

Radio Frequency (RF) Safety and Esthetic Concerns

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Abstract- Recent years has witnessed a rapid proliferation of wireless systems use in all walks of life. This proliferation has caused some concerns about safety and esthetics due to unprecedented increase of human exposure to EMF as a result of widespread use of electrical appliances and mobile telecommunication devices. At this time it does not look like either type of concern will have too much effect on the proliferation of these systems, but we should look at them. Safety, in particular, should be kept in mind by anyone working on or with these wireless systems.

Key words: wireless systems, EMF, safety

I. INTRODUCTION

WITH the rapid development of communication technology, as well as with the high improvement of the life level, the amount of wireless systems more so the mobile telephones has been increased extremely. It has become a popular tool for the communication in the modern society. Meanwhile, it has been a highlight problem that whether the radiation from the systems and mobile handset may make some side-effect on the human body, especially on some organs such as the eyes or the ears. When phone call, the eyes are very near to the antenna of a mobile handset so that the eyes are exposed in the field of the induction and the radiation from the RF electromagnetic field [1].

This increasing use of radio frequency (RF) applications has led to the growing presence of electromagnetic waves in various locations. As mentioned above there is an increasing concern regarding the effects of electromagnetic waves emanating from wireless communication devices on the health of humans. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE) have issued guidelines that specify safe limits of exposure to

electromagnetic fields (EMFs). According to these guidelines, the safety of the RF-EMF is evaluated by the specific absorption rate (SAR), which is the amount of RF energy absorbed per unit weight of the body and is used as a measure of the thermal effects in the body that are caused by the absorption of electromagnetic energy. SAR is defined by the following equation:

$$SAR = \frac{\sigma}{\rho} E^2 \quad [W/kg] \dots\dots\dots(1)$$

where s is the conductivity of the tissue [S/m]; ρ , the density of the tissue [kg/m³]; and E , the electric field strength (r.m.s.) inside the tissue [V/m]. The SAR of a human body exposed to RF-EMF is, however, very difficult to measure directly because SAR includes the internal electric field strength and conductivity of the body, as shown in the equation above [2]. All these concerns have led to research on different aspects of RF radiation including [2] - [17].

II. RADIO FREQUENCY (RF) RADIATION

The term 'RF' covers all frequencies used for communications, radar, satellites, etc., up to the nominal ceiling of 300GHz. However, it is suggested that some people regard 'RF' as applying only to the lower part of this spectrum. Consequently the word 'microwave' can also used to refer the upper part of the spectrum. In some cases the term microwave is only specifically used when the topic involves something to which the term normally attaches, e.g. microwave oven, microwave antenna, etc.

The subject of RF radiation is still regarded as mysterious and something of a black art. This is no doubt due to the fact that it cannot be seen or touched. There was also an element of magic in some of the very early experimental work, particularly that of Tesla, who seems to have mixed science and showmanship.

Perhaps because RF is unseen, it has also become confused with ionising radiation in the minds of many people. It is

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essential to distinguish the difference between the two since, with our present state of knowledge, the consequences of exposure to them can confidently be stated as being very different.

Although we cannot see radio waves, most people will, at school or college, have done the classical experiments with magnetic fields and iron filings to demonstrate the patterns of the fields and used an electroscope to demonstrate the presence of electrostatic charge and the force which causes the gold leaf to move.

From these early and rudimentary experiments with static fields it should at least be possible to conceive that such fields are not magical and are very common in any electrical environment.

III. HISTORY OF RADIO TRANSMISSION

Radio transmission is, relatively speaking, a very new technology which had its beginnings in the theoretical work of Maxwell in the nineteenth century and the experimental work of Hertz, the German physicist, in the last two decades of the nineteenth century. Many others also made contributions, including the development of devices which could detect the presence of radio waves. Whilst the question of who first transmitted radio signals is not without controversy, the subsequent practical development of radio communications systems is attributed to Guglielmo Marconi who was born in Italy in 1874.

His first British patent was taken out in 1896 and covered the use of a spark transmitter. There are many accounts written of the experimental work carried out at various locations on land and on ships during the course of which the range of such equipment was very much increased. By 1921, the thermionic transmitter tube became available and made it possible to design transmitters to operate on a range of frequencies. The power output available increased with the development of electronic tubes which could, increasingly, handle higher powers with the aid of air or liquid cooling systems.

Over the years, and stimulated by the needs of the First and Second World Wars, radio transmission has become an established technology which is taken for granted and which, among other things, provides for the broadcasting to our homes of entertainment, news and information of every kind in both the radio and television spheres. The most recent development, resulting in the domestic satellite dish antenna, brings the quasi-optical nature of microwaves to the notice of the consumer.

The use of semiconductor devices (transistors) has become commonplace and as a result the mass and volume of electronic products for a given function is much less than that of their earlier counterparts which used electronic tubes. However, in the high power transmitter field electronic tubes are still the mainstay of transmitters. These use very high voltages, depending on power output. 40kV or more is not unusual for very high power equipments. High power systems such as MF and HF broadcasting systems need considerable provision for cooling the vacuum tubes used and in some cases the resulting heat is transferred to the station heating system!

Semiconductor devices are being used in transmitters of more modest power and also in spaced array radar equipments and do not need high voltages. Semiconductor devices do also have a considerable role in transmitter drives, audio circuits and in control systems. In the latter application, sophisticated logical control circuits are easy to achieve and occupy the smaller volumes attributable to the small size of transistors and integrated circuits.

With the vast increase of terrestrial and satellite broadcasting and communications, and the enormous number of mobile phones now in use, homes, work and recreational places are irradiated by a vast number of electromagnetic signals. Many are intended to operate receiving equipment, most of which are at very low levels because the high sensitivity of receivers does not necessitate large signals. Mobile phones do however communicate both ways and thus incorporate transmitters and receivers. As usage increases there is pressure for the use of more frequencies such that governments now sell licences to use parts of the RF spectrum.

Some radiation is unintentional, resulting from the leakage of energy from devices which have no radiation function, for example, due to inadequate shielding, unblocked apertures in metal cases, and similar shortcomings. Apart from any effects of leakage on people, it also causes interference with other equipment. It is not surprising that the presence of so much electromagnetic interference has caused people to question whether they can be harmed by it.

The word 'wireless' largely passed out of use many years ago. Radio is now the more general term in use, though strangely enough in domestic use it tends not to have the same wide use, mainly being interpreted as meaning sound broadcasting with the term 'television' or 'TV' to describe television picture and sound broadcasting. There are many words used to describe forms of radio system including satellite

communications, radar, microwave links, mobile telephones, etc.

Despite the profusion of terms in use to describe the transmission of intelligence by electromagnetic waves, the nature of these waves is basically the same, the variable being the way in which the intelligence (signal) is added. It is therefore convenient to refer to these electromagnetic waves as 'radio waves' and the frequencies of the waves as 'radio frequencies'.

