

Radiation Survey of Dielectric (RF) Heaters in Canada*



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ABSTRACT

Surveys of dielectric radio-frequency heaters were conducted at various plants throughout Canada in 1979. The heaters were used for plastic sealing and for gluing wood pieces. The devices operated at frequencies between 4 and 51 MHz and their power output ranged from 0.5 to 90 kW.

The intensities of the electric and magnetic fields in the vicinity of 82 devices were measured. A significant number of the devices exposed their operators to the fields having the equivalent power density greater than 1 mW/cm², and some greater than 10 mW/cm².

INTRODUCTION

Dielectric heaters utilize radio-frequency (RF) energy for heat processing of dielectric materials. The most common application is in sealing plastics. Other uses include drying glue to join pieces of wood, curing particle boards and panels, baking sand cores, heating webs, fabrics and paper [1]. These heaters operate at frequencies between 1 and 100 MHz, but most often at the frequencies allocated for industrial, scientific and medical (ISM) uses, namely 13.56, 27.12 and 40.68 MHz. 27.12 MHz is the frequency most commonly utilized. The output power of the heaters ranges from a few hundred watts to about 100 kW. The material processing is accomplished between shaped parallel plate electrodes forming a capacitor. The shape of the applicator electrodes, (also called dies), is usually compatible with the shape of the material to be processed. Heating of a single load of material is achieved in a relatively short period of time. For instance, 2–3 seconds are typical for a plastic sealing operation, and 1 minute for edge gluing of wood.

The relatively high output power of dielectric heaters and use of unshielded electrodes in many of them can produce relatively high stray RF fields around them. Surveys in the US indicated that 60 percent of 82 devices measured exposed the operators to the electric field intensity greater than 200 V/m, and 29 percent to the magnetic field intensity greater than 0.5 A/m [2].

The evaluation of the dose rate of the absorbed radiation at the frequencies of operation of dielectric heaters is very difficult for two reasons. Exposures take place in the reactive region of the radiators, so the electric field and the magnetic field intensities are both of importance. The dimensions of the human body are comparable with the wavelength, and therefore the average specific absorption rate as well as the distribution of the absorbed power can only be determined from complex modeling and analysis. The energy deposition from exposure in the near field of a radiator such as an RF heater has only recently been addressed [3].

In this paper the results of surveys of dielectric heaters, which were conducted in Canada in 1979 are reported. Data for 200 devices was compiled and measurements were taken on 82 units [4]. The instrumentation and survey technique are outlined and the measurement results are summarized.

CHARACTERISTICS AND OPERATION

A typical RF heater consists of a cabinet housing the RF generator, power supply and control circuitry, a press, an applicator (die) and a system to support and move the processed material. The heater is fed manually or automatically.

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The heaters surveyed can be divided into two groups according to the application.

- (1) devices used to heat-seal plastic material, called RF sealers, and
- (2) devices used to cure and dry glue, used for joining pieces of wood, called edge glue dryers.

All edge glue dryers have an applicator consisting of a parallel plate capacitor with rectangular plates of a relatively large surface area. Pieces of wood coated with glue are assembled either inside the applicator, or outside on a tray and then transported to the applicator. Some machines have a two tray assembly, one is under the heater while the other is being assembled. Typically one or two people operate the device.

Plastic sealers display a greater variety of designs than the edge glue dryers. The applicators usually have the capacitor plates specially shaped depending on the shape of the material processed. On the basis of general appearance and the material feeding system, RF sealers can be divided into the following types:

- (1) sewing machine,
- (2) shuttle tray,
- (3) turntable,
- (4) pressure sealed applicator.

The sewing machine sealer is always operated by one person. A number of operators for the other types varies from one to six (for some turntable units). The pressure sealed applicator unit has the active electrode completely enclosed in a metal shield.

