IEEE Committee on Man and Radiation

TECHNICAL INFORMATION STATEMENT ON:

BIOLOGICAL AND HEALTH EFFECTS OF ELECTRIC AND MAGNETIC FIELDS FROM VIDEO DISPLAY TERMINALS

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INTRODUCTION

Video display terminals (**VDTs**) are commonly used for information display together with a computer and keyboard. Questions have been raised about adverse health effects associated with the electric and magnetic fields found near the cathode ray tube (**CRT**) used in a VDT. Television receivers also use CRTs in a similar fashion but concerns about health effects have centered around the VDT, perhaps because it is usually used in closer proximity.

Neither laboratory nor epidemiological research has shown convincing evidence that the electromagnetic fields emanating from VDTs adversely affected the health of VDT operators. Studies of effects on pregnant women using VDTs have failed to establish a link between VDT fields and miscarriages or birth defects. However, not all research issues have been settled and it will be valuable for research to continue until it is possible to come to a still firmer conclusion.

This paper addresses health issues related to the electric and magnetic fields of VDTs. It was developed by the Committee on Man and Radiation (**COMAR**) of the Institute of Electrical and Electronics Engineers, Inc. (**IEEE**), and represents the considered judgment of an international group with expertise in the subject area. It updates an earlier statement on this topic that was issued in August 1990.

BACKGROUND

Video display terminals (VDTs), which are also known as video display units or monitors, produce low levels of electromagnetic energy because of the techniques used to generate and move an electron beam that illuminates the screen of a cathode ray tube (CRT). These displays are used in television receivers, computers, automated teller machines, video games, and other such devices. Different technologies, such as transistor displays and liquid crystal displays, are used in laptop computers and do not have the same electromagnetic characteristics as CRTs. All relevant health research on VDTs pertain to CRTs.

The basic electronics of VDTs may also produce electromagnetic fields. For designs with power transformers, a 50/60 Hz sinusoidal field may be generated. The electronic circuits used to process the video signal may produce radiofrequency fields.

A CRT is an evacuated glass envelope with an electron gun located in the narrow neck at the rear of the tube and a phosphor-coated screen at the front face. There are several wire coils located around the outside of the neck that are known collectively as the deflection yoke. The yoke and the circuitry used to drive it, in particular the flyback transformer, are the major sources of magnetic fields.

The energy generated by a VDT extends over a broad spectrum, including:

1. x-ray and ultraviolet light (wavelengths below 400 nm),
2. visible light (700-400 nm, 4.3-7.5x10^14 Hz),
3. infrared radiation from heat generated by the electronics,
4. very low and low frequency energy (VLF and LF, 3-300 kHz),
5. extremely low frequency energy (ELF, 30-300 Hz), and
6. static electric fields.

CRTs are constructed so that the x-rays and ultraviolet rays are absorbed by the glass screen and only visible light is transmitted.

The electron beam paints the phosphor screen on the face of the CRT with a series of horizontal lines. Successive lines are displaced vertically in order to cover the screen from top to bottom. The horizontal and vertical steering of the electron beam is done by fast-changing magnetic fields at the neck of the tube.

For each horizontal line the beam must be swept steadily across the screen by an increasing magnetic field while the electron beam is turned on. Once the beam reaches the right-hand edge of the screen, the electron beam is turned off and retraced to the left side of the screen by a

rapidly decreasing magnetic field. This combination of slow- and fast-changing magnetic fields produces a sawtooth shaped waveform.

For a typical VGA mode computer monitor, about 31,500 horizontal lines are painted each second. This requires a 31.5 kHz magnetic field aligned, or polarized, in the vertical direction. Computer horizontal deflection frequencies vary from approximately 15.75 kHz to over 60 kHz. Although the magnetic field is configured to interact with the electron beam inside the CRT, vertically polarized sawtooth fringing fields at the horizontal deflection frequency occur around the CRT. The vertical deflection of the electron beam requires a horizontally polarized magnetic field which also produces horizontal fringing fields at a distance from the yoke. Several hundred horizontal lines (typically from 200 to over 800) must be painted while the beam is swept from top to bottom, the sawtooth shaped magnetic field used for vertical deflection is at a frequency several hundred times lower than the horizontal deflection frequency and involves a proportionately smaller amount of energy. Typical frequencies lie between 30 and 75 Hz, depending on the graphics mode.

