IONIZING AND MICROWAVE RADIATION
GENERAL EDUCATIONAL INFORMATION

CONTENTS PAGE

1. GENERAL

1.01 This section is issued to provide general educational information for supervisory and staff personnel who are responsible for handling ionizing and microwave radiation matters in the operational phases of the business. It also discusses the principal considerations for recognizing and handling Bell System radiation matters.

1.02 This section is reissued to bring the Bell System microwave radiation limits in conformity with the United States of America Standards Institute, Standard C95.1-1966 and to provide information on the Bell System microwave radiation protective garment.

1.03 The hazards of ionizing and microwave radiation, when understood, are just as readily controlled by the use of reasonably simple safety precautions as have been continuously demonstrated over the years with respect to other hazards of everyday life or telephone work activity.

1.04 Telephone equipment in use in the Bell System generally presents no appreciable radiation exposure problem and few special precautions are required when working with that equipment.

1.05 Specific areas of certain customer locations may present the possibility of significant exposure. These areas are clearly designated with radiation signs and markings under strict Atomic Energy Commission requirements and are subject to stringent control. Telephone supervision in cooperation with such customers should make sure that all possible safeguards are observed.

1.06 Microwave radiation matters involving high-power radar transmitters and other devices, particularly at some of the military installations, will require special considerations. Many military areas have been surveyed for potential hazards and posted with radiation warning signs by the Government where required. Not all sites have been surveyed, however, and some sites have had equipment changes since the previous survey. Therefore, telephone supervision should assure itself that proper safety precautions are taken before employees are permitted to enter.

2. FUNDAMENTALS OF RADIATION

Structure of the Atom

2.01 The atom is the simplest particle into which an element can be divided chemically and is composed of three primary components which are arranged into two main parts, the nucleus and the electron cloud.

2.02 *Nucleus:* This is the core of the atom and contains two of the three primary components, neutrons and protons. The neutron is the larger of the fundamental particles and has no charge. The proton is slightly smaller in mass than the neutron and has a positive charge. These two components account for practically all of the mass of the atom.

2.03 *Electron Cloud:* The electron cloud surrounds the core, or nuclear portion, of the atom and contains the electrons. These particles are the lightest part of the atom and are in motion about the nucleus. Since the atom as a whole is electrically neutral, the number of electrons (negative charges) in the electron cloud is equal to the number of protons (positive charges) in the nucleus.

2.04 The results of various studies of the electron arrangements in atoms indicate that the electrons are grouped into shells or regions each having a definite energy and a definite maximum number of electrons. These well-defined shells are often referred to as energy levels, since a definite minimum amount of energy is required to remove an electron from a particular shell.

Atomic Nomenclature

2.05 *Atomic Number:* This refers to the number of protons present in the atomic nucleus. This number is always the same as the number of positive charges and is called the atomic number of the element. Since atoms are electrically neutral, the number of electrons in the electron cloud is the same as the number of protons within the nucleus. Each element has an atomic number which is characteristic of the element.

2.06 *Isotopes:* When the atoms of an element have the same number of protons but a different number of neutrons, they are said to be "isotopes" of the element. Such atoms are, in general, indistinguishable chemically. The chemical properties of the isotopes of a particular element are almost identical because the chemical properties depend on the number of (orbital) electrons surrounding the nucleus, which in turn is determined by the number of protons in the nucleus.

2.07 *Nuclide:* A given element may have one or more isotopes. The collective term used to refer to the isotopes of all the elements is known as "nuclides".

Radioactivity

2.08 This is the process whereby certain nuclides undergo spontaneous disintegration in which energy is liberated, generally resulting in the formation of new nuclides. Some elements are naturally radioactive while others become radioactive after bombardment with neutrons or other particles. The process is accompanied by the emission of one or more types of radiation. The three major forms of radiation are alpha, beta and gamma, named for the first three letters of the Greek alphabet.

Natural Radioactivity

2.09 Natural radioactivity, that is, radioactive or unstable nuclides occurring as such in nature, has been investigated for many years in order to better understand it. The understanding was culminated with the experiments of Rutherford, who in 1903 clearly showed that there were three principal kinds of radioactive emissions; namely: alpha, beta and gamma.

2.10 *Alpha Particles:* These are the least penetrating of the three major types of radiation and can be absorbed or stopped by a few centimeters of air or a thin piece of paper. Their electric charge is positive and twice that of an electron. They are identical with the nucleus of the helium atom and are made up of two neutrons and two protons. Only relatively heavy radioactive materials, such as uranium and radium, decay by alpha emission. By the emission of these fast moving particles, the unstable nucleus attempts to achieve stability by decreasing its atomic number.

