Electromagnetic radiation emissions from video display terminals (VDTs)

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This paper presents quantitative measurements of the non-ionising (radiofrequency, ultraviolet and visible) and ionising (x-ray) electromagnetic radiation emitted from 67 different colour and monochrome video display terminals.

Measurements of the electric field strength and the magnetic field strength were made over the range of frequencies from 14 kHz to 100 MHz. Broadband measurements from 10 MHz to 26 GHz were also made.

Ultraviolet spectral irradiance measurements were made over the wavelength range 320 to 400 nm. The visible (400 to 750 nm) spectral irradiance was also measured.

The results have been compared with Australian and International occupational and general public recommended exposure limits. Relative to these limits, the emission levels are low to very low. It is therefore concluded that electromagnetic radiation emissions from VDTs do not pose a health hazard to operators.

Keywords: Video display terminals, electromagnetic radiation emissions, radiofrequency spectral analysis, spectral irradiance.

A video display terminal (VDT) is a device comprising a screen on which information is displayed and, usually, a keyboard which controls the processing of that information. VDTs serve as an interface between a computer and the operator and, as computers have become more common, so too have VDTs.

There are probably several hundred thousand VDTs in Australia and tens of millions worldwide, in workplaces, educational institutions and homes.

Most VDTs use a cathode-ray tube (CRT) as the display. However, VDTs that use a solid-state display in place of the CRT are now available, but are not included in this study. The CRT is an evacuated glass tube, which has a source of electrons at one end and a screen, which is coated on the inside with a phosphor, at the other.

When a high voltage (typically, 12-25 kilovolts) is applied a beam of electrons is produced which is focused onto the screen. When the electrons strike the phosphor coating, visible radiation plus a small amount of ultraviolet radiation (UVR) is emitted.

This interaction of the electron beam and the phosphor also produces, by secondary emission, low energy ionising radiation (that is, x-rays) which are absorbed by the glass screen. The electronic components and circuits of the VDT, which control the movements of the electron beam, are sources of radiofrequency (RF) radiation. This radiation is emitted in all directions.

As a result of concern expressed by the scientific community and sections of the workforce about the

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possible adverse health effects of electromagnetic radiation emitted by VDTs, a study of VDTs was initiated in 1982 and the results and conclusions have been published in Australian Radiation Laboratory reports.[1,2] The measurement programme is continuing and this paper presents the results obtained to date.

Extensive measurements of the emissions of ionising and nonionising radiation have been published.[3-9] Other studies have focused on particular areas such as x-radiation,[10] radiofrequency radiation,[11-15] extremely low frequency (ELF) radiation[16,17] and electrostatic fields.[17]

The debate has not been restricted to possible deleterious health effects of the radiation emissions. Questions on ergonomic requirements for VDTs and VDT workplaces, optical characteristics of the display and their psychological interactions and organisational aspects have also been raised but these are answered in detail elsewhere.[18]

Non-ionising radiation

Radiofrequency radiation

The RF region of the electromagnetic spectrum extends from 10 kHz to 300 GHz. The microwave region is a subset of the RF region and has frequencies between 300 MHz and 300 GHz which correspond to wavelengths between 1 m and 1 mm respectively. An RF signal has an electric (E) and a magnetic (H) field component, and each must be measured separately.

The sources of RF radiation within a VDT include the horizontal deflection system and the associated high voltage circuit, the cathode ray tube (CRT) and the digital electronics.

The function of the horizontal deflection system is to move very rapidly (at least once every 70 μs) the electron beam across the screen of the CRT. This requires the circuitry to be pulsed at a frequency of at least 14 kHz.

To produce the high voltage required to accelerate the electron beam in the CRT, a high voltage transformer is also pulsed at a frequency of at least 14 kHz by a signal derived from the horizontal deflection circuitry. This transformer is referred to in the literature as the EHT or fly back transformer. The pulsating high voltage of the EHT transformer creates E-field emissions. These emissions vary in time at the fundamental frequency of the horizontal deflection circuitry and at harmonics thereof.

The pulsating high voltage is rectified and fed into the CRT which is essentially a large capacitor that provides the necessary filtering to produce the smooth high voltage pulse required to accelerate the electron beam. The time-varying components of this high voltage pulse flow to ground via the CRT capacitance and produce similar time-varying E-field emissions from the screen.

The crystal clock frequency is divided into the frequencies necessary for digital character generation. It is this clock, which operates at a frequency between 1 and 10 MHz, that produces most of the radiated signal from the digital electronics section.

The currents which flow in the EHT transformer and the horizontal deflection coil are responsible for the H-field emissions above 14 kHz.