The frequency content of the electromagnetic emissions from a CRT contains more than the fundamental frequencies of the two sawtooth waves. Sinusoidal components of these signals extend out to at least 200 kHz [1], even though the amplitudes of the higher frequency components are much lower than the fundamental frequencies. As much as 94% of the energy is at the fundamental frequency of the horizontal deflection circuit [2,3].

VLF and LF magnetic energy is generated by the horizontal deflection system that moves the electron beam from left to right. ELF magnetic energy is generated by the vertical deflection system that moves the electron beam from top to bottom. Concerns about potential health effects have focused on magnetic fields over all these frequencies. The ELF frequency fields generated by VDTs raise issues similar to those involving power frequency electric and magnetic fields which are also in the ELF region. IEEE COMAR has prepared a Technical Information Statement, "Biological Effects of Power-Frequency Electric and Magnetic Fields" [4] treating many topics on ELF fields. VLF and LF magnetic fields induce larger electric fields in the body than lower frequency magnetic fields of the same strength and are thus an additional concern with VDT technology.

Characteristics and typical strengths of VDT electric and magnetic fields

The electric and magnetic fields near a VDT are characterized by frequencies and polarizations that are similar for like designs, such as monochrome, CGA, EGA, VGA, and SVGA. The field strengths emanating from different units vary with product design. Electric field strengths and magnetic flux densities at a distance of 30 cm from the CRT screen were measured for many different models, including those specifically designed to reduce field strengths (often called "low emission monitors"). The measurement distance, which is approximately one foot, is less than the typical distance at which a user sits from the screen and represents a worst- case distance. These data are summarized in Table 1.

Frequency Band	Maximum Electrical Field	Typical Electrical	Maximum Magnetic Flux	Typical Magnetic	References

	Strength*	Field Strength*	Density*#	Flux Density*#	
VLF (3-30 kHz) and LF (30-300 kHz)	less than 50 V/m	1.6 V/m	less than 1.5 µT	0.02-0.50 µT	[1, 5, 6, 7]
ELF (30-300 kHz)	less than 65 V/m	1-20 V/m	less than 1.2 µT	0.2 µT	[1, 6, 7, 8]
Static (0 Hz)	less than 25,000 V/m	2-500 V/m	not applicable	not applicable	[7, 8(at 50 cm), 9]

*** Field levels are given as root-mean-square values.**
 # 0.1 µT = 1 mG

Comparisons with occupational and public exposure guidelines.

Threshold limit values (TLVs) have been developed by the American Conference of Governmental Industrial Hygienists (ACGIH) [10,11] for occupational exposures. These TLVs are 614 V/m (electric field strength over the range 30-3000 kHz) and 205 µT (magnetic flux density over the range 30-100 kHz). Above 100 kHz this guideline reduces the allowable magnetic field; at 300 kHz the TLV is reduced to 68.3 µT. Other values are shown in Table 2. These values match those found in IEEE/ANSI Standard C95.1-1991 [50] and are similar to those recommended by other national and international bodies. The LF and VLF electric and magnetic field levels produced by VDTs, as shown in Table 1, fall below the recommended limits. Therefore, exposures at distances of 30 cm or more from VDT screens are within current exposure standards and guidelines.

The Swedish Standards Institution (SIS) has developed an emission standard (MPR-III) for VDTs [12] that is fundamentally different from the standards developed by other agencies, such as ACGIH [11, 12], IEEE [50< /A>] or the Canadian Bureau of Radiation and Medical Devices (BRMD) [52]. The MPR-III standard is based on emission levels which are technically achievable and not on exposure limits based on health research. Three categories of electric and magnetic field emissions are defined in two frequency ranges at a fixed measurement distance of 50 cm. The SIS frequency band II (2-400 kHz) overlaps the range from 30-400 kHz where ACGIH and IEEE provide guidelines. For VDTs that perform within the SIS limits, electric and magnetic fields at 50 cm are far below exposure standards; many such VDTs are sold as "low radiation monitors."

