrm{HPBW})}{360^\circ}$$

Where: W = averaged scanning power density at the point of interest

W_0 = stationary power density at this point of interest

HPBW = antenna pattern beam width (half power) = $60\lambda/D$ (approximately)

λ = wavelength (m)

D = antenna diameter (m)

7. Exposure of Personnel.

a. Limited Occupancy Areas.

(1) Exposure of personnel within limited occupancy areas is permitted only for the length of time such that the energy level averaged over any 0.1 hour period does not exceed 1 mW·hr/cm^2. This length of time can be calculated from the equation

$$T(\mathrm{min}) = \frac{60}{W}$$

where W is the power density in mW/cm^2. It is not feasible to control limited exposures of less than 1.2 minutes and consequently the equation should not be applied to power densities exceeding 50 mW/cm^2. *Exposure to power density levels greater than 10 mW/cm^2 should only be allowed when the mission precludes turning off the radiating source.* Then the length of time of such exposures should be controlled by personnel other than those subject to the exposure.

(2) Although exposure of personnel to microwave/RF radiation levels between 10—50 mW/cm^2 is allowable for limited periods of time, it should be understood that *unnecessary* exposure to power densities greater than 10 mW/cm^2 is not allowed. The limited exposure guideline is to be utilized only in those situations where maintenance and repair operations of the systems would be unduly restricted, or mission function precludes shutting down the transmitter. The duration of exposure of the individual must be monitored by another individual external to the field.

(3) Transient passage through potentially hazardous areas may be authorized when necessary because of the location of existing roadways, walks, etc., where such roadways and walks cannot be relocated or the antenna raised in elevation to a positive elevation angle, provided the permissible time of exposure is not exceeded. Appropriate warning signs with permissible exposure time should be conspicuously posted.

(4) Reduction of power density from the nonscanning level to the scanning (360° only) level is permitted for power densities less than 50 mW/cm^2 since even if the antenna stops scanning but continues to radiate the power density levels present would not exceed the maximum permissible exposure levels. If the reduced intensity of the scanning antenna is less than 10 mW/cm^2, the area will be considered limited occupancy so long as the radiating antenna is not scanning, since the power density level of the antenna when stationary will be greater than 10 mW/cm^2.

b. Denied Occupancy Area. Under no circumstances will personnel be exposed to intensities equal to or greater than 50 mW/cm^2.

8. Exposure Control. If an evaluation of RF/microwave hazards reveals the existence of limited or denied occupancy areas, the following measures may be used to reduce unnecessary exposures:

a. Where feasible, radiating systems should be located to minimize personnel exposures in areas adjacent to or within military installations. All limited and denied occupancy areas within military installations as well as entries to such areas should be conspicuously posted with appropriate warning signs. Evaluation of each anticipated operating condition will include consideration or development of procedures for ensuring proper placing of warning signs for the operation. Local SOPs will prescribe procedures for the placing of temporary or permanent signs during periods of operations. Signs such as those shown in figures 2A and 2B should be used (AR 385-30, Safety Color Code Markings and Signs). Dimensions and coloring of these signs should be the same as that indicated in figure 1.

b. Whenever possible, the RF radiation hazard warning sign (fig. 2A) should be posted to inform personnel of possible RF radiation hazard areas. The "denied occupancy" sign (fig. 2B) should be used but only for the duration of

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Figure 2A. General WARNING sign.

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Figure 2B. Denied occupancy sign.

the requirement. All signs should be conspicuously displayed.

c. Where operation allows, antenna positioning (pointing angles) should be restricted in order to minimize potential exposure areas, thus reducing unnecessary hazards. Permissible restrictions can be implemented through sector blanking; that is, installation of cutoff devices in the electrical or mechanical components of a system which will automatically end transmission when the antenna is pointed in a restricted direction. Restricted zones are also established by instructing operating personnel not to transmit into certain azimuth and/or elevation angles. Such restrictions should be enforced by unit SOPs.

d. During test or maintenance procedures requiring free space radiation, the use of appropriate antenna positioning restrictions is mandatory if radiated power densities could exceed 10 mW/cm^2.

e. The use of dummy loads to absorb the RF or microwave energy output is advocated when free space transmission is not necessary; i.e., at schools and other training areas.

f. Free space transmission within buildings such as schools, repair facilities, etc., is normally prohibited.

g. The use of barriers and interlock systems is required to prevent entry by personnel into denied occupancy areas.

h. Where an antenna is not permanently installed, the antenna may be relocated to reduce power densities in potentially occupied areas to acceptable levels.

i. In situations where operations would be unduly restricted by implementation of the above methods, suitable attenuation of power density levels may be accomplished by the shielding of potentially exposed areas. After installation this shielding should be tested to ensure its effectiveness. An attenuation chart for various materials and frequencies is shown in table 2 as a guideline.