Methods

The RF emissions in the frequency range from 10 kHz to 100 MHz were measured using a spectral analysis technique. The field components of the RF emissions are detected with either an E- or H-field probe and the resulting signals are separated, by a calibrated spectrum analyser, into the fundamental and associated harmonic frequencies such as is shown in *Figure 1*. This standard technique allows the accurate determination of the magnitude of these frequencies, and has been used in other studies to measure the RF emissions from VDTs.[1,4,8,15]

The E-field probe used during this study consisted of a 130 mm dipole mounted on a Tektronix P6046 balanced high impedance probe and is usable from 0 to 100 MHz. The E-field probe was calibrated over the frequency range of 10 kHz to 20 MHz.

The main factor limiting the length of a dipole is the nonuniformity of the field that exists in the vicinity of the source. The error in measurement caused by the finite length, L, of the dipole can be calculated from the equation given by Kucia,[19] namely

$$L \leq 2R\,(1 - (p+1)^{-1/2})^{1/2}$$

where R is the distance from the centre of the dipole to the E-field source and p is the error in measurement. If, however, the length of the dipole is too short, there is insufficient response. It was decided to limit the error in measurement due to the finite length of the dipole to + 10% (p = 0.1). Therefore, for p = 0.1 and R = 300 mm, the required dipole length, L, is 130 mm.

Two H-field probes were used during this study. The first was a 44 turn, 255 mm diameter loop and the second was a 36 turn, 130 mm diameter loop. The loops were shielded from E-field interference. Each loop was calibrated over the frequency range 10 kHz to 2 MHz.

The measurement accuracy was therefore a function of the following factors; probe calibration accuracy, error due to the finite length of the dipole, capacitive coupling and the field perturbation effects of the probes. Thus the overall uncertainty in the measured levels in this study was estimated to be within +40% and -30%.

A systematic survey over all accessible surfaces of each VDT was performed with both E- and H-field probes at a measurement distance of 300 mm. For each measurement the probes were rotated to obtain maximum response. Of particular interest were the emissions from the screen of the VDT. Where possible, all VDTs were measured with the screen filled with "M"s and set at maximum intensity.

All emissions from the screen and every accessible surface of the VDT within a factor of 0.1 of the maximum emission (which in all cases was at the fundamental frequency of the horizontal deflection system) were measured. The root mean square (rms) value of all the

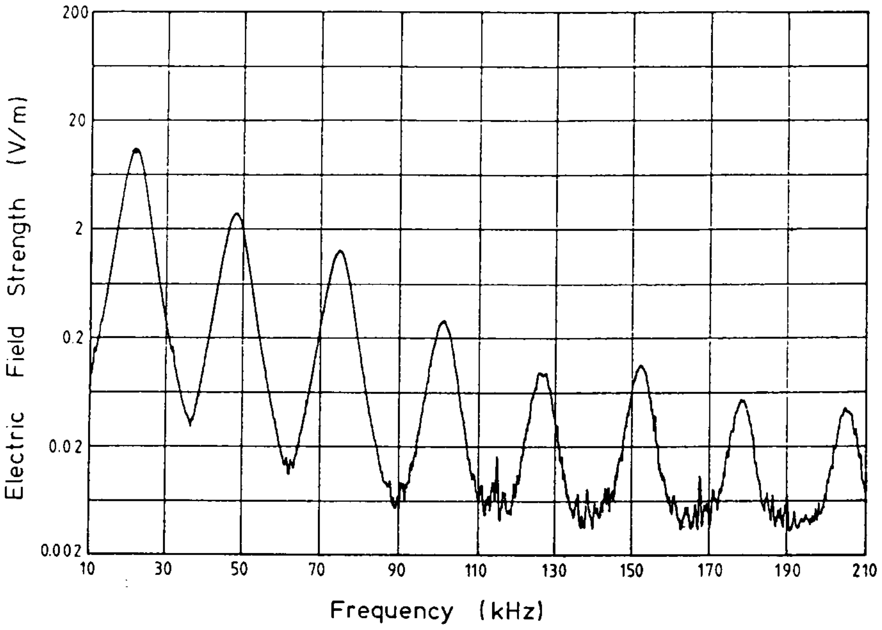

Figure 1. A typical plot of the RF emissions from VDTs, showing the variation of electric field strength (E) with frequency. Note the logarithmic scale for the E-field axis.

measured emissions was taken to be the total RF output. Under these conditions, the error in determining the total RF output would not exceed 1%.

In the earlier survey,[1] insufficient measurements were taken of the E-field emissions from the sides of two VDTs to satisfy the 0.1 cut-off criterion. The error in determining the total RF output in these two cases is estimated to be less than 10%.

In this latest survey, measurements were taken at a distance of 300 mm from the VDT surface for the following reasons.

1. The error in measurement due to the finite length of the dipole increases as the distance from the surface of the VDT decreases, for example at a distance of 100 mm, the error in measurement is 200%.
2. The normal operator position is not likely to be any closer than 300 mm.

Results

The rms field strengths or total RF output for both the E- and H-field emissions from the screen of each VDT tested are presented in *Table 1*.

