AN INVESTIGATION OF ELECTRIC AND MAGNETIC FIELDS AND OPERATOR EXPOSURE PRODUCED BY VDTs: NIOSH VDT EPIDEMIOLOGY STUDY

FINAL REPORT

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NOTE

Portions of this report have been adapted from material contained in the User Manual for the Holaday Industries, Inc. Model HI-3600 VDT radiation survey meter which was developed under contract by Richard Tell Associates, Inc. for Holaday Industries, Inc.

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Summary

This report addresses the subject of electric and magnetic field emissions of video display terminals (VDTs), both radiofrequency (RF) and extremely-low frequency (ELF), at AT&T and Bellsouth telephone operator facilities. The study represents one component of a larger study of possible reproductive effects in VDT operators being conducted by the National Institute for Occupational Safety and Health (NIOSH). The purpose of this study was to assess the strength of the electric and magnetic fields produced by the different types of displays to which participants in the NIOSH study could have been exposed. Because of the study design used in the epidemiology investigation, the exposure evaluation included a study of the fields associated with VDTs and two other forms of displays which do not use cathode-ray-tube technology; these two non-VDT types of displays represent the equipment used by the control population in the NIOSH study. The non-VDT displays were designated as either NGT (nixie glow tube) or LED (light emitting diode) and the VDTs were designated as CCI or IBM, after the names of their manufacturers (Computer Consoles, Inc. and International Business Machines).

A study of 96 displays, selected at random, and located in nine cities, was conducted during April 23 through May 6, 1990. The comprehensive survey included measurements of very-low-frequency (VLF) RF electric and magnetic field emissions associated with the horizontal deflection circuits of the VDTs, at a distance of 30 centimeters (cm) from all accessible surfaces of each VDT. In addition, measurements of the ELF electric and magnetic fields produced by the vertical deflection circuits associated with the vertical refresh of the screen display were measured at a distance of 30 cm. The deflection frequencies were also measured. The amount of electrical current induced in the body by exposure to VDT electric field emissions was determined and contrasted with those currents

normally induced in individuals by exposure to environmental levels of radio broadcast station signals. For completeness, measurements of the waveforms of the electric and magnetic fields were made for comparison with recommended limits used in Sweden for the time-rate-of-change of magnetic fields. Each display selected for the study was also scanned for the presence of low-energy x-ray emissions.

Instrumentation used in the project consisted of commercially available instruments designed specifically for VDT type field measurements manufactured by Holaday Industries, Inc. Separate instruments, the Model HI-3600-01 and Model HI-3600-02, were used to measure the electric and magnetic fields in the VLF and ELF bands respectively. Prior to the field study, each instrument was subjected to a thorough evaluation relative to its calibration accuracy and all data collected in the study were appropriately corrected for individual instrument response.

It was found that the two different types of VDTs produced essentially the same horizontal deflection frequency, the CCI units with a nominal frequency of 15 kHz and the IBM units nominally 16 kHz. Vertical deflection frequencies were observed to be nominally 45 Hz for the CCI displays and 60-Hz for the IBM units. The results of the study showed that VLF electric and magnetic field strengths at 30 cm from the VDT screens fell predominantly in the range of 1.3-8.5 volts per meter (V/m) and 4.0-161 milliamperes per meter (mA/m) respectively. A single value of 47 V/m was the one outlier compared to the rest of the VLF electric field measurements. Measurement of field strengths in the VLF range for the NGT and LED displays were significantly less, electric fields being about 0.12-1.2 V/m and magnetic fields in the range of 1.3-1.7 mA/m at 30 cm from the displays. The strength of the fields decreases extremely rapidly with increasing distance from the VDT screen. Hence, exposure of individuals using VDTs is strongly related to how far they sit away from the VDT. Clearly, VDT exposure to RF emissions can become more a function of the manner in which the VDT is used by the operator, in particular the distance that the operator sits from the display, than of the emission characteristics of the unit.

A survey of the ELF electric and magnetic fields found that the field strengths were generally in the range of 0.61-6.4 V/m and 71-571 mA/m at 30 cm in front of the screens of the VDTs.