2.11 *Beta Particles:* These are negatively charged particles. They have the same mass and charge as an electron and the only difference between them and electrons is that they originate in the nucleus in contrast with ordinary electrons which exist in the orbits around the nucleus. Beta particles travel several hundred times the distance traveled by alpha particles in air and require the equivalent of a few millimeters of aluminum to stop them. Beta activity can be expected in instances where the ratio of neutrons to protons

(N:P) is high. The effect within the nucleus of a beta emission would be the changing of a neutron into a proton, thus decreasing the N:P ratio towards stability.

2.12 ***Gamma Rays:*** When an alpha or beta particle is emitted, it may be accompanied by a burst of excess energy. This energy leaves the nucleus in electromagnetic wave form, gamma rays, and travels with the speed of light. The basic difference between gamma rays and visible light is their frequency. Since these electromagnetic waves have essentially no mass and no charge, they are the most penetrating of all radiations, having the longest range, and are the most difficult to protect against.

2.13 ***Positron Particles:*** These are similar to beta particles except that they are positively charged. Thus, the positron can be considered to be a positively charged high-speed electron which originates in the nucleus.

Artificial Radioactivity

2.14 Radioactive isotopes of nearly every element have been produced by bombarding a stable isotope with charged particles or neutrons. The nuclei produced as a result are unstable in somewhat the same manner as naturally occurring radioactive elements. Naturally radioactive nuclides, in becoming stable, generally emit beta or alpha particles, by means of a series of transmutations, whereas artificial radionuclides rarely decay by alpha emission, but usually decay by beta or positron emission or by orbital electron capture. In contrast to natural radioactivity, induced radionuclides generally revert to stability in a single decay step.

Radioactive Decay

2.15 ***Curie:*** In order to be able to determine the activity or rate at which a radioactive material emits particles, a unit of quantity of radioactivity has been established. At present this unit, called the curie, is that quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{10} atoms per second. Smaller and often more convenient units are the millicurie (10^{-3} curie), microcurie (10^{-6} curie), or micromicrocurie (10^{-12} curie).

2.16 ***Half Life:*** The activity of any sample of radioactive material decreases, or decays, at a rate which is characteristic of that particular radionuclide. The most conveniently used means of representing the rate of decay of the material is by the term "half life". This is merely the length of time required for one half of the original number of nuclei to disintegrate. Half lives range from fractions of seconds to billions of years.

Interaction of Radiation With Matter

2.17 All radiation possesses energy either inherently, as in the case of electromagnetic radiation, or as kinetic energy of motion, as in the case of particle radiations, or both. Absorption of radiation is the process of transferring this energy to atoms of the medium through which the radiation is passing. The process of absorption is of fundamental interest in the field of radiological health because of the following reasons.

(a) Absorption in body tissues may result in physiological injury.

(b) The degree of absorption is a primary factor in determining shielding requirements.

Ions and Ionization

2.18 The transfer of energy from the emitted particle to atoms of the absorbing material may occur by the following most important mechanism. All atoms in their natural, lowest energy state have the same number of electrons as protons, and therefore carry no residual electric charge. When atoms combine to form compounds, the resulting molecule has the same total number of electrons as it does protons, and the molecule is also electrically neutral. Since the electron is the lightest part of the atom and since each electron is not bound as tightly to the nucleus as the protons and neutrons are bound to each other, it is more mobile and can be removed from the atom or molecule without expending much energy. As soon as an electron is added to or removed from a neutral atom or molecule, the resulting component has an electric charge, because the number of protons is less than or greater than the number of electrons. The resultant charged atom or molecule is called an ion. Ions may be charged positively or negatively and may exist in crystals, liquids, or gases. Positive ions are produced by removing electrons from neutral atoms or molecules, whereas negative ions are created when electrons attach themselves to neutral atoms or molecules. Ionization is the process of producing ions. Anything which is able to bring about the removal of electrons from (or addition of electrons to) neutral atoms or molecules is capable of causing ionization or an ionizing event.

X-rays

2.19 X-rays are similar to gamma rays except that gamma rays come from within the nucleus of the atom, whereas X-rays are generated outside the nucleus by the interaction of high-speed electrons with the atom. In an X-ray tube, electrons emitted from a cathode and accelerated by a high potential are caused to strike a target substance from which the X-rays are emitted.

3. SOURCES OF RADIATION

A. Ionizing Radiation

3.01 ***Background Radiation:*** Man has continually been exposed to ionizing radiation of low-level intensity consisting of cosmic rays from outside the earth's atmosphere and from natural radioactive materials in the earth's crust. These are the primary sources of external exposure in the natural environment. Some of these radionuclides may become internal sources of radiation through natural processes, such as dissolving into ground and surface waters. They may then be drunk by man or gain access to his food supply. The reshaping of these natural resources into various forms of building materials creates additional natural sources of radiation exposure in an artificial environment. All of this low-level intensity radiation is commonly referred to as background radiation. This background, to which man has been exposed since his origin, serves as a basis in establishing safe levels of exposure.