Example:

Assume a power density of 150 mW/cm^2 at a frequency range of 4.5-6 GHz at the outside of a

Table 2. Shielding Attenuation Factors

MATERIAL	1-1.5 GHz	2.5-3.5 GHz	4.5-6 GHz	8-12 GHz
60 × 60 mesh screening	20 dB	25 dB	22 dB	20 dB
32 × 32 mesh screening (window screen)	18 dB	22 dB	22 dB	18 dB
¼″ mesh (hardware cloth)	18 dB	15 dB	12 dB	10 dB
Window Glass	2 dB	2 dB	3 dB	3.5 dB
¾″ pine sheathing	2 dB	2 dB	2 dB	3.5 dB
8″ concrete wall (solid)	20 dB	22 dB	26 dB	30 dB

Factors are given for the most commonly used frequency regions. For information concerning higher or lower frequencies or other attenuating materials contact USAEHA.

screened window. The power density level inside the window would be attenuated by a factor of 22 dB (screen) plus 3 dB (window) for a total of 25 dB. Refer to the negative 25 dB column in the table, appendix C, for power ratio factor of 0.003. Multiply 150 mW/cm^2 by 0.003. The resulting power density inside the window would be 0.45 mW/cm^2. The path of least attenuation should always be considered. If the building were of frame construction with ¾″ pine sheathing on the exterior and ⅜″ sheet rock on the interior of the walls, the power density would be reduced by a factor of 2 dB (¾″ pine) plus 1 dB (⅜″ sheet rock) for a total of 3 dB. Referring to the negative 3 dB column of appendix C multiply the incident power density by 0.5. The resulting power density inside the building, except in front of the windows, would be 75 mW/cm^2. Other building materials such as ⅜″ sheet rock, ½″ celotex, ¼″ and ¾″ plywood, all have attenuation factors less than 2 dB above 1 GHz and are not considered suitable for shielding.

9. Examples of Hazards Encountered With Typical Radar Sets. Three possible personnel exposure conditions can exist at a radar site: safe, potentially hazardous, and hazardous. The criteria determining these conditions and radar sets typifying each are listed below:

a. Safe. Unlimited occupancy permitted.

(1) Power densities do not exceed 10 mW/cm^2 at any accessible location.

(2) Radiated beam inaccessible to personnel.

Example:

See figure 3. With the antenna depressed to the minimum elevation angle, the beam axis would be approximately 3.7 m above ground level and at a +2.0° inclination with respect to the horizontal. For the terrain features shown in figure 3, the beam would not be accessible to personnel, so no health hazard would exist and protective action would not be required. However, should elevated structures, such as buildings, vehicles, etc., be placed within 54.9 m of the set the beam may become accessible. Caution must be exercised to make certain that side lobes from the radiating antenna do not generate "hot spots" of power density levels greater than 10 mW/cm^2 in areas considered to be safe for personnel occupancy.

(3) Averaged scanning power density.

Example:

Assume that a vehicle is placed at a distance of 91.5 m from an antenna which is 3.7 m in diameter and that personnel standing on top of the vehicle would be exposed to the beam. The stationary power density to which they would be exposed is 32 mW/cm^2. Assume that this system's frequency is 5.4 GHz and the antenna continuously rotating. The stationary power density may be reduced to an averaged scanning power density as follows:

$$W = W_0 \frac{1.5\ (\text{HPBW})}{360} = 32 \frac{1.5\ (0.9)}{360}$$

$$W = 0.12 \ \text{mW/cm}^2$$

where

W = power density, continously rotating
W_0 = stationary power density at 91.5 m
HPBW = Half Power Beam Width
$= 60 \ \lambda/D$ (approximately) $= \frac{(60)\,(0.06)}{(3.7)} = 0.9^\circ$

Since the averaged scanning power density would be less than 10 mW/cm^2, no hazard to personnel would exist provided the antenna continuously rotated.

b. Potentially Hazardous. Transient exposure permitted. Power densities exceed 10 mW/cm^2 but less than 50 mW/cm^2 and the beam is accessible.