Electric fields produced by VDTs can be strongly perturbed by the presence of objects near the VDT, including the operator. The degree to which the operator's body can influence the local strength of the electric field was examined in operators positioned at each of the 96 displays showing that facial exposure is typically greater than that which the rest of the body receives. Because of the complicated manner in which the human body couples with the electric and magnetic fields produced by the VDT as a source, a more fundamental dosimetric parameter, for quantifying exposure, may be the current which is induced in the body by the very nonuniform exposure fields. A study of induced currents in all 96 operators found that, in terms of the magnitude of the currents, an individual's exposure to ambient levels of AM radio broadcast station signals generally results in significantly greater induced currents; hence, in this sense, VDTs represent a relatively minor contribution to everyday exposure.

The magnetic field waveform data indicated that the time-rate-of-change of the magnetic field, represented mathematically by the expression dB/dt, for locations 50 cm in front of the screen of the VDTs evaluated, ranged from 0.22 to 37.6 millitesla per second; the largest values were associated with the horizontal deflection system in the VDTs.

Examination of the measured electric and magnetic field strength values obtained in this study shows that in no instance do either of the two fields, determined at the position of the operator, exceed any of the standards for public exposure to RF fields from any country in the world, including applicable guidelines in the United States. In addition, the values of dB/dt at a point 50 cm in front of the screen, corresponding to the distance specified by a recent recommendation in Sweden, were, with two exceptions, less than that value presently used by the Swedes as a procurement specification for importing VDTs in Sweden. Based on the findings of this study, it is concluded that typical personnel exposures to VDT, NGT or LED electric or magnetic field emissions in the telephone offices investigated are relatively low, within the range of other exposure data on VDTs reported by other researchers, and are substantially less than any electric and magnetic field exposure limits developed for radiation protection purposes by organizations within the United States and many other countries.

On a comparative basis, the non-VDT type displays are distinctly different in terms of operator exposure levels when compared to the two types of VDTs used by operators in this study for VLF fields; the NGT and LED displays, not possessing internal magnetic field deflection systems, simply do not produce VLF fields above instrumentation background levels. For ELF fields, such a distinction is less clear. For example, the LED displays produced operator ELF magnetic field exposures which were similar to the values found for operators of both the CCI and IBM VDTs, however, the NGT ELF magnetic fields were significantly less than those produced by either of the VDTs. When taken as a whole, operators of non-VDT displays (NGTs + LEDs) would have, on average, been exposed to lower ELF magnetic fields than their counterpart operators at VDT units. For ELF electric fields, the NGT displays produced operator exposure values less than those for the CCI units but similar to those found for the IBM VDTs. It is concluded that, for the most part, the ELF electric fields appear to be principally a function of the room electrical environment, probably being more representative of electrical wiring systems used in the building than of any peculiar characteristic of the display. The ELF electric fields found for the CCI VDTs as a group appear, however, to be demonstrably above those values found for the rest of the displays, including the IBMs.

Conclusions

This report has elaborated on how VDT's work and how, through the action of the various electronic circuits, incidental electric and magnetic emissions are produced. A substantial amount of data on the characteristics of these emissions, including field strengths, frequencies and waveform peculiarities has been provided showing that VDTs are at the same time not unusual sources of exposure of individuals to electric and magnetic fields and yet, are unique in some respects. More specifically, VDTs can lead to exposures not dissimilar to that experienced near common television receivers. Television sets were found to possess even stronger emissions in some cases. But the unique character of the electric and magnetic field waveforms and exact frequency spectra (the spectrum caused by the fundamental flyback frequency and its associated harmonics) do make the VDT different in these respects.

Taken as a class, the non-VDT type displays are distinctly different in terms of operator exposure levels when compared to the two types of VDTs used by operators in this study for VLF fields. Table 15 is a simplified summary of the measurement results for frontal emissions, chest exposure and induced currents for the NGT, LED, CCI and IBM displays. The NGT and LED displays, not possessing internal magnetic field deflection systems, simply do not produce VLF fields above instrumentation background levels. For ELF fields, such a distinction is less clear. For example, the LED displays produced operator ELF magnetic field exposures which were similar to the values found for operators of both the CCI and IBM VDTs. For ELF electric fields, the NGT displays produced operator exposure values less than those for the CCI units but similar to those found for the IBM VDTs. It is concluded that, for the most part, the ELF electric fields appear to be principally a function of the room electrical environment, probably being more representative of electrical wiring systems used in the building than of any peculiar characteristic of the display. The ELF electric fields found for the CCI VDTs as a group appear, however, to be demonstrably above those values found for the rest of the displays, including the IBMs. Table 15 summarizes the measurement results in a simplified format for easier comparison between the NGT, LED, CCI and IBM displays for frontal emissions, chest exposure and keyboard induced currents. The results imply that the greatest difference in overall exposure would exist between operators of the NGT and CCI displays; in terms of VLF field exposure, both the NGT and LED displays are markedly lower than either the CCI or IBM VDTs.