Standard or Guideline	Frequency Range	Electric Field	Magnetic Flux Density	Notes
SIS MPR-III [12]	0.005-2 kHz	less than or equal to 10 V/m	less than or equal to 0.20 µT	"Category A" classification at 50 cm from center of screen.
	2-400 kHz	less than or equal to 1 V/m	less than or equal to 0.025 µT	

ACGIH (1996) [10, 11]	0.001-30 kHz	625-25,000 V/m	200-60,000 µT	Frequency dependent occupational ceiling threshold limit values
	30-100 kHz	614 V/m	205 µT	
	100-300 kHz	614 V/m	205-68.3 µT	
IEEE/ANSI C95.1-1991 [50]	less than 3 kHz	no recommendation	no recommendation	
	3-100 kHz	614 V/m	205 µT	
	100-300 kHz	614 V/m	205-68.3 µT	MPE(magnetic) = 205/f (kHz)
Mass OSHA 453 CMR 5.00/1986 [51]	10-3000 kHz	no recommendation	2.0	Occpational limit
Canadian BRMD Safety Code 6 - 1991[52< /A>]	10-1000 kHz	600 V/m	6.2 µT	Occupational limit
	10-1000 kHz	280 V/m	2.8 µT	General public limit

Abbreviations: ACGIH - American Conference of Governmental Industrial Hygienists; ANSI - American National Standards Institute; BRMD - Bureau of Radiation and Medical Devices; OSHA - Occupational Health and Safety Administration (Massachusetts, U.S.A.); SIS - Swedish Standards Institute.

Biophysical Factors of Static, ELF and VLF Fields.

Several physical and biophysical mechanisms may be involved when human beings are exposed to VDTs. Because a strong static electric field exists at the CRT face, aerosols are attracted to the surface as is evident from the rapid accumulation of dust. These aerosols may increase exposure to airborne allergens [13]. VDT users can be electrostatically charged and thereby attract particles to their bodies.

In addition to electric fields directly associated with high voltage circuitry in VDTs, time varying magnetic fields also induce electric fields in conductive media, such as the human body. The magnitude of the induced electric field depends on the strength of the magnetic field and its rate of change.

It is unknown whether the internal electric and magnetic field, if either, can produce biological effects in the tissues of an exposed human being or animal. As a result, both electric and magnetic fields need to be considered. For a similar reason, there is no accepted dose measure for personal exposure to VDT fields. Most research reports root-

mean-squared amplitudes of the electric field strength and magnetic flux density in units of V/m(rms) and & #181;T(rms), respectively.

Health Studies in Human Populations.

There have been many epidemiological studies of workers exposed to VDTs on the job. To date, all studies have been limited by inadequate assessment of field exposures to the individual subjects. Some recent studies have used field strength meters at selected work sites and some obtained estimates of the number of hours of exposure per week. Other research simply contrasted VDT users with non-users. Some took into account the great diversity of models found in most offices, but other did not. No study was able to fully distinguish effects of VDT use, which include potential job related stress and the effects on eyes, hands and the musculoskeletal system, from effects of exposure to fields.

More than a dozen studies have focused on reproductive effects, such as rates of spontaneous abortion and birth defects. Other studies have dealt with effects on vision and the musculoskeletal system. Ocular studies of workers have not shown any relationship between VDT use and ophthalmologic disease or abnormalities, including cataracts [14, 15 , 16].

A statistically significant association was reported between a type of brain cancer, glioma, and self-reported occupational exposure to ionizing and non- ionizing radiation in Australian women [17]. These results were based on 25 cases, 7 that reported "radiation" exposure. In 6 of the 7 cases, CRTs were cited as the exposure source. For CRT exposures, the age adjusted odds ratio was 4.99 (95% CI: 1.43-17.38), with a slightly lower value of 4.34 (95% CI: 0.95-19.72) when only "good quality, non-proxy interviews" were used as a basis for CRT exposure. Male glioma cases showed no such effect. The authors cautioned that the results were difficult to interpret in view of the small number of cases, possibility of recall bias, lack of exposure information, and the possibility that the elevated odds ratios for CRT users were a chance occurrence in a study where many comparisons were made.