It was found that

1. The choice of display colour had no effect on the emission levels from the colour VDTs.
2. Over 95% of the RF emissions from all of the VDTs occurred between 14 kHz and 250 kHz.
3. For the **colour VDTs**, the total RF output from the screen varied between 0.39 V/m and 3.1 V/m for the E-field emissions and between 7.3 mA/m and 78 mA/m for the H-field emissions. The total RF output from any other accessible surface of the VDT varied between 0.01 V/m and 4.5 V/m for the E-field emissions and between 9.5 mA/m and 190 mA/m for the H-field emissions.
4. For the **monochrome VDTs**, the total RF output from the screen varied between 0.09 V/m and 15 V/m for the E-field emissions and between 0.3 mA/m and 76 mA/m for the H-field emissions. The total RF output from any other accessible surface of the VDT varied between 0.01 V/m and 50 V/m for the E-field emissions and between 0.1 mA/m and 430 mA/m for the H-field emissions. This latter high reading was localized to an area above the top surface of a particular VDT directly above the horizontal deflection coil and well away from the normal operator's position.
5. The E-field emissions were radially directed and decreased approximately as the cube of the distance from the source. For the emissions from the screen, the source is taken to be the point where the EHT enters the CRT.
6. Shielding the EHT transformer and the digital electronics and filtering the high voltage supply greatly reduced these E-field emissions.
7. The H-field emissions exhibited a degree of polarization which results from the particular orientations of the source coils. The H-field emissions decreased approximately as the cube of the distance from the source coil. These observations are in agreement with those of Harvey.[12]
8. The magnetic field emissions were unperturbed by the presence of conductive surfaces and by the arms and hands of the investigator.
9. The previously unused AWA model VTE-6 terminal showed a large increase in E-field emission levels when the contrast and brightness were increased from normal operating settings to maximum settings.

   To a lesser extent, the Honeywell DIS003 terminal exhibited the same effect. CRT output, which decreases with age, and the type of video generating system used are two of the probable factors responsible for this phenomenon.
10. The E- and H-field emission levels from the ECS model T-03 terminal had not changed significantly over a period of 27 months.

Evaluation of electrically conductive nylon filters

Fitted electrically conductive nylon filters were found to be ineffective in attenuating the E-field emissions

