NON-IONIZING RADIATION: AN OCCUPATIONAL APATHY

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ABSTRACT

Non-ionizing radiation (NIR) is widely used in various modern applications to the extent that its presence is common in some work places. However, due to inability of human beings to detect its presence make the radiation 'invisible' to the workers most of the time. Of late it is known that the radiation can be hazardous to human health if the exposure received is excessively high. Such proven health effects has led international organizations, such as, IRPA establishing standard guidelines and maximum permissible limits to control its exposure. Recent studies reveal that some work places do indicate the presence of the radiation at levels far exceeding the IRPA recommended limits. It is, therefore, the objective of this paper to highlight such hazardous situations, magnitude of the hazard involved and ways and means how to overcome the hazard so that workers can take necessary precaution and action to minimize the health risk associated with the hazard. However, due to time and space constraint, only five types of the non-ionizing radiation are elaborated in this paper, namely ELF, RF and microwave, UV, IR and laser.

1. INTRODUCTION

Non-ionizing radiation or in short NIR is not something new to the population living on this planet. Without our knowledge, we have been subjected to this radiation for generations. Its presence in our environment originally as natural sources but quite recently more of its contribution comes from man-made sources. The latter becomes even more pronounced in term of exposure it causes to the working group of the population as more modern and sophisticated equipment and systems used in our modern industries make use of this radiation or it is produced indirectly as a result of operation of the systems. Most of the time workers are unaware about the presence of this radiation around them and the exposure they receive simply because the radiation itself cannot be sensed by them.

Besides ionizing radiation (see Fig. 1) NIR is, of late, also known to be hazardous to human health. Even tough acute exposure to this radiation is relatively well understood, but much of the present concern is directed to the possible effects of chronic exposure to the radiation of low intensity, which is unable to produce immediate health effects. A lot of studies have been carried out to determine the extent of the hazard as a result of exposure received by workers from these sources. This article presents some basic facts about NIR and results of some surveys carried out to determine the exposure level present around some identified work places and machines producing such radiation. It is hoped that by knowing these facts and the potential hazard it may cause on human beings, workers can appreciate its present and take necessary steps to minimise and protect themselves and others from the hazard. The paper also presents various protective measures that could be taken so that any work place where NIR radiation sources are present can be ensured safe for workers to work in. However, due to limited time and space, only five types of the radiation, namely extremely low frequency (ELF) electromagnetic field (EMF), radiofrequency (RF) and microwave, ultra-violet (UV), infrared (IR), and laser are covered in this paper.

2. WHAT IS NON-IONIZING RADIATION?

In order to recognise the presence of NIR and its ability to cause hazard, first of all, it is important for one to understand the radiation itself and its nature. Non-ionising radiation is a form of energy produced by a source (a machine, an instrument, a light bulb etc) which travels in space in the form of electromagnetic waves with certain wavelengths. Thus, naturally it occurs as part of electromagnetic spectrum and appears at the frequency lower than the ionising radiation (x-rays). As can be seen from Fig. 1, it starts from the lower end of the spectrum which is extremely low frequency (ELF) electromagnetic fields (EMF) and goes a little bit higher into radiofrequency and microwave and much higher into infra-red (IR), visible light and ultra-violet (UV). The energy it carries is