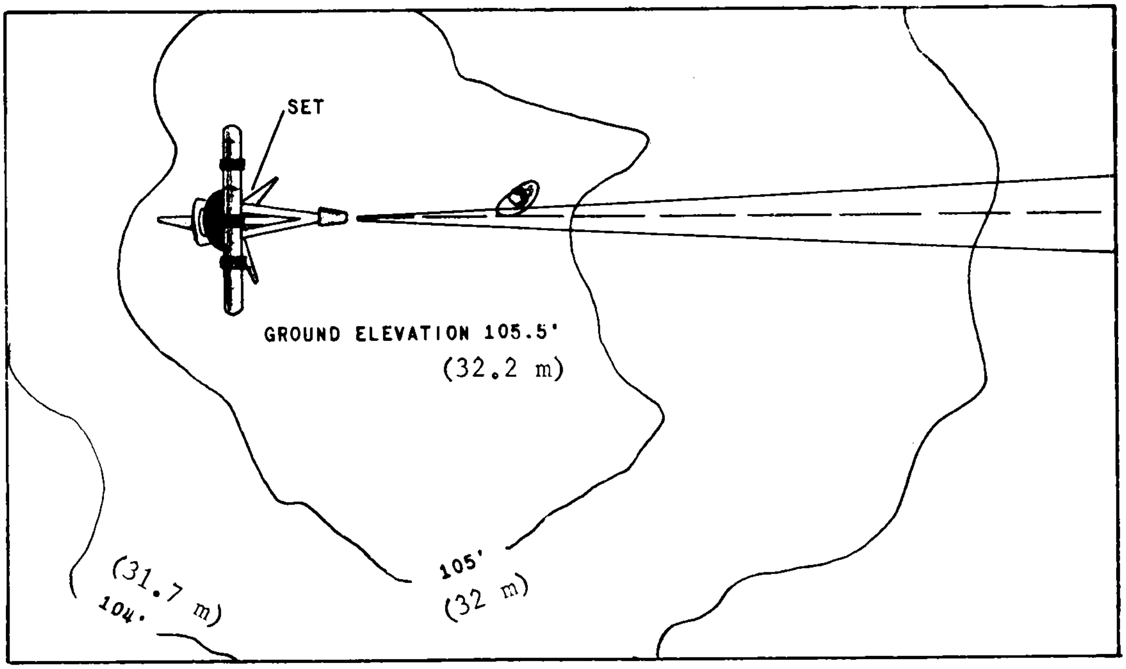
c. Hazardous. Exposure prohibited. Power densities of 50 mW/cm^2 or greater, and the beam is accessible.

Example:

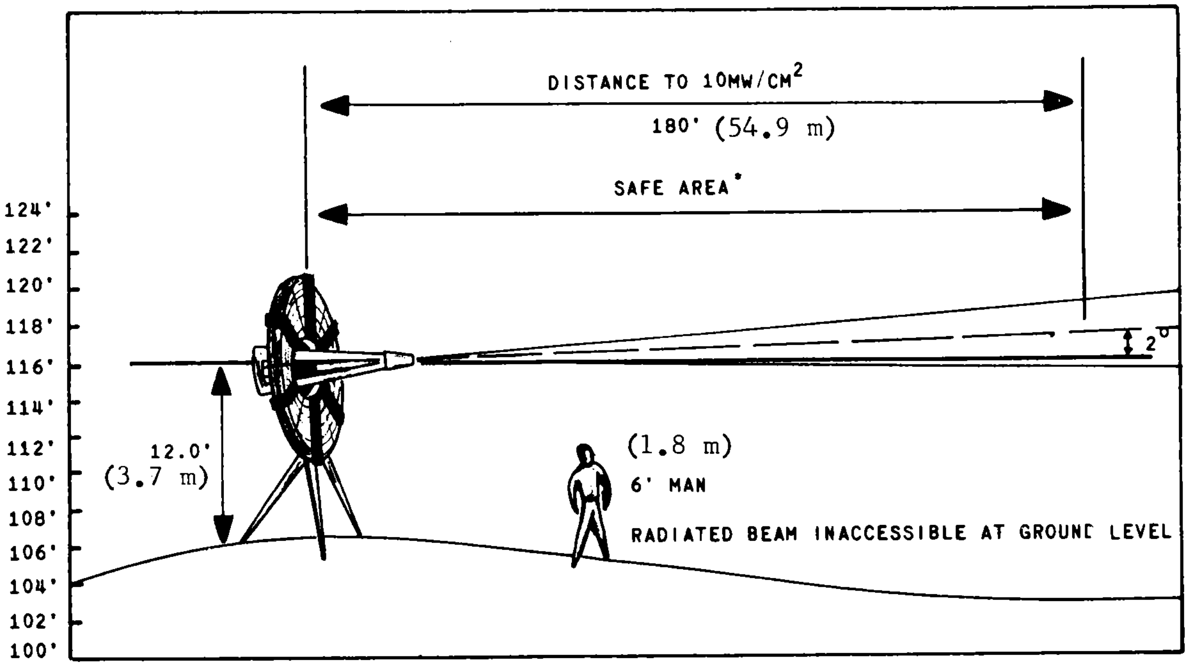
See Figure 4. With antenna depressed to the minimum elevation angle, the beam axis would be approximately 3.1 m above ground and at a −11.5° inclination with respect to the horizontal. For the terrain features shown in figure 4, the beam would be accessible (less than 1.8 m above ground level) approximately 4.3 m from the antenna surface. Therefore, a denied occupancy area would exist between 4.3 m and 49.6 m from the antenna. Movement of personnel in this area would be prohibited and action would be required to assure that personnel are not inadvertently exposed. A limited occupancy area would exist at ground level between 49.6 m and 108.5 m from the antenna. Movement of personnel in this area must be controlled in accordance with paragraph 8a.