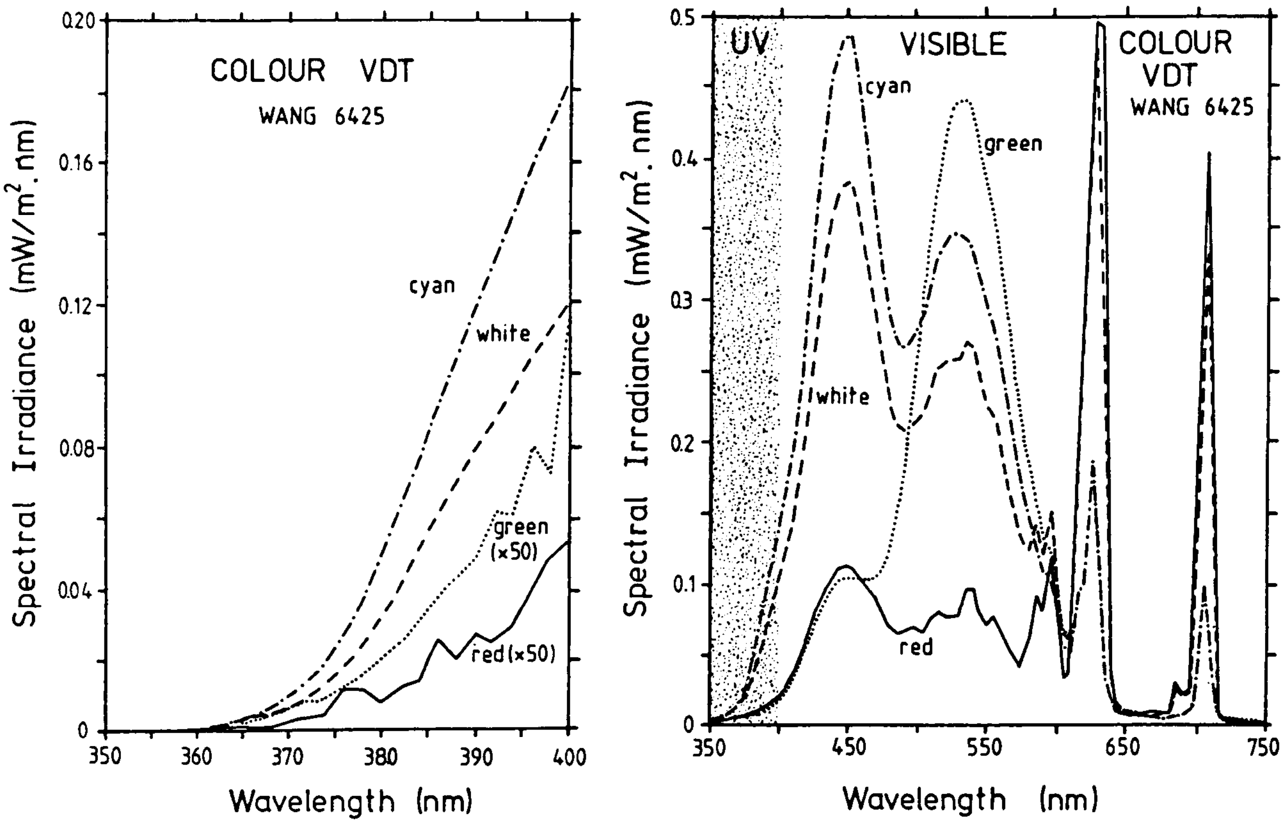

Figure 2(a)

Figure 2(b).

Figure 2. Measured ultraviolet (a) and ultraviolet/visible (b) spectral irradiances for a Wang 6425 colour VDT with characters generated in each of the four colours, cyan, white, green and red. The ultraviolet spectral irradiances for red and green characters shown in (a) have been multiplied by 50 for ease of comparison with those of the cyan and white.

with frequencies greater than 14 kHz unless the cabinet is similarly conductive. They were also found to be ineffective in attenuating the H-field emissions regardless of whether or not the VDT cabinet was conductive.

Broadband measurements

Broadband measurements in the frequency range from 10 MHz to 26 GHz have been made on more than 80 terminals some of which were not included in this study. The survey instrument used was a Narda model 8616 Radiation Monitor, fitted with either a Narda model 8631 probe for the frequency range 10 MHz to 300 MHz or a Narda model 8621B probe for the frequency range 300 MHz to 26 GHz. Field strengths equivalent to 0.1 W/m^2 are detectable.

Measurements were made at a distance of 300 mm over all the accessible surfaces of the VDT. No emissions were detected. This was not unexpected because the spectral analysis results showed that above 1 MHz the field strengths of the emissions, if present, were well below a level equivalent to 0.1 W/m^2.

Great care must be exercised in the choice and use of broadband monitors for measuring the emissions from VDTs for two reasons:

1. The frequency response of the monitor must cover the frequency range over which emissions occur. As 95% of the total RF output occurs between 14 kHz and 250 kHz, the monitor must have a known response in this frequency range.
2. Broadband monitors may be unduly influenced by capacitive coupling, or the high voltages which exist on EHT transformers. Monitors so affected may read high or low depending upon the polarity of the video pulse.

An Inexpensive Broadband Probe

To facilitate the measurement of VDT emissions, the Australian Radiation Laboratory has developed a low cost broadband monitor. In this monitor, the E-field is sensed via a short dipole antenna, the output of which is fed into a very high impedance balanced amplifier. The signal is converted into DC via a true rms detector which drives the meter movement, with a scale calibrated to read directly in volts/metre. Thus the monitor measures the true rms value of the E-field emissions.

Extremely Low Frequency (ELF) Emissions

The ELF emissions (5-500 Hz) were not measured in the present study but other studies have shown that the levels are similar to those from fluorescent lights and household appliances.[16]