IV. SOURCES OF RADIO FREQUENCY RADIATION

RF equipment is now extremely widely used in applications which would not have been conceived twenty or thirty years ago. Apart from the enormous diversity of equipment available in the established fields of communications, broadcasting, radar, navigation, production processing and medical therapy, there is an increasing use in applications such as anti-theft systems in shops, vehicle location, motorway control, telemetry to operate control systems remotely and many other novel applications. Uses are continually extending, as evidenced by the use of mobile telephones. In the amateur radio field also modern equipments are smaller and more compact, facilitating mobile use in motor vehicles. Most of the sources include;

Broadcasting MF and HF broadcasting- Broadcast transmitters in the MF and HF bands use considerable power, 250kW to 750kW being common.

UHF and VHF broadcasting-Television and VHF radio broadcasting is now taken for granted in most of the world. The number of broadcasting stations has increased considerably over the last thirty years and the need for full coverage with television and VHF radio has resulted in many lower power repeater transmitters being used to bring the services to local communities.

Tropospheric scatter systems-Tropospheric systems for land communications are trans-horizon microwave communication systems. Long hop distances (up to several hundred kilometres) are obtained by deflecting high power microwave signals off the tropospheric layer of the atmosphere to overcome the earth's curvature between widely separated sites.

Air traffic control (ATC) communications-Air traffic control communications systems involve highly organised networks of VHF and UHF transmitters and receivers to communicate with aircraft in the ATC control zone. Usually several

transmitters are operated simultaneously to secure adequate zone coverage. The typical transmitter power output is about 50 watts.

Satellite communication systems-Satellite communication systems use microwave beams to communicate with satellites. The diameter of the dish antennas can vary from a few metres to tens of metres and may have very high gains. The narrow beams are used at suitable elevations for the appropriate satellite and give rise to very little radiation exposure at ground level away from the antenna.

Radar systems-There are many varieties of radar equipment in use around the world. Most involve movement of the antenna system, i.e. rotation or movement in azimuth, movement in elevation, etc. Leaving aside HF radar, radar systems are generally characterised by using microwave beams which are usually relatively narrow in azimuth but the characteristic in the elevation plane depends on the nature and function of the radar. Some have a mean power of 550W and a peak power of 650kW. The frequency coverage is 2.7 to 2.9GHz.

RF machines-The use of RF generators in manufacturing processing is very widespread, covering a large range of materials and processes. Low frequency induction heating has been used for at least 50 years for metal processes. Some such microwave equipment is used in production processing of some foodstuffs and care may be needed if the personnel concerned are not so technically knowledgeable as those in radio engineering. Indeed with RF processing machines in general, some knowledge of the effect of different processing procedures and the different types of work pieces involved may be needed for machines which process a variety of different products, since the leakage and possible operator exposure may be affected by the type of product. There are many other sources of RF power including signal generators for testing work which can offer tens and hundreds of watts output. Often the magnitude of the output of such devices is not appreciated by the user. This is particularly the case where generators are used to power microwave waveguide benches. It is not unusual for people to disconnect live waveguides without bothering to switch off first and the author has had to investigate several such cases where the engineer concerned suddenly realised that he was taking risks.

V. EFFECTS OF RADIO FREQUENCY RADIATION

A. The Exposure of Human Beings to RF Radiation

Perhaps the best introduction to this topic is this reminder that real knowledge requires defining and quantifying. Standards and guides need to express safety limits in numbers which can be verified in order to safeguard people. It is therefore essential that research is based on measurement and the progress in the development of suitable instruments has led to the possibility of measuring RF field quantities more reliably.

Safety management is concerned with safeguarding the well-being of people. The World Health Organisation (WHO) defines health as:

‘The state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Humans respond to many stimuli as part of the normal process of living. A biological effect can lead to a health hazard (unfavourable effect on physical, mental and social well-being) if the change is outside the range of the body’s compensation mechanisms.’

This is a fairly challenging definition and would appear to take in unfavourable effects on people due to unfounded fears of radiation as well as fears of risks which are well established.

A great deal has been written over the last thirty years or more about the actual and alleged hazards of RF radiation. The vast majority has been in the form of serious contributions and includes a large number of research papers. Lack of accurate methods of measuring fields obviously affected some of the work of the earliest workers. As technology has improved and field measurements can now be made more accurately, the experimental methods have improved. However not all research is equally well conducted with the effect that the results of some studies are treated with some scepticism. Also some research is released to the media without any form of peer review and may be given more credence than it is worth.

We see this also in the so-called food research which adds and removes the same items from our menus so rapidly that few people take the slightest bit of notice! It also does some harm to the credibility of research work.

The problems of research in the RF radiation field are fairly obvious as very few tests can be carried out on human beings. As a result, most practical work has been done on small animals such as rats, mice, rabbits, bacteria, yeast cells, fruit flies and similar subjects. There is then the problem of the

extrapolation of the results to human beings when some fundamental factors, e.g. the physical sizes, and thus the resonant frequencies of the various subjects are so markedly different. Also, where thermal effects are involved, the differences in the thermo-regulatory systems of the test subjects pose a very considerable problem. Hence such extrapolation is likely to be dangerous.

An even greater problem is the fact that the radio frequency spectrum is so very wide (perhaps 10kHz to 300GHz) and it is well-nigh impossible to extend research to the whole spectrum, to low and high levels of field, different modulation methods and so on. This is further complicated by the suggestion that some effects only occur in RF frequency ‘windows’ and modulation frequency or pulse rate ‘windows’.

The term ‘window’ here implies that an effect has been claimed to occur at some RF frequencies and not at others or at low field levels and not at higher field levels of the same frequency or that the effect occurs at certain modulation rates and not at others. The variables, RF frequency, RF amplitude, modulation frequency and type, provide an almost infinite number of combinations to be studied. This illustrates the real difficulty in determining which combinations to explore. Any research results obtained from some of these combinations will always be challenged by someone on the basis that the wrong combinations have been investigated!

In more practical terms there is also the cost of equipment capable of generating all the frequencies and modulations at levels large enough for practical work. Hence work will often be done with frequencies determined only by the equipment available.

It is scarcely surprising that from time to time some particular research may be challenged, either because of something related to the experimental situation or because of the conclusions drawn. In general, the replication of research findings elsewhere is looked for but is not easy to achieve when finance is not available to pay for the work.

Some individuals express extreme views on RF radiation hazards, which are often drawn from the research of others, but which differ from those of the researchers concerned and from those of others working in the field of RF radiation. Where such views are genuinely held and the person concerned has a reasonable competence to handle the research concerned, this is no problem. It may even provide some impetus for more research, if the views are not so extreme as to be ignored.