3.02 ***Radiation-Generating Machines and Radioactive Materials:*** Today, radiation from background is only one of many sources to which man is exposed. Radiation-producing machines and radioactive materials constitute the principal man-made sources. X-ray machines are continuing to find wide spread use in industry, medicine, dentistry, commerce, and research. All such uses are potential sources of radiation exposure, but can be easily controlled if simple precautions are taken. The clinical use of these machines that we are all familiar with is in medical and dental X-ray procedures. In industry, X-ray devices are used for determination of defects in castings and welds, and detection of foreign material in packaged foods. High voltage X-ray machines are also being used in many research laboratories in universities and similar institutions. Other research units which are sources of machine-produced radiation include particle accelerators, such as cyclotrons, synchotrons, betatrons, and Van De Graff generators. The use of more powerful microwave radar and communications systems has created additional ionizing radiation sources. Tubes in some of these systems operate at potentials above 15 kilovolts and generate amounts of X-radiation which can be dangerous unless proper precautions are observed as indicated in 6.12.

3.03 ***Naturally occurring Radioactive Materials:*** The most widely used naturally occurring radioactive material is radium. In the medical field, it is used for certain therapeutic treatments on patients. In industry, radium is used principally for radiography, and also in luminous compounds. The textile, paper, and printing industries employ polonium or radium as static eliminators. It should be kept in mind that naturally occurring radioactive materials can be purchased on the open market and that no formal application is required in order to obtain these materials.

3.04 ***Artificially Produced Radioactive Materials:*** The Atomic Energy Commission is continually producing artificial reactor-produced radionuclides for use by several thousand universities, hospitals, and research laboratories in the United States. The use of these materials, however, is covered by AEC licensing. Accelerator-produced radio isotopes, which are not subject to AEC licensing, are distributed by commercial suppliers.

3.05 ***Nuclear Reactors:*** Nuclear reactor operation is steadily on the increase with a large number of reactors operating presently and more in the planning stage or under construction. Major colleges and universities will in the future have reactors for research and instructional purposes. The number of utility power company reactors is also increasing, especially as the cost of operation per generated kilowatt of electricity becomes more attractive. Along with the growing number of nuclear powered naval vessels, other military plans call for construction of power reactors in the future. Each of these nuclear reactor operations is a potential source of radiation. Included in these sources is the reactor itself, the ventilating and cooling wastes, and the actual removal and reprocessing of its "spent" fuel.

Ionizing Radiation in Bell System Operations

3.06 For some time the advantages of using radioactive materials for certain applications have been recognized by the Bell System, as they have by other industries. It was discovered that small quantities of radium salt in cold cathode tubes improve their operation and reliability. After investigation, it was determined that there was no increase in work hazards when employing these tubes in various office equipment. It was also discovered that static on teletypewriter paper could be eliminated by using a radioactive device called an Ionotron Static Eliminator. Since certain state regulations requested registration of these devices, additional special surveys were made of various types of central office and station installations to satisfy the public authorities that no radiation hazards existed. In order to avoid the administrative problem involved in registration and to be even more conservative regarding sources of radiation, a replacement program was undertaken with a new and more efficient cold cathode tube. This tube contained a krypton gas with a much lower radiation level. The replacement of the Ionotron with an electronic static eliminator was also recognized as a good objective and is being completed. Some Operating Companies have employed fire detection devices of outside manufacture which incorporate a source of ionizing radiation. The problems of registration and periodic maintenance should be taken into account when considering their use. The various installations above constitute the radiation matters over which the System has direct control. It should be emphasized that they are of minor importance and create no real hazard to anyone. However, Bell System personnel are required to enter various customers' premises to maintain installations which contain other sources of ionizing radiation. These include laboratories and research centers, hospitals, various industries employing isotopes, and nuclear power plants. Each of these installations normally provides very adequate radiation protection, but as employers we must see that all necessary safety precautions are complied with by Bell System personnel during the telephone activities in these areas. A high degree of cooperation should be maintained between the Operating Companies and these various industries.

B. Microwave Radiation

Environmental

3.07 Microwave radiation is simply the generation of very shortwave radio energy. Any electronic device which is capable of producing an output at a frequency which falls in the microwave spectrum is a source of microwave radiation. Originally, diathermy machines first utilized the shortwave radio frequency energy for therapeutic treatments, heating of muscular and joint structures. With the advent of radar having higher power output, studies were made to determine whether any hazards existed in front of the transmitter due to tissue heating effects. Because of the low order of power output, no harmful effects were observed. However, in recent years, the power output has greatly increased for some applications and it is apparent that such microwave installations can present a hazard. Special precautions should be followed as covered in 5.08 and 6.16.