10. X-Ray Production by Microwave Generating Equipment.

a. The high voltages required to operate the electronic tubes used in generating microwave energy produce ionizing radiation in the form of x-rays. The generation of x-rays from such tubes is an unwanted byproduct and its generation will not be detected by any change in the normal indicators of the system operation.



PLAN VIEW



ELEVATION VIEW

*NO PERSONNEL OR ELEVATED LOCATIONS EXPOSED

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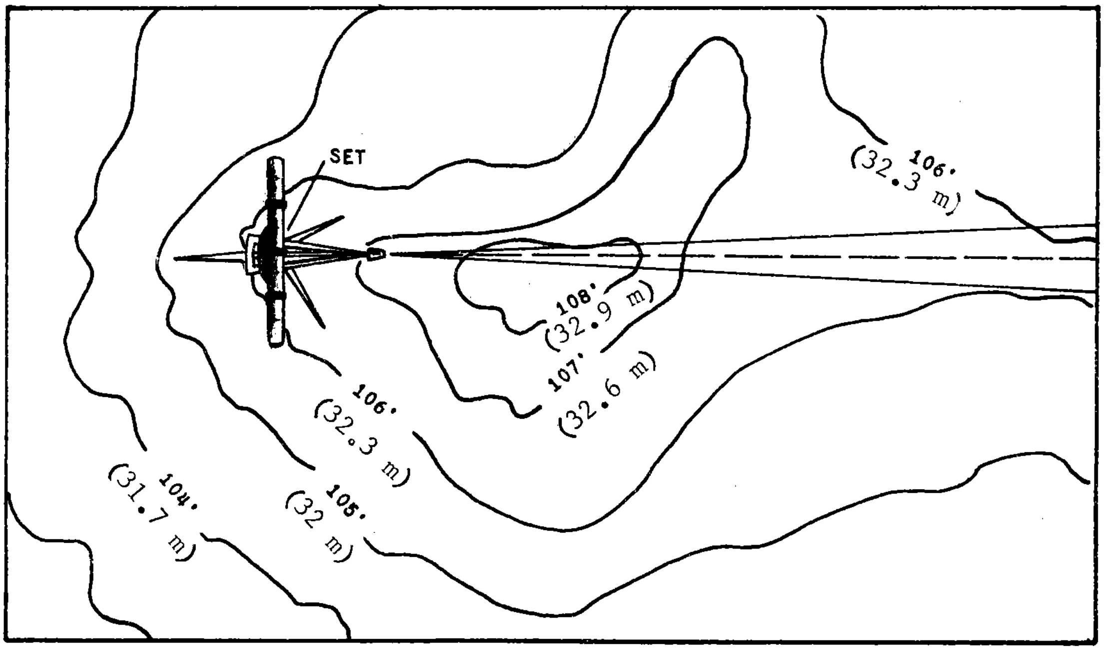
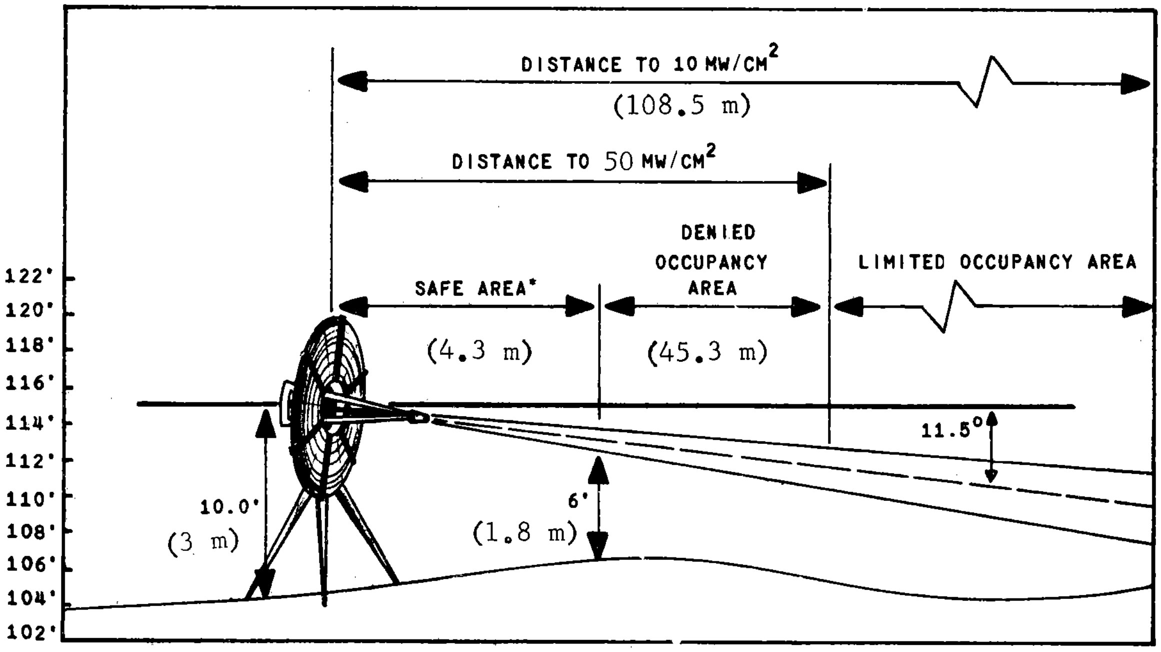
Figure 3. Example: Safe site conditions.

