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Nonthermal Effects of Radar Exposure on Human: A Review Article

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ABSTRACT
Microwave is part of the electromagnetic spectrum that has different application such as communications, military, air-traffic Control and etc... Previous studies showed that radar frequency could be a health hazard agent. This review article mentioned some of the studies that investigated non-thermal effects of radar frequencies. Reproductive effects, cancers, blood effects, genetic, adverse immune effects and mental effects are non-thermal effects that presented in this report. There are many unknown aspects of the biological effects and many of them did not determined very well such as oxidative stress and mental effects. Compliance with permissible exposure limits, reduction in exposure, and shielding are some of the controlling methods to protect workers from the exposure of microwave and among them, The use of shielding is a superior method for prevention of microwave exposure and among them, electromagnetic Nano composites shields is appropriate for protection of workers from radar exposure.

Key words: Microwave, Radar exposure, Non-thermal effect, Occupational health, Radiation

INTODUCTION
Microwave is part of the electromagnetic spectrum with frequency of 300MHz-3000GHz and wave length from 1mm to 1m .These waves vary applications such as satellite, communications, military, Network, navigation, air-traffic Control, navigation, marine and weather. Therefore , many workers are exposed to these waves [1-3]. In microwave spectrum, radar frequencies with 1-300 GHz range are very important and divided to 11 spectrums that including: L ،S ،C،X،Ku ،K ،Ka ،V ،W ،mm and μm [1, 4] . Many workers have exposed to radar energy, so their health is threatened by that. According to the WHO definition, health is a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity. Therefore , a health hazard is a biological effect outside the normal range of physiological compensation that is detrimental to health or well-being [5] . Previous studies showed that radar frequency could be a health hazard agent. Adverse health effects of microwave are divided into thermal and non-thermal effects [1, 3].

THERMAL AND NON-THERMAL EFFECT DESCRIPTION
Thermal effects
In microwave frequency, the interaction between the incident radio frequency (RF) energy and molecules of the human body (mainly water) occurs mainly as a thermal process. The absorbed photons are transformed to thermal energy in a Joule-type processor dielectric loss. This microwave irradiation is associated with an internal energy rise. In living organisms this absorbed energy is dissipated because of thermo regulatory mechanisms of heat loss (swearing, blood flow) as the other metabolic energy which exists inside the body. When the level of electromagnetic exposure is high enough then heating of the whole body or an affected region is sufficient to increase the temperature. The threshold for thermal effects has been established on the level when the internal temperature increase is approximately 1 or more. This effect is called thermal effect [3].Cataracts, skin burns, and damage to the testes are some of the thermal effects of microwave [1, 6].

Non-thermal effects
In the case of exposure with intensities less than thermal effects, there are biological effects of electromagnetic fields, but described effects are not scientifically conclusive. Because of this, there is a trouble to prove that they could be an adverse for health and safety of people, especially in epidemiological investigations. These biological or medical effects are so-called non-thermal effects [3]. Non-thermal effects of radar frequencies are very wide, so this review article mentioned some of the studies

that investigated non-thermal effects of radar frequencies.

Reproductive effects

Møllerløkken *et al.* carried out a cross-sectional study of naval military men by questionnaire. They reported a possible relationship between exposure to radio frequency fields during work with radio frequency equipment and radar and reduced fertility .They categorized the work "Tele/communication," "electronics" and "radar/sonar" as being exposed to electromagnetic fields. Logistic regression adjusted for age, ever smoked, military education, and physical exercise at work. This study showed increased risk of infertility among tele/communication and radar/sonar with odds ratio 1.72 and odds ratio 2.28 respectively. The electronics group had no increased risk [7.]

Mailankot *et al.* stated that exposure to 0.9/1.8 GHz for one hour continuously per day for 28 days cannot cause a significant difference in total sperm count. Nevertheless, at a significantly reduced percentage of motile sperm and significant increase in lipid peroxidation and low glutathione content in the testis and epididymis were observed [8] .

Goldsmith *et al.* reported that exposure to radar frequencies can lead to impairment of reproductive outcomes, especially increased spontaneous abortion [9]

Jauchem *et al.* noted a review article and reported two studies Liu *et al.*, Ding *et al.* that investigated the effect of radar exposure on the reproductive system. In accord that, reductions in sperm motility and viability in radar operators and an increase in ‘‘sperm dysmorphia’’ in subjects who worked with radar were accrued.