3.08 Today, there are many sources of microwave radiation. The most dangerous sources include various kinds of radar transmitters, tropospheric scatter transmitters, diathermy equipment, and industrial induction heating equipment. As explained below, line-of-sight radio relay systems are not likely to create dangerous fields, but the energy is concentrated in waveguide runs and exposure to open waveguides should, therefore, be avoided. Radar, originally used exclusively by the military, is finding increasing employment in civil aviation, navigational, and meteorological applications. In the future, the use of microwaves will certainly increase and the trend toward higher-power radar will continue. The increase in power output of microwave radar, and to some extent scatter communication systems, may also create an ionizing radiation hazard. Tubes in these systems generally operate at potentials above approximately 15 kilovolts and, due to this high accelerating voltage, generate X-radiation. As a result, special engineering considerations are given to ensure that these tubes are properly shielded against ionizing radiation that could be hazardous to personnel. However, catuion always should be exercised by operating and maintenance personnel in the vicinity of high-powered components as covered in 6.12.

Microwave Radiation in Bell System Operations

3.09 ♦The majority of Bell System microwave transmitters, such as the TD, TE, TH, TM, TJ and TL equipment, use low power, 0.1 to 12.5 watts per transmitter; however, the practice of utilizing a single transmitting antenna for several radio transmitters results in some cases of potentially hazardous power density directly in front of these antennas. For the same reason, employees are cautioned never to look into an open waveguide which is connected to these transmitters when they are energized. Bell System tropospheric scatter transmitters, however, have a higher power output and restricted area precautions have been taken to protect employees from those areas of field intensity which exceed recommended limits as covered in 5.08. Military radar installations are the most common source of high-level microwave energy to Bell System personnel. The power output of these systems will continue to increase in the future and, accordingly, so will the hazards due to microwave and ionizing radiation. In general, military authorities operating these systems have established radiation safety programs, which Bell System personnel will be required to follow. Some military protection guides do not take environmental conditions into account. Bell System personnel should be alert for heat stress if required to enter military microwave radiation areas under conditions of abnormal environment (T.H.I. of greater than 70). Other specific precautions are listed in 6.16.♦

4. BIOLOGICAL EFFECTS OF RADIATION

A. Ionizing Radiation

4.01 The basic effect of ionizing radiation on any living organism is the damage or destruction of cells. Depending on the length of radiation exposure, size of the dose, and body area exposed, the effect will vary considerably.

4.02 In general, the short-term effects or early symptoms to severe radiation exposure are nausea, vomiting, fever, and itching and burning of the skin. These acute effects may appear within a matter of minutes, days, or weeks.

4.03 The long-term effects, arising years after a severe or prolonged exposure, are usually in the nature of leukemia, skin or bone cancer, and a possibility or premature aging. In addition, irradiation of the eye by X-rays or gamma rays can result in the formation of cataracts. The genetic effects are of major importance since radiation may cause an increase in undesirable gene mutations in direct proportion to the size of the dose. At present levels of radiation due to fallout, medical X-rays, and occupational exposure, this is not of particular significance.

4.04 Superficial radiation burns are produced by soft radiations, such as beta, because of their inability to penetrate deeply into the tissues. External radiation from alpha-emitting material will not even affect the skin, but is dangerous when the material has been inhaled or ingested, or has penetrated into the body through cuts or abrasions.

4.05 If the radionuclide is soluble in body fluids, it can become deposited in some critical organ of the body. This internal radiation exposure then continues until the material has decayed radioactively or has been eliminated biologically from the system. Since some materials concentrate in particular organs, they are used therapeutically when it is desired to irradiate these areas.

B. Microwave Radiation

4.06 At the present time, it is believed that the prime effect of microwave radiation on the human body is to produce heating of the living tissues. The major factors contributing to the amount of damage are the length of exposure and density of the microwave field.

4.07 The parts of the body which seem to be most prone to thermal damage are those organs having minimal heat exchange capacity by virtue of their limited circulation. It has also been established that with sufficient exposure cataracts can be produced regularly in the lens of the eye.

4.08 Although it is believed that there are no other biological or genetic effects at present, the trend toward increasing power output of radar and communication microwave generators has resulted in continuous study of this matter both within and outside the Bell System.

4.09 ♦Because the body can absorb energy from the microwave radiation, the Bell System has adopted permissible exposure power density limits for employees who work in the vicinity of microwave generators. These limits, which are covered in 5.08, are in agreement with United

States of America Standards Institute, Standard C95.1—1966.◀

5. UNITS OF RADIATION DOSE AND PRESENT LIMITS

A. Ionizing Radiation

Units of Radiation Dose

5.01 ***Roentgen:*** Basically, ionizing radiation exposure that exceeds prescribed safe limits may result in physiological injury due to energy absorption by body tissues or cells. The damaging process appears to be related to ionization interaction between the radiation and atoms within the tissue. The amount of ionization provides some measure of the damage that might be expected from a dose. Using this as a basis, the exposure dose of X- or gamma radiation is a measure of the radiation that is based upon its ability to produce ionization in air. The unit used for expressing this exposure is the roentgen (r) and is the basic unit of radiation measurement.