Typical dielectric heaters are illustrated in Fig. 1 to 5 and the operation frequency and output power are shown in Table 1, and typical operation characteristics are summarized in Table 2. The duty cycle is defined as the ratio of the time period when the RF power is "on" to the

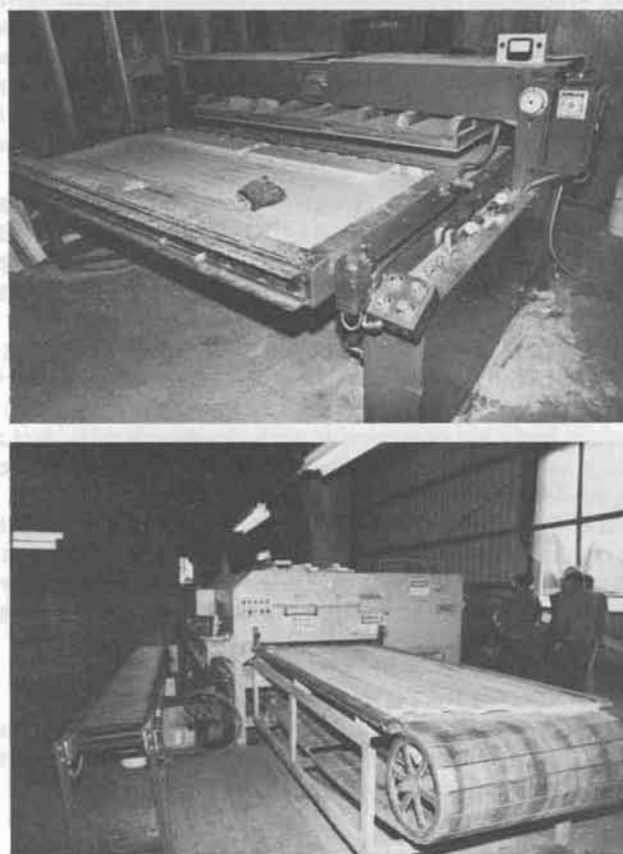


Figure 1 Edge-glue dryers. The operators (usually two) stand in front of the device.

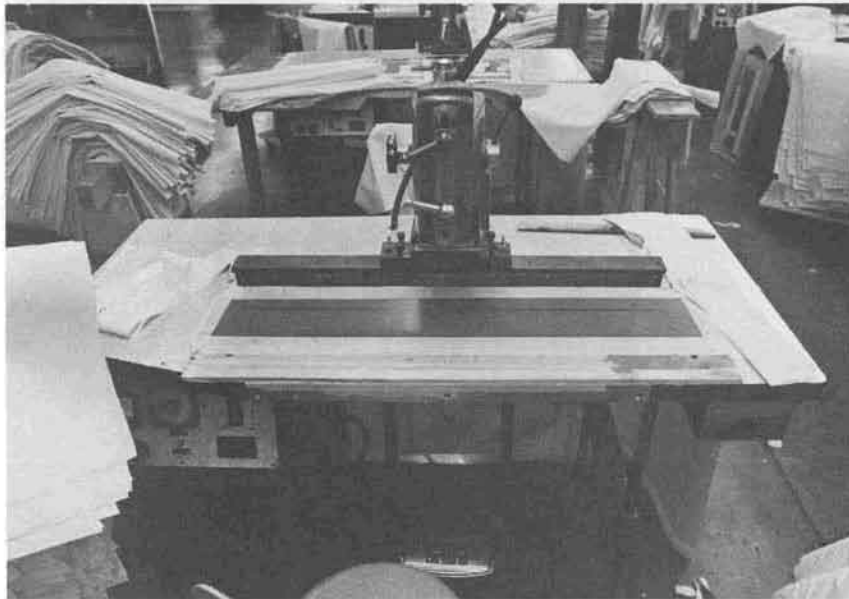


Figure 2 RF plastic sealer — sewing machine type. The operator (single) sits at the device.