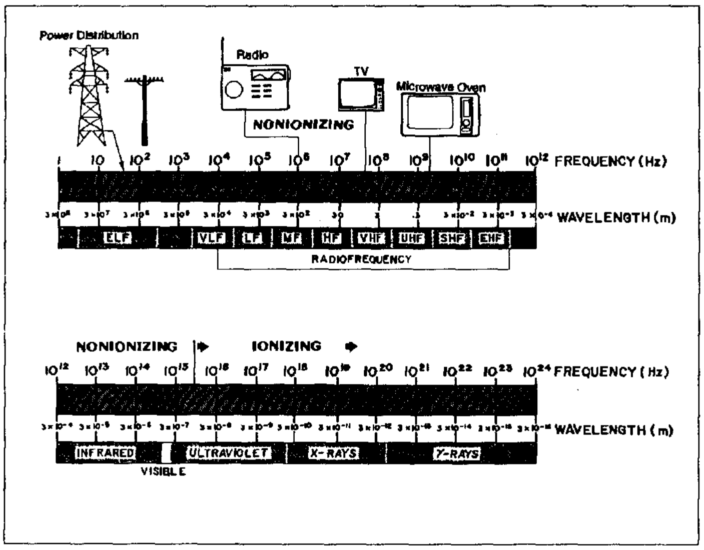

Fig 1 The location of NIR within electromagnetic spectrum

weaker than that of ionising radiation and, therefore, it is incapable of causing ionisation process in the exposed subject, unlike ionising radiation. For this reason it is called non-ionising radiation (NIR) and the hazard caused is obviously less damaging compare to what can be done by ionising radiation. Almost all types of the radiation (apart from visible light) have wavelengths that fall outside the visible range and the radiations are, therefore, invisible to the naked eyes. Since they are invisible, most of the time, workers are unaware of its presence in work places.

3. SOURCES OF NON-IONIZING RADIATION IN WORK PLACES

There are many equipment and machines used in work places that can produce non-ionising radiation (NIR). These equipment and machines produce radiation that covers almost the entire spectrum of electromagnetic fields, starting from extremely low frequency (ELF) to radiofrequency and microwave, infra-red (IR), and to the very high frequency of ultra-violet (UV). These equipment and machines are commonly found and used in manufacturing plants, workshops, laboratories and even in ordinary offices. In addition to those sources, some work activities are also capable of producing NIR. Work, such as, welding generates a lot of UV and heating of materials to a very high temperature may generate significant amount of IR (see Fig. 1).

3.1 EXTREMELY LOW FREQUENCY

Extremely low frequency (ELF) electric and magnetic fields are produced by 50 Hertz (Hz) AC power supply systems and electrical devices. The field strengths generated vary according to the strength of the current and voltage involved. Higher voltage will generate higher electric fields and similarly higher current produces higher magnetic fields. The strongest electric and magnetic fields is generally found around transformer units at the substations, in the transformer rooms, along high voltage power cables and wiring, around machines consuming high current and also at close distance from some electrical devices used in the factories, laboratories and houses.

A radiation survey made around some of the transformer units in a manufacturing plant indicate the presence of electric and magnetic fields which vary between 2 to 20,000 V/m and 500 - 1170mG. A radiation survey made in some work places close to the electrical devices and components indicates variation of the fields as shown in Table 1.

3.2 RADIOFREQUENCY AND MICROWAVE

Radiofrequency (RF) and microwave are widely used in communication, broadcasting, surveillance and navigational systems and in some processing applications in industries and treatment in hospitals. They are used as a medium to transfer and received messages and data and also as a source for heating and drying. With the advent of modern communication and broadcasting networks, more of this radiation is produced and used and sources are located in many more work places. As a result, more workers are expected to get measurable exposure of the radiation.

Table 1 Measured ELF fields around some sources.

Work place/device	Electric Fields (V/m)	Magnetic Fields (mG)	References
HV Sub-station(near HV equipment)	20,000	NA	Stuchly et al 1987
Transformer Room (@ 0.5m for 8 hrs)	2 - 4	500 - 1170	MINT, November 1998
Manufacturing plant(@ 0.5m)	NA	0.2 - 164	MINT, November 1998
Workshop machines (@ contact)	NA	0.03 - 64	Mohd Yusof Mohd Ali et al April 1999
NDT Device (magnetic particles @ contact)	5 - 142	4600 – 20,000	Mohd Yusof Mohd Ali et al April 1999
Welding machine (at contact)	NA	100,000	Stuchly et al 1987
Personel working in a plant(8 hrs)	2.8	7.7	MINT, November 1998

The strength of the radiation depends very much of its application, which indirectly is determined by the distance and the amount of energy required to achieve the purpose of the application. Among known sources of RF and microwave, surveillance and navigational radars and TV and radio broadcasting antennas are normally found to produce very high intensity radiation in order to allow for the signal generated to travel and cover areas at great distances from the station. Measurements taken at a few tens of metres from such towers indicate the radiation strength in the order of 100 – 200 V/m. It is expected that the radiation level on the tower close to the antennas, which is normally occupied by maintenance workers, will be much higher. Typical field strengths measured around these sources reveal values which some of the are very significant as indicated in Table 2.