VDTs and Pregnancy.

The question of whether VDT use affects pregnancy arose after a few reports of apparent clustering of spontaneous abortions (miscarriages) at workplaces in which VDTs were used by the affected women. These reports prompted a series of epidemiological studies to examine whether or not miscarriages occurred more frequently in women who used VDTs. A finding of higher miscarriage rates may have various explanations, which could include exposure to electromagnetic fields, ergonomic factors, sitting for long periods, and psychological stress related to job conditions.

Interest in this issue was enhanced by reports that women who spent more time at VDTs had more miscarriages. Goldhaber and Polen [18] interviewed women receiving prenatal health care from a large health care group in California to obtain data relating the amount of time spent at a VDT to the occurrence of miscarriages. The self-reported duration of daily VDT use was correlated with miscarriage frequency with an odds ratio of 1.8 (95%

CI: 1.2-2.8). Because miscarriage rates were not consistently affected within specific occupational categories, the validity of the association of VDTs and miscarriage is questionable. A study by McDonald et al. [19] indicated a small risk, but the majority of the studies which followed found that use of VDTs did not increase the risks of either miscarriage or birth defects [20, 21, 22, 23].

In a recent large prospective epidemiological study [24], subjects were interviewed during pregnancy rather than afterward, as in previous studies. Intrauterine growth rate of the fetus and birthweight were not altered by VDT use. There was no information on miscarriage rates. A meta-analysis of nine published papers showed no association between VDT use and miscarriage, low birth weight, or birth defects [25]. The power of this analysis was estimated to exclude risk increments of 20% or more.

Two studies of workers who used VDTs are of particular interest because they obtained information on exposure levels. In the first, VDT users were compared with other employees whose jobs were similar except that they used older equipment without CRTs [26, 27]. The study design allowed separation of any effects of physical and psychological job characteristics from those of VDT emissions. Measurements showed that VDT-related ELF exposures to the abdomens of these workers were comparable to background levels. VLF fields at the abdomen, although higher for the VDT users, were low and well within exposure guidelines. The results showed no difference in spontaneous abortion rates among 323 telephone operators during any month of pregnancy (odds ratio for the first trimester = 0.93, 95% CI: 0.63-1.38), nor did the rate vary by the amount of VDT use per week.

In the second study [28] VDT workers also were found not to be at increased risk for spontaneous abortion (odds ratio = 1.1, 95% CI: 0.7- 1.6). VDT magnetic fields were measured in the laboratory. When the subset of VDT workers exposed to the highest ELF fields (greater than 0.9 µT peak-peak, 0.3 µT rms) was compared to those in the low exposure group (less than 0.4 µT peak-peak, 0.15 µT rms) the odds ratio was 3.4 (95% CI: 1.4-8.6). There was no such increase when the high ELF field group was compared to non-users of VDTs (odds ratio = 1.6, not significant) and there appeared to be a protective effect for the group exposed to low-level ELF fields (odds ratio = 0.4, 95% CI: 0.4-0.8). These latter findings are unexpected and inconsistent. They serve to warn about possible statistical anomalies in this data set. Since the majority of VDTs in use today are classified as "low emission" monitors, it may not be possible to establish or disprove by future studies the suggested ELF association found by this study.< P>

VDTs and Electrosensitivity.

Problems such as burning or tingling sensations, and fatigue or dizziness have been reported by individuals who work with VDTs. The symptoms are subjective and occur in the general population. Like other reported reactions to weak electric or magnetic fields, these have been called "electrosensitivity" although it is not known if the various complaints are etiologically related. Studies of VDT users have focused on job conditions, stress, electromagnetic fields, or humidity, which may be related to skin sensitivity. Complaints are rare in comparison to the number of people who use VDTs [29].