Moreover, the quality of semen 'changed when radar electromagnetic wave frequency, distance, intensity, lasting time and protection shield were changing [10]. Another study mentioned that exposure to microwave radiation had different biological effects on reproductive system [11]

Yan Suwen *et al.* investigated the effect of low intensity microwave exposure on the reproduction and offspring health of men. Their Results showed that Incidence of abnormal sexual function in the radar group was 23.8%, while it was 14.7% in controls. The natural impregnation rates after 0.5 and 1 year of marriage in the radar group were 13.8% and 39.8% respectively, and 31.3% and 49.6% in the controls, respectively. The natural impregnation rates after 2 and 3 years of marriage in the radar group was 30.4% and 12.5%, and that in the control group was 10.9% and 6.1%. The results showed that there were significant differences between the two groups. There was no difference in the reproductive outcome and sex ratio of offspring’s between the two groups. Prolonged microwave exposure at a low intensity had an adverse effect on male sexual function. It might delay impregnation after marriage. However, it seems that there was no significant effect on the pregnant outcome and offspring health [12]

Schrader *et al.* conducted a more complete study as a follow-up to the pilot study of semen quality of soldiers with various military assignments. Thirty-three men were exposed to radar as part of their duty assignment in the Signal Corps, 57 men were involved with firing the 155 mm howitzer (potential lead exposure), and 103 soldiers had neither lead nor radar exposure and served as the comparison control group. Both serum and urinary follicle-stimulating hormone and luteinizing hormone and serum, saliva, and urine testosterone levels were determined in all men. A complete semen analysis was conducted on each soldier. For statistical analysis, the primary study variables were: sperm concentration, sperm/ejaculate, semen volume, and percent normal morphology, and percent motile, percent viable (both vital stain and hypo osmotic swelling), curvilinear velocity, straight-line velocity, linearity, sperm head length, width, area, and perimeter. Variables were adjusted for significant confounders (e.g., abstinence, sample age, race). No statistical differences were observed in any measurement. While these results are in agreement with two previous studies assessing soldiers firing the 155-mm howitzer, they contradict our previous report indicating that radar exposure caused a significant decrease in sperm numbers. A possible explanation is that the radar exposure in this study was that used in Signal Corps operations while the men in the previous study were using different radar as part of military intelligence operations. The data presented herein men firing the 155-mm howitzer combined with the results from the previous studies confirms that there are no defects in semen quality in these men. The contradiction between the results of the radar exposure studies indicates that more data are needed to evaluate the relationship of military radar and male reproductive health [13]

Ding *et al.* investigated the relationship between microwave radiation and male reproductive. After filling out questionnaire and body check, molecular epidemiological studies were carried out, using single cell gel electrophoresis (SCGE) and sperm automatic analysis among people working on radar. Their results showed that quality of semen and semi-clinical injury of sperm among the people working on radar had changed when radar electromagnetic wave frequency distance, intensity, lasting time and protection shield were changing. The dose-response relationship was noticed and the increase of sperm dysmorphia played a principal role. The results between exposed group and control group showed significant differences. These findings suggested that People working on the radar that suffered from non-ionization for a long time and had bad radar shield protection would show semi-clinical injury on sperm and bad semen quality. However, it did not affect the male reproductive function. It was necessary to reinforce the protection of non-ionization and to improve male reproductive health care of people working on radar [14]

Oxidative stress

Vera Garaj-Vrhovac *et al.* found that pulsed microwaves from working environment can be caused by cell alterations and oxidative stress. In other words, radar frequencies can be genotoxic and one of the possible mechanisms of DNA and cell damage. This study investigated workers exposed to pulsed microwave radiation, originating from marine radars. Electromagnetic field strength was measured at assigned marine radar frequencies (3 GHz, 5.5 GHz and 9.4 GHz) and corresponding specific absorption rate values were determined. Their Results showed that cytogenetic alterations occurred after microwave exposure, and the glutathione concentration was significantly decreased. Whereas the concentration of malondialdehyde was significantly increased (1.74 vs. 3.17), that indicate the oxidative stress was occurred [11]

An imbalance between oxidants and antioxidants in favor of the oxidants, potentially leading to damage, is termed 'oxidative stress'[15].It is noticeable that oxidative stress is one of the most important non-thermal effects of microwave that plays an important role in many human diseases such as types of allergies, cancers, heart and lung diseases, metabolic and genetic disorders, infectious diseases [16], infertility [17-20] Neurodegenerative, Alzheimer's, Parkinson's and vision problems such as cataracts and glaucoma [16, 21, 22].

Cancers

Cherry *et al.* presented a review article about Evidence of brain cancer from occupational exposure to pulsed microwaves from police radar microwave. Their result showed that radar is genotoxic and when exposing an officer over many months, will produce a significantly increased risk of astrocytoma brain tumor.