Apart from communication antennas and radars, RF producing machines are also used as sealing devices in industry and as treatment devices in hospitals. These devices are known to be hazardous to the workers because of their operation require the operators to stand close to the machines. Studies carried out in some countries indicate that occupational exposure received by the workers can be very significant and, in some situations, exceed the safe limits recommended by IRPA.

Table 2 Measured RF and microwaves radiation levels around some sources

Work place/source	Distance	E-Field/H-field/Power density	References
TV/Radio Station	at 30 – 100m(on the ground) at close contact (on tower)	44 - 275 V/m < 1000 V/m, < 5 A/m	ICNIRP 1996 IRPA 1988 Stuchly et al 1987
Communication parabolic disk antenna	at 2m off centreline	0.4 – 0.6 mW/cm^2	MINT, October 1999
Satellite communication parabolic antenna	at 100 km (off centreline)	0.3 mW/cm^2	ICNIRP, 1996
Surveillance radar	at about 7m (off centreline)	174 V/m	MINT, July 1999
Air Traffic Control Radar	at 19m (stationary)	2 mW/cm^2	ICNIRP 1996
Marine radar	at 1m	1 mW/cm^2	ICNIRP 1996
RF sealer (0.5 – 80 kW)	at about 0.5m	280 - 900 V/m, 0.1 - 2.5 A/m	IRPA 1988 Stuchly et al 1987
Short & microwave diathermy (27 – 2450 MHz)	at 5 – 200cm	30 – 1000 V/m 0.1 – 1.0 A/m 2.5 – 50 mW/cm^2	ICNIRP 1996 IRPA 1988 Stuchly et al 1987

3.3 INFRARED

Infrared (IR) is used for heating and drying in most of the manufacturing plants and research laboratories. It is produced by devices, such as, heaters, IR lamps, ovens and furnaces, which are especially designed for the purpose, or it can also be produced by processes involving high temperature, such as, smelting and milling of ores and metal fabrication. IR exposure is quite serious in some work places, such as, steel mills, steel fabrication plants, glass and ceramic manufacturing plants and even in some research laboratories. However, not much information has been made available to assess seriousness of the problem to the workers (see Table 3).

Table 3 IR exposure level around some IR sources

Work place/source	Distance	Irradiance (W/m^2)	References
Arc welding	At 30 cm	2315	IRPA 1988
Glass blower			
Furnace			
Oven			

3.4 ULTRA-VIOLET

The ultra-violet (UV) radiation found in work places is generally produced by a variety of sources, which many of them are very well known and familiar to workers. These sources can be natural or man-made. The only natural source known to be hazardous to the workers is the sun. According to a study, this UV source contributes about 25% of the ambient UV exposure received by outdoor workers as compared to less than 4% received by indoor workers. Thus, this UV source is important to be considered especially for personnel who spend a great deal of their time working outside in an open field.

Man-made or artificial sources, on the other hand, are many. They are becoming more and more common nowadays as their number is increasing because of wide spread uses of new machines and devices in many different applications that work based on UV radiation technology. These man-made UV radiation sources are usually available in the form of

- germicidal lamps (germ free cupboard);
- sterilising equipment,
- curing and polymerising equipment;
- mercury lamps
- printing ink polymerising equipment;
- detection, inspection and identification equipment;
- fluorescence equipment;
- sun lamps (suntan machine);
- welding equipment(UV is produced as a by-product of a welding work);
  laser in the UV range.

Table 4 Typical UV exposure levels around some UV sources.

Work place/source	Distance	Irradiance (W/m^2)	References
Afternoon sun in Bangi	On the ground (cloudy day)	UV-A < 22 UV-B < 0.8	Mohd Yusof et al, 1999
Welding work	At 1m	0.03 - 5	IRPA 1988
UV machine for QA test	At contact	0.0007 - 0.005	MINT, 1998
Germ-free cabinet	At contact	UV-A: 0.02 – 0.08 UV-C: 1.2 – 6.3	Mohd Yusof et al, 1999
UV Curing machine	At contact	UV-A: 0.3 – 90 UV-B: 0.2 – 2.8	Mohd Yusof et al, 1999
Photocopy Machines (cover open)	At 10cm	UV-A: 0.7 – 1.3	Mohd Yusof et al, 1999

The man-made UV radiation is usually produced either by heating a material to incandescence, by an electrical discharge in a gas or vapour, by luminescence in a material or by a combination of these. Some are also produced indirectly as a result of carrying out certain work activity such as welding and smelting. The UV radiation sources, which are commonly found in industrial and medical applications and their potential exposures, are summarised in Table 4.