Nevertheless, when compared to other sources of electric and magnetic fields commonly found in the workplace and the home environment, it was suggested that personal exposure to VDT produced fields could be compared by examining the electrical currents which are induced in the body by alternating electric and magnetic fields. Use of the induced current as an index of exposure, despite the fact that it does not differentiate various waveforms, facilitates the comparison of exposures caused by a wide variety of sources, especially sources which lead to highly nonuniform exposure over the body, like that of a VDT. When viewed in this context, it is found that induced currents can be categorized as those caused by exposure to the electric field and those caused by the magnetic field. While the currents induced by the electric field generally lead to currents which flow throughout the body and through body contact, like the feet or hands, to grounded surfaces, those currents that are magnetically induced generally circulate about the periphery of the body or exposed object (arm, hand, abdomen, etc.).

Measurements of currents flowing between operators of the displays examined and ground showed that very measurable differences exist between the VDTs (both CCI and IBM types) and the non-VDT displays represented by the NGT and LED displays. The VDTs produced consistently significantly greater induced currents.

By considering the currents typically induced by AM radio broadcast stations, as an example, it was found that normal exposure to VDT's in the workplace is not significantly different from that induced virtually all of the time by ambient radio station signals to which everyone is exposed. Exposures in the vicinity of some low frequency communications and radio-navigation stations which use high powers and frequencies very similar to the VDT range could cause substantially greater induced currents than caused by the VDT.

When the field strengths found near VDT's are compared to various standards which specify maximum safe human exposure to electric and magnetic fields one is also impressed by the generally wide margin which exists between the limits and VDT exposure levels. Examination of the measured electric and magnetic field strengths reported in summary Tables 5-8 and in Appendix B shows that in no instance do either of the two RF fields, determined at the position of the operator, exceed any of the standards in Table 12, even the extremely stringent Polish and Czechoslovakian standards for the general public. Based on this finding, it is concluded from measurements on 96 displays comprised of both VDT and non-VDT type displays that typical personnel exposures to electric and magnetic fields are (1) relatively low, (2) within a relatively confined range of magnitudes reported by many researchers, (3) are not highly dissimilar to exposures commonly encountered from radio stations and other devices routinely found in the home or workplace and (4) are generally substantially less than any electromagnetic field exposure limits developed for radiation protection purposes by organizations within the United States and many other countries. In addition, measures of dB/dt, the time-rate-of-change of the magnetic field, were found to be, with three exceptions for the units examined, nominally equal to or less than the recommended limit for VDTs imported in Sweden.

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Table 5. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 NGT displays. Indicated values are the geometrical means and (geometrical standard deviations).

NGT Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	0.137 (1.814)	1.38 (1.036)	1.19 (1.687)	30.0 (1.691)
Front	0.077 (2.05)	1.36 (1.044)	0.470 (1.400)	30.3 (1.724)
Bottom	0.056 (1.987)	1.38 (1.036)	0.351 (1.328)	32.7 (1.826)
Back	0.059 (1.505)	1.38 (1.036)	0.452 (1.436)	33.6 (1.737)
Left side	0.044 (1.353)	1.39 (1.023)	0.282 (1.223)	43.7 (1.787)
Right side	0.048 (1.204)	1.37 (1.034)	0.388 (1.175)	44.2 (1.772)

NGT Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.177 (1.636)	1.6 (1.0)	0.405 (1.92)	32.4 (2.01)
Chest	0.099 (1.653)	1.6 (1.0)	0.308 (1.530)	33.0 (1.877)
Face	0.147 (1.515)	1.6 (1.0)	0.813 (1.417)	32.6 (1.808)

NGT Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	0.019 (1.021)
Finger touching screen	0.018 (1.024)
Hand placed flat on screen	0.019 (1.022)

Table 6. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 LED displays. Indicated values are the geometrical means and (geometrical standard deviations).