It is an unfortunate fact of life that people are very easily frightened by the media and often do not accept reassurance from those more familiar with the subject. Indeed it has to be said that most people do not accept the pronouncements of governments and of their scientists on the subject of safety because their track records are generally not very convincing!

As a result, much time has to be given by RF safety specialists to explaining to both non-technical and technical people the current views on RF radiation. Reassuring people is not easy nor can it be totally authoritative since, if we are honest, surprisingly little is known with any real certainty on the subject of RF radiation insofar as the athermal effects, if such exist, are concerned. Usually, the most that can be said is that there is no evidence to support a particular viewpoint, to which the inevitable answer is 'you have not looked well enough'!

It appears to the writer that we human beings have an approach to risks and fears which emphasises things which are not directly attributable to ourselves. Hence the carnage on our roads is accepted on the basis that the other driver is responsible, and that apart from building more roads, little can be done. Reducing speed is usually subject to strong objections except where things are speeding through our residential area! RF radiation, for those not working with it, is something inflicted by others and therefore suspect. When our children are affected then the strength of feeling is much increased since we are all very defensive in this respect.

This is not to say that a healthy suspicion of potentially harmful situations is undesirable since most safety provisions tend to develop from 'people pressure'. On the contrary, people need to try and understand the basis of their fears in practical terms so that they can judge and challenge statements even though they do not have professional knowledge of the subject. This in turn means that that reports intended from the media should be shorn of jargon and scientific terms and explained in a simple language which gives some idea of the relative risk and of the source and accuracy of the data on which it rests. Where research work is quoted, extracts should not be quoted without also indicating the actual conclusions of the authors since it is quite common for people to represent their own views by selective quoting when the conclusions do not suit them! We use the word 'safe' in everyday conversation and in legal provisions and it is worth examining it. In the United Kingdom in the last statistics seen by the writer, accidents in the home contributed 1000 deaths and 250000 accidents involving referral to hospital in one year. Yet we consider home as a safe place.

The most practical use of the concept is 'reasonably safe' since this is the most that we can aim for when part of the risk exists in the actions of the individual, and part in a lack of knowledge. There is a statistical risk in everything we do, whether or not we know the statistics and we can worsen these if we do not take the right precautions.

A senior medical consultant lecturing on RF radiation safety mentioned that even burnt toast is toxic – but it would involve eating about 100 slices at the same time! Our concerns about risks therefore need to be related to the probability of occurrence of some harmful effect.

Nevertheless, human psychology in the risk field seeks perfection and has to be accepted as a fact of life, now coloured on occasions by the chance to sue somebody. The author believes that there is little chance of establishing with any certainty, the more complex of the so called 'athermal risks' associated with RF radiation – if any exist – in any meaningful way, since there are too many confounding factors and equivocal results, too little money to fund really good work, and cogent reasons why the priorities for research expenditure should be towards known life-threatening illnesses. Probably the most that can be done in the long term is to refine permitted limits, where necessary, to provide more prudent assurance.

Whatever the difficulties, standards for RF radiation safety are needed and practical safety limits for everyday work have to be set by some sort of consensus amongst those experienced in the field, having regard to such research as is available. If the limits are just set arbitrarily low, the use of RF power may become a serious practical problem, without offering any assurance that the low limits actually achieve anything.

In this connection, the World Health Organisation (WHO) has in hand a very large collaborative study which may in the long term provide a standard on an international basis together with supporting documents which could assist in promoting a more systematic approach to RF radiation safety management.

B. The Nature of Potential Hazards

We can define the potential hazards of RF radiation in terms of:

Direct effects on people

- ✓ Thermal effects attributable to the heating of the human body due to the absorption of RF energy. At lower frequencies this includes heating due to

excessive current densities in some parts of the body.

- ✓ Shocks and burns which may result from contact with conductive objects, e.g. scrap metal, vehicle bodies, etc., located in electromagnetic fields.
- ✓ The so called ‘athermal’ effects, if any, where it is postulated that the fields act directly on biological tissue without any significant heating being involved.

Indirect effects on people

Effects on people wearing implantable devices such as heart pacemakers, insulin pumps, passive metal plates and other related hardware due to interaction with some aspect of the implantable device. Some effects in this category affect the quality of life rather than physical health, e.g. interference with hearing aids and other electronic devices.

Effects on things in the environment

Ignition of flammable vapours and electro-explosive devices, e.g. detonators.

Interference with equipment above may, of course, also involve people who may be present near the subject and may be affected by fire or explosion, people in aircraft where critical equipment is interfered with and the aircraft may be in jeopardy. With the widespread use of mobile phones risks extend to interference with critical medical equipment in hospitals. Hence many people are likely to be affected in some way ranging from these obvious examples down to the merely irritating cases of interference with computers and domestic radio sets.

Before proceeding it is worth noting that a perceived ‘effect’ is not necessarily synonymous with ‘harm’ or ‘injury’. Our environment affects our bodies daily and some effects are of value, some harmful, and some have no apparent effect.

Some aspects of these topics may be differentiated in a general way in relation to the frequencies involved. Standards do tend to differ considerably in the detail of these.

C. Coupling Mechanisms

Low-frequency electric fields

Electric fields external to the body induce a surface charge on the body; this results in induced currents in the body, the

distribution of which depends on exposure conditions, on the size and shape of the body, and on the body’s position in the field.

Low-frequency magnetic fields

The physical interaction of time-varying magnetic fields with the human body results in induced electric fields and circulating electric currents. The magnitudes of the induced field and the current density are proportional to the radius of the loop, the electrical conductivity of the tissue, and the rate of change and magnitude of the magnetic flux density. For a given magnitude and frequency of magnetic field, the strongest electric fields are induced where the loop dimensions are greatest.

D. Absorption of energy by the human body

This can be divided into four ranges (Durney et al.):

- ✓ Frequencies from about 100kHz to less than about 20MHz, at which absorption in the trunk decreases rapidly with decreasing frequency and significant absorption may occur in the neck and legs.
- ✓ Frequencies in the range from about 20MHz to 300MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g. head) resonances are considered.
- ✓ Frequencies in the range from about 300MHz to several GHz, at which significant local, non-uniform absorption occurs.
- ✓ Frequencies above about 10GHz, at which energy absorption occurs primarily at the body surface.

Note that standards differ with regard to the frequencies at which electric and magnetic fields have to be measured separately. This is usually indicated by the absence of power density limits for those frequencies in the standard concerned, or their presence for information only. It is generally accepted that plane wave relationships are not applicable below 10MHz.

E. Occupational and public safety limits

There is one general issue amongst those creating standards which results in strong differences in views. This is the question of whether separate limits are needed for these two groups.