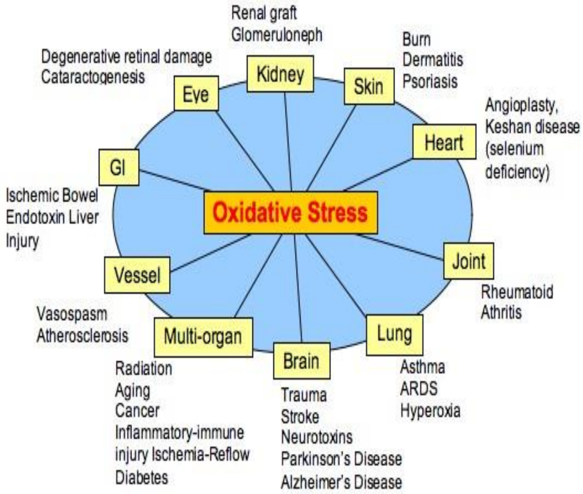

Fig.1:-Schematic of the diseases due to oxidative stress[23]

All of these effects occur for exposures well within existing standards [24].

Richter *et al.* has reported on five young patients who had brain tumors that appeared within 10 years of initial occupational exposures to radar. Four of the patients were less than thirteen years of age when the diagnoses were initially made. Brief induction periods that follow high exposures in individual sentinel patients are a recognized indicator of impending risk group, and these periods call attention to the need for precautionary measures.

Similarly, reports of short induction periods for brain cancer on the side at the head in which there has been prior use of cell phones may also indicate increased risk [25].

Richter *et al.* reported exposure-effect relationships with sentinel patients and their co-workers, who were technicians with high levels of exposure to RF/MW radiation. Information was obtained from interviews, medical records, and technical sources. One patient was a member of a cohort of 25 workers with six tumors. This study estimated relative risks for cancer in this group and latency periods for a larger group of self-reported individuals. Index patients with melanoma of the eye, testicular cancer, nasopharyngioma, non-Hodgkin's lymphoma, and breast cancer were in the 20–37-year age group. Information about work conditions suggested prolonged exposures to high levels of RF/MW radiation that, produced risks for the entire body. Clusters involved many different types of tumors. Latency periods were extremely brief in index patients and a larger self-reported group. The findings suggest that young persons exposed to high levels of RF/MW radiation for long periods in settings where preventive measures were lax .So the sentinel patients were at increased risk for cancer. Very short latency periods suggest high risks of high-level exposures. A calculation derived from a linear model of dose-response suggests the need to prevent exposures in the range of 10-100 μw/cm^2 [26.]

Anders *et al.* reported a review of epidemiological studies that showed there have been a large number of occupational studies over several decades, particularly, on cancer, cardiovascular disease, adverse reproductive outcome, and cataract, in relation to RF exposure. The results from these studies give no consistent or convincing evidence of a causal relation between RF exposure and any adverse health effect.

On the other hand, the studies have too many deficiencies to rule out an association. A key concern across all studies is the quality of assessment of RF exposure. Despite the ubiquity of new technologies using radio frequency, little is known about population exposure from RF sources and even less about the relative importance of different sources [27]

Kubacki *et al.* found that exposure of the human head to peak pulsed microwaves (MW) can result in biological effect called at microwave hearing [3]. The possible carcinogenic potency of microwaves is still an open and controversial issue.

The majority of published epidemiological studies do not confirm links between environmental exposure to microwave and risk of cancer diseases. However, single reports indicate that occupational exposures to microwave may be associated with increased cancer risk in workers [3.]

Davis *et al.* noted a cohort study that investigates 340 police officers. Six incident cases of testicular cancer occurred between 1979 and 1991. Held radar was the only shared risk factor among all six officers, and all routinely held the radar gun directly in proximity to their testicles. He suggested that further research into a possible association with testicular cancer is warranted [28]

Anders *et al.* and Đinđić *et al.* presented a review article and reported studies that state that there is not enough evidence that radar frequencies could be Caused of testicular cancer [27, 29]

In addition, in accord that to Anders et al (2004) report, most informative studies provide little evidence of brain tumors and leukemia. The one possible exception was an increased risk of nonlymphocytic leukemia in radar-exposed navy veterans [27.]

Đinđić *et al.* noted that brain tumors, leukemia and increased risk of non-lymphocytic leukemia. This study was found a significantly raised risk for testicular cancer and lung carcinoma for self-reported occupational exposure to microwave and other radio waves [29.]

