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Guidelines for protection against the hazards of radiofrequency and microwave radiation in the frequency range from 100 kHz to 300 GHz

1 INTRODUCTION

Devices emitting microwave and radiofrequency radiation have become an indispensable part of the activities at CERN and of our modern life style in general. Typical applications at CERN can be found in the radiofrequency systems of the accelerators, radio transmission systems, etc., while microwave ovens and communication devices, such as CB radios amongst others, are sources of a more general nature. It has been realized over the past few decades that these radiations may, under certain conditions, give rise to health hazards. This has led to the establishment in many countries of limits for exposure of human beings. The present safety note gives guidelines for the protection against microwave and radio-frequency radiation hazards at CERN.

2 BIOLOGICAL EFFECTS OF RADIOFREQUENCY AND MICROWAVE RADIATION

Radiofrequency and microwave radiation is absorbed by body tissue. This energy absorption gives rise to a temperature increase of the exposed tissue and this may lead to thermal effects on the body tissue, depending on the frequency and intensity of the radiation. A well-known thermal effect caused by microwave radiation is for example cataract induction which can be explained as follows: the heat generated in tissue is normally removed by the blood circulation. However, in areas of low vascularity such as the lens of the eye, thermal damage may occur due to poor heat removal. The threshold for lens opacities is generally assumed to be at least 100 mW/cm^2, which is well above the limits proposed in this safety note.

There are differences of opinion between specialists working in the field of microwave bioeffects, some of whom claim that low-level microwave exposure (< 1 mW/cm$^{2)}$ will cause reversible disturbances of the central nervous system, like headaches, emotional instabilities, changes in the electroencephalogram and alterations in blood chemistry. However, most specialists consider that these phenomena have not been proven.

Interference with the functions of pacemakers has been a matter of concern since the pacing catheter can act as an antenna and pick up the radiation. Therefore, modern devices use shielded cables between the pacemaker and the heart to eliminate this effect. Nevertheless problems may still arise. Tests have been carried out [ref. 1] to determine below which electric and magnetic field strength 95% and 100% of 111 types of pacemakers are not disturbed as a function of frequency. These threshold values were compared [ref. 2] with the proposed exposure limits of IRPA [ref. 3] and found to be very close but still below these exposure limits. This implies that the IRPA exposure limits do not provide full protection for all pacemakers. Furthermore, external pacemakers may be more sensitive to interference because of the absence of a screening layer of tissue. Finally the problem of conducting elements, such as spectacles frames or body implanted nails and sheets, exposed to strong magnetic RF fields should be mentioned. Such conditions are met in the electrothermal industry. Electrically conducting elements may become hot, leading to damage of the surrounding tissue.

3 SOURCES OF MICROWAVE AND RADIOFREQUENCY RADIATION

During 1980 an enquiry on exposure to microwaves and radiofrequency radiation was made at CERN amongst persons having declared that they were occupationally exposed to this type of radiation. This survey revealed a wide variety of potential sources like microwave ovens, RF systems involving klystrons, tetrodes, solid-state sources, amplitrons, magnetrons, travelling wave tubes and carcinotrons. The devices listed above were operating at frequencies ranging from 13.57 MHz to 140 GHz. Most sources are meant to be used inside tight enclosures. An exception is the ST radiotransmitter used for the CERN staff location system and operating at 465 MHz. Leakage radiation may, however, be present and must be properly monitored before any such system is put into operation. The survey also revealed some confusion concerning the hazards due to video display terminals (VDTs). It should therefore be emphasised that VDTs are of no concern with respect to exposure to RF, microwave and ionizing radiation. Surveys of many different types of VDTs have shown negligible levels of such radiations in their vicinity.

Broadcasting transmitters, radar systems, dielectric heaters used in the industry for sealing plastics, etc., and microwave ovens are considered to be important sources of occupational and general public exposure outside CERN. Medical applications are found in physiotherapy, where shortwave (27.12 MHz) and microwave (2.45 GHz) diathermy units are commonly used. Hyperthermia for cancer therapy purposes is presently under development. This method is based on heating malignant tissue to temperatures between 41°C and 43.5°C with or without radiotherapy or chemotherapy in order to improve the destruction of this tissue.