UV machines in radiopharmaceutical, biological and chemical laboratories are mostly used to provide germ free environment and for surface coating work. Unlike the former machines, which usually use low power UV sources that emit mostly UV-C, the latter ones use high-powered sources that emit mostly UV-A. In addition, those who frequently work out-door in an open field, they are also subjected to abundant natural UV from the sun, which is mostly UV-A and B.

3.5 Laser

Like other NIR sources, laser (stands for Light Amplification by Simulated Emission of Radiation) devices are also widely used for various purposes and are quite common to some work places. They are used either as a laser unit by itself or as part of a system or equipment. In the latter case, most of the equipment that has a laser unit in it has been made safe because of total containment of the laser beam produced by using various in-built safety features. Most modern laser devices operate within the frequency of UV, visible light and infrared (IR) and, therefore, they are especially hazardous to the eyes. What makes laser devices so hazardous is actually the properties of the laser light itself which is coherent and high degree of directionality and brightness that eventually makes the beam able to travel at great distances without losing much of its intensity. Due to these unique properties of laser make the devices more attractive in term of application where the overall system or equipment can be made very much smaller in size and yet with great precision and ability for automation. Therefore, it is common nowadays to find laser devices are being used in medicine, industry, meteorology, survey work and entertainment for surgery, cutting metals, marking products, reading information, drilling, welding, alignment, measuring distance and speed, and a laser show.

In view of its potential hazard and seriousness of injury that can be inflicted on the exposed person, the use of laser devices is usually regulated in most countries. Under international requirements, all manufacturers of laser devices and equipment are required to classify their products into the following four classes, which are recognized internationally. These classes indicate the level of hazard possessed by the laser devices which, in turn, depends strongly on the power of the devices. The class should be clearly marked on each individual device produced and sold in the market:

CLASS I
- exempt lasers and laser systems.
- cannot emit radiation in excess of maximum permissible exposure.
- intrinsically safe by virtue of either low power or engineering design.

CLASS II
- low risk lasers and laser systems.
- visible lasers only.
- low power visible laser which may injure retina when view directly for more than 0.25 seconds.
- minimum eye protection is required.

CLASS III - divided into two:

* CLASS IIIA
  - moderate risk lasers and laser systems.
  - visible lasers only.
  - moderate power output i.e. < 5 mW
  - potentially harmful to the eye if viewed for more than 0.25 seconds.
  - more stringent eye protection required.

* CLASS IIIB
  - moderate risk lasers and laser systems.
  - hazardous if shine directly on the eye.
  - power output < 500 mW for visible and IR, < 1.5 mW for UV.

CLASS IV
- high risk lasers and laser systems.
- very high power output i.e greater than class IIIB.
- operating in the visible, UV and IR range.
- hazardous not only direct beam or specular reflection but also

diffuse reflection.
- hazardous to the skin.
- extreme caution needed when in use.

4. HAZARD OF NON-IONIZING RADIATION

Non-ionizing radiation is basically non-penetrating. Only the lower frequency RF and ELF can go a little bit deeper into the body. Thus, its interaction with human body is normally limited to external part of the body, namely the skin and the eyes. These two organs are mostly affected by the radiation exposure and they are, therefore, considered as critical organs. The nature and degree of the health effects of exposure to the radiation depend on the total energy absorbed by the body and the spatial distribution of the interaction. The main health effect is usually the heating of body tissues. This effect occurs as a result of energy from the radiation is absorbed by the exposed body at the rate much higher than the rate of energy dissipation by its natural thermo-regulatory system. In other word, the effect is likely to show off when the body is unable to dissipate the heat fast enough to avoid increase in body or organ temperature.