5.02 ***The RAD (Radiation Absorbed Dose):*** In order to relate the exposure dose or roentgen unit, to the energy absorbed in any material, an additional unit is required. This unit of absorbed dose is the "radiation absorbed dose" (RAD), the unit which can be used for all types of ionizing radiation. One RAD equals 100 ergs of energy per gram of irradiated material.

5.03 ***The RBE (Relative Biological Effect):*** Since the absorbed dose, in RADS, which will produce a certain effect, can vary for different types of radiation, a quantity called "relative biological effect" (RBE) is used to express this behavior. The RBE of a given radiation is the ratio of the absorbed dose in RADs of gamma radiation to the absorbed dose of the given radiation required to produce the same biological effect. The value of the RBE for a particular type of radiation depends upon several factors, such as the energy of the radiation, the kind and degree of biological damage, and the nature of the organisms or tissue under consideration. Typical values of the RBE for radiations of several types are given in Table A.

TABLE A

RELATIVE BIOLOGICAL EFFECTIVENESS FOR RADIATIONS OF DIFFERENT TYPES

RADIATION	RBE
X- or gamma	1
Beta	1
Proton	10
Alpha	10
Neutron	20

5.04 ***The REM (Roentgen Equivalent Man):*** In order to relate the effectiveness of the different types of radiation in producing biological damage to the quantity of absorbed dose, an additional unit is required. This unit of biological dose is the REM, which is arrived at as follows:

$$\text{Dose in REMS} = \text{RBE} \times \text{Dose in RADs}$$

Since the RBE for gamma rays is nearly 1, the biological dose in REMs is numberically equal to the absorbed dose in RADs. It is also roughly equal to the exposure dose in roentgen (r).

Present Dose Limits

5.05 In protection rules or recommendations in which numerical values of permissible dose are given, certain values are the highest ones permissible under the stated conditions of exposure. These values or limits, called "maximum permissible doses" (MPDs), are the total doses of ionizing radiation to which an individual can be exposed with no apparent resultant damage. The present exposure limits as set by the Atomic Energy Commission on January 1, 1961 are as follows:

(a) ***Radiation Occupational Workers:*** The maximum permissible dose (MPD) from external sources of ionizing radiation of any type to the whole body shall be 5 REMs per year. For administrative purposes, 0.1 REMs or 100 millirems per week is used. At any age the accumulated exposure of any individual shall not exceed 5 times the number of years of his age past 18. In other words, the accumulated MPD equals 5 (N–18) REMs, where N is the person's age. A further provision states that within any period of 13 consecutive weeks, 1 calendar quarter, the dose shall not exceed 3 REMs.

(b) ***Nonradiation Workers:*** These limits are set at one-tenth of the maximum possible dose as indicated above in (a) for a radiation occupational worker. They apply to all persons not working in a controlled area. Thus, for whole body exposure of individuals in this category, the radiation dose should not exceed 0.5 REMs per year (10 millirems per week for administrative purposes). All telephone employees are included in this category.

5.06 ***Radiation Protection Guide:*** The current recommended maximum permissible levels for radiation exposure (now called "radiation protection guide") for general population groups is 13 REMs, a dose of genetic importance from birth to age 30. These estimated levels are as follows:

Medical and Dental	4.5 REM
Natural Background	3.4
Fallout	0.3
Occupational	0.15
Plant Environs	0.15
Reserve	4.5

5.07 ***Exposure to Internal Sources of Radiation (Within the Body):*** Some radioactive materials upon entering the body become uniformly absorbed. The maximum permissible dose for whole body exposure solely from these materials is the same as from external sources as indicated in 5.05. When determining total exposure, both internal and external exposure must be considered when applying the MPD figure. However, other radioactive materials seem to localize in certain body organs. For these materials, concentration values have been specified and are termed "radioactivity concentration guides".

B. Microwave Radiation

5.08 The Bell System has adopted microwave radiation limits based on average power density of the nonionizing radio fields. These limits, which are in agreement with United States of America Standards Institute Standard C95.1—1966, are as follows:

Radiation Protection Guide—Radiation level which should not be exceeded without careful consideration of the reasons for doing so.

Recommendations—For normal environmental conditions and for electromagnetic energy of frequencies from 1 MHz to 100 GHz, the radiation protection guide is 10 mw/cm^2 (milliwatt per square centimeter) as averaged over any possible 0.1-hour period. This means the following:

Power Density: 10 mw/cm^2 for periods of 0.1 hour or more.

Energy Density: 1 mwh/cm^2 (milliwatthour per square centimeter) during any 0.1-hour period. The guide numbers are appropriate for moderate environments. Under conditions of moderate to severe heat stress the guide number given should be appropriately reduced.

5.09 In order to define normal environmental conditions, and to provide an exposure guide for unusual (not normal) environmental conditions, the following method of adjusting the radiation protection guide is recommended.