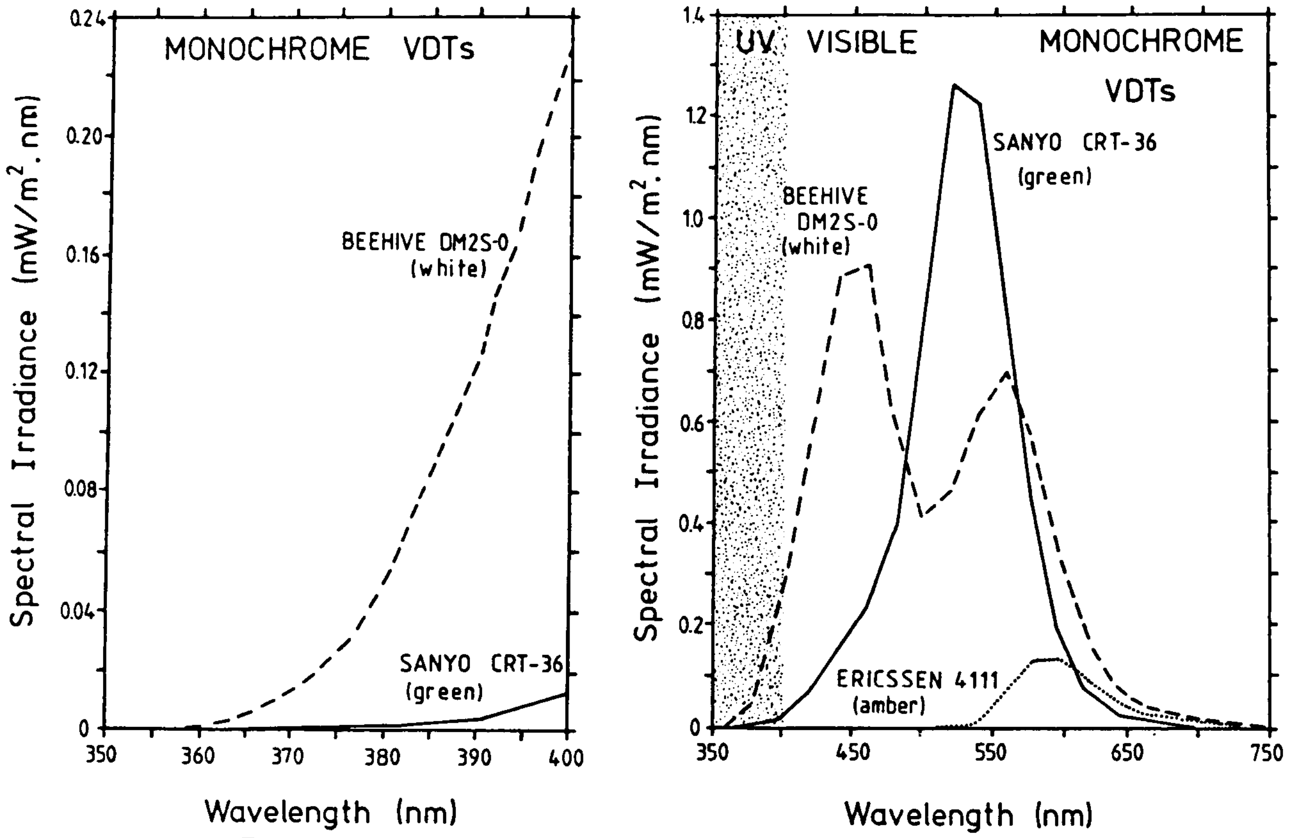

Figure 3(a) Figure 3(b)

Figure 3. Measured ultraviolet (a) and ultraviolet/visible (b) spectral irradiances for three monochrome VDTs with different screen phosphor colours.

Discussion

Comparison of Results with International Standards

Over 95% of the total RF output from VDTs was within the frequency range from 14 kHz to 250 kHz. The International Radiation Protection Association (IRPA) in cooperation with the Environmental Health Division of the World Health Organization (WHO) has published a set of guidelines on exposure to radiofrequency fields in the frequency range from 100 kHz to 300 GHz.[20]

These guidelines recommend that in the frequency range from 100 kHz to 1 MHz the exposure of the general public should be limited to 87 V/m for the E-field and 230 mA/m for the H-field. Countries that have occupational exposure standards covering frequencies below 100 kHz have the same limit below 100 kHz as they have at 100 kHz.[21,22]

This rationale is conservative and implies that the IRPA limits may be applied equally over the frequency range from 14 kHz to 1 MHz. IRPA[20] also state that measurements of exposures to determine adherence to the limits should be made at positions normally occupied by operators.

The maximum emission levels at 300 mm from the screens of either the monochrome or colour VDTs do not exceed 17% and 34% of the IRPA E- and H-field limits respectively.

Ultraviolet/visible radiation

Methods

Spectral irradiance measurements were made using an Optronics model 740A spectroradiometer. This instrument incorporates a 0.2 m focal length single grating monochromator and a radiometer. A non-standard grating (blazed at 300 nm) was used. This improves the performance of the system in the UV region. Unwanted spectral orders and stray radiation can be a significant problem in the UV region with most single grating monochromators.

The wavelength scan drive controls an automatic filter wheel which positions optical blocking filters, covering the wavelength ranges 280 to 360 nm, 360 to 610 nm and 610 to 1070 nm, in the radiation beam. The spectroradiometer system has a standard Optronics model 85 quartz cosine receptor attached to the monochromator entrance slit.

Measurements of the UVR emissions were made using a solar blind photomultiplier as the spectroradiometer detector. With this photomultiplier, the response of the system to visible radiation (which is the main contributor to the stray radiation in the system) is sharply reduced, falling by a factor of 15 between 400 and 420 nm, and above