In the laboratory, a double blind study of individuals who reported VDT related skin symptoms showed the subjects could not reliably distinguish between similar-appearing units that had low or high levels for static electric fields and ELF and VLF magnetic fields [30]. In a controlled study, subjects reported that skin sensitivity was somewhat reduced as a result of shielding electric fields [31]. Objective signs of disease have been studied and were not found to be more prevalent in those who worked with VDTs, nor were they linked with electromagnetic fields [32]. A case controlled study based on questionnaires examined factors in the "total electrical environment" with the findings that electrostatic fields were not associated with skin sensitivities but ambient 50 Hz electric fields and VDT generated ELF magnetic fields were [29, 33].

The Swedish National Board of Health and Welfare has reviewed the relevant data on electrosensitivity and does not ascribe it to any specific environmental exposure or condition [34]. Their summary regarding general health effects of electric and magnetic fields states:

> **"The range of symptoms and the reported effects of treatment of the electrically sensitive can best be understood within a psychological explanatory framework -- which neither denies the existence of the symptoms nor claims they are feigned."**

Information from Biological Experimentation.

Tests on developing embryonic systems can provide sensitive warning signals for hazardous effects. Likewise, the absence of effects in developing systems would suggest VDT associated electric and magnetic fields are unlikely to cause adverse effects in more mature systems. Several studies of laboratory animals looked at the possibility of teratogenic effects from exposures to VDT-like fields. Tribukait et al. [35] found no greater incidence of mouse embryo mortality or fetal resorptions with VLF sawtooth or pulsed magnetic field exposures during gestation but did find a significant increase in malformations for exposures to sawtooth magnetic fields. On the other hand, Frölén et al. [36] found no effects of VLF sawtooth magnetic fields on malformations but did observe higher rates of fetal resorption for mouse embryos exposed early in pregnancy, although litter size was unaffected. A number of other reproductive studies have been conducted with rats and mice, some with wholly negative findings [37, 38, 39, 40]. One study showed effects on drug treated mice [41]. A number of studies with chick embryos [42] have established a large and inconsistent set of results on developmental defects in this avian species. However, mammalian species are considered to be the appropriate model for predicting developmental toxicity in humans. In a review, Chernoff et al. [43] concluded that although inconclusive, the laboratory data leave open the possibility that under some experimental conditions adverse reproductive and developmental effects occur in laboratory animals.

Laboratory research using novel experimental approaches continues to appear. For example, Dimberg [44] reported that brain development was altered in mice exposed to sawtooth VLF magnetic fields in utero. He reported that various brain neurochemicals and

brain weight were affected, particularly when studied at 308 days of age. Additional research is warranted to resolve outstanding issues. The resolution may identify specific experimental conditions needed for consistent observations of biological effects or conclude that the reported positive results, generally small in number, are chance events of no biological or health significance.

Other Reviews of VDT Effects.

Several scientific organizations have reviewed the relevant literature, both epidemiological studies of VDT use and laboratory studies of ELF and VLF exposures. A scientific advisory group to the National Radiological Protection Board (NRPB) of Great Britain concluded that the studies did not support the idea that exposure to ELF and VLF energy causes abnormal effects on the growing fetus or congenital malformations (birth defects), nor is there evidence of an increase in miscarriages for VDT users [45]. A working group of five scientists convened by the International NonIonizing Radiation Committee (INIRC) of the International Radiation Protections Association (IRPA) also reviewed the literature and summarized their findings as follows [46]:

> **"Based on current biomedical knowledge it can be concluded that there are no health hazards associated with radiation or fields from VDUs [VDTs]. Thus there is no scientific basis to justify shielding or radiation monitoring, nor eye examinations to search for ocular pathology due to radiations in VDU operators. However, since a large number of people are involved in VDU work, it is important that further knowledge is gained on certain areas where our knowledge must be regarded as incomplete."**

Other groups offered similar conclusions concerning possible reproductive effects from ELF electric and magnetic fields. The International Conference on Large High Voltage Electric Systems (CIGRÉ) working group from Australia, Canada, France, Great Britain, Italy, Sweden, and the United States concluded that, "In general, studies of EMF exposure and reproduction do not demonstrate evidence of harm." [47]. A scientific panel convened by the Oak Ridge Associated Universities reached a similar conclusion regarding reproductive effects from electric and magnetic fields [< A HREF="#48">48].