Blood effects

Kubacki *et al.* stated that some studies about Blood Brain Barrier (BBB) in organisms exposed to pulse-wave and compare it with the continuous wave. He noted that those reports did not provide a resolution to the problem because there are differences in blood-brain barrier permeability as a result of pulsed exposure rather than continuous exposure at same average power levels. Last investigations with BBB have revealed that this effect is significantly due to distinct energy increase in the organism even the whole-body temperature is not elevated. However, some observations have reported that pulsed microwaves at an extremely low average level of exposition can influence on the human blood-brain barrier as well [3.]

Williams *et al.* noted a case-report that two airmen encountered to radio-frequency radiation 38 times above the Air Force permissible exposure level were medically evaluated for physical effects from exposure. Initial anxiety and hypertension were found [30.]

Goldsmith *et al.* reported some studies about blood count changes that its results are as follows: increase in immature red blood cells , changes in blood cell counts, Decrease in leukocytes and red cells , decrease in thrombocyte and leukocyte count, mutagenic effects both in vivo and in vitro, occurrence and repair of chromosomal aberrations [9.]

Jauchem *et al.* reported a review article that showed the high prevalence rate of cardiovascular disease in personnel working on a civil aircraft radar-tracking system [10]

Genetic:

Goldsmith *et al.* stated some studies that investigated the biological effects of radar exposure on human and animal models. The results demonstrated that genotoxic effects of radar exposure depend on some factors such as power density, specific absorption

Rate (SAR), time exposure, radar frequencies and modulation. Those genotoxic effects are included: Mutagenic effective both in vivo and in vitro, chromosomal aberrations, damage to cell genomes and changes in chromosome structure and human lymphocytes [9.]

Garaj-Vrhovac *et al.* showed that microwave exposure prevents DNA from entering into the S-phase of the cell cycle. Furthermore, the direct interaction of radiation with DNA molecules in vitro conditions result in cell genome damages, which persist in the cell for a distinct period of time that might cause different malignancies [11]

Garaj-Vrhovac *et al.* studied on Human whole-blood samples that were exposed to continuous microwave radiation, frequency 7.7 GHz, power density 0.5, 10 and 30 mW/cm^2 for 10, 30 and 60 min. In this study a correlation between specific chromosomal aberrations and the incidence of micronuclei after in vitro exposure was observed. In all experimental conditions, the frequency of all types of 3 was significantly higher than in the control samples. In the irradiated samples the presence of dicentric and ring chromosomes was established. The incidence of micronuclei was also higher in the exposed samples. The results of the structural chromosome aberration test and of the micronucleus test were comparatively analyzed. The values obtained showed a positive correlation between micronuclei and specific chromosomal aberrations (acentric fragments and dicentric chromosomes).The results of the study indicate that microwave radiation causes changes in the genome of somatic human cells and that the applied tests are equally sensitive for the detection of the genotoxicity of microwaves [31.]

Garaj-Vrhovac *et al.* were performed analysis of structural chromosome aberrations in a group of radar station personnel who were engaged in repairing radar devices a couple of days earlier. This study showed a major decline from the values recorded by regular mutagenic monitoring in terms of a significantly increased number of chromosome breaks, acentric fragments, dicentric and polycentric chromosomes with accompanying fragments, ring chromosomes and chromatic interchange. Multiply repeated mutagenic testing demonstrated in all subjects a fall in the total number of chromosome aberrations as a function of time. During a 30-week-long follow-up study a decrease in the total number of chromosome aberrations was observed. In the same period the presence of unstable aberrations such as dicentrics and ring chromosomes persisted, together with a relatively unchanged incidence of stable aberrations [32.]

Vera Garaj-Vrhovac *et al.* determined the effects of radiofrequency electromagnetic radiation (RFR) on the cell kinetics and genome damages in peripheral blood lymphocytes .In this study investigated the lymphocytes of 12 subjects occupationally exposed to microwave radiation. The results showed an increase in the frequency of micronuclei (MN) as well as disturbances in the distribution of cells over the first, second and third mitotic division in exposed subjects compared to controls. This finding suggested that micronucleus assay can serve as a suitable indicator for the assessment of exposure to genotoxic agents (such as RFR) and the analysis of mitotic activity as an additional parameter for the efficient biomonitoring [33.]

Verschaeve *et al.* found that RF-exposed individuals have increased frequencies of genetic damage (e.g., chromosomal aberrations) in their lymphocytes or exfoliated buccal cells [34.]

Garaj-Vrhovac *et al.* reported that exposure to continuous radiation could lead to chromosome aberrations. They Cultured V79 Chinese hamster cells were exposed to continuous radiation, frequency 7.7 GHz, power density 30 mW/cm^2 for 15, 30, and 60 min. The parameters investigated were the incorporation of [3H] thymidine and the frequency of chromosome aberrations. Mutagenic tests performed concurrently showed that even DNA macromolecules were involved in the process. In comparison with the control samples there was a higher frequency of specific chromosome lesions in cells that had been irradiated. Results discussed in this study suggest that microwave radiation causes changes in the synthesis as well as in the structure of DNA molecules [35].