TABLE 1
SUMMARY OF SCREEN EMISSION MEASUREMENTS

MODEL	RMS FIELD STRENGTHS E-FIELD at 300mm (V/m)	RMS FIELD STRENGTHS H-FIELD at 300mm (mA/m)	IRRADIANCE UV at 100mm ($\mu W/m^2$)	IRRADIANCE VISIBLE at 100mm (mW/m^2)	
COLOUR VDTs					
AWA 8602	1.8	22	95	11	(white on black)
Commodore 1701	1.3	7.3	8200	270	(light blue on blue)
Digital VR241-A	2.1	15	820	60	(white on black)
Ericsson 4112	0.6	12	360	26	(black on white)
IBM 3279	1.2	41	100	7	(blue on black)
Intecolor 2427	0.75	27	1400	94	(white on purple)
Raytheon 2000	0.39	72	500	58	(white on black)
Sanyo CRT-70	1.9	25	1000	84	(white on purple)
Sigma Data VC-001B	0.80	32	620	a	(blue)
Telex TC079	2.2	64	84	a	(white)
Texas Instr. 3219	0.75	39	690	36	(blue background)
Toshiba PA162EA	0.57	29	5300	92	(cyan on blue)
Wang 6425	3.1	78	2700	77	(cyan on black)
			1800	72	(white on black)
			26	56	(green on black)
			7	9	(green on black)
			14	36	(flash. red on black
MONOCHROME VDTs (White Display)					
AWA VTE-6	2.0	7.1	2000	170	
	0.15	7.1	(Brightness and contrast half maximum)		
	0.13	7.1	(Brightness and contrast minimum)		
AWA VTE-6H/1	0.3	52	260	15	
Beehive DM2S-0	2.8	15	3000	130	
Data General D200	1.9	63	490	a	
ECS T-03	1.3d	2.0d	340	18	
	0.94	1.6			
GCS IV	15	38	470	29	
HP 2622A	2.7	35	1800	150	
HP 2645A	0.82	15	63	13	
Honeywell DIS003	0.42	16	380	24	
	0.09	16	(Brightness and contrast half maximum)		
IBM 4978-2/1	0.9	3.4	8700	a	
IBM 4979-2/2	1.2	3.0	11000	a	
Microfusion II	5.2	22	13000	340	
			9000c	230c	
			280d	16d	
			180dc	10dc	
Soroc 133LY	0.91	12	2500e	110e	
			2300	110	
Volker-Craig VC404	0.58	26	260e	51e	
			570	43	

MODEL	RMS FIELD STRENGTHS E-FIELD at 300mm (V/m)	RMS FIELD STRENGTHS H-FIELD at 300mm (mA/m)	IRRADIANCE UV at 100mm ($\mu W/m^2$)	IRRADIANCE VISIBLE at 100mm (mW/m^2)	
MONOCHROME VDTs (Green Screen)					
Apple IIc	0.5	2	<5b	5	
Apple III	1.1	15	<5b	9	
AWA2	3.2	11	9	10	
AWA3	2.7	6.0	7	a	
Beehive ATL-004	0.41	7.5	140	18	
			600	67	(reverse video)
Burroughs B21-45	1.2	7.9	7	a	
	0.38	12	(disc drive)		
Burroughs B25	1.2	32	53	a	
Data General D410	2.3	21	24	a	
ECS 4500	0.2	0.3	80	9	
Facom 9526R	0.36	8.6	<5b	2	
Genesis One G77c	4.5	21	140	15	
HP 2392 A	1.5	16	100	55	
Inforex 2901	0.41	14	<5b	1	
Lanier L100	0.28	10	<5b	8	
Lear Siegler ADM 11	1.9	38	110	a	
Lee Data 1220	0.32	69	7	17	
Lee Data 1220/1999	0.59	76	5	11	
Linoscreen 400	2.0	37	7	a	
Microfusion MF20.0	0.69	11	89	120	
Microbee SV-1290X	1.0	3.9	26	27	
NEC APC-HO2C	0.59	8.1	<5b	a	
Raytheon PTS-100	1.0	30	37	28	
Raytheon Telex R1078	0.46	7.1	33	a	
Raytheon Telex R4078	0.51	38	11	a	
Ricoh EX5120	1.1	57	<5b	28	
Sagem TX	0.22	19	11	3	
Sanyo CRT-36	1.8	18	120	120	
Seiko 8620	0.09	17	95	100	
Sigma Data VM-001A	1.5	19	69	a	
Telex TC078	1.5	28	<5b	a	
Time Office Comp. 6000	3.7	69	38	a	
Toshiba PA7151EA	0.62	9.7	10	60	
Visual 50	0.88	6.4	31	12	
			160	53	(reverse video)
Wang 5320	12	44	230	a	
Wang PC-PM004	1.2	35	330	a	
Zentec Z-4000	1.4	14	51	a	
MONOCHROME VDTs (Amber Screen)					
AWA1	2.5	12	<5b	11	
Ericsson 4111	2.5	32	<5b	11	
Nixdorf BA14	0.94	19	<5b	30	
Raytheon R1078	0.37	13	<5b	a	

a no measurement made
b integration range ≥375 to 400 nm, no emission detected below 375 nm
c measurement distance was 300mm
d normal viewing intensity
e measurement made in 1982

460 nm is 2 to 3 orders of magnitude below the UV response. Tests with a tungsten halogen standard lamp and a series of Schott cut-off filters showed that the contribution was less than 0.1% for the wavelength range 280 to 400 nm.

The spectroradiometer system was calibrated over the wavelength range 280 to 410 nm using a quartz halogen standard lamp traceable either directly to the US National Bureau of Standards or indirectly via the National Measurement Laboratory of the Commonwealth Scientific and Industrial Research Organisation. Measurements were made over the wavelength range 300 to 410 nm at 2 nm intervals with a 2 nm bandwidth. The minimum detectable level at 350 nm was 200 nW/m^{2}nm.

