

## 9. HEALTH HAZARD ASSESSMENT

### 9.1 Introduction

The purpose of reviewing the scientific literature on effects of exposure of various biological systems to RF fields is to assess its possible impact on human health. Such an assessment is necessary for the development of standards and guidelines limiting exposure to RF of the general and working populations.

One of the problems encountered in assessing the possible health effects of RF exposure over the whole range of frequencies covered in this publication (i.e., 300 Hz-300 GHz) is that most studies have been conducted at frequencies particularly in the low GHz region. Little information is available from studies of human populations and only limited data have been obtained on other biological systems, particularly animals exposed to RF at frequencies below 10 MHz and above 10 GHz.

The following categories of effects must be considered for risk assessment. The first two of these are sufficiently well understood to be used in risk assessment and the development of recommended limits of exposure. The third category is reasonably well understood, but quantitative data are sparse and any comprehensive recommendations to protect workers and the general population have to be based on data at other frequencies. The effects noted in the last two categories are elaborately described and poorly understood. In view of their importance in the possible promotion of cancer or of reproductive failures, they must be considered. However, the lack of understanding and the total absence of quantitative relationships between these effects and either exposures or the outcomes in question makes it impossible to derive recommended limits of exposure.

Points to consider for a health risk assessment of exposure to RF fields are:

- (a) Absorption of RF energy causes tissue heating. This is recognized and has been well studied. This effect occurs from the absorption of RF fields, especially at the higher end of the frequency range (above about 1 MHz). RF heating is not directly equivalent to heating by other forms of energy, because

of the very non-uniform energy deposition that occurs in biological systems.

- (b) At frequencies below about 100 MHz, currents can be induced in humans by physical contact with ungrounded metallic objects (see section 6.5). From 300 Hz to approximately 100 kHz, such currents may result in the stimulation of electrically excitable tissues above the threshold for perception or pain. At frequencies between approximately 100 kHz and 100 MHz, contact currents of sufficiently high density may cause burns.
- (c) For frequencies below several hundred kHz, the predominant effect is stimulation of excitable tissue resulting from currents directly induced in the body by the RF fields. At these lower frequencies, thermal interactions occur only at energy levels much higher than interactions with excitable tissue.
- (d) When RF energy is absorbed in the form of pulsed fields, the peak power density in the pulse should be considered separately from the average. Auditory perception is one example of a pulsed RF field effect.
- (e) When RF fields are amplitude modulated, effects in tissues have been noted that do not manifest themselves with unmodulated RF fields. Such effects are reported to have a complex dependence on intensity and ELF modulation frequency. Too little information is available to determine whether such effects occur in humans and, thus, this effect cannot be used in a health risk assessment or for setting human exposure limits.

## **9.2 Thermal effects**

A number of factors in everyday life tend to increase the heat load on the human body, such as high ambient temperatures, solar radiation, and basal and exercise metabolism. Energy production can reach levels of 3-6 W/kg in healthy people. In most individuals, the thermoregulatory system can remove heat from the body at these rates for extended periods of time. Limited experimental evidence and theoretical calculations suggest that the exposure of resting humans in moderate environmental conditions at whole body SARs of the order of 1-4 W/kg for 30 minutes results in body temperature increases of less than 1 °C. In addition, a review of the animal data

(see section 7.3.4) indicates a threshold for behavioural responses in the same 1-4 W/kg range. Therefore, an occupational RF exposure guideline of 0.4 W/kg, based on thermal consideration, leaves a considerable margin of safety for other limiting conditions, such as high ambient temperature, humidity, or physical activity. Higher energy absorption rates in extremities and limited body regions, do not appear to cause adverse effects, for SAR values below thresholds that are dependent on the body part and the volume.

In infants, the frail elderly, and in individuals taking certain drugs, the thermoregulatory capacity may be much reduced and, as a result, their tolerance for the combined effects of RF exposure, exercise, solar radiation, and high ambient temperature, may be much lower. Recognition that this tolerance is lower dictates that guidelines for population exposure to RF fields be reduced. A whole-body average SAR of 0.08 W/kg offers an additional safety factor.

Significant overexposures at the higher frequencies that may occur in occupational environments may result in very high SARs in parts of the body, thus producing local burns. In such cases, the SAR is so high that the normal avenues of heat transfer from the exposed area are inadequate. The local tissue temperature quickly rises to levels that denature proteins. Such burns may occur at depths much greater than those usually associated with contact burns.

Thus, standards should be developed that, at a minimum, limit exposure of the healthy and aware (occupational) population, so that the whole-body average SAR does not exceed 0.4 W/kg. Additional precautions must be exercised for situations that might cause large peak values of the SAR, in order to eliminate rapid elevation of local temperature by more than 1 °C. This requires that the peak (or local) SARs should not exceed about 2 W/100 g in the extremities and 1 W/100 g in any other part of the body. The eye may need special consideration, possibly by averaging over a mass of 10 g (i.e., 100 mW/10 g).