b. Production of x-rays in microwave or RF transmitting systems occurs because certain electronic tubes, such as *klystron*, *magnetron*, *amplitron*, *traveling wave*, and high voltage *thyratron tubes*, possess the basic physical parameters which allow them to act as x-ray generators. Manufacturers of electronic tubes for microwave generation usually incorporate



PLAN VIEW



ELEVATION VIEW

*RADIATED BEAM IS INACCESSIBLE TO PERSONNEL AT GROUND LEVEL TO A DISTANCE OF 14' FROM ANTENNA.

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Figure 4. Example: Hazardous site conditions.

sufficient shielding into the design of their equipment to afford adequate protection of personnel. Studies by USAEHA and other investigating organizations have established that no potential personnel health hazard, attributable to x-rays produced by microwave systems, is present so long as the manufacturer's protective shielding remains intact. During routine maintenance or normal operating procedures, the integrity of tube shielding must be preserved to avoid exposure of personnel. Interlocks, introduced into system components, are of considerable value in accomplishing this purpose. There are systems where shielding of high voltage tubes was not considered necessary at the time of manufacture; but since then the tube could have become an x-ray generator. All microwave or RF transmitting systems utilizing high voltage tubes should be considered as potential x-ray generators.

c. Major maintenance operations, necessitating removal of manufacturer's shielding, should be conducted only by personnel aware of the hazards involved. This type of maintenance usually entails disassembling the microwave generating elements and does not come within the realm of routine unit maintenance.

11. Interference Phenomena—Medical Diagnostic and Therapeutic Devices.

a. General. In addition to biological damage by microwave/RF radiation, there is another, more subtle electromagnetic effect which is called EMI. EMI occurs when waves (or signals) generated by electronic or electromechanical devices adversely affect the operation of other electronic devices. The offending signals can be intended signals such as radio or television broadcast transmissions, or spurious (unintended) signals such as those produced by automobile ignition systems, electric motors, electric razors, diathermy, etc. Furthermore, the signal levels which produce EMI effects are considerably smaller than 10 mW/cm^2 (or 194 V/m). (Refer to appendix B for power density/field strength conversion.) Electronic health care equipment, particularly devices such as hearing aids, cardiac pacemakers, electroencephalographs (EEG), electrocardiographs (ECG), electromyographs (EMG), and various monitors such as oscillographs and recorders can be susceptible to certain types of EMI which may cause malfunction, reliability degradation, functional damage, and even direct electrical shock. The potential hazards associated with the above, range from nuisance and minor discomfort to serious injury and death.

b. Pacemaker Interference. Cardiac pacemakers fall into two general categories, the demand (synchronous) type, and the continuous (asynchronous) type. There are between 100,000 and 300,000 pacemaker users in the United States, with the majority of implants being the demand type. This type of pacemaker is the more popular because it provides pacing only when the normal depolarization signals of the heart are not sensed. When this condition occurs, the pacemaker then delivers a fixed rate electrical impulse to stimulate the ventricular muscle. The stimulus is applied until the pacemaker circuitry senses normal heart function again. The older, continuous type of pacemaker is still used to some extent where there is complete or chronic atrioventricular (AV) heart block. The continuous type of pacemaker is less susceptible to EMI than the demand type because it lacks the sensitive circuits required to sense the low level depolarization impulses of the heart. Demand type pacemakers usually have interference circuitry built in to detect EMI of a CW nature. When this type of interference is detected, the pacer usually reverts to fixed rate pacing. Fixed rate pacing will not seriously affect the user provided the rate is sufficiently high to sustain the user's activity without producing competitive rhythms which may cause fibrillation. The most serious type of interference to the demand type of pacer is that which "fools" the pacer into its inhibit mode, thereby denying the heart proper stimulus. Should the heart be in AV block when the inhibit occurs, death could result. Although there is no recorded incident of death, there have been many reported cases of loss of consciousness, faintness, vertigo, slurred speech, and other symptoms of syncope attributable to loss of pacemaker stimulus through interference. The type of EMI most likely to cause the demand pacemaker to inhibit, and thereby skip beats, is pulsating in nature, usually at a rate close to the normal heart rate. The interference patterns caused by the main and side lobes of scanning radars and microwave ovens using mode stirrers are prime examples of this pulsed effect. Also, simply walking through a fixed field with automobiles, buildings, or other obstructions interposed between the pacemaker wearer and the RF source has been known to produce syncope. Cases have been recorded where interference levels with field strengths of less than 1 V/m (or 0.3 microwatts per square centimeter) have caused pacemaker malfunction. Overall shielding can decrease the susceptibility of the pacemaker itself, but it is generally acknowledged that the catheters, acting as antennas, are the pickup points for the interference. Radio frequencies above the UHF band (300-3000 MHz) do not pose a great problem, even for particularly sensitive pacemakers, since the body (or skin) provides considerable attenuation to upper band frequencies.