Some people feel that since there is no accepted concept of 'dose' for RF radiation such as exists for ionising radiation, there is no scientific case for separate limits for the two groups. (As a basic concept, dose = dose rate multiplied by the exposure time.) Consequently such people see the issue as a social and political matter. On the other hand some people believe that the duration of exposure is a significant factor in determining risks. It is true that, in general, populations feel protected if they are subject to tighter limits than those whose occupation requires them to be exposed. This is probably a universal feeling to which most of us would subscribe, especially if it relates to some occupation other than our own. There could be a case on these grounds alone for lower limits for the public, though there are economic costs for such a decision. A factor often overlooked is the general acceptance by most bodies that the 'public' includes those non-technical personnel working for organisations using RF radiation. Thus there is a mixing of groups in employment and some sort of segregation is implicit.

The medical aspects raised include:

- ✓ Members of the public include the chronic sick, including people with impaired functions such as the thermo-regulatory functions and who may therefore be subject to risks which might not apply to fit people.
- ✓ The recent suggestion that children might in some way be more susceptible to some RF radiation both because their bodies are developing and, in relevant cases, because their body resonance, being a function of height, differs from those of adults.
- ✓ The suspicion that RF radiation may have undesirable effects on people taking some types of drugs for medical conditions.
- ✓ The fact that the athermal effects of RF radiation (if such exist) may eventually prove to have adverse effects on human health.
- ✓ The possibility that RF radiation effects are cumulative, i.e. related in some way to 'dose'.

As it can be seen, these statements are of the precautionary type, the argument being that those who have to work with RF radiation choose to do so but the public in general have not made any such choice.

The fact that the arguments either way are not proven does not preclude the taking of a decision which is believed to err on the safe side, though the economic consequence is the likely cost involved in segregating the two groups, especially

where the limitations of land ownership or occupation affect radiation levels at the interfaces with the public.

Some standard, tackle this problem by defining the need for RF radiation safety measures in terms of 'areas' rather than groups of people, namely 'controlled areas' and 'uncontrolled areas'. The former is an area where people who are knowledgeable about RF radiation are employed. The latter covers all other people. Extra safety factors are included for the last category. Even this approach is not without problems. This concept of control by segregated areas broadly follows the practice for ionising radiation, though it would be very undesirable for the comparison to cause any confusion between the two types of radiation.

Some standards only have one set of limits for all people, whilst others have separate provisions for occupational work and for the 'public'. Sometimes scientific accuracy leads to a psychologically unsound concept. In the NRPB current guidance the two categories identified are 'adults' and 'children present'. The reason involves the different resonant frequencies applicable to children, but this would not be known to most people and any specific reference to children sets the alarm bells ringing!

VI. KNOWN EFFECTS OF RF RADIATION ON PEOPLE

A. Thermal effects

There is general agreement that the main demonstrable effect on the human body above about 100kHz is the thermal effect, i.e. the transfer of electromagnetic field energy to the body. A very high percentage of the human body is made up of water and water molecules which are polar molecules liable to be influenced by impinging electromagnetic fields. Hence those tissues having a significant water content are most liable to be influenced by fields. Some other tissues also have large polar molecules. The effect of RF on such body tissues is to cause polar molecules to attempt to follow the reversals of the cycles of RF energy. Due to the frequency and the inability of the polar molecules to follow these alternations, the vibrations lag on them, resulting in a gain of energy from the field in the form of heat which causes an increase in the temperature of the tissue concerned.

With the widespread use of microwave ovens, most people have a practical awareness of the fact that microwaves can heat tissue, as represented by the animal tissues used in cooking, and should not find it too difficult to understand the nature of the thermal hazard.

The amount of heating depends on the amount of energy absorbed and the activity of the human thermo-regulatory system. In turn, the amount of energy available depends on the power of the source and the duration of the exposure, 'cooking time' in the oven context.

B. Human thermo-regulation

In the healthy human body, the thermo-regulatory system will cope with the absorbed heat until it reaches the point at which it cannot maintain the body temperature satisfactorily. Beyond this point, the body may become stressed.

Excessive exposure can give rise to hyperthermia, sometimes referred to as heat exhaustion, an acute, treatable condition which, if neglected could have serious results. Excessive heating can also cause irreversible damage to human tissue if the cell temperature reaches about 43C.

A rise in body core temperature of about 2.2C is often taken as the limit of endurance for clinical trials. For RF radiation purposes, a limit of an increase of 1C in rectal temperature has often been postulated as a basis for determining a specific absorption rate (SAR) limit for human exposure. Most western occupational standards are based on an SAR of 4Wkg^{-1} divided by ten to give a further safety margin. Thus the general basis is 0.4Wkg^{-1} . It has already been noted that people with an impaired thermo-regulatory system or with other medical conditions which affect heat regulation may not be so tolerant to the heating permitted by standards which have been set for healthy people. Those taking some forms of medication may also be affected adversely. There are also factors other than general health which affect the ability of the human body to handle heat energy. For example, a period of strenuous physical work can elevate the rectal temperature.

Another factor is the environmental condition – ambient temperature and relative humidity can make a considerable difference in the ability of the human body to get rid of excess heat. Consequently, a given SAR may, for a constant ambient temperature and specified exposure time, give different body temperatures if the relative humidity is changed from a high figure, say 80%, to a low one, say 20%. Put the other way round, a specific increase of rectal temperature of, say, 1C

will require a much higher SAR at low relative humidity than is needed at high humidity.

In 1969, Mumford identified this aspect and proposed a 'comfort index' whereby the higher safety level then in use (100Wm^{-2} for all the frequencies covered) was reduced as his temperature–humidity index increased. Current standards generally claim to accommodate environmental factors in the large contingency allowance put into the permitted limits.

A particularly interesting paper on the thermo-regulatory mechanisms of the human body is that of Adair. The paper describes the regulatory mechanism in some detail. It notes experimental work done to establish the thermal equivalence of heat generated in the body during physical exercise and passive body heating such as that from HF physiotherapy equipment. It also makes reference to the radical difference between the thermal responses of man and various animals and the consequent difficulty in extrapolating animal exposure data to human beings on this account, quite apart from any resonance differences.

C. RF penetration in human tissues

In considering the amount of energy absorbed by the human body, it is necessary to recognise that the percentage of incident radiation which is actually absorbed depends on frequency and the orientation of the subject relative to the field.

In human tissues, RF radiation may be absorbed, reflected or may pass through the tissue. What actually happens will depend on the body structure and the tissue interfaces involved. These interfaces are the transitions from tissue to tissue or tissue–air–tissue and are clearly complex in the human body.

The depth of RF penetration of the human body is also an important factor. In the HF band, the deeper penetration is used for diathermy treatment where the deposition of heat is intended to have a beneficial effect on that part of the body considered to need treatment. The deep deposition of RF energy needs to be carefully controlled to avoid damage to tissues which might not be noticed by the subject due to lack of sensory perception of heat in the organs concerned.