LED Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	0.160 (1.391)	1.6 (1.0)	1.270 (1.885)	69.6 (1.855)
Front	0.114 (1.161)	1.604 (1.012)	0.376 (1.103)	72.3 (1.682)
Bottom	0.196 (1.147)	3.811 (1.439)	0.409 (1.059)	62.2 (2.01)
Back	0.524 (1.582)	1.6 (1.0)	12.2 (1.534)	79.0 (1.607)
Left side	0.113 (1.092)	1.620 (1.026)	0.449 (1.229)	59.2 (2.83)
Right side	0.110 (1.052)	1.621 (1.026)	0.471 (1.309)	55.2 (2.61)

LED Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.081 (1.346)	1.97 (1.150)	0.351 (1.175)	62.4 (2.79)
Chest	0.059 (1.475)	1.53 (1.067)	0.299 (1.107)	69.6 (2.70)
Face	0.073 (1.957)	1.39 (1.025)	0.317 (1.105)	80.4 (2.57)

LED Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	0.014 (1.009)
Finger touching screen	0.008 (1.007)
Hand placed flat on screen	0.009 (1.009)

Table 7. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 CCI displays. Indicated values are the geometrical means and (geometrical standard deviations).

CCI Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	3.06 (1.31)	61.4 (3.11)	3.23 (1.588)	401. (4.11)
Front	4.22 (1.54)	98.9 (2.61)	1.85 (1.633)	314. (1.216)
Bottom	0.302 (3.45)	15.9 (3.04)	1.65 (4.654)	172. (2.23)
Back	2.46 (1.75)	62.2 (2.11)	4.25 (1.762)	507. (2.10)
Left side	0.749 (1.55)	82.6 (1.332)	2.09 (2.56)	504. (2.13)
Right side	1.10 (1.95)	82.5 (1.461)	8.49 (1.678)	487. (1.712)

CCI Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.544 (1.683)	17.4 (1.741)	0.845 (3.610)	62.30 (1.590)
Chest	1.05 (1.399)	14.8 (1.903)	1.020 (1.987)	80.6 (1.653)
Face	1.41 (1.424)	41.7 (1.597)	1.90 (1.894)	81.6 (1.597)

CCI Induced Current Statistical Summary, N=24

Hand Location	Induced Current (μA)
Hands on keyboard	4.13 (4.42)
Finger touching screen	14.6 (3.10)
Hand placed flat on screen	87.8 (2.19)

Table 8. Statistical summarization of data on emission field strengths, operator exposure levels and induced currents for 24 IBM displays. Indicated values are the geometrical means and (geometrical standard deviations).

IBM Emission Field Strength Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Top	0.177 (1.567)	27.5 (2.01)	0.560 (1.483)	232. (2.62)
Front	3.26 (2.07)	22.1 (4.68)	1.78 (1.929)	236. (2.14)
Bottom	0.086 (1.745)	2.21 (1.32)	0.839 (2.31)	46.9 (2.08)
Back	0.151 (1.455)	16.4 (2.10)	0.708 (1.889)	140. (1.909)
Left side	0.139 (1.755)	11.8 (2.57)	0.453 (2.03)	306. (1.888)
Right side	0.115 (1.566)	15.6 (1.391)	1.25 (2.31)	205. (1.928)

IBM Operator Exposure Statistical Summary, N=24

Position	VLF-E (V/m)	VLF-H (mA/m)	ELF-E (V/m)	ELF-H (mA/m)
Abdomen	0.142 (1.710)	3.98 (1.852)	0.429 (1.698)	57.7 (2.12)
Chest	0.328 (1.864)	4.23 (2.13)	0.506 (1.780)	66.6 (2.12)
Face	0.543 (1.682)	6.72 (3.00)	0.779 (1.867)	76.4 (1.918)

IBM Induced Current Statistical Summary, N=24

Hand Location	Induced Current (µA)
Hands on keyboard	0.377 (4.65)
Finger touching screen	6.64 (1.968)
Hand placed flat on screen	69.1 (1.600)

Table 11. A summary of VDT electromagnetic field emission data from the technical literature.+