The visible radiation emissions were measured using a calibrated silicon photodiode detector over the wavelength range from 400 to 750 nm at 10 nm intervals and with a 10 nm bandwidth. The minimum detectable level at 450 nm was 7.0 μW/m^{2}nm. It should be remembered that the usefulness of the VDT screen as a means for information display depends upon the emission of visible light which is generated by the interaction between the electron beam and the screen phosphor. The visible spectral irradiance was measured so as to determine the relationship between the visible and UV emission levels for particular screen colours.

Measurements were made with the spectroradiometer positioned such that the cosine receptor on the monochromator entrance slit was 100 mm from the centre of the VDT screen, with the optical axis of the receptor perpendicular to the screen. For all tests, except where indicated in *Table 1*, the screen was filled with "M"s and set at maximum intensity. When it was not possible to display "M"s on the screen, measurements were performed on a fully illuminated screen set at maximum intensity.

Results

Colour VDTs

For the colour VDTs, an International Light model IL700A radiometer with a UV-A detector was used to select the character and background display colours for which the maximum UV irradiance was obtained. These colours were then used for the subsequent ultraviolet and visible spectral irradiance measurements. These measurements for all the VDTs evaluated in the present programme are given in *Table 1*.

For the Wang model 6425 colour VDT four of the individual display colours are plotted in *Figure 2b*. The ultraviolet portion of this figure (that is, the region below 400 nm) is plotted on a larger scale in *Figure 2a*. The irradiance is the area under the curve between the appropriate wavelength limits. It can be seen from *Figure 2b* that the UV emission is in fact the "tail" of the visible emission and it follows that the closer the maximum of the visible emission is to the blue end (that is, towards 400 nm) of the spectrum the greater will be the UV emission. For the Wang 6425 the UV emission for white and cyan are approximately 100 times greater than that for the red or green. This result is typical of all the colour VDTs measured.

Monochrome VDTs

The monochrome VDTs evaluated were models with either white, green or amber screens. Typical UV/visible spectral irradiance plots are given in *Figure 3a* and *Figure 3b*. Four amber VDTs have been evaluated but no significant UV emission was detected from any of these.

Illuminated Screen Area

Measurements were made with the screen completely filled with "M"s, in order to illuminate the screen with as many bright dots as possible. With a 512 x 256 matrix screen, 1920 "M"s are displayed and this results in approximately 25% of the screen being illuminated.

The effect of increasing this area can be seen for the Beehive ATL-004 where measurements were also made in the reverse video mode, that is, black "M"s on a green screen. In this mode at least 75% of the screen is illuminated. Measurements revealed an approximate four fold increase in both UV and visible levels.

Screen Intensity

Measurements were made at maximum intensity in order to obtain "worst-case" operating conditions. The UV and visible irradiances measured at "normal" intensity were considerably lower, usually by a factor of between 3 and 20, although only a selection of the VDTs were checked.

The "normal" setting is, of course, subjective and it was found that the setting selected as normal by six colleagues resulted in a variation of a factor of two in the measured irradiance.

Screen Phosphor Ageing

After several years of use, the screen phosphor begins to show signs of deterioration and it is likely that higher intensity settings would then be required for normal operation. Some of the VDTs evaluated had substantial screen discoloration, but, unfortunately, information was not generally available on the age of the VDT or of the extent of use.

Several units were measured in 1982 and again two years later. No evidence of substantial changes in emission levels or characteristics was found. The results of measurements made in 1982 and 1984 on the Soroc 133LY showed that the radiation emission has remained almost constant, despite the fact that the unit has been in constant use.

Viewing Distance

The distance between the cosine receptor of the spectroradiometric system and the VDT screen was 100 mm compared with the usual operator distance of 300 mm or more. The Microfusion II VDT was measured at both of these distances and it was found that the measured irradiance at 300 mm was about two-thirds of that at 100 mm.

Broadband Measurements

Spectral irradiance measurements

are expensive in terms of time and equipment cost. Broadband measurements can provide considerable savings in both areas, but problems arise when standard UV-A silicon photodiode detectors are used for the UV measurements. The main problem in their use is that the maximum spectral sensitivity is generally in the region of 360 nm but the response has dropped by a factor of four by 380 nm and is practically zero between 390 and 400 nm where typically at least 60% and often 70-80% of the UVR emission lies.

If a detector/filter combination is used which ensures all the UVR is detected, then because of the transmission characteristics of broadband filters the result will be affected by visible radiation.

The visible radiation contribution so measured may be larger than that due to the UVR, however a correction can be made if the relative spectral responsivity of the detector/filter combination as well as the relative spectral distribution of the emission is known.