c. Medical Monitoring and Diagnostic Equipment. Electronic medical equipment such as

EEGs, ECGs, EMGs, oscillographic displays, recorders, etc., because of their circuit sensitivities, types of installation, and the length of sensors normally required, are also particularly susceptible to common EMI. Interference with this type of equipment, though it may not have as dramatic an effect as pacemaker failure, has been known to cause erroneous indications which compound the diagnostic problem, equipment malfunction through component failure (transistor damage, etc.), and even RF burns via skin electrodes. The EMI problems associated with this type of equipment are often further compounded by the need for their portability and flexibility. Since most of the above equipment can be thought of as receivers of one type or another, extraneous EMI levels in the millivolt per meter (0.001 V/m) range could affect proper operation.

d. Medical Equipment as Interference Sources. Medical electrical/electronic equipment itself can be a source of EMI. RF and microwave diathermy, electrocoagulation units, microwave blood warmer and some monitor readout devices such as digital voltmeters and counters are all sources of potentially harmful interference. Electromechanical devices, such as motors, pumps, relays, and switches, and even alternating current power cables, can also be added to the list of potential offenders. Interference from the above devices has been measured from millivolts per meter through hundreds of volts per meter.

e. EMI Remedies. Since World War II, the US military has recognized the need for providing electromagnetic susceptibility and compatibility standards for the design, production, and use of electronic equipment. These standards are constantly under revision since both the average powers generated and sensitivities achieved increase with advances in technology. Most commercial electronic equipment has to meet certain Federal Communications Commission (FCC) emission standards, but these standards are far less stringent than the military ones. However, much can be done in providing compatible coexistence if a common sense approach to their use is adopted. As wave phenomenon, EMI follows certain physical laws, and its effects and remedies can be predicted. It can be diminished or eliminated by separation, shielding, filtering, and proper installation (grounding, bonding, etc.). The gross shielding technique of building screen room enclosures around operating theaters, EEG-, ECG-, EMG- diagnostic centers, etc., to exclude outside interference has been very successfully used. Other, less expensive techniques are available and should be adopted as minimum precautions for military hospitals, clinics, and aid stations. These precautions are:

(1) Separate known and suspected EMI-producing devices from sensitive electronic equipment; i.e., physical therapy clinics containing RF/microwave diathermies, should be placed as far as possible from intensive care or cardiology wards and operating theaters.

(2) Conspicuously display warning signs identifying potentially harmful generators of EMI such as RF/microwave diathermies, microwave ovens, etc., whenever the devices are in use, so that cardiac pacemaker wearers can avoid the area. This type of warning philosophy can be extended to military and industrial areas where potentially harmful radiations such as radars, communication systems, etc., exist.

(3) Judiciously follow equipment manufacturers' operating, calibration, and installation procedures when using such equipment. This usually ensures a degree of compatibility with other electronic devices.

(4) Should EMI problems that cannot be solved on the local level persist, technical assistance can be obtained by contacting the appropriate agency listed in paragraph 13.

12. Ultrasound.

a. Nature of Ultrasound. Ultrasound refers to acoustic energy which is oscillating at frequencies above 20,000 Hz. Like electromagnetic energy, ultrasound propagates through and interacts with a wide range of media at varying velocities dependent generally upon the density of the medium and/or its physical state (solid, liquid or gaseous). Unlike electromagnetic energy, ultrasound will not propagate through a vacuum. In most cases, ultrasound is generated by the application of an oscillating electric field to a natural or synthetic piezoelectric crystal. This produces an acoustic field proportionate in frequency and intensity to the applied electric field. The generated acoustic or sound energy is coupled to the desired medium by establishing direct mechanical contact between the crystal or crystal mount and the medium. Coupling efficiency is related to the integrity of the mechanical contact, and when irregular surfaces are involved, a coupling medium is often used, such as water or mineral oil or some similarly viscous substance to effect maximum surface contact. At frequencies greater than 100 kHz propagation of ultrasound through air is very inefficient, and the possibility of potential hazards from airborne ultrasound is virtually nonexistent.

b. Applications. Ultrasound energy is widely used by the military in both industrial and clinical applications. The most common industrial use involves ultrasound stimulation in cleaning and vapor degreasing tanks. These operations normally function at frequencies below 50 kHz, and at power densities above 3 watts per square centimeter (W/cm^2). Acoustic energy is coupled directly into the tanks and such systems are generally considered as nonradiating. A brief description of three clinical uses for ultrasound is given below.