The measurement of the RF characteristics of human tissue can, for the most part, only be done with chemical simulation of tissue, since there are problems with the use of excised human tissue for this purpose. The penetration depth is usually given as the depth where the incident power density

has been reduced by a factor of e^{-2} , i.e. down to about 13.5% of the incident power density.

The penetration decreases as frequency increases as shown by Schwan. Also tissues with a low water content have significantly deeper penetration.

At the microwave end of the RF spectrum, deposition of energy is confined to the surface layers of the skin. The penetration depth at the higher microwave frequencies may only be a few millimetres. Deposition of energy in the surface layers of the skin may lead to thermal injury, the risk increasing as the frequency increases.

D. Hot spots

The human body is made up of a mixture of types of tissue, for example, skin, blood, bone, muscle and fat. When the human body is exposed to RF radiation, there is, as described earlier, some degree of absorption of the energy in the form of heat. However, the absorption of RF energy in the human body which is made up of such a complex mixture of tissues, can result in a non-uniform distribution of heat. Hot spots (high local SARs) may occur in the human body over the range of about 30 to 400MHz.

These hot spots will be evident at frequencies around body resonance where absorption is greatest and at sub-resonances in parts of the body. Gandhi [14] gives the adult human head resonance range as being of the order of 350 to 400MHz with a volume-averaged SAR of 3.3 times the whole-body SAR at resonance and the absorption cross-section as about three times the physical cross-section. He also gives some local SAR values for knees, ankles and the neck for body resonance in the grounded man (about 34MHz) and the ungrounded man (about 68MHz).

The measurements were made with scaled human phantoms and showed hot spots at the knees, ankles, elbows and, in the case of the nonearthy model, the neck. These have some 5 to 10 times the average wholebody SAR.

It is difficult to tackle the problem of non-uniform heat absorption by seeking to identify the location and temperature of such hot spots. Using physical models poses the problem of carrying out measurements without affecting the distribution and magnitude of the effects due to the presence of the measuring devices and, as mentioned previously, physical models cannot simulate the human thermo-regulatory system.

Work has been done on the subject of 'hot spots' using computer modelling but this again poses the problem of

validating such models as being an adequate and correct representation of the functioning human body. The reason that attention has been given to this problem is a simple one. If a safety standard defines a safe power density limit for a particular frequency on the basis of the average whole-body SAR but some small parts of that body reach significantly higher temperatures than others, there must be concern as to whether these can be harmed in some way.

Some high ratios between mean body temperatures and hot spot temperatures have been noted. Ratios suggested from experiments using magnetic imaging range from 10 to 70, though this reduces to a factor of 2 to 4 when the SAR is averaged over individual organs. The theoretical end point could be where the hot spot is so hot as to cause cell damage, in which case it would be necessary to adjust the average permitted levels to reduce the hot spot temperatures. It has to be said that little is known about the real effects in a healthy individual with an efficient thermo-regulatory system as contrasted with computer or model simulation.

A paper by Gandhi and Riazi looks at the power capabilities of RF sources in the frequency band 30 to 300GHz and identifies the possibility of high energy deposition rates for the skin at frequencies in that range due to the very shallow penetration depths. It also looks at the possibility that dry clothing may act as an impedance transformer, increasing the amount of energy coupled into the body. The thickness of clothing in this frequency band is a significant fraction of the incident wavelength. This could, for a given incident power density, exacerbate the situation by further increasing the deposition in the superficial layers of the skin.

As previously mentioned, standards now recognise the problem of energy deposition in the superficial skin areas by progressively reducing the averaging time for exposures at above 10GHz from the usual 6 minutes to a shorter period.

VII. SUSCEPTIBLE ORGANS

From the thermal transfer point of view, the two organs which are considered more susceptible to heat effects than others are the eyes and the male testes. Neither of these have a direct blood supply and hence do not have that means of dissipating the heat load.

A. Effects on the eyes

The production of cataracts in animal experiments using RF has been well established. It is generally considered that this

effect is a thermal one. Experimental work has been limited to animals and the different physical characteristics of the eye structure in different types of animal do give rise to different results. Also, the depth of penetration of the eye tissues is dependent on the frequency of the radiation.

It is thought that for human beings the frequencies most likely to cause cataracts lie between 1 and 10GHz. In experiments with rabbits, noted in reference 27, with exposures of two to three hours the threshold temperature for cataract induction was between 41 and 44C and the corresponding local SAR about 100 to 140Wkg⁻¹. Experiments with monkeys, where the eyes more closely resemble those of humans, with higher fields than that causing cataracts in rabbits, did not produce cataracts.

Whilst it is easy to do animal experiments with small localised fields, in practice, people exposed to RF fields related to antenna systems are likely to experience whole-body radiation and these sort of levels for whole-body radiation are far in excess of those permitted for microwave work.

Some reported work claims that microwave radiation at low levels, particularly with pulsed radiation, can affect susceptible parts of the eye. Gandhi and Riazi referred to experiments on rabbits at 35GHz and 107GHz where some eye damage (albeit reversible) had been sustained with a total absorption in the eye of 15 to 50mW. They suggested that at millimetric wavelengths, the power absorption of the human eye might be of the order of 15 to 25mW for an incident power density of 100Wm⁻² after 30 to 60 minute exposures.

ICNIRP quotes sources suggesting that in the higher frequency range 10 to 300GHz, ocular damage can be avoided if the power density is less than 50Wm⁻². The Stewart report looking specifically at mobile phones, tabulated seven report results with monkeys and rabbits. A disparity between the findings of two of the reports which both involved pulsed radiation is evident. It was thought possible that difference in results might be due to differences in peak SAR per pulse. This highlights the need to know the energy per pulse when using pulsed RF radiation.

It is clear that eye exposure should be treated with caution especially with high power pulsed sources. Where it is so difficult to establish safety levels for human beings from animal experiments there is no other option but to limit exposure levels and durations. At some microwave frequencies there is also the possibility that metal framed spectacles may add to the exposure level.

In the author's view there is often unnecessary exposure to the eyes, for example by holding the head close to open RF power amplifier circuitry when aligning or diagnosing on a bench without bothering to switch off. The problem is made worse by the need to read small markings on small components. The problem can usually be avoided by better safety disciplines and by the use of modern optical aids including bench magnifiers and optical fibre inspection equipment.

There is similarly a need for caution in working with RF radiation so as to avoid the unnecessary eye exposure which can sometimes occur where waveguide flanges are removed without the source being switched off, and worse still, by the silly practice of looking down such waveguides. Although people think that the old practice of looking down the waveguide with power on to look at the vacuum tube stopped long ago, cases still occasionally arise.