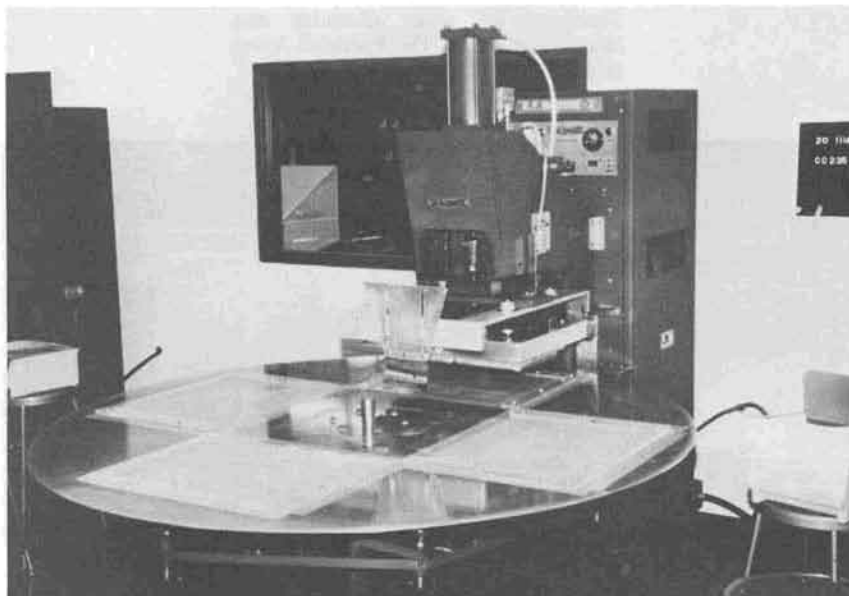


Figure 3 Turntable RF sealer. The operators (three in this case) sit around the turntable.

duration of a typical operational cycle (i.e. the sum of the time period when the power is “on” and “off”). The average duty cycle represents the mean value for the number of units reported. The worst case duty cycle was obtained by taking the maximum “power on” duration and the minimum “power off” duration. Only a few heaters operate under these conditions.



Figure 4 RF sealer (included into shuttle-tray type). The operators (two) stand in front of the device.

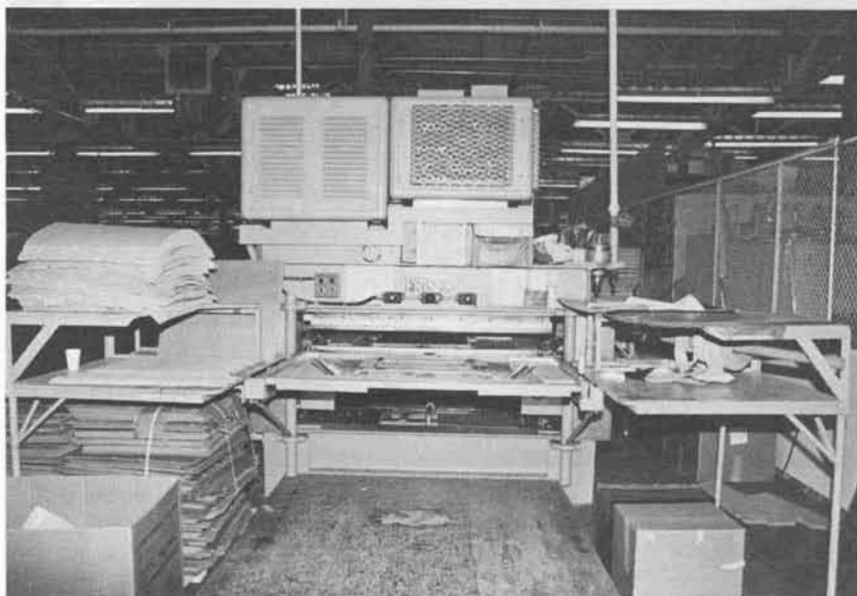


Figure 5 Pressure sealed applicator type RF sealer, automotive industry. The operator(s) (max. two) stand in front of the device.

Table 1 Frequency and power of dielectric heaters

HEATER TYPE	NO. UNITS	FREQUENCY (MHz)				POWER (kW)				
		4-10	11-20	21-30	31-51	0.5-1	2-5	6-10	11-20	21-100
Sewing Machine	61/65			35 (57%)	26 (43%)	4 (6%)	36 (55%)	22 (34%)	3 (5%)	
Shuttle Tray	38/36		1 (2.5%)	34 (89.5%)	3 (8%)		8 (22%)	26 (72%)	2 (6%)	
Turntable	21			20 (95%)	1 (5%)		3 (14%)	16 (76%)	2 (10%)	
Pressure Sealed Applicator	22		10 (45%)	12 (55%)				10 (45%)	5 (23%)	7 (32%)
Edge-Glue Dryer	7	5 (71%)	2 (29%)				4 (57%)		2 (29%)	1 (14%)