The most widespread household application of microwaves is certainly the microwave oven, operating usually at 2.45 GHz. National standards and safety procedures have resulted in an improved design of ovens, leading to less leakage of radiation, better interlocks, etc., so that personal exposures arising from the use of such devices are now very small indeed.

4 EXPOSURE LIMITS

Most countries, including Switzerland [see ref. 2], are supporting the guidelines on limits of exposure to radiofrequency fields between 100 kHz and 300 GHz proposed by IRPA [ref. 3]. These limits are therefore also used at CERN. However, it should be kept in mind that also here the basic principle used for ionizing radiation protection shall be observed, i.e. exposures shall always be kept *"as low as reasonably achievable"* (ALARA).

In the IRPA guidelines, the basic limits of exposure for the frequency region above 10 MHz are expressed in terms of specific absorption rate (SAR) which is the power absorbed per unit mass. The SI unit of SAR is watt per kilogram (W/kg). The SAR may be spatially averaged over the total mass of an exposed body or its parts, and may be temporally (time) averaged over a given time of exposure or over a single pulse or modulation period of the radiation. For practical purposes (ease of measurement) derived limits of exposure are also given in the IRPA guidelines. They are expressed in terms of power density (energy flux density) in the body-absent situation. The SI unit of power density is watt per square meter (W/m^2).

For frequencies below 10 MHz, the concept of SAR has limited significance because the biological effects resulting from human exposure are mainly related to the current density generated in the body. Therefore in this frequency region the exposure limits are expressed in terms of "effective electric field strength" E_{eff} and the "effective magnetic field strength" H_{eff}. The SI units of E_{eff} and $^{H}_{eff}$ are V/m and A/m respectively.

a) Occupational exposure limits

Occupational exposure to RF radiation below and up to 10 MHz shall not exceed the levels of unperturbed RMS (root mean square) electric and magnetic field strengths given in Table 1, where the squares of these field strengths are averaged over any 6-min period during the working day, provided that the body-to-ground current does not exceed 200 mA and that any hazards of RF burns are eliminated. Pulsed electric and magnetic field strengths when averaged over the pulse width shall be limited to 32 times the values given in Table 1.

Occupational exposure to frequencies above 10 MHz shall not exceed a SAR of 0.4 W / kg when averaged over any 6-min period and over the whole body, provided that in the extremities (hands, wrists, feet and ankles) 2 W per 0.1 kg shall not be exceeded and that 1 W per 0.1 kg shall not be exceeded in any other part of the body.

The limits of occupational exposure given in Table 1 for the frequencies between 10 MHz and 300 GHz are the working limits derived from the SAR value of 0.4 W / kg. For pulsed fields, it is suggested that the P_{eq} as averaged over the pulse width does not exceed 1000 times the P_{eq} limits in Table 1, provided that the limits of exposure averaged over any 6-min period are not exceeded.

b) Exposure limits for the general public

Exposure of the general public to RF radiation at frequencies below 10 MHz shall not exceed the levels of unperturbed root mean square (RMS) electric and magnetic field strength given in Table 2. Exposures above 10 MHz shall not exceed a SAR of 0.08 W / kg when averaged over the whole body and over any 6-min period. The limits given in Table 2 between 10 MHz and 300 GHz are derived from the SAR value of 0.08 W / kg. Those limits do not apply for medical exposures.

c) RF shocks and burns

RF shocks and burns can result from touching ungrounded metal objects that have been charged up by the field or from contact of a charged-up body with a grounded metal object. If the current at the point of contact exceeds 50 mA, there is a risk of burns.

Table 1

Occupational exposure limits to radiofrequency electromagnetic fields

Frequency f (MHz)	Unperturbed RMS field strength Electric E (V/m)	Magnetic H (A/m)	Equivalent plane wave power density P_{eq} (W/m^2)	P_{eq} (mW/cm^2)
0.1-1	614	$1.6/f$	-	-
> 1-10	$614/f$	$1.6/f$	-	-
> 10-400	61	0.16	10	1
> 400-2000	$3\ f^{1/2}$	$0.008\ f^{1/2}$	$f/40$	$f/400$
> 2000-300 000	137	0.36	50	5