Another approach used successfully here on about 20 VDTs is to measure the total UV plus visible radiation emission and to calculate the UVR using the ratio of UV/visible radiation obtained from earlier measurements. This ratio is not constant but is dependent on the screen colour. The ratios, calculated to a 95% confidence level, are as follows — red/amber (<0.001), green (<0.009), white/blue (<0.04), and cyan (<0.08).

Discussion

Summary and Comparison with Standards

The measured UV irradiances cover the range $<5\ \mu W/m^2$ to $13\ mW/m^2$. It should be emphasized that measurements are made at maximum brightness and in most cases the VDT would not be usable under those conditions. However, the UV irradiance from the 'worst case' VDT (Microfusion II) at maximum intensity is still substantially lower than that from normal fluorescent room lighting.

The maximum measured UV emission from a VDT is $124\ mW/m^2$ reported by Cox.[7] It should be noted that this figure was obtained with the detector in contact or in close proximity to the screen. It was also found[7] that the majority of the 200 types tested had irradiances of less than $10\ mW/m^2$.

For the UV-A region, both IRPA[23] and the American Conference of Governmental Industrial Hygienists (ACGIH)[21] recommend that an irradiance upon the unprotected skin or eye should not exceed $10\ W/m^2$ for exposure periods of greater than 1000 seconds over an 8 hour working day. This figure is conservative.

It is based on the erythemal effectiveness of 315 nm radiation and assumes, in the absence of good photobiological data for the UV-A region, a constant biological response for wavelengths up to 400 nm. The results of van der Leun[24] suggest that the erythemal effectiveness of 400 nm radiation is a factor of 30 to 40 lower than that of 315 nm.

The threshold for eye damage (photokeratitis, conjunctivitis, cataract) resulting from exposure to UV-A radiation is thought to be considerably higher than that for erythema, although again there is a scarcity of good data, particularly for chronic exposure.

For all VDTs measured the UV emission occurred at wavelengths longer than 350 nm. In fact for all VDTs more than half of the UV emission occurred in the range 390 to 400 nm.

The average UV irradiance measured in the present study was $1.43\ mW/m^2$ with maximum and median values of $12.9\ mW/m^2$ and $140\ \mu W/m^2$ respectively. These values range between approximately three and five orders of magnitude below the IRPA and ACGIH recommended limits.

Ionising radiation (X-Rays)

Methods

Each VDT was surveyed with a Victoreen model 440RF/C exposure rate meter. The detector has a sensitive area of $1000\ mm^2$ and a minimum detection level of 0.05 milliroentgen per hour (mR/hr). Measurements were made 50 mm from the VDT screen, again with the screen filled with "M"s and set at maximum intensity. No ionising radiation above background was detected for any of the VDTs.

Results and Discussion

The National Health and Medical Research Council of Australia[25] recommends for television viewers that the ionising radiation exposure rate shall not exceed 0.5 mR/hr averaged over an area of $1000\ mm^2$ at a distance of 50 mm from any point on the external surface of the receiver. This recommendation can be equally applied to VDTs. All VDTs evaluated complied with this recommendation.

VDT emissions and the eye

No ocular injury due to exposure to RF radiation at frequencies less than 500 MHz has been reported in the literature. As there is no emission detected at frequencies above 500 MHz in this or the other surveys cited, it can be concluded that there is no ocular hazard from the RF emissions from VDTs.

The main responses of the eye to excessive amounts of UVR are photokeratitis, conjunctivitis and lenticular cataracts. As photokeratitis and conjunctivitis are induced mainly by radiation of wavelengths less than 320 nm,[26] they are unlikely to be produced by VDTs, which emit no UVR below 350 nm.

The effects of UVR with wavelengths greater than 350 nm on the human eye, in particular the lens, where most of the absorption at these wavelengths takes place, is less well documented.

The available evidence[26] suggests that extremely large doses of UVR of wavelengths greater than 350 nm are required to induce cataract formation, perhaps of the order of 0.5 to $1.0\ MJ/m^2$. Exposures received from VDTs are at least 3 to 4 orders of magnitude below this.

Notwithstanding these facts, it has been claimed in unrefereed literature[27,28] that patients developed cataracts following VDT use. These claims were reviewed recently by a US National Research Council Panel on Impact of Video Viewing on Vision of Workers[29] which concluded that of the 10 anecdotal cases reported, only 4 had significant lenticular opacities, and each of them had known pre-existing disease or exposure to cataractogenic agents.

Conclusions

The maximum radiofrequency emission levels at 300 mm from the screens of either the monochrome or colour VDTs do not exceed 17% and 34% of the IRPA[20] electric and magnetic field limits respectively.

The ultraviolet emission levels are several orders of magnitude lower than the recommended maximum exposure levels of IRPA[23] or ACGIH.[21]

There was no ionising radiation detected from any of the VDTs.

Relative to current exposure standards, the levels of electromagnetic emissions from VDTs reported here are low to very low. It is therefore concluded that electromagnetic emissions from VDTs do not pose a hazard to the health of operators.

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