Table 2 Typical operation conditions of RF heaters

Heater Type	No. Units	P (kW)	F (MHz)	POWER ON (s)			POWER OFF (s)			DUTY CYCLE	
				Min	Mean	Max	Min	Mean	Max	Average	Worst-Case
Sewing Machine	20	0.75-12	20-51	0.5	1.8	30	1	14.3	30	0.11	0.5
Shuttle Tray	10	3-15	20-50	2	3.4	5	3	11.3	20	0.23	0.63
Turntable	5	3-6	27-49	3	4.1	5	2	5.5	15	0.43	0.71
Pressure Sealed Applicator	20	10-90	13-28	7	12.0	18	6	13.7	22	0.47	0.75
Edge Gluer	7	3-20	4-13	5	30	60	30	60	180	0.33	0.5

MEASUREMENT TECHNIQUE

To determine the exposure to the operator from an RF heater, it is necessary to measure the intensity of both the electric (E) and the magnetic (H) fields. Since the personnel exposure takes place in the near-field, both intensities have to be known to evaluate the power deposition in the body of the operator. The well known relationship for the plane wave, $E/H = 377\Omega$, does not apply in the near-field. Whenever power density is used, it refers to the equivalent plane-wave power density, which represents what would be the power density of the equivalent plane-wave having the same electric or magnetic field intensity. An indication to which field intensity the power density refers, is always given. The equivalent power density is calculated as

$$W (W/m^2) = E^2(V/m) / 377,$$

where E is the electric field intensity (rms value), or

$$W (W/m^2) = H^2 (A/m) \times 377$$

where H is the magnetic field intensity (rms value).

The following instruments were used during the surveys:

- (1) E field survey meter, Narda, model 8616, probe model 8644,
dynamic range: 0.1 mW/cm² - 2 W/cm²,
- (2) H field survey meter, model 25540, probe model 8635,
dynamic range: 0.1 - 25 (A/m)²,

- (3) H field survey meter, model 8616, probe model 8633
dynamic range: 0.1 mW/cm² – 100 mW/cm²

All these instruments operate at frequencies from 10 MHz to 300 MHz, are calibrated with an accuracy of ± 0.5 dB, and their probes have isotropic spatial response.

- (4) Electric field sensor, Instrument for Industry,
model EFI,
dynamic range: 1 – 300 V/m
frequency: 10 kHz – 200 MHz,
calibration accuracy: 5% (the meter only)
spatial response: unidirectional

This E field sensor has a probe consisting of one dipole and is therefore sensitive only to the field component parallel to it. Measurements were taken by rotating the probe in mutually perpendicular directions and the total field calculated from the three readings using the following equation

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

where E_x , E_y , E_z are the field intensities in the directions x , y , z , respectively.

Measurements were performed in all plants during working hours and under normal operating conditions. Field intensities were measured without the operator in the vicinity of the test position and with the operator at the normal operating position. During all the measurements the operator of the sewing machine type sealer had to remain about 0.5 m from the device to operate the device.

To map the fields in the vicinity of the applicator without the operator (minimal perturbation to the measured field) a tape measure was used to determine the distance within ± 0.5 cm. Measurements were taken only at the plane of the applicator.

The probe was located 15 cm from the operator towards the sealer to determine the operator exposure. The operator remained in his normal closest position, so that the highest possible exposure could be measured.

The measurement accuracy was a function of the following factors: the instrument calibration accuracy, the spatial response of the probe, the near-field error of the probe, and the perturbation to the field by the meter, the surveyor and in most cases the operator. Overall uncertainty in the measured equivalent power density was estimated at ± 3 dB.

RESULTS AND DISCUSSION

The fields in the vicinity of the applicator were mapped in the horizontal plane of the applicator for the sewing machine type of devices. The operator was as far away from the applicator as possible, at least 0.5 m. Figure 6 shows the average field intensities (expressed in the equivalent power density) for 17 units. The equivalent power densities for both E and H fields decrease with distance in a nearly linear fashion (note that the ordinate scale is logarithmic). Similar dependence of the field intensities on distance from the applicator was observed for individual sealers. For most sealers of this type, the equivalent power density of the electric field was greater than that of the magnetic field at the same location close to the applicator.

It is clear that, where exposures take place close to the applicator as in sewing machine type sealers, an underestimate or overestimate of the actual exposure occurs, if only one field intensity (E or H) is monitored. If the E field equivalent power density is taken as a measure of exposure one overestimates the actual exposure, and vice versa for the H field.