Immune systems:

Jauchem *et al.* found some study that suggested radar operators exhibited elevated IgM and decreased total T8 lymphocytes. Additionally, an increase on the number of micronuclei was found in RFE-exposed subjects. This study reported that the effect of microwave radiation on the immune system depends upon the character of an exposure [10].

Moszczyński *et al.* assessed the immunoglobulins' concentrations and T lymphocyte subsets during occupational exposures to microwave radiation. In the workers of retransmission TV center and center of satellite communications on increased IgG and IgA concentration and decreased count of lymphocytes and T8 cells was found. However, in the radar operators IgM concentration was elevated and a decrease in the total T8 cell count was observed. The different behavior by examining immunological parameters indicates that the effect of microwave radiation on immune system depends on the character of an exposure. This finding suggested that disorders in the immunoglobulins' concentrations and in the T8 cell count did not cause any clinical consequences [36].

Yang *et al.* exposed Hamsters to repeated or single doses of microwave energy and monitored for changes in core body temperature. Circulating leukocyte profiles, serum corticosteroid levels, and natural killer (NK) cell activity in various tissues. Repeated exposure of hamsters at 15 mW/cm^2 for 60 min/day had no significant effect on natural levels of spleen-cell NK activity against baby hamster kidney (BHK) targets. Similarly, repeated exposure at 15 mW/cm^2 over a 5-day period had no demonstrable effect on the induction of spleen NK activity by vaccinia virus immunization, that is. Comparable levels of NK were induced in untreated and microwave-treated animals. In contrast, treatment of hamsters with a single 60-min microwave exposure at 25 mW/cm^2 caused a significant suppression in induced spleen NK activity. A similar but less marked decrease in spleen NK activity was observed in sham-exposed animals. Moreover, the same effects on NK activity were not predictable and appeared to represent large individual animal variations in the response to stress factors. Depressed spleen NK activity was evident as early as 4 h post microwave treatment and returned to normal levels by 8 h. Hamsters exposed at 25 mW/cm^2 showed an elevated temperature of 3.0–3.5 °C that returned to normal within 60 min after termination of microwave exposure. These animals also showed a marked lymphopenia and neutrophilia by 1 h post treatment that returned to normal by 8–10 h. Serum glucocorticosteroids were elevated between 1 and 8 h after microwave treatment. Sham-exposed animals did not demonstrate significant changes in core body temperature. peripheral blood leukocyte (PBL) profile, or glucocorticosteroid levels as compared to minimum-handling controls[37].

Rao *et al.* examined the effect of a single whole-body exposure of hamsters to microwave (mw) energy (2.45 GHz; 5–25 mW/cm^2; 1 h) on the IgM antibody (Ab) response of spleen cells to sheep red blood cells (SRBC). MW-exposed, sham-exposed, and cage-control hamsters were immunized with SRBC and plaque-forming cells (PFC) in the spleens assayed using the direct hemolytic plaque assay. In cage-control hamsters the Ab response was highest between days 4 and 5, returning to baseline by day 9. MW exposure [25 mW/cm^2 for 1 h) significantly augmented PFC response only on days 4 and 5 postimmunization, causing approximately 4.3- and 3.5-fold increase over controls, respectively. This study showed that exposure to 15 mW/cm^2 caused a lesser, but significant increase in PFC. Also, Exposure to intensities below 15 mW/cm^2 for 1 h did not produce any increase in response. Immunization with different concentrations of SRBC following 1 h of 25 mW/cm^2 MW exposure revealed stimulation in PFC at all concentrations ranging from 5×10^7 to 5×10^8 SRBC. Pretreatment of hamsters with MW radiation prior to immunization showed that the animals retained an increased sensitivity to SRBC for as long as 4 days after MW exposure. In contrast, exposure of hamsters to MW energy on different days after immunization showed an effect of the PFC response only if given between 0 and 1 day after immunization. These results suggest that MW exposure augments the primary IgM response to SRBC by affecting some early event in the immune response process. The various possible explanations for this phenomenon are discussed [38].

Mental effects

Dehghan *et al.* noted needing a good tonic, headache, tightness or pressure on the head, insomnia, getting edgy and bad-tempered. This study showed that occupational exposure to radar microwave radiation leads to changes in somatic symptoms, anxiety and insomnia, social dysfunction, and severe depression. Altogether , these results indicate that occupational exposure to radar microwave radiations may be linked to some adverse health effects [39].