(a) Normal environmental conditions for the purpose of administration of the radiation protection guide are any temperature-humidity conditions resulting in a temperature-humidity index (T.H.I.) of 70 or less. In order to compensate for unusual environmental conditions, the radiation protection guide should be reduced by 1 mw/cm^2 for each unit number above 70 of the current T.H.I. at the point of exposure. For example, with a T.H.I. of 74 the radiation protection guide would be 10 - 4 or 6 mw/cm^2. The threshold of significant heating on the human body is considered to be 1 mw/cm^2; therefore, for all T.H.I.s above 78 the radiation protection guide should be 1 mw/cm^2.

(b) The T.H.I. is a convenient indicator of the environmental conditions which affect the ability of the human body to adjust to heat stress. A T.H.I. of 70 or less is considered to be an environment safe for the 10 mw/cm^2 radiation level as averaged over any possible 1/10-hour period.

(c) Calculation of the T.H.I. was established using dry-bulb and wet-bulb temperature (T_d and T_w, respectively). T.H.I. = 0.4 ($T_d + T_w$) + 15.

Note: It is not always convenient to obtain the wet-bulb temperature. The relative humidity (RH) and dry-bulb temperature (T_d) are more often available. Therefore, a method of obtaining approximate T.H.I. utilizing this information may be used. Approximate T.H.I. = 0.8 T_d + RH/10 + 5. The accuracy is quite adequate, better than ±1 percent for relative humidities above 50 percent, in this case the area of concern.

5.10 Anticipating the introduction of newer and higher-power microwave equipment, the Bell System is presently cooperating with the military and other industries investigating possible cumulative and nonthermal effects of microwave radiation. As more information is obtained, the limitations above may be revised.

6. DETECTION, CONTROL, PROTECTION, AND PRECAUTIONS

A. Ionizing Radiation

Detection

6.01 Since man's senses are not capable of responding to the presence of radioactivity, instruments are required for its detection and measurement. All methods of detection are based on the ability of radiation to cause ionization. The instruments may be designed to measure either total cumulative radiation exposure, dose rate, or disintegration rate.

Personnel-Monitoring Instruments

6.02 In order to protect individuals, certain devices are designed to measure total cumulative radiation exposure in units which can be related to absorbed dose. The principal personnel-monitoring instruments are film badges, pocket dosimeters, and pocket chambers. Each of these is designed to be worn by the individual when in radiation areas. There are no such areas in Operating Company premises which indicate a need to use these instruments. However, they are used in certain areas of a few customers' premises.

(a) The film badges, lucite- or bakelite-enclosed film packets, are the most commonly used of the personnel-monitoring instruments. The advantage of the badge is that it provides a permanent record of cumulative exposure. The disadvantage of the badge is that time is required for developing the film and reading the badge.

(b) The pocket dosimeter, a pencil-like ionization instrument, will determine cumulative exposure at any time, while continuing to monitor. The dosimeter need only be charged prior to use and then can be read at any time for an immediate indication of integrated exposure.

(c) The pocket chamber is a simple device which must be charged and read with a separate device called a "charger reader". This unit is an inexpensive means of measuring exposure.

Survey Instruments

6.03 This class of instruments is designed to measure exposure rate in terms of dose rate units, such as roentgens per hour, milliroentgens per hour, or, in some cases, disintegration rate in counts per minute. Readings made with these instruments will obtain information as to extent and types of radiation levels in the area. The principal types of common survey instruments, their uses, and ranges are described in the following paragraphs.

6.04 ***Ionization Chambers:*** This type of instrument measures gamma radiation. On some instruments the ionization chamber can be connected to the electronic circuit and indicating mechanism by an extension cable. Another type consists of a charger-reader mechanism and several detachable ion-chambers which can be left in the radiation field for a given time.

(a) The "cutie-pie" is a typical attached ionization chamber instrument which is widely used for beta or gamma surveys. It measures dose rate with full-scale ranges of 25 mr/hr to 5 r/hr.

(b) The stray radiation chamber is one type of instrument with the detachable ion-chambers and is very reliable and accurate for X- and gamma radiation surveys. It measures cumulative dose with full-scale ranges available from 1 to 10 mr, depending on the chamber used.

(c) When it is necessary to survey for X-radiation in the vicinity of high-power radar transmitters, the microwave radiation has a tendency to affect the electronic circuits of some instruments, resulting in erroneous readings. Of the instruments at present commercially available, the Victoreen Radgun appears to be best suited for this type of survey. This instrument is capable of detecting beta and gamma radiation in the range of 0.01 mr/hr to 10 kr/hr.

6.05 ***Geiger-Müller Instruments:*** This type, more commonly referred to as a Geiger counter, is used for low-level beta, X-, and gamma radiation survey work. Most counters are available with full-scale ranges from 0.2 mr/hr up to 50 mr/hr. The G-M tube is contained in a housing or probe and is usually connected to the indicating instrument by a flexible retractile cord.