During the surveys the fields in the vicinity of the operator were measured for 33 sewing machine type sealers, 16 shuttle tray, 4 turntable, 21 pressure sealed applicator and 7 edge glue dryer devices. The field intensities in the vicinity of the operator were measured about 15 cm from the operator toward the applicator. The operator was positioned in the normal operating position closest to the device. Thus, the readings can be considered as the upper limits for typical operating conditions. The results are summarized in Table 3; it should be noted that the data is not corrected for the duty cycle. The highest intensities of the RF fields as well as the

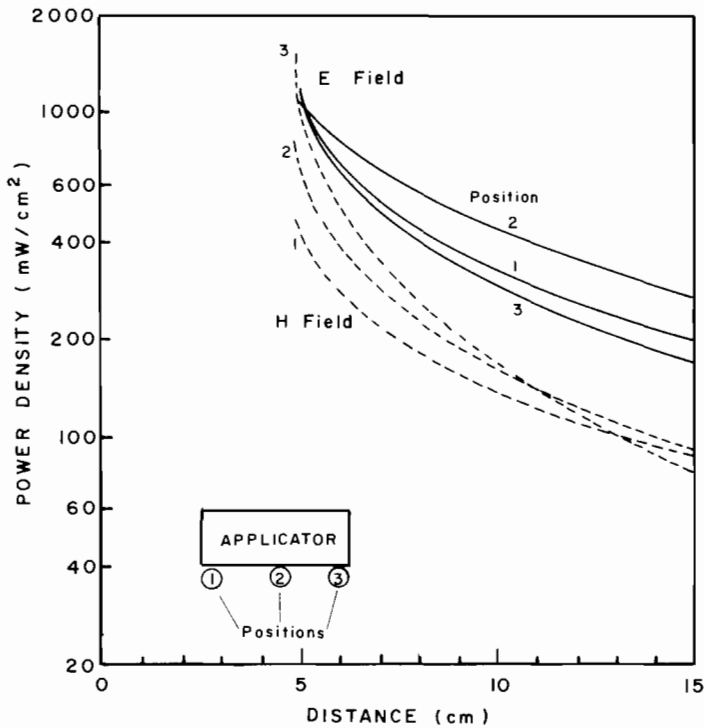


Figure 6 Mean values of the electric and magnetic field intensities expressed in units of the equivalent power density for 17 sewing machine RF sealers.

greatest number of devices having relatively high intensities were found for the sewing machine type sealers. It is worth noting however, that the total RF power output of this sealer type is relatively low. For most machines the output power was between 1 and 6 kW, with a few up to 10 kW. No correlation between the power output and measured field intensities could be established. The stray fields, even very close (about 5 cm) to the applicator for the pressure sealed applicator devices were very small, generally below the sensitivity of the survey instruments (i.e. 75 V/m and 0.32 A/m).

Table 3 The operator exposure — summary

RF Heater Type	Number of Units	E field Exposure (mW/cm ²)			H field Exposure (mW/cm ²)			Body Part max exposed
		mean	min	max	mean	min	max	
Sewing Machine	33	28 (325 V/m)	<0.1*	124 (680 V/m)	10.9 (0.53A/m)	<0.05*	74.4 (1.4A/m)	chest
Shuttle Tray	16	6.2	0.1*	18.6 (260 V/m)	4.7	9	27.7 (0.85A/m)	head
Turntable	4	5.2	1.9	11.8	5.1	1.0	15.0	waist
Pressure Sealed Applicator	21	< 1.5*	<1.5*	<1.5*	<4*	<4*	<4*	N/A
Edge Glue Dryer	7	< 0.1*	<0.1*	<0.1*	<0.1*	<0.05*	0.8	waist

* Since various meters were used during the surveys, the minimum field intensity which could be measured varied.

Table 4 shows the number of devices for each type of RF heater, whose operators are exposed to the electric or magnetic fields with equivalent power densities greater than 5 mW/cm². For the sewing machine sealer 48% had a maximum E field intensity (not corrected for the duty cycle) above 200 V/m and 24% had a maximum H field intensity above 0.5 A/m. Thirty-nine percent of the units exposed the operator to the E or H field having the equivalent power density greater than 25 mW/cm². Whenever the operator's hands are within 15 cm of the applicator while the RF power is on they are exposed to fields greater than 25 mW/cm² for over 90% of the units surveyed.