Summary of non-thermal effects studies has been presented in tables 1.

Table1: summery of non-thermal effects from exposure to radar frequency

Authors	Publish year	Non-thermal effect	Results
Møllerløkken [7]	2008	Reproductive	• infertility
Mailankot *et al.*[8]	1980		• No significant difference in total sperm count • significantly reduced percentage in motile sperm • significantly increase in lipid peroxidation • low glutathione content in the testis and epididymis
Goldsmith JR. [9]	1997		• increase spontaneous abortion
Jauchem JR. [10]	2008		• reductions in sperm motility and viability • increase in ‘‘sperm dysmorphia
Suwen Y. *et al.*[12]	1997		• Incidence of abnormal sexual function • no difference in the reproductive outcome and sex ratio of offsprings • delay impregnation after marriage
Schrader SM. *et al.* [13]	1998		No statistical differences were observed
Ding XP. *et al.* [14]	2004		• Change in quality of semen • semi-clinical injury of sperm
Garaj-Vrhovac V. *et al.* [32]	1993	Oxidative Stress	• Decrease in glutathione concentration • Increase in malondialdehyde concentration
Cherry N. [24]	1999	Cancer	significantly increased risk of astrocytoma brain tumor
Richter ED. *et al.* [25]	2002		• brain tumors in the four of five young patients
Richter ED. *et al.* [26]	1990		• increased risk for cancer
Anders A. *et al.* [27]	2008		• No consistent or convincing evidence of a causal relation between RF exposure and any adverse health effect.
Davis RL., *et al.* [28]	1993		• testicular cancer
Anders A., *et al.* [27]	2004		• No enough evidence for testicular cancer
Đinđić N., *et al.* [29]	2011		• brain tumors • leukemia • increased risk of non-lymphocytic leukemia
Kubacki R. [3]	2008	Blood	influence on the human blood-brain barrier
Williams RA., *et al.* [30]	1980		• hypertension
Goldsmith JR., [9]	1997		• Increase in immature red blood cells • Changes in blood cell counts • Decrease in leukocytes and red cells • Decrease in thrombocyte and leukocyte count
Jauchem *et al.* [10]	2008		• cardiovascular disease
Goldsmith JR. [9]	1997	Genetic	• Mutagenic effect both in vivo and in vitro • chromosomal aberrations • damage to cell genomes • changes in chromosome structure and human lymphocytes
Garaj-Vrhovac V. *et al.* [11]	2010		• prevents DNA from entering into the S-phase of the cell cycle
Garaj-Vrhovac V. *et al.* [31]	1992		• chromosomal aberrations • incidence of micronuclei
Garaj-Vrhovac V. *et al.* [32]	1993		• increased number of chromosome breaks • acentric fragments • dicentric and polycentric chromosomes with accompanying fragments • ring chromosomes and chromatid interchange
Garaj-Vrhovac V. [33]	1999		• increase in frequency of micronuclei (MN) as well as disturbances in the distribution of cells over the first, second and third mitotic division
Verschaeve L. *et al.* [34]	2009		• genetic damage
Garaj-Vrhovac V. *et al.* [35]	1990		• chromosome aberrations
Jauchem JR. [10]	2008	Immune	• elevated IgM • decrease in total T8 lymphocytes

Moszczyński P. *et al.* [36]	1999		• Increase in IgG and IgA concentration • Decrease in count of lymphocytes and T8 cells
Yang HK. *et al.* [37]	1983		• Depressed spleen NK activity • marked lymphopenia and neutrophilia • increase in Serum glucocorticosteroids
Rao GV. *et al.* [38]	1985		• significant increase in PFC
Dehghan N. *et al.* [39]	2013	Mental	• changes in somatic symptoms, anxiety and insomnia, social dysfunction, and severe depression

CONCLUSION

The electromagnetic radiation presents important pollution in the occupational environment. The effects for human health are cumulative, and they are not visible in short time. In addition, the standards are based on tissue heating and ignore the evidence of non-thermal effects.

Therefore, since there are many unknown aspects of the biological effects and many of them did not determined very well such as oxidative stress and mental effects. So, preventive measures is highly recommended. Compliance with permissible exposure limits, reduction in exposure, and shielding are some of the controlling methods to protect workers from the exposure of microwave.

The International Association of Electrical Engineers (IEEE) and American conference of governmental industrial hygiene (ACGIH) determined 10 mw/cm^2 as the occupational exposure limit of 6 minutes and 6.67 mw/cm^2 for public exposure [40]. Remarkably, the permissible exposure limits have been developed based on thermal effects, therefore, comply with these standards does not prevent non-thermal effects of microwave.