The eye is particularly sensitive to thermal effects because the low volume of blood transfer through the eye prevents rapid dissipation of absorbed heat following exposure to the radiation. Serious exposure to the lens of the eye may increase eye' temperature which eventually produces irreversible protein denaturation and the subsequent formation of opacities in the lens of the eye (cataracts). This effect will slowly reduce eyesight and over a long period of time may turn it into temporary or partial blindness. However, if the retina is damaged which is normally caused by the radiation within the visible range, such as, laser; it can result in permanent eye damage which, in turn, may lead to permanent blindness. Less penetrating radiation, such as, UV may cause more damage to the external layers of the eyes (e.g. cornea) and under acute exposure will cause inflammation of these tissues.

Skin chronic exposure, on the other hand, may lead to rapid ageing of the skin and, in some situations, may also lead to formation of skin cancer over a long period of time. Its acute exposure may result in immediate effects, such as, erythema and suntan. In the case of whole body acute exposure, it may lead to heat exhaustion, heat stress and heat stroke. In case of acute exposure involving pregnancy, rises in the temperature of the foetus of 2.5 to 5 ^{o}C may lead to defects in the unborn.

Exposure to the radiation of lower frequencies, in particular, RF and ELF can also take place in term of induced current formed in the body and this is penetrating. It can take place deep inside the body. Such induced current may result in increase in body temperature and modifications of atomic or molecular fields and to cells that lead to formation of other effects called non-thermal or athermal effects. Long term exposure to radiation levels insufficient to cause thermal effects has been reported to cause a wide range of these athermal health effects including insomnia, irritability, headaches, and alterations of the immune and central nervous systems. However, the significance and reproducibility of some of these effects is subject to a lot of questions by scientific community. Due to poor statistical evidence and exposure dosimetry, there is, until now, no conclusive evidence to either support or deny such findings. In addition, there are limited evidences, which indicate that chronic exposure to these radiations over a period of time may also lead to some kinds of cancer. However, its association is again unclear and uncertain due to a small number of observations that claim such effects out of such big number of studies that have been carried out.

In short, the biological effects of NIR caused on an exposed person can be summarized as described in Table 5. In view of a strong possibility of such potential health hazards to appear on the exposed persons resulting from significant exposure to the radiation, an international scientific community through its technical association called International Radiation Protection Association (IRPA) has formulated safety standards for working with NIR which specify, among others, the maximum exposure limits allowed to be received by workers and members of the public. These limits are given in Table 5 (IRPA 1999). The limits imply that so long the exposure can be kept below those figures, it is unlikely that the effects will occur.

Table 5 Health effects and permissible exposure limits of some NIR

TYPE OF NIR	FREQUENCY	HEALTH EFFECTS	IRPA PERMISSIBLE EXPOSURE LIMITS
ELF	1 – 100 Hz	- Induced current/shock - Behaviourial changes - Cancer	H-fields for 8 hours : 5000mG E-fields for 8 hours: 10 kV/m
RF and Microwave		Contact current - shock Thermal - heat stress/exhaustion/ stroke Non-thermal – insomnia, headaches, changes in immune and central nervous systems	E-field: 61 – 137 V/m H-field: 0.16 – 0.36 A/m Power density: 1 – 5 mW/cm^2
UV	UV-A UV-B and C	Skin – Erythema/suntan Rapid ageing Cancer Eyes – Welder's flash Cataract	Unprotected skin and eyes for 8 hours < 347 mW/m^2 Unprotected skin and eyes for 8 hours < 1 mW/m^2
IR		Skin – superficial burn Heat stress Eyes – cataract, retinal burn	< 100 W/m^2
Laser	Visible range (400nm – 700nm)	Skin – Skin and tissue damage Eyes – Permanent eye damage	For 8 hours < 0.32 W/m^2

5. HOW TO ASSESS NON-IONIZING RADIATION HAZARD?

Except for visible light, the presence of other types of non-ionising radiation cannot be sensed by human beings. Therefore, assessment of the hazard can only be made using a special instrument that can detect and measure the radiation. There are quite a number of instruments available in the market, ranging from a very simple one, a portable type that can measure only one or two parameters, to a very sophisticated one that can measure in detail the whole spectrum of a specific type of the radiation.