Table 2

General public exposure limits to radiofrequency electromagnetic fields

Frequency f (MHz)	Unperturbed RMS field strength Electric E (V/m)	Magnetic H (A/m)	Equivalent plane wave power density P_{eq} (W/m^2)	P_{eq} (mW/cm^2)
0.1-1	87	$0.23\ f^{1/2}$	-	-
> 1-10	$87/f^{1/2}$	$0.23\ f^{1/2}$	-	-
> 10-400	27.5	0.073	2	0.2
> 400-2000	$1.375\ f^{1/2}$	$0.0037\ f^{1/2}$	$f/200$	$f/2000$
> 2000-300 000	61	0.16	10	1

5 USE OF RADIOFREQUENCY AND MICROWAVE EQUIPMENT AT CERN

In view of the potential hazards of RF and microwave exposure outlined above, it is necessary to follow a number of recommendations for the use of such equipment at CERN. Most of them have been taken from the Canadian safety code for such devices [ref. 4].

a) Warning signs (see Fig. 1) indicating the presence of RF and/or microwave radiation shall be posted.

b) The immediate vicinity of unmanned, high-power sources of RF/microwave radiation (e.g. radiotransmitters) shall be fenced off to prevent unauthorized access.

c) RF and microwave devices shall be positioned as far away as possible from areas normally occupied by personnel.

d) There shall be no unnecessary metal object near any radiating RF or microwave device. The presence of such objects may result in high-intensity fields in certain locations.

e) Shielding or screening shall be achieved by the use of absorptive rather than reflective materials.

f) A microwave power generating component shall never be tested without an appropriate load connected to its output. The power generated must never be allowed to radiate freely into occupied areas.

Safety procedures to be followed by operators of RF and microwave equipment shall include the following requirements:

1) Replacement components must be equivalent to original components. In particular, waveguides, gaskets, flanges, etc., shall have the same operating characteristics as the original components.

2) Testing of a device either before or after completion of repair work shall be carried out after protective shields, waveguides and other components have been put back in their designated locations.

3) Adjustments of voltages, replacement of RF or microwave energy generating components, dismantling components or refitting waveguides shall not be undertaken by persons not specially trained for such assignments.

4) The power mains shall be disconnected before reaching into any openings in the RF or microwave equipment.

5) Operators shall not disable any safety interlock.

6) Maintenance personnel and operators of RF and microwave devices shall be aware of the potential hazards of RF and microwave radiation.

The TIS Commission (Radiation Protection Group) should be asked to inspect any new or already operating installation and will carry out the necessary radiation surveys with specialized equipment. Warning signs can be obtained from TIS/RP. It is recommended that for each major installation a designated person, who is informed about the hazards involved and precautions to be taken, is registered with TIS/RP.

TIS/RP will keep a record of all RF and microwave equipment at CERN exceeding 7 W of input power. Equipment below 7 W of input power, such as hand-held or mobile radiotransceivers, is excluded provided it emits at 1 GHz or less, since it will result in a lower rate of energy absorption than allowed for the whole body in spite of the fact that it may emit localized fields exceeding the exposure limits.

In analogy with the distance adopted for ionizing radiation it is common practice to perform radiation survey measurements to evaluate the exposure hazard at a distance of 5 cm or more from any object.

The RF and microwave equipment may present additional hazards like X-ray emission and electrical dangers which will have to be evaluated separately. Concerning X-rays the following procedures and exposure limits are recommended:

i) The RF or microwave power generating component shall be inspected to determine if specified X-ray shields are in their designated locations.

ii) With the shields located correctly, an X-ray survey shall be carried out to ensure that the intensity of X-rays averaged over an area of 10 cm^2 at 5 cm from the external surface does not exceed 5 µSv/h.

iii) Survey instruments used for the measurement of X-rays must not be susceptible to RF or microwave radiation.

6 MEDICAL SUPERVISION

Taking into account the possible biological effects described in chapter 2, a periodical examination by the Medical Service of those persons regularly exposed to radiofrequency or microwave radiations is desirable. Such an examination will in particular concern the lens of the eye and haematological and biochemical parameters. Moreover, any accidental exposure suspected to exceed 100 mW/cm^2 must be reported immediately to the Medical Service and Radiation Protection Group. Wearers of pacemakers are advised to consult the Medical Service prior to work in the presence of RF and microwave radiation, since exposure to radiofrequency and microwave fields may be incompatible with the use of their type of pacemaker.

References

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3 IRPA, International Non-Ionizing Radiation Committee of the International Radiation Protection Association. Guidelines on Limits of Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 100 kHz to 300 GHz. Health Physics 54, 115 (1988).