In occupational health, use of engineering measures to prevent adverse health effects is a priority. Thus, the use of shielding is a superior method for prevention of microwave exposure. Today, with the advent of nanotechnology, the use of nanocomposites is a new approach to prevent Electromagnetic interference that recently developed for raising the performance of Electromagnetic interference shields [41, 42].

As we know , the aim of occupational health is a workplace health promotion [43-45]; therefore , it appears to useful electromagnetic nanocomposites shields is appropriate for protection of workers from radar exposure.

REFERENCES

[1] Cember H, Johnson TE. Introduction to health physics. 4th ed. Mc Graw Hill; New York ; 2009

[2] X band. available from http://en.wikipedia.org/wiki/X_band.

[3] Kubacki R. Biological interaction of pulse-modulated electromagnetic fields and protection of humans from exposure to fields emitted from radars. Microwaves, Radar and Wireless Communications, IEEE, MIKON, 17th International Conference on; 2008.

[4] Gairola SP, Vermaa V, Kumarb L, Abdullah Dara M, Annapoornib S, Kotnala RK. Enhanced microwave absorption properties in polyaniline and nanoferrite composite in Xband. Synthetic Metals 2010; 160 (21-22): 2315-8.

[5] Repacholi MH. Health risks from the use of mobile phones. Toxicology Letters. 2001;120 (1-3):323–31.

[6] Cleary S, Pasternack B, Beebe G. Cataract incidence in radar workers. Archives of environmental health, 1965; 11(2):179-82.

[7] Møllerløkken OJ. Is fertility reduced among men exposed to radiofrequency fields in the Norwegian Navy? Bioelectromagnetics, 2008; 29 (5): 345-52.

[8] Mailankot M, Kunnath AP, Jayalekshmi H, Koduru B, Valsalan R. Radio frequency electromagnetic radiation (RF-EMR) from GSM (0.9/1.8 GHz) mobile phones induces oxidative stress and reduces sperm motility in rats. Clinics. 2009; 64(6):561-5.

[9] Goldsmith JR. Epidemiologic evidence relevant to radar (microwave) effects. Environmental Health Perspectives, 1997; 105(Suppl 6):1579.

[10] Jauchem JR. Effects of low-level radio-frequency (3 kHz to 300 GHz) energy on human cardiovascular, reproductive, immune, and other systems: A review of the recent literature. International Journal of Hygiene and Environmental Health, 2008; 211:1-29.

[11] Garaj-Vrhovac V, Gajski G, Pažanin S, Sarolić A, Domijan A-M, Flajs D, et al. Assessment of cytogenetic damage and oxidative stress in personnel occupationally exposed to the pulsed microwave radiation of marine radar equipment. International Journal of hygiene and environmental health. 2010; 214(1):59-65.

[12] Suwen Y, Jie T, Ning Z. The effect of low intensity microwave radiation on male reproductive health. Medical Journal of Chinese People's Liberation Army. 2005;1.

[13] Schrader SM, Langford RE, Turner TW, Breitenstein MJ, Clark JC, Jenkins BL, et al. Reproductive function in relation to duty assignments among military personnel. Reproductive Toxicology. 1998; 12(4):465-8.

[14] Ding XP, Yan SW, Zhang N, Tang J, Lu HO, Wang XL, et al. A cross-sectional study on