(1) *Diagnostic.* Because of the complex interaction between acoustic energy and biological structures, ultrasound is finding increasing application in clinical diagnosis. One or more ultrasound transducers may be used, coupled with very sensitive generating and sensing instrumentation. Typical applications involve pulsed waveforms at power densities less than 0.1 W/cm^2. Depending upon the particular procedure involved, the transducer will vary from a small handheld probe providing audible information to a complex scanning head in a precisely known position relative to the patient, producing video information (imaging).

(2) *Therapeutic.* At power density levels typically between 1 and 3 W/cm^2, ultrasound will produce deep heating of the body tissue. This phenomena is utilized in the physical therapy of joint and muscle disorders. The ultrasonic transducer, when utilized in physical therapy, is usually termed an applicator. Ultrasound energy is coupled from the applicator directly into the tissue utilizing a coupling medium (mineral oil, etc.). A unidirectional applicator which localizes the heating effect of the ultrasound energy is most often used.

(3) *Surgical.* Ultrasound energy is used in some cases to destroy tissue, as an alternate to surgical removal with the destructive mechanism thought to be local and sustained temperature rise. A power density level of 5 W/cm^2 is normally considered the lower limit for tissue destruction using ultrasound; however, this threshold level is known to vary depending, among other things, on tissue construction, its location, and proximity to other more or less dense material. Surgical or destructive applications of ultrasound energy require the use of highly specialized equipment under carefully controlled conditions.

c. Biological Effects. Ultrasound energy propagating through a biological system interacts with the system. The specific kind and degree of interaction is dependent upon many variables, including frequency, waveform, modulation, and intensity, as well as the chemistry and biology of the system. While certain controlled interactions find wide application in health and life services, very little is actually known of the biological effects associated with exposure to ultrasound. It is general knowledge, for example, that in certain therapeutic applications, the thermal energy may be sufficiently high at tissue interfaces to cause periosteal burning. The discomfort or ache associated with such heating is a secondary biological effect of ultrasound. Cumulative and/or synergistic biological effects, if any, still require study. Various ultrasonic levels at which the whole variety of living tissue begins to experience alteration, whether reversible or not, have yet to be catalogued. In addition, the effect of ultrasound on pathological tissue, artificial organs or tissue, or other implants is largely unknown. However, those power levels associated with diagnostic ultrasound equipment (see para 12b(1)) are considered to be nonhazardous.

d. Personnel Hazards. The personnel hazards associated with clinical and industrial applications of ultrasound considered to be important are related to the capacity of ultrasound to destroy tissue. As more information becomes available concerning possible additional effects of ultrasonic interaction with biological structure, other potential personnel hazards may be defined. Currently, ultrasonic therapeutic devices and their proper administration and application are of primary importance with regard to personnel safety and ultrasound radiation. However, other areas of concern include:

(1) The absolute output levels of ultrasound diathermy devices should be in agreement with the indicated output levels. The measurement errors in indicated output level of some devices could be sufficiently high so that these devices could be radiating destructive levels of ultrasound energy.

(2) The accuracy of timing devices should be maintained within normal specified limits.

(3) Accurate calibration techniques and realistic schedules for maintenance should be established in accordance with the manufacturers' directives.

(4) Inventories of all ultrasound sources should be maintained. As a minimum, recorded data should include manufacturer, model, serial number, location, schedule for maintenance and calibration as required and any special features peculiar to a specific item of equipment.

(5) SOP's should be established, published, and issued for all types of potentially hazardous ultrasonic devices. The Commander, US Army Health Services Command, ATTN: HSPA-P, will provide, upon request, guidelines for such SOP's based on a thorough analysis of the performance parameters of individual equipment.

(6) A protection program specifically addressing the potential hazards of ultrasound energy should be established at the appropriate command levels relative to each given situation. Elements of a program should include at least maintenance of inventories, establishment of SOPs and appropriate training of personnel relative to the hazards of ultrasound.

13. Request for Technical Assistance.

a. Information pertaining to personnel hazard evaluation on various systems may be requested from USAEHA, Aberdeen Proving Ground, MD 21010. This Agency maintains a capability for investigating and evaluating personnel hazards created by the equipment discussed in this publication. The services of the Agency are available on the written request through appropriate channels to Commander, US Army Health Services Command, ATTN: HSPA-P, Fort Sam Houston, TX 78234, for continental United States (CONUS) and to The Surgeon General, Department of the Army, (HQDA (DASG-PSP)), Washington, DC 30214, for outside continental United States (OCONUS).

b. The Deputy Chief of Staff for Operations has Army staff responsibility for planning, programming, coordinating, and supervising all Department of Army electromagnetic compatibility and RF spectrum management activities. This includes related projects, tasks, and priorities which are essential to the discharge of this responsibility. Information on electromagnetic compatibility and RF spectrum management is available from HQDA (DAMO-TCF), Washington, DC 20314.

APPENDIX A

Metric and Exponential Systems

The following are tables of commonly used quantities, prefixes and equivalent units. An explanation of the "powers of 10" exponential system is included.

a. Units of Measurement.