B. Effects on the testes

Experiments with anaesthetised mice and rats showed that male germ-1 cells are depleted by exposure to SARs of about 30Wkg and 8–10Wkg⁻¹, respectively. Conscious mice exposed to 20Wkg⁻¹ and 9Wkg⁻¹ respectively, did not show any effect. The difference is regarded as being due to the fact that the anaesthetised animals were not able to regulate their testicular temperature. Other studies with rats reported a transient decrease in fertility with an SAR of about 6Wkg⁻¹. The NRPB93 document reports that repeated heating of the testes by 3 to 5C in animal studies, resulted in a decrease in sperm count lasting for several weeks.

There seems to be little if any published information regarding such problems with human adult males.

It seems likely that the whole-body SAR required to produce a sufficient temperature increase in the testes of an adult male would produce some basic signs of warmth and discomfort, resulting in withdrawal of the subject from the RF field. This is, of course, purely speculative since the author is not aware of any research carried out with men. However, with many years working in a large organisation manufacturing high power transmitters, no complaint of this kind has arisen.

C. Hearing effects

It has long been known that some people can 'hear' the pulse repetition frequency of radars and similar equipment. In this field it is not usually difficult to find human volunteers for tests so that there is no problem of relating other animals to

people. It is therefore surprising that more work has not been done in this field. The work of Frey reported in 1961 involved tests with volunteers using two transmitters of frequencies 1.3GHz and 2.9GHz, the former being pulsed with a 6 s pulse (244Hz repetition rate) and the latter with a 1 s pulse (400Hz repetition rate).

He gave the mean power density threshold of hearing for those able to hear anything as 4Wm^{-2} and 20Wm^{-2} respectively. The corresponding peak pulse power densities were 2.6kWm^{-2} and 50kWm^{-2} . It was stated that the human auditory system responds to frequencies at least as low as 200MHz and at least as high as 3GHz. In another paper, Frey reported that the sounds heard included buzzing, hissing, and clicking and depended, among other things, on the modulation characteristics. In these tests Frey used a frequency of 1.245GHz. A constant repetition rate of 50Hz was used and longer pulse widths (from 10 to 70 s). The pulse width was changed to adjust mean power and peak power densities. The volunteers were required subjectively to assess the loudness of the sound heard relative to a reference sound which had been transmitted.

The general finding was that the perceived loudness was a function of the pulse peak power density, rather than the average power. The peak power density for perception was less than 800Wm^{-2} . The nature of the effect has been the subject of much investigation. It seems generally agreed that the pulsed RF energy causes an expansion in the brain tissue due to the small but rapid temperature change involved. This causes a pressure wave which is transmitted through the skull to the cochlea where the receptors respond as for acoustic sound. It is not necessary to have the middle ear intact. The temperature increase which causes the pressure wave is considered to be less than 10^{-5}C . It is perhaps worth noting that sometimes the pulse repetition frequency of high power radars can be heard from objects such as old wire fencing, and this can easily be confused with the above phenomena. Presumably the effects on old fences involves some form of rectification of the RF currents due to corroded junctions within the fence, and the consequent vibration of some fence elements at the pulse repetition rate.

Although the results of laboratory tests have been published, little, if anything, seems to have been published in recent times regarding the practical experience of those working on transmitting sites and any problems they may have noticed. With the low levels mentioned as thresholds for hearing, it might be thought that many radar personnel would experience this phenomenon (for a typical duty factor of

0.001 and the old 100Wm^{-2} mean power density limit, the peak pulse power density would be 100kWm^{-2}). A survey was carried out by the author across 63 engineers working with the transmitting side of radar. Many of the participants had 30 years or more experience in that work. The survey has no scientific basis, being limited to the collection of anecdotal evidence from those concerned by means of a questionnaire.

The results were interesting in that only three people claimed to have heard the pulse repetition frequency (or sounds related to it) and for two of these, each cited only a single experience in unusual circumstances. Both occurred on a customer's premises, during the Second World War.

Both of these people considered that the circumstances led to exposure to very high fields but there was no measuring equipment available in those days and in consequence, little safety monitoring. The third case was interesting in that it seemed to imply a different mechanism, one which has occasionally been reported in the past. This person claimed that he had heard the pulse repetition frequency on a customer's premises and attributed this to a tooth filling. (The Frey work in 1961 did include the use of shielding to exclude the 'tooth filling' possibility.) It was further claimed that this ceased when the tooth was extracted.

Strangely enough, another person who gave a negative answer to the basic question did claim to hear a local radio amateur when at home, again attributing this to a tooth filling with the same claim that it ceased after the tooth was extracted!

Outside of this survey, there was one engineer in the same organisation who regularly claimed to hear the pulse repetition frequency on company premises, but was able to live with it. This applied in an environment which was maintained within the old ANSI C95.1-1982 standard. This account is again anecdotal, the experience extending over a number of years. It was the only case in which this phenomena occurred on company premises.

Assuming that none of the respondents to the questionnaire had chosen to suffer in silence, this particular company, which designs and manufactures high power civil and military radars, does not seem to have a problem with auditory effects despite the high radar peak powers usually involved and the fact that much of their high power work lies within the 0.8 to 4GHz frequency range. Allowing that this was solely a collection of anecdotal evidence, it seems strange that, having regard to the Frey threshold data, more cases had not arisen especially since the engineers concerned had

worked for many years prior to standards being produced and most had no knowledge of any aural effects.

D. RF shocks and burns

At low frequencies and up to about 100MHz, contact with passive objects in RF fields may result in currents flowing through that part of the body in contact, usually the hands, causing shock and sometimes burns. These effects can result from contact with almost any conductive object such as fences, scrap metal, unused dish and similar antennas or other equipments stored in the open, vehicles, farm machinery, metal buildings, etc. Burns may result when the current density (mA/cm) is excessive due to the contact area being relatively small. The possibility of a burn is reduced with the greater area of a full hand grasp. However, this is rather academic since contact is usually inadvertent and often involves the finger tips.

E. Athermal effects of RF radiation

This term is used to describe any effect which is thought to arise by mechanisms other than that involving the production of heat in the body. It has been somewhat controversial, some people disputing whether such effects existed. However, most people now probably accept the need at least to investigate observations which do not seem to be linked to the thermal deposition of energy in the human body.

With regard to tumours, there seems to be a degree of consensus amongst most bodies. This is probably best expressed in the UK NRPB press release on the report of the Advisory Group on Non-Ionising Radiation which stated 'We conclude from a review of all the evidence, including both that relating to humans in ordinary circumstances of life and that relating to animals and cells in the laboratory, that there is no good evidence that electromagnetic radiations with frequencies less than about 100kHz are carcinogenic; this includes those produced by electrical appliances, television sets and video display units.

'With higher frequencies there is room for more doubt, some laboratory evidence suggesting that they may act as tumour promoters, although in this case the effect may be secondary to local tissue heating.' It goes on to recommend further research on the subject.