### **9.3 RF contact shocks and burns**

At frequencies below a few hundred kilohertz, the electrical stimulation of excitable membranes of nerves and muscle cells is a well established phenomenon. These effects exist at very high environmental field strengths, unlikely to occur in the general

environment. On the other hand, current densities sufficient for stimulation and other potentially harmful effects can be produced, if an individual makes contact with a conductive object energized by the electric field component of an RF source.

For frequencies between 300 Hz and 100 kHz, perception, pain, startle, or even inability to let go, may result from physical contact with energized objects (see section 8.1.6). The thresholds are expressed in terms of the current and are strongly frequency dependent. Superficial and deep burns may occur as a result of contact with metallic objects exposed to RF fields over a wide frequency range. Sufficiently high current densities for contact burns can be attained in RF fields that are too low to cause direct heating or stimulation. Thresholds depend on the size and shape of the object, field frequency, length and type of contact, and other parameters.

Field exposure guidelines should also contain RF limits to eliminate hazards from shocks and burns. In this context, it should be kept in mind whether the exposures occur under controlled or uncontrolled conditions. Under uncontrolled exposure conditions, it is not always possible to limit contact currents for some objects (e.g., vehicles) so that electric field strengths have to be reduced to protect the general population. For workers, other measures, such as protective clothing or contact avoidance, provide viable alternatives for protection.

#### **9.4 Induced current densities**

At frequencies below approximately 1 MHz, interactions of RF fields with biological systems and potential hazards can be considered in terms of induced currents and their densities (see section 8.1.4). The use of induced current densities, however, is only appropriate for the assessment of acute, immediate effects, while it may have some limitations for the complete evaluation of long-term effects. The waveform of the RF field is an important factor to be considered in the response of biological systems. However, peak instantaneous fields strengths appear to be important in considering nerve and muscle cell stimulation and for perturbing cell functions. Generally, for frequencies above 300 Hz, the thresholds for effects increase with frequency, up to frequencies where thermal effects dominate. For the establishment of derived limits, the distribution of the current

densities within the body induced from RF fields have to be considered. The treatment of this problem is restricted, at present, to relatively simplified situations.

## **9.5 Pulsed RF fields**

Experimental data suggest that thresholds for the biological effects of absorbed energy at frequencies above hundreds of megahertz, when in the form of short duration pulses (approx. 1-10  $\mu$ s), are lower than those for continuous fields at the same average energy level and the same SAR. This indicates that the peak value of energy transfer to the biological object can be an important determinant of the biological effect. A well-investigated effect is the perception of pulsed fields, such as from radar, as an audible sound described as a click, chirp, or knocking sensation (see section 8.1.3).

Pulsed RF exposure effects observed in animals are suppression of a startle response, stunning, ocular effects, and alterations in responses to certain drugs. Thresholds in terms of the energy density per pulse or the peak electric field strength for a given pulse duration are known for these effects only at a limited number of frequencies. Suppression of startle response was observed for pulse durations of up to a few seconds. Shorter pulses with the same or greater energy had a slightly enhanced effect on startle.

Since a single pulse, or a series of short pulses, of RF of very high peak power density, but very low average power density, can produce potentially harmful biological effects, it is necessary to limit the maximum energy density per pulse. The available scientific evidence is incomplete, and, therefore, the formulation of exposure limits for pulsed fields presents difficulties.

## **9.6 RF fields amplitude modulated at ELF frequencies**

Effects have been reported in *in vitro* systems and animals exposed to RF fields of low intensities amplitude modulated at ELF. Some of the same or similar effects have also been observed as a result of exposure to ELF and VF fields. The effects usually exhibit "window" characteristics, i.e., the effects occur only within relatively narrow ranges, in both the modulation frequency and field intensity. Even though the intensities of the fields in tissue at which these

effects occur are below the broadband thermal noise, there are hypotheses that might account for such apparently aberrant behaviour. The biological significance and possible adverse health impact, if any, of the reported effects cannot be determined at this time.

## **9.7 RF effects on tumour induction and progression**

There have been isolated reports that, in certain cell lines and in intact animals, RF exposures have been associated with increased growth rates of cells and tumours and with increases in the incidence of neoplastic transformations. Very few epidemiological studies have been reported. The available evidence does not confirm that RF exposure results in the induction of cancer, or causes existing cancers to progress more rapidly. Because of incompleteness and inconsistencies, the available scientific evidence is an entirely inadequate basis for recommendations of health protection guidelines.