6.06 ***Proportional Survey Instruments:*** These are seldom used for beta, gamma, or X-ray surveys, but mostly for alpha surveys. The meter indication is in counts per minute.

6.07 ***Scintillation Survey Instruments:*** These instruments can detect extremely low levels of activity and may be used to survey for alpha, beta, gamma, or X-radiation.

6.08 ***Proper Use of Instruments:*** It is most important to remember that none of the instruments above will give accurate indications unless they are calibrated and properly maintained. In this manner it will be ensured that the instruments will be in operating condition when needed and will be as accurate as necessary for the survey intended. Any advice on purchase of survey instruments should be obtained from those individuals who have the responsibility to keep informed on radiation detection methods and test equipment.

Protection and Control

External Radiation

6.09 X-rays and gamma rays are the most common type of radiation hazard and are capable of deep penetration into the body. The prime means of protection from external radiation exposure is a combination of three factors: time, distance, and shielding.

(a) ***Time*** can be used as a safety factor by controlling the length of exposure time so that the maximum permissible exposure levels are not exceeded. The amount of radiation received is in direct proportion to the time exposed; therefore, any radiation safety control and protection program will use this factor as a principal means of safe regulation.

(b) ***Distance,*** in many cases, is the most easily applied and most effective principle of radiation protection. The radiation intensity from a point follows the inverse square law since it varies inversely as the square of the distance from the source. For example, if the distance from the source is doubled, the intensity of the radiation decreases to one-fourth the original value. Therefore, one of the most fundamental rules of radiation protection is to maintain the maximum possible distance from a radiation source.

(c) ***Shielding:*** The radiation intensity of any source can be reduced to safe levels by placing material (shielding) around the source to absorb some of the radiation. Shielding is one of the most important principles of radiation protection. Depending on the intensity of the source and its purpose of use, various shielding materials are used and in various ways. For example, where it is necessary to see through the shielding material while remotely performing certain operations, water might be used as the material. Lead, iron, concrete, and water are some of the more common materials used for shielding purposes.

Internal Radiation

6.10 Any radioactive material which gains access to the body by ingesting, inhalation, or absorption through the skin is an internal source of exposure. As it was mentioned under biological effects, the extent depends, among other things, upon the type of radiation emitted, the energy of radiation emitted, the effective half-life of the radionuclide, and the particular organ where material localizes. Radioactive materials which are alpha emitters present the greatest internal exposure. Beta emitters present a lesser degree of exposure and accordingly the relative biological effect is much less than that of alpha radiation. Therefore, it is obvious that the principal means of protection from internal radiation exposure is to prevent radioactive materials from entering the body. The most effective way to accomplish this is by preventing and controlling contamination by using the two fundamental principles of contamination control: containment and cleanliness.

(a) ***Containment:*** By restricting radioactive materials to controlled areas, the spread of radioactive contamination can be eliminated or lessened. The choice of suitable operating techniques is an important part of this contamination control. An important point to remember in order to avoid ingesting some radioactive materials is that food, drink, or smoking materials should not be taken into the controlled areas and nothing should be placed in the mouth.

(b) ***Cleanliness:*** Cleanliness in a controlled area will also help to lessen the spread of contamination. Regular monitoring of all equipment, personnel, and surfaces in the area is necessary to determine where decontamination is required.

Specific Precautions

6.11 When Bell System employees are required to handle specially marked cold cathode tubes containing radiym bromide, they should refer to Section 024-700-801 covering method of handling.

6.12 Based on results obtained thus far, it appears that certain precautionary measures should be employed to safeguard Bell System employees when working near high-powered radar and tropospheric scatter equipment. The following safety measures are recommended:

(a) At heavy radar sites employees should be instructed not to enter the transmitter room when the equipment is operating and the shielding of the final stages is removed or cabinet doors of the rectifier or modulator are open.

(b) In areas where surveys indicate that a total ionizing radiation exposure of more than 10 mr/week is possible, employees should be furnished film badges. Where possible, these film badges should be stored at the location and the employee should be reassigned the same badge for 2- to 4-week intervals, at which time the badge should be sent to a processing laboratory for development and evaluation. All film badge reports should be made a permanent part of the employee's medical or personnel records.

(c) Prior to the initial entry of personnel into these areas, an ionizing radiation survey of the transmitting room should have been conducted. If radiation levels in excess of 1 mr/hr are detected at distances greater than 2 feet from the transmitting tube shield, personnel should be denied admittance to the area. Further, the responsible authorities should be notified of the survey results and be advised that the area is considered hazardous and that corrective steps should be taken. This survey should be repeated at each location as frequently as local conditions seem to warrant.

(d) The personnel assigned to this type of work should be thoroughly instructed in the potential hazards, both ionizing and microwave, associated with this type of equipment and of the dangers associated with disregarding the recommended safety precautions.