The ICNIRP98 document discusses some of the studies which seemed to suggest possible cancer implications, pointing out problems involved in the methods and citing cases where other work failed to show the same effects. With regard to a

1997 Australian study carried out by Repacholi using a genetically manipulated strain of mice prone to develop specific tumours, which produced results thought to be statistically significant, some points were made about certain aspects of the control of exposures and the desirability of replicating the study. It also raises the question of establishing whether tests with transgenic animals, such as this study, can be generalised to human beings.

The NRPB issued a press release on this study which noted that the experimental design and quality assurance look to be sound. They point out that the authors of the paper indicated that the results for human health are far from clear without supporting biological evidence, the complete range of factors that may have resulted in the increased number of tumours in this sensitive strain of mice remains uncertain and it will be important for further studies to replicate the findings. The NRPB notes that this further emphasises the need for more high quality research to be carried out on the biological effects of electromagnetic fields.

Needless to say, there are people who do not subscribe to the current views and since there are so many uncertainties reflected about the role of electromagnetic fields, if any, in cancer promotion, it is not possible to do more than pursue research in this field. In this connection it can be seen how important the comments of those who conducted the above study are in providing perspective. Whilst there are these sort of unanswered questions it is not possible to be categorical one way or the other.

Nevertheless the situation will often be coloured by the fact that whilst we are all subject to the possibility of incurring cancer, some of those engaged in electrical and radio work who suffer the disease will, understandably, be inclined to attribute cancer to their occupation.

The topics encountered under the heading of 'athermal' effects cover almost everything to do with the human body. Reports and papers are very technical, requiring considerable practical familiarity with the subject matter. They range from the possibility of RF causing cancers as mentioned above, through the operation of all the systems and constituents of the human body, cells, tissues, organs, the immune system, reproduction, DNA, etc., to the psychological aspects claimed by some researchers.

F. Effects on people wearing implantable devices

There are a number of implantable devices, active and passive, which are fitted into the human body. Perhaps the

most common one is the heart pacemaker on which many people depend. There are two basic types of heart pacemaker. The first could be described as a demand pacemaker which will make up for missed heart beats as needed. The second type is the fixed pacemaker which operates continually at a fixed rate with no other form of control. There may be modern developments of these devices too.

It is possible that some sources of RF radiation could interfere with the operation of pacemakers, the significance of such interference depending on the type of pacemaker fitted. The potentially more serious consequences of interference relate to interference with the fixed rate pacemaker. However, the two descriptions above are basic. With current developments in electronic devices there is always the possibility of the use of more sophisticated devices and the possibility of new problems of vulnerability to interference.

Many of these pacemakers are subjected to interference (EMC) testing by the manufacturer but the relevant information does not normally get communicated to those responsible for safety at work, because of patient confidentiality. Consequently, those responsible for the operation of RF transmitters and similar sources who may become involved with visitors wearing a heart pacemaker have no means of carrying out their responsibilities for the individual safety of such people.

The only recommendation that can be made is that such sites should have a sign requiring visitors to notify the manager that they are wearing a pacemaker. They can then be excluded from RF fields. A similar problem can occur at exhibitions where equipment is being demonstrated and where many people may be present. There are other devices such as insulin pumps which are implanted and the views of medical authorities may need to be sought on these and any new types of implanted devices.

In the EC there is a Directive on Active Implantable Devices but the current draft does not fully tackle the problem of the electrical characterisation of devices in terms of interference testing though it does mention the subject. There are also many types of passive devices fitted in the human body. These may include metal plates, rods and fixings. There is always the chance of these being resonant at the frequency in use at a particular site.

For those employed with RF radiation, it seems desirable to record any such implants fitted when personnel are first employed and thereafter, should the situation arise. It is then

possible to exercise supervision over the exposures to RF of such people.

In summary, the situation on all types of implantable devices is a dynamic one in which there is constant innovation. It may be necessary to ensure that surgeons and physicians have some understanding of the implications for those involved in RF radiation, so that their patients can be given meaningful advice.

G. The application of exposure limits – recent developments

Although standards try to set exposure limits in such a way that they have a direct proportionality to the actual exposure effects experienced the relationship between the exposure and the SAR distribution is very much affected by the frequency, field polarisation and the specific characteristics of the human bodies involved. Human bodies have complex variations in tissue properties, surfaces, internal structures and interfaces.

Also, human bodies in fields can alter the field distribution and this can be further disturbed by metal objects which they may be carrying. When very close to a source, i.e. in the near field, the nature of the coupling between the body and the source can vary according to the impedance of the source. Sources, effectively high impedance, will tend to couple predominantly with the electric field and low impedance sources with the magnetic field.

This problem has been highlighted with the use of mobile phones where the antenna and body of the instrument are not only very close to the head but also subject to the movements most of us make when using them. Similar considerations apply to other ranges of hand-held transmitter receivers with integral antennas, which usually have more power than commercial mobile phones.

This means that exposure limits do not have full validity unless they cover worst case situations. On the one hand, some sources may exceed the exposure limits but not result in much absorption whilst, on the other hand, in the close conditions discussed above, sources which meet the exposure limits may result in excess absorption in small masses of tissue. Some standards exempted low power sources under defined conditions but as a result of research into the issues raised by the public regarding mobile phones this provision had to be re-examined.

H. The other side of the coin – beneficial effects of RF radiation

Discussion of the effects of RF radiation on people would not be balanced without a brief reference to the beneficial effects which have been and are being applied in the medical field. Some current uses are, in summary, as follows:

Bony injuries-There is considerable evidence that the application of RF energy at the site of a fracture speeds up the healing of both soft tissues and bony injuries. This is now fairly well established as a technique, though the mechanism by which such healing takes place has not been established with any certainty.

Treatment of malignant tumours-If cancer cells can be heated rapidly enough to the cell thermal death point, they can be destroyed. Microwave energy lends itself to application for this purpose. Current use is generally in association with other treatment, chemotherapy (cytotoxic drugs) or 'radiotherapy' (ionising radiation). Getting the RF energy to the tumour site can be a problem and care is needed to avoid unnecessary damage to healthy cells.

Other organs-Techniques have been described which enable the application of RF to the male prostate gland to shrink the gland. Surgery is not needed and patients can usually return home the same day.

Commercial products-There are many devices on sale to individuals which use RF or LF and which claim to treat various conditions. In general, there is little substantive evidence either way made available for many of these devices although some claiming to reduce pain have supportive users who consider them to be valuable.

Inevitably there will be some excessive claims for such devices based on the fact that for some people who have not found conventional help for their condition, they may try anything and if a device benefits them, it is understandable that they will not await some evidence of the approval of such equipment. It is unlikely that freely available items of this kind will pose any known radiation risk [18].

VIII. SAFETY

Safety concerns surrounding wireless equipment are of three kinds: distraction of drivers by mobile-phone use, causing accidents; health effects due to radiation; and possible adverse effects due either to radiation or possible sparks, in dangerous environments.