nonionizing radiation to male fertility. Zhonghua liu xing bing xue za. 2004; 25(1):40-3.
[15] Sies H. Oxidative stress: oxidants and antioxidants. Experimental physiology. 1997; 82 (2): 291-5.
[16] Mates.J Mea. Antioxidant Enzymes and Human Disease. clinical Biochemistry. 1999; 32 (8): 595-603.
[17] Gharagozloo P, Aitken RJ. The role of sperm oxidative stress in male infertility and the significance of oral antioxidant therapy. Human reproduction, 2011, 26(7):1628-40.
[18] Said TM, Fischer-Hammadeh C, Refaat K, Hammadeh ME. Oxidative Stress, DNA Damage, and Apoptosis in Male Infertility. Studies on Men's Health and Fertility: 2012; 433-48.
[19] Said, T.M.& Gokul, S.R.& Agarwal, A., "Clinical consequences of oxidative stress in male infertility. Studies on men's health and fertility – oxidative stress in applied basic research and clinical practice"[chapter 24], Springer, 2012,
[20] Makker K, Agarwal A, Sharma R. Oxidative stress & male infertility, Indian J. Med. Res., 2009; 129, 357-367.
[21] Lin M.T., Flint Beal M, The oxidative damage theory of aging. Clinical Neuroscience Research. 2003; 2(5-6): 305–15.
[22] Roberta Ricciarelli FA, Maria A. Pronzato CD. Vitamin E and neurodegenerative diseases. Molecular Aspects of Medicine. 2007; 28 (5-6): 591-606.
[23]http://www.oxidativestressresource.org/img/oxidative_stress_oval.jpg. [cited]; Available from.
[24] Cherry N. Evidence of brain cancer from occupational exposure to pulsed microwaves from a police radar. www.neilcherry.com, 2001.
[25] Richter ED, Berman T, Levy O. Brain cancer with induction periods of less than 10 years in young military radar workers. Archives of Environmental Health: An International Journal. 2002; 57(4): 270-2.
[26] Richter ED, Berman T, Ben-Michael E, Laster R, Westin JB. Cancer in radar technicians exposed to radiofrequency/microwave radiation: sentinel episodes. International journal of occupational and environmental health. 2000; 6(3):187-93.
[27] Anders A, Adele G, Leeka K, David S, Anthony S. Epidemiology of Health Effects of Radiofrequency Exposure. Environ Health Perspect. 2004;112 (17):1741-54.
[28] Davis RL., Mostofi FK., Cluster of testicular cancer in police officers exposed to hand-held radar. American Journal of Industrial Medicine. 1993; 24(2): 231-3.
[29] Đinđić N, Jovanovi J, Veličković V, Damnjanovi I, Đinđić B, Radović J. Radiofrequency and microwave radiation health effects and occupational exposure. Acta Medica Medianae. 2011;50 (4) 74-78.
[30] Williams RA, Webb TS. Exposure to radio-frequency radiation from an aircraft radar unit. Aviation, space, and environmental medicine. 1980; 51(11): 1243.
[31] Garaj-Vrhovac V, Fučić A, Horvat D. The correlation between the frequency of micronuclei and specific chromosome aberrations in human lymphocytes exposed to microwave radiation in vitro. Mutation Research Letters. 1992; 281(3): 181-6.
[32] Garaj-Vrhovac V, Fučić A. The rate of elimination of chromosomal aberrations after accidental exposure to microwave radiation. Bioelectrochemistry and Bioenergetics. 1993; 30: 319-25.
[33] Garaj-Vrhovac V. Micronucleus assay and lymphocyte mitotic activity in risk assessment of occupational exposure to microwave radiation. Chemosphere. 1999; 39(13):2301-12.
[34] Verschaeve L. Genetic damage in subjects exposed to radiofrequency radiation. Mutation Research. 2009: 681(2-3) :259-70.
[35] Garaj-Vrhovac V, Horvat D, Koren Z. The effect of microwave radiation on the cell genome. Mutation Research Letters. 1990; 43(2): 87-93.
[36] Moszczyński P, Lisiewicz J, Dmoch A, Zabiński Z, Bergier L, Rucińska M, et al. The effect of various occupational exposures to microwave radiation on the concentrations of immunoglobulins and T lymphocyte subsets. 1999; 52 (1-2): 30-4.
[37] Yang HK, Cain CA, Lockwood J, Tompkins WAF. Effects of microwave exposure on the hamster immune system. I. Natural killer cell activity. Bioelectromagnetics. 1983; 4(2):123-39.
[38] Rao GV, Cain CA, Tompkins WAF. Effects of microwave exposure on the hamster immune system. IV. Spleen cell IgM hemolytic plaque formation. Bioelectromagnetics. 1985; 6(1):41-52.
[39] Dehghan N, Taeb S. Adverse health effects of occupational exposure to radiofrequency radiation in airport surveillance radar operators. Indian Journal of Occupational and Environmental Medicine, 2013; 17(1):7-11
[40] ACGIH. 2010 TLVs® and BEIs® Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. 2010.
[41] Al-Saleh MH, Sundararaj U. Electromagnetic interference shielding mechanisms of CNT/ polymer composites. CARBON. 2009; 47 (7): 1738-46.
[42] Jalali M, Dauterstedt S, Michaud A, Wuthrich R. Electromagnetic shielding of polymer–matrix composites with metallic nanoparticles. Composites Part A: Applied Science and Manufacturing. 2011; Part B 42 (6):1420-6.
[43] Rantanen J, Fedotov IA. Standards, principles and approaches in occupational health services, 1995;5:7, In Encyclopaedia of Occupational Health

and Safety Occupational Health. Jeanne Mager Stellman, International Labour Organization, ILO, 1998

[44] O'Donnell MP. Health promotion in the workplace, third ed., Delmar, Albany, 2001.

[45] Acutt J, Hattingh S. Occupational Health: Management and Practice for Health Practitioners, ethird ed. Juta, South Africa, 2004.