(e) Installation of telephone equipment in the transmitter room should be kept to a minimum. Any equipment which it is necessary to locate in this area, including telephone sets, should be installed on a plug-and-jack basis to the extent possible, to minimize any potential exposures to employees.

B. Microwave Radiation

Detection

6.13 Since it is known presently that the biological effects of microwave radiation are thermal and do constitute a potential hazard to personnel, conservative exposure limits have been adopted by the Bell System as indicated in 5.08. In order to properly detect, measure, and evaluate the radio fields in the vicinity of high-power transmitters, reliable and portable instruments are required. Because the exposure will be influenced by the power output, distance, from the antenna, frequency, direction of the beam, and other factors, the radiation detector must be able to integrate each of them into a meter reading which indicates whether or not the field intensity is within Bell System microwave exposure limits.

Survey Instrument

6.14 One survey instrument, NARDA Model B-86B3, which has been tested and evaluated, is designed to measure radiation with a range of 0.5 to 20 mw/cm^2. This encompasses the present exposure limits. This portable unit is designed to evaulate radio fields in any polarization in the frequency range of 400 to 10,000 mHz. Only those persons who are qualified, such as engineers or people with radiation training should use, or supervise the use of, this instrument.

Personnel Monitoring Instruments

6.15 Some radar sites require all personnel, including visitors, to wear a simple device which indicates the presence of RF radiation. This personnel monitor is a miniature neon lamp which is attached to the outside clothing of the individual in a manner similar to a film dosimeter. Although the lamp cannot be used to give an accurate indication of RF power level, any glow of the lamp is a sign for personnel to leave the area.

Control, Protection, and Precautions

6.16 Many employees work directly with the military on projects involving powerful radar installations. These employees are cautioned to abide by the following rules.

(a) Never enter an area posted for microwave radiation hazard without verifying that all transmitters have been turned off and will not be turned on without ample notice.

(b) Never look into an open waveguide which is connected to energized transmitters.

(c) Never climb poles, towers, or other structures into a region of possible high-radar field without verifying that all transmitters have been turned off. On certain military radar sites, personnel are prohibited from entering hazardous RF radiation areas without special protective clothing designed to limit their exposure to permissible levels. Entry to these areas must be specifically authorized in writing by the site manager. It is the responsibility of the site manager to adopt and enforce the established radiation safety rules and procedures.

(d) ◆***Antenna Work:*** Protective clothing (described in 6.17 through 6.21) should be worn whenever personnel are required to work in front of microwave antennas that have a combined transmitter power input of 150 watts or more under conditions of a normal environment (T.H.I. of 70 or less). Under conditions of severe abnormal environment (a T.H.I. of 79 or greater), antenna exposures of 15 watts or greater input power should be permitted only to personnel wearing protective clothing.

(e) ***Hot Patching:*** Protective clothing should be worn at all times when making hot patches with more than 30 watts of power in the waveguides to be patched, or in any case where a separation distance of 12 inches or more cannot be maintained as prescribed in Section 010-150-002.

Protective Clothing

6.17 A standard Bell System garment is available and may be used to reduce the thermal effect of microwave radiation on the body to safe limits. The use of such clothing may be particularly useful in antenna repair work or other conditions of prolonged exposure to microwave radiation. This clothing effectively reduces the thermal effect associated with microwave radiation. The use of the Bell System protective clothing permits work under conditions of greater than 10-mw/cm^2 field density exposures for extended periods of time.

6.18 The microwave protective garment will provide a 30-dB (1000 times) reduction of the microwave field density. This amount of attenuation will be more than adequate for all microwave point-to-point systems presently in use or planned for future use under existing Federal Communications Commission rules in the frequency bands presently allocated for common carrier use. The adequacy of the protection suit for use around tropospheric scatter system antennas, earth station antennas, or high-power radars should be verified by calculation prior to such use. If the calculated power density exceeds 10,000 mw/cm^2 in the proposed work area, the protective clothing may not provide adequate protection. (See Section 010-150-003.)

6.19 In any case where there is a requirement to wear the microwave protective garment inside a central office or microwave repeater station and the work location is within reach of exposed electrical potentials, a cotton coverall garment should be worn over the microwave protection suit. In addition, care should be taken to avoid contact between these potentials and the hood of the suit. These precautions and the rarely occurring requirement to wear the suit indoors should minimize this problem.

6.20 Tears or openings in the garment reduce its attenuation. For this reason the closure down the back of the suit should be securely pressed together along its entire length. The garment should be inspected prior to each use to be sure that it is free from tears or ripped seams. Any such tears or rips should be repaired by sewing them together with a tight seam before reusing the suit.

6.21 Ordering information for the microwave radiation protection garment was provided to the field in E.L. 27, December 1, 1966, Topical Index Code 1S3.107.◆