The first problem is easily dealt with. Portable phones are a distraction to drivers, of course, and must be dealt with like any other distraction. Some jurisdictions have made it illegal

to use a portable phone when driving; in others, users should exercise caution. Hands-free setups and speed dialing can obviously help.

The second problem is more complex. Certainly wireless equipment is not harmful in the same way that X rays and gamma rays are. It is well known that ionizing radiation, including X rays and gamma rays, can cause cancer by breaking molecular bonds and altering cell structure. Television receivers and computer monitors emit low levels of X rays, and household smoke detectors emit gamma rays. There is no safe level for this radiation, but traditionally the danger has been assumed to be negligible if the user's total radiation dose is not increased significantly above the background level that is present all the time.

Ionization depends on the energy per photon of radiation, which increases with frequency. Radiation from radio equipment is at far too low a frequency to cause ionization, regardless of its power level.

On the other hand, there are other physiological effects due to RF radiation. Localized heating is the best documented. Such heating effects are particularly dangerous to the eyes as mentioned above, which have insufficient circulation to remove heat. Radar technicians have become blind from working near operating radar equipment. However, the power density levels from wireless equipment are much lower than that, and as long as reasonable precautions are taken when working on base-station transmitting antennas, there should be no danger on that score.

Whether there is any danger at all from exposures at levels below those which cause damage from heating is not clear. There are many anecdotal reports of people who use cell phones getting brain cancer for instance, but this kind of juxtaposition hardly constitutes proof. After all, people who do not use cell phones also get cancer.

Studies of the effects of radiation, or of any other environmental factor, are of two basic types. There are epidemiological studies, which try to link rates of various diseases to the exposure of the people to radiation. These use statistical methods in an attempt to determine whether people exposed to the environmental factor have more illness than those whose lives are similar except for this factor. Epidemiological studies are not concerned with the way in which the damage is done.

There have also been laboratory studies made on mice that have been exposed to radiation. To date no serious

epidemiological studies have shown any correlation between RF fields at the levels encountered by wireless equipment users and illness. There has been some evidence that quite high levels of radiation (well above current safety standards) may contribute to cancer in mice. Whether the effect on humans would be similar is not clear.

The second major way to study radiation, or other environmental factors, is to look for physiological changes in the presence of radiation. Some studies have looked at the cellular level and claim to have found some effect on cellular biology; again, quite high levels of radiation were used.

The problem with research into radiation safety is that it is impossible, or nearly so, to prove that a particular radiation level is safe at all times and for all people. A consensus has to be developed, subject to change as more data is received. There are many variables, including power level, frequency and duration of exposure, distance of the source from the person, frequency of the radiation, and even the type of modulation in use (for instance, pulsed radiation may have more damaging effects than continuous radiation.)

Most countries have standards that limit exposure to RF radiation. In the United States and Canada, the limit at cellular frequencies is 0.57 mW/cm^2 ; at personal communication systems (PCS) frequencies it is 1.2 mW/cm^2 . These standards are set at 2% of the level at which it appears there may be some effects.

Certainly studies must be continued to see whether there are any problems with radiation that meets current standards. Obviously the question of danger from RF radiation at low levels is of great concern to the whole wireless industry, but at present the attitude of the industry seems to be to keep quiet and hope the problem goes away. There may be some logic to this: as the industry gradually moves to systems that use smaller cells and lower transmitted power levels, the danger due to RF radiation, if there is any, is likely to diminish.

Sometimes cellular providers have trouble establishing base stations at good locations because of neighbors' concerns about radiation. However, the effects of radiation, if any, will undoubtedly be greater from using a phone in close proximity to one's body than from a tower-mounted antenna hundreds of meters away. Even though base-station transmitters are more powerful than those in portable phones, the field strength on the ground from such transmitters is very much lower than that from a phone held at one's ear, because of the square-law attenuation of free space. Most such concerns are probably more esthetic than safety-oriented.

Interaction of radio transmitters with the nonhuman environment is much easier to understand. For many years highway construction crews have posted notices for motorists to turn off radio transmitters in the neighborhood of blasting operations. This is because of the possibility that the wiring from the detonator to the blasting cap may pick up radiation, creating an electrical current in the wire that could prematurely set off an explosive charge. This is much less likely with cell phones and PCS than with the higher-powered transmitters found in taxicabs, police cars and utility vehicles, but it would still be wise for the cell phone user to comply.

Other situations pose interference dangers. Cell phone use is not allowed on airplanes for two reasons: the signals could possibly affect aircraft navigation or operation, but more likely a cell phone signal at an altitude of several kilometers could easily be received by many cell sites, placing a greater than normal load on the system.

Cell phones can also cause problems with sensitive electronic equipment in hospitals. The best solution to that problem would be better shielding of the affected equipment, but in the meantime it would be prudent for wireless phone users to obey admonitions to turn off their phones in hospitals and similar locations.

On the other hand, there are some alleged dangers that are more urban myth than reality. For instance, some gasoline stations demand that people refrain from using cellphones while their cars are being refilled. This is supposed to be due to the danger of a spark setting off an explosion. The RF radiation from cell phones is certainly not sufficient to cause arcing in external devices and the chances of an internal spark setting off an explosion are less from portable phones than from simpler devices, such as flashlights, since once the phone is turned on, all the switching in cell phones is done electronically. Still, it could do no harm to avoid using *anything* electrical while refilling a vehicle.

In all of these situations, it should be remembered that cellphones, PCS phones and two-way pagers may transmit even while no one is making a call. The only way to make sure they do not is to turn them off completely [19], [20].

IX. ESTHETICS

Esthetic considerations are not subject to objective measurement and evaluation. The proliferation of wireless devices using many different standards has caused an equivalent proliferation of towers and antennas. This situation will become worse as cell sites become smaller. PCS base stations must be located in residential areas, for instance, if people are to have coverage in their homes. This causes problems for people who are used to seeing antenna towers in industrial and commercial areas but not in their own neighborhood.

Various techniques are available to minimize the impact of antenna installations. Antennas can be installed on, and sometimes even inside, buildings (church steeples are a favorite location, though sometimes the parishioners complain about an imagined danger to their health). Antenna masts have even been disguised as trees.

As cellular and PCS antennas become more ubiquitous and as more people use them, the chances are good that people will stop noticing them, in much the same way they tend to ignore utility poles or street lights (in fact, antennas for microcells are often fastened to street light poles). It certainly appears that wireless communication is here to stay, and people who want to get its benefits will have to put up with some minor nuisance [20].

X. CONCLUSION

There is a need to be aware of all equipment which may generate significant RF power and the nature of the operation of each item. Also when handling mobile phones and any other device which deals with RF one needs to be precautionary more so receiving calls while driving. The best solution to this is using headphones or car mp3 player when driving.

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