Recommendations for Users of CRT-based Devices.

Based on present information, there is no basis for programs to monitor or reduce CRT emissions in occupational settings. The use of "protective" devices, such as "radiation screens" has not been shown to be helpful; such devices are ineffective in reducing magnetic field strengths and affect only the electric fields. Special monitoring of user health because of VDT use also is not warranted. VDT users need to be aware of ergonomic problems, which can be ameliorated by the use of antiglare screens, proper eyeglasses, good habits for the use of eyes, and furniture that assists good posture. Consumers should know that inexpensive "EMF meters" do not provide useful information about electromagnetic fields from CRT-based devices. However, consumer advice and worker training on VDTs are appropriate and encouraged. Topics should include ergonomic hazards to the eyes and

musculoskeletal system and education about electromagnetic exposures with a summary of the scientific knowledge concerning human health [49].

CONCLUSIONS

Cathode ray tube devices, including VDTs and television receivers, utilize electromagnetic energy over a broad spectrum. For VDTs, the measured electric and magnetic fields in the ELF, VLF, and LF frequency ranges are well within existing exposure guidelines. The consensus drawn from several epidemiological studies is that workplace use of VDTs is not a risk factor for either miscarriage or birth defects, the topics raised to prominence by early observations and research. Based on animal studies and epidemiological study, no other disease or syndrome has been conclusively associated with VDT use. These facts lead to recommendations for education of users on the ergonomic and electromagnetic aspects of VDT use but mitigate against the need for programs to reduce or monitor exposures or to have health surveillance programs for any specific disease or adverse outcome.

The scientific literature is, however, incomplete in important ways. The duration of exposures in many studies has been brief compared to either human working years, life span, or latency periods for diseases such as cancer. Exposure assessment for users of CRTs has been weak or absent in most epidemiological studies. The inconsistency of laboratory studies in a number of relevant areas needs resolution; this requires additional research. Although, at present, there is good evidence showing that miscarriages and birth defects are not associated with VDT use, there has been little health research on other possible adverse outcomes.

CONTRIBUTORS

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GLOSSARY OF TERMS

CI: Confidence Interval. A measure of statistical reliability. A smaller range shows greater reliability. In epidemiology, a range for an odds ratio that excludes 1.0, for example, 1.3 to 2.6, indicates a statistically reliable increase in risk; a range such as 0.2 to 0.5 indicates reliably reduced risk. Typically, the range is selected for a 95% chance of including the true risk ("95% CI").
computer monitor: A CRT-based display used with a computer; VDT; VDU.
CRT: Cathode ray tube.
ELF: Extremely low frequency, 3 to 300 Hz.

frequency: The rate of variation of a periodic signal.
hertz: The MKS unit of frequency, abbreviated Hz. Equal to cycles per second.
LF: Low frequency, 30 to 300 kHz.
microtesla: One millionth of a tesla, abbreviated μT. Equal to 10 milligauss.
non-sinusoidal: A waveform where the rate of change does not follow the trigonometric sine function. Examples include sawtooth, square wave, pulsed, triangle wave, speech and music.
polarization: The direction along which an electric or magnetic field is aligned. For example, the magnetic field from a loop of wire in the horizontal plane is perpendicular to the loop and is said to be polarized vertically.
sawtooth: A waveform in which the signal changes at two rates. For example, after a period of slow increase, the signal rapidly decreases to the original value. The resulting pattern resembles the teeth of a saw blade.
sinusoidal: A waveform in which the rate of change of a signal varies from zero to a maximum value in a smooth and regular manner that is described by the trigonometric sine function.
spontaneous abortion: Miscarriage, the unintended loss of a fetus.< br> tesla: The MKS unit of magnetic flux density, abbreviated T. Equal to 10,000 gauss.
VDT: Video display terminal.
VDU: Video display unit.
VLF: Very low frequency, 3 to 30 kHz.

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Notes added to the Web version:

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