Unit	*Abbreviation*	*Measure*
meter	m	Length
centimeter	cm	Length
millimeter	mm	Length
micrometer	μm	Length
hertz	Hz	Frequency
megahertz	MHz	Frequency
gigahertz	GHz	Frequency
joule	J	Energy
second	s	Time
Watt	W	Power

b. Metric System Prefixes.

Prefix	*Abbreviation*	*Value*
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

c. Equivalent Units.

1 m = 100 cm = 1,000 mm = 39.37 inches
1 cm = 0.39 inches; 1 inch = 2.54 cm
1 millisecond = 1/1,000 second = 1×10^{-3} second
1 microsecond = 1/1,000,000 second = 1×10^{-6} second
1 hertz = 1 cycle/second
1 kilohertz = 1,000 hertz = 1×10^{3} hertz
1 megahertz = 1,000,000 hertz = 1×10^{6} hertz
1 gigahertz = 1,000,000,000 hertz = 1×10^{9} hertz
1 joule = 1 watt-second = 1 W-s
1 W = 1 joule/second = 1 J/s

d. Exponential System. For convenience in writing and manipulation, unwieldy numbers are written as factors of appropriate powers of 10. The following examples will illustrate:

2,380,000,000 = 2.38×10^{9}
238 = 2.38×10^{2}
0.238 = 2.38×10^{-1}
0.000000238 = 2.38×10^{-7}

APPENDIX B

Field Strength vs Power Density

(Related by free space impedance = 377 ohms)

VOLTS/METER (v/m)	dB v/m	mW/cm^2	dBm/cm^2
10,000	200	26,500	+44
5,000	194	6,630	+38
2,000	186	1,060	+30
1,000	180	265	+24
500	174	66	+18
200	166	11	+10
100	160	2.7	+4
50	154	0.66	−2
20	146	0.11	−10
10	140	0.027	−16
5	134	66.3×10^{-4}	−22
2	126	10.6×10^{-4}	−30
1	120	2.7×10^{-4}	−36
0.5	114	0.66×10^{-4}	−42
0.2	106	10.6×10^{-6}	−50
0.1	100	2.65×10^{-6}	−56
0.01	80	2.65×10^{-8}	−76
0.001	60	2.65×10^{-10}	−96
100×10	40	2.65×10^{-12}	−116
10×10^{-6}	20	2.65×10^{-14}	−136
1×10^{-6}	0	2.65×10^{-16}	−156

APPENDIX C

Decibels vs Power Ratio

POWER RATIO (MINUS)	-dB+	POWER RATIO (PLUS)	POWER RATIO (MINUS)	-dB+	POWER RATIO (PLUS)	POWER RATIO (MINUS)	-dB+	POWER RATIO (PLUS)
1.000	0	1.000	.199	7.0	5.012	.016	18.0	63.10
0.977	0.1	1.023	.178	7.5	5.623	.014	18.5	70.79
0.955	0.2	1.047	.159	8.0	6.310	.013	19.0	79.43
0.933	0.3	1.072	.141	8.5	7.079	.011	19.5	89.13
0.912	0.4	1.096	.126	9.0	7.943	.010	20.0	100.0
0.891	0.5	1.122	.112	9.5	8.913	.008	21.0	125.9
0.871	0.6	1.148	.100	10.0	10.0	.006	22.0	158.5
0.851	0.7	1.175	.089	10.5	11.22	.005	23.0	199.5
0.832	0.8	1.202	.079	11.0	12.59	.004	24.0	251.5
0.813	0.9	1.230	.071	11.5	14.13	.003	25.0	316.2
0.794	1.0	1.259	.063	12.0	15.85	.0025	26.0	398.1
0.708	1.5	1.413	.056	12.5	17.78	.0020	27.0	501.2
0.631	2.0	1.585	.050	13.0	19.95	.0016	28.0	631.0
0.562	2.5	1.778	.045	13.5	22.39	.0012	29.0	794.3
0.501	3.0	1.995	.040	14.0	25.12	.0010	30.0	1000.0
0.447	3.5	2.239	.035	14.5	28.18	1×10^{-4}	40.0	1×10^{4}
0.398	4.0	2.512	.032	15.0	31.62	1×10^{-5}	50.0	1×10^{5}
0.355	4.5	2.818	.028	15.5	35.48	1×10^{-6}	60.0	1×10^{6}
0.316	5.0	3.162	.025	16.0	39.81	1×10^{-7}	70.0	1×10^{7}
0.282	5.5	3.548	.022	16.5	44.67	1×10^{-8}	80.0	1×10^{8}
0.251	6.0	3.981	.020	17.0	50.12	1×10^{-9}	90.0	1×10^{9}
0.224	6.5	4.467	.018	17.5	56.23	1×10^{-10}	100.0	1×10^{10}

The proponent agency of this bulletin is the Office of The Surgeon General. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) direct to HQDA (DASG-PSP-E) WASH, DC 20310.

By Order of the Secretary of the Army:

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