4 Safety Code 6, Recommended Safety Procedures for the Installation and Use of RF and Microwave Devices in the Frequency Range 10 MHz-300 GHz, 79-EHD-30, Canada (1979).

Appdx

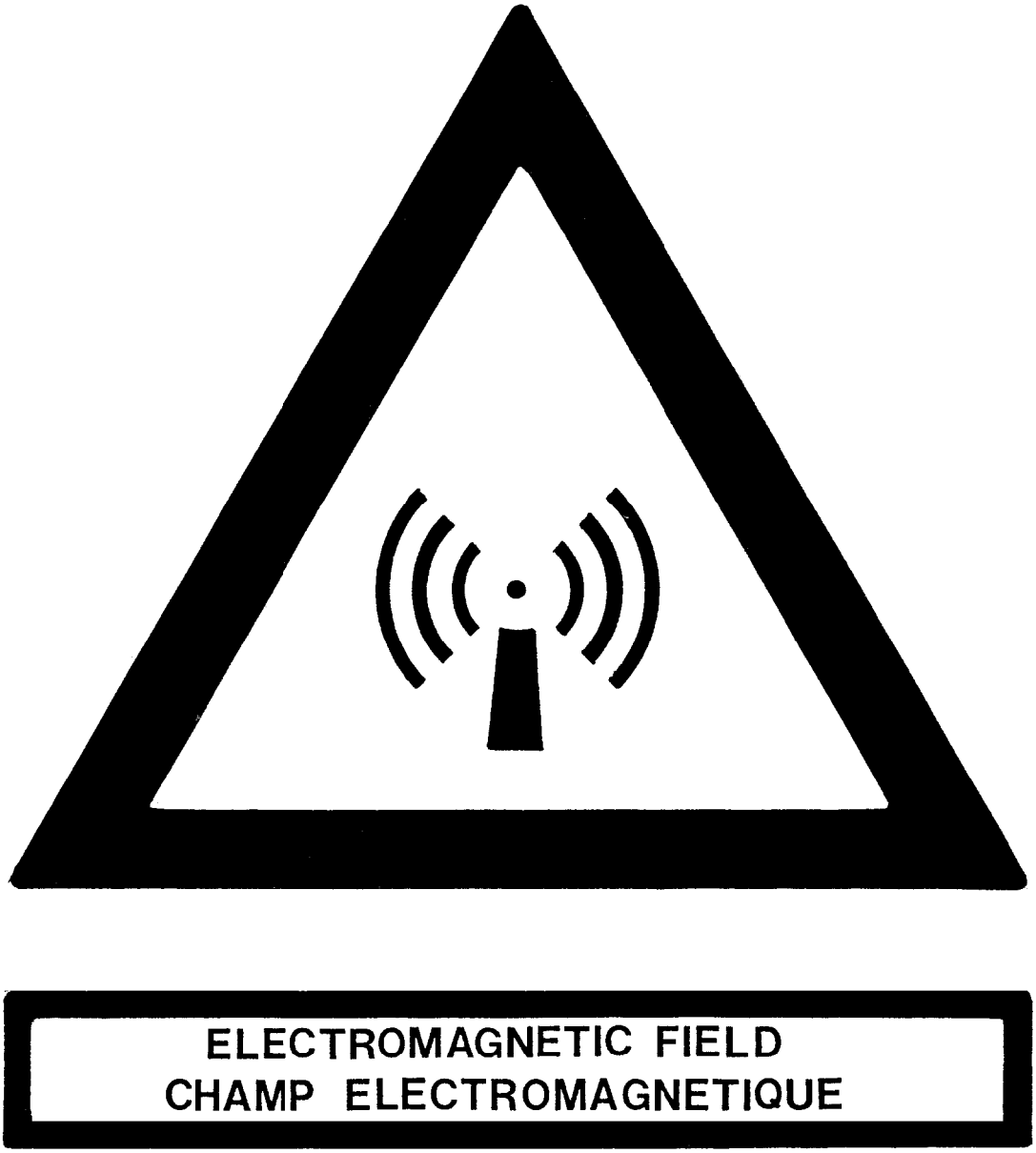

Figure 1

Warning sign indicating the presence of RF and/or microwave radiation

(yellow background, black edging)