Table 4 Exposure to the operator exceeding 5 mW/cm (without correction for duty cycle)

Sealer Type	Total Number of Units	Number of units					
		5-10 mW/cm ²		11-25 mW/cm ²		Over 25 mW/cm ²	
		E	H	E	H	E	H
Sewing Machine	33	3	6	5	5	11	3
Shuttle Tray	16	6	1	1	3	0	1
Turntable	4	0	0	1	1	0	0

For the shuttle-tray type 6% produced exposure in excess of that value. The maximum field intensities for the shuttle tray devices were 265 V/m (18.6 mW/cm²) and 0.85 A/m (27.5 mW/cm²) (for the same device). However, only 6% of the devices had the E field exceeding 200 V/m and 25% had H field exceed 0.5 A/m. The output power of this type of sealer is between 3 and 15 kW. The operators are exposed to lower field intensities, since they normally stand at greater distance from the applicator.

To obtain more representative data for the dielectric heater exposure, the measurements should be corrected for the duty cycle as shown in Table 5.

The average intensities of the fields (corrected for the duty cycle) for many devices exceeded the equivalent power density of 1 mW/cm², which was recently recommended as the maximum level by the Canadian Federal Government [5], and even 10 mW/cm², the limit advised by the ANSI standard [6].

Table 5 The operator exposure, corrected for the average duty cycle

Heater Type	Number of Units	Above 1 mW/cm ²		Above 10 mW/cm ²	
		—	%	—	%
Sewing Machine	33	19	58	13	39
Shuttle Tray	16	10	63	1	6
Turntable	4	2	50	0	0
Pressure Sealed Applicator	21	0	0	0	0
Edge-Glue Dryer	7	0	0	0	0
All	81	31	38	14	17

RECOMMENDATIONS AND CONCLUSIONS

The survey of RF heaters in use in Canada has indicated that there is a large variety of devices, and that some may pose a health hazard from exposure to high intensity RF fields. While some types of the heaters do not expose the operators to RF fields greater than 1 mW/cm^2 or 10 mW/cm^2 , for other (sewing machine) sealers, more than half and nearly 40% of the devices expose the operator to fields greater than 1 mW/cm^2 , and 10 mW/cm^2 , respectively.

The results of the survey indicate the presence of a potential health hazard needing solution. However, this survey data alone is insufficiently comprehensive for a conclusive analysis. Since only a limited number of units in some categories (e.g. turntable type) were surveyed, and for others only one parameter was measured (due to instrumentation problems), some of the data gathered may not be fully representative.

On the basis of the survey results obtained, however, the following recommendations can be made. Further surveys should be performed. A study to determine the effect of field perturbations due to the operator's presence should be conducted. A corrective and educational program should be developed to limit exposure to the operator from RF leakage.

Reliable and accurate survey instrumentation is needed for monitoring the fields in the vicinity of the devices to develop safe working practices.

Research effort should be directed toward the following areas: the rate of energy deposition in the human body exposed to the near-field radiation of an RF sealer to determine its biological consequences; the biological effects of exposure to RF fields, having relatively low average power densities but high maximum power densities (e.g. sealers having a low duty cycle) should receive much greater attention.

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REFERENCES

- 1 R. Serota, "Heating with Radio Waves", *Automation*, September 1973.
- 2 D.L. Conover, W.E. Murray, E.D. Foley, J.M. Lary and W.H. Parr, "Measurement of Electric and Magnetic Field Strengths from Industrial Radiofrequency (6-38 MHz) Plastic Sealers". *Proc. IEEE*, Vol. 68, no. 1, 1978.
- 3 I. Chatterjee, M.H. Hagmann and O.P. Gandhi, "Electromagnetic Energy Deposition in an Inhomogeneous Block Model of Man for Near-field Irradiation Conditions", presented at IEEE/MTT-S Intern. Microwave Symp., Washington, D.C., May 28-30, 1980.
- 4 "Report on the Surveys of Radio Frequency Heaters", Environmental Health Directorate, Health and Welfare Canada, Document No. 80-EHD-47, 1980.
- 5 Safety Code — 6. "Recommended Safety Procedures for the Installation and Use of Radiofrequency and Microwave Devices in the Frequency Range 10 MHz-300 GHz". Environmental Health Directorate. Health and Welfare Canada. Document No. 79-EHD-30, 1979.
- 6 ANSI C 95.1-1974. "Safety Level of Electromagnetic Radiation with Respect to Personnel", 1974.