			RMS E Field Strength (V/m)			RMS H Field Strength (mA/m)			
No. Units	Band	VDT/TV	Mean(+/- SD)++	Min.	Max.	Mean(+/- SD)	Min.	Max.	Reference
44	VLF	VDT				50.0 (45.5)	0.72	172.8	Paulsson(1984)
3	VLF	VDT				56.7 (46.5)	25	110	Harvey(1983b)
5	VLF	VDT	12.4(13)	4	35				Harvey(1984a)
54	VLF	VDT	0.48*	0.05	2.64				Harvey(1984b)
38	VLF	VDT			20**				Marha(1983)
21	VLF	VDT	6.92(2.13)	3.0	10.2	49.3 (14.5)	30	76	Guy(1987a)
11	VLF	VDT	0.83(0.83)	0.22	2.7	27.8 (26.6)	0.26	76	Roy(1983)
11	VLF	VDT(color)	1.31(0.83)	0.39	3.1	33.4 (23.0)	7.3	78	Joyner(1984)
39	VLF	VDT	1.96(2.98)	0.2	15	20.4 (17.6)	0.3	76	Joyner(1984)
39	VLF	VDT	6.4 (1.5)		47				Boivin(1986)
52	VLF	TV	8.6 (0.5)		21				Boivin(1986)
3	ELF	VDT				85.3 (26.9)	54	103	Stuchly(1983)
7	ELF	VDT				260 (52.6)	200	350	Juutilainen(1986)
4	ELF	VDT	12.0(12.4)	3	30				Harvey(1982)
3	ELF	VDT				293 (234)	120	560	Harvey(1983b)
5	ELF	VDT	30.0(24)	10	65				Harvey(1984a)
86	VLF	VDT		<1	4.4				Canada(1983)

* Equivalent median unperturbed field strengths derived from a measurement of perturbed field.
** Measured at 20 cm in front of the screen
+ Measured at 30 cm in front of the screen.
++ Arithmetic means and standard deviations given in this table

Table 12. Selected standards for exposure to radiofrequency fields pertinent to the VDT frequency range. E = electric field strength; H = magnetic field strength; B = magnetic field flux density; Occ = occupational; GenP = general public.

Standard/ref	Occ	GenP	E(V/m)	H(A/m)*	B(μT)	f(MHz)
ACGIH(1990)	X		614	1.63	1.98	0.03-3
ANSI(1982)	X	X	632	1.58	1.98	0.3 -3
Australia(1985)	X		194	0.515	0.647	0.3 -9.5
Australia(1985)		X	87	0.23	0.29	0.3 -9.5
Canada(Stuchly, 1989)	X		600	4.0	5.0	0.01-1.2
Canada(Stuchly, 1989)		X	280	1.8	2.3	0.01-1.2
Czech(Czerski, 1985)	X		50	-	-	0.03-30
Czech(Czerski, 1985)		X	5	-	-	0.03-30
IRPA(1988)	X		614	$1.6/f^{1/2}$	$2.0/f^{1/2}$	0.1 -1
IRPA(1988)		X	87	$0.23/f^{1/2}$	$0.24/f^{1/2}$	0.1 -1
Italy(Grandolfo, 1986)	X		140	0.36	0.45	0.1 -10
Germany(1986)	X	X	1500	2500	3141	0.03**
MASS(1983)		X	275	0.729	0.916	0.3 -3
NATO(1979)	X		1000	2.6	3.3	0.01-1
NRPB(1989)	X	X	614	4.89/f	6.14/f	0.03-1
Poland(Szmigielski, 1989)	X		70	10	12	0.1 -10
Poland(Szmigielski, 1989)		X	20	-	-	0.1 -10
Portland(1987)		X	283	0.707	0.888	0.1 -3
Seattle(1989)		X	283	0.707	0.888	0.1 -3
Telecom (1986)	X	X	87	0.23	0.288	0.010 - 10
USAF(1987)	X	X	632	1.58	1.98	0.01-3
USSR(1984a)	X		50	5.0	6.3	0.06-1.5
USSR(1984b)		X	25	-	-	0.03-0.3

* 1A/m = 12.57 mG in free space and most biologic media

** Values given are for 30 kHz but vary according to formula in standard.