In order to assess non-ionising radiation hazard, its present in the work place has to be surveyed and measured using the right instrument. The instrument has to be properly calibrated to indicate the actual situation of the hazard caused by a specific type of the radiation. The radiation survey is usually done once during commissioning of the machine before it is put into operation and thereafter whenever a modification is made on the machines. It is important to note that such a survey should be done by somebody who is knowledgeable about the subject and the instrument used.

Consultant work and expert services on NIR hazard assessment and instrument testing and calibration can also be obtained from Malaysian Institute for Nuclear Technology Research (MINT). It is one of the roles of the Institute to assist users of the NIR producing machines in alleviating the risk involved while at the same time maximising the benefit of the technology involving the use of NIR.

6. NON-IONIZING RADIATION HAZARD CONTROL

Protection against non-ionising radiation hazard may be achieved by a combination of the following means:

a. Administrative control measures;
b. Engineering control measures;
c. Personal protection

However, emphasis should be placed on administrative and engineering control measures to minimise the need for and problem associated with personal protection.

Administrative control measures

Such measures may consist of the following basic requirements:

a. Limitation of access
   Access to an area where equipment emits non-ionising radiation should be limited to those persons directly concern with its use;

b. Hazard awareness

All persons involved with the operation or use of equipment producing non-ionising radiation should be made aware of the radiation's ability and should be informed of its hazards;

c. Hazard warning signs and lights
Hazard warning signs should be used to indicate the presence of a potential non-ionising radiation hazard. In situations where non-ionising radiation cannot be totally enclosed, additional warning lights may be used to show that the equipment or system is energised;

d. Distance as a safety factor
The user should keep far away from the non-ionising radiation source as is practicable. For most of the non-ionising radiation generated (except laser), at greater distances from the source, the intensity of the radiation falls off as the square of the distance from the source. At shorter distances, the intensity falls off approximately linearly with distance;

e. Limitation of exposure time
The exposure time to the radiation should be kept to the minimum, and the maximum recommended exposure limits should not be exceeded; and

f. Maintenance work on equipment
The power supply must be disconnected before any maintenance work is carried out.

Engineering control measures

Such measures may consists of the following:

a. Containment
Indiscriminate emission of non-ionising radiation into the workplace must not be allowed. This can be prevented either by carrying out the process/work within a sealed housing or by providing a shielded area;

b. Sealed housings
Where possible, the non-ionising radiation should be contained within a sealed housing. If observation ports are required, they should be made of suitable absorbent materials;

c. Shielded areas
Where the exposure process takes place external to the source housing, a shielded area should be provided for the associated work to be carried out. Such an area would be subject to the administrative control measures outlined above. Persons entering the area should be adequately protected from the non-ionising radiation, as described in the following section;

d. Use of interlocks
Interlocks should be fitted to the source housing to prevent excessive and unnecessary exposure. Interlocks are necessary where the removal of a cover from the housing could result in a high exposure. They should be of fail-safe type;

e. Elimination of reflected non-ionising radiation
Many surfaces of objects or materials are good reflectors of non-ionising radiation. To reduce the intensity of reflected non-ionising radiation, the material of the objects should be properly selected and their surfaces be properly designed; and

f. In the case of UV, if there is a possibility for high concentration of ozone to be formed by the radiation interaction with air, a proper ventilation system to remove the gas should be provided.

Personal protection

Due to unique nature of non-ionising radiation, protection of personnel against the radiation can only be considered for UV, IR and laser. Protection can be achieved by the following means:

a. For skin, the areas usually at risk are the backs of the hands, the forearms and the face and neck. The hands can be protected by wearing gloves. The arms should be covered with long sleeves of material with low radiation transmission. The face, on the other hand, can be protected by a face shield and this will also provide eye protection; and

b. The eyes can be protected from the radiation by wearing goggles, spectacles or face shields that can absorb the radiation.

7. CONCLUSION

Non-ionizing radiation is widely used in modern applications and its presence is real and common in some work places. Recent surveys indicate that the presence of such radiation is indeed high in some work places and in a few work places it even exceeds the IRPA recommended exposure limits. In view of its potential hazard, it is, therefore, necessary to take certain precaution and immediate actions to minimize its associated health risk. A radiation survey may need to be carried out to determine the level of hazard present and safe working procedures to be established and observed by the workers.

8. REFERENCES

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