MEASUREMENT OF RADIATION LEAKAGE FROM MICROWAVE OVENS

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Thesis

Entitled

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MEASUREMENT OF RADIATION LEAKAGE FROM MICROWAVE OVENS

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ABSTRACT

Electromagnetic radiation from microwave ovens in Bangkok areas were investigated by microwave leakage detector model No. MD 2000. The survey was carried out for 738 ovens used in households, restaurants and convenient stores from December 2002 to September 2004. The ovens were from 1 year to more than 10 years old with operating power ranging from 700 to 1000 watt.

The measured leakage was 0.235 ± 0.662 mW/cm^2 and 0.196 ± 0.607 mW/cm^2 without and with water test load respectively. Five ovens (0.68%) were found to leak more than 5 mW/cm^2 limit specified in the standard. The maximum leakage was found at the door screen in a higher percentage (97.4%) of the surveyed ovens but still within the acceptable limit.

In relation to user type, none of the convenience store ovens (4.61%) and restaurant ovens (3.79%) emitted radiation exceeding the limit. In 91.6% of the household ovens, only 0.7% emitted radiation more than 5 mW/cm^2. Ovens used in restaurant are older than the household and convenience store ovens and had a higher operating power.

Statistical analysis by two-way ANOVA showed that there is no relationship between the quantity of radiation leakage and oven age but significantly related to their operating power ($p<0.05$). Based on the statistical calculations, 97% of the ovens emit less than the public exposure limit set by most international standards (1 mW/cm^2) and only 0.68% emit more than the occupational exposure limit of 5 mW/cm^2. Based on the findings in this study and due to the safety of microwave oven design to comply to standards and regulations, no detrimental health effects are expected from microwave ovens in our survey. However, Thailand should have its own standards and regulations to limit radiation from microwave ovens used in the country.

KEY WORDS: MICROWAVE OVEN / RADIATON LEAKAGE / MICROWAVE LEAKAGE LIMIT/ MD 2000

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การตรวจวัดปริมาณรังสีรั่วจากเตาไมโครเวฟ (MEASUREMENT OF RADIATION LEAKAGE FROM MICROWAVE OVENS)

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บทคัดย่อ

การศึกษาวิจัยนี้เพื่อตรวจวัดคลื่นแม่เหล็กไฟฟ้าจากเตาไมโครเวฟในกรุงเทพฯ โดยใช้เครื่องตรวจวัดคลื่นไมโครเวฟรั่ว รุ่น MD-2000 เตาไมโครเวฟที่สำรวจมีจำนวน 738 เครื่อง ที่ได้มาจากบ้านเรือนทั่วไป ร้านค้า และร้านสะดวกซื้อ ในช่วงเดือนธันวาคม พ.ศ. 2545 ถึง เดือนพฤศจิกายน พ.ศ. 2547 เตาไมโครเวฟที่สำรวจได้มีช่วงอายุการใช้งานตั้งแต่ 1 ปี ถึง มากกว่า 10 ปี และมีกำลังไมโครเวฟตั้งแต่ 700 – 1000 วัตต์

ผลการสำรวจพบว่าค่าเฉลี่ยของรังสีรั่วจากเตาไมโครเวฟทั้งหมดมีค่า 0.235±0.662 mW/cm^2 ในกรณีที่ไม่มีโหลดทดสอบ และ 0.196 ± 0.602 mW/cm^2 ในกรณีที่มีโหลดทดสอบเป็นน้ำ และมีจำนวนเตาไมโครเวฟที่มีปริมาณรังสีรั่วเกิน 5 mW/cm^2 ที่ระยะห่าง 5 cm จำนวน 5 เครื่อง (ร้อยละ 0.68) ตำแหน่งของเตาไมโครเวฟที่ตรวจพบปริมาณรังสีที่รั่วสูงสุด คือ ตรงกลางบริเวณฝาปิด-เปิดเตา ซึ่งเตาไมโครเวฟส่วนใหญ่ตรวจพบรังสีรั่วในปริมาณสูงสุด ณ บริเวณดังกล่าวจำนวน 576 เครื่อง (ร้อยละ 91.6) โดยมีปริมาณรังสีรั่วอยู่ในระดับที่ยอมรับได้

จำนวนเตาไมโครเวฟที่สำรวจและตรวจวัดส่วนใหญ่ได้มากจากบ้านเรือนทั่วไป (ร้อยละ 91.6) ซึ่งพบว่าร้อยละ 7 ของเตาไมโครเวฟมีปริมาณรังสีรั่วมากกว่า 5 mW/cm^2 ที่ระยะห่าง 5 cm ในขณะที่เตาไมโครเวฟที่ได้จากร้านอาหาร (ร้อยละ 3.79) และร้านสะดวกซื้อ (ร้อยละ 4.61) มีปริมาณรังสีรั่วไม่เกินระดับที่ยอมรับได้ โดยที่อายุการใช้งานและกำลังไมโครเวฟของเตาไมโครเวฟที่สำรวจได้จากร้านอาหารมีค่าเฉลี่ยมากที่สุดเมื่อเทียบกับแหล่งอื่น ๆ

การวิเคราะห์ทางสถิติโดยใช้วิธีการวิเคราะห์ความแปรปรวนแบบสองทาง พบว่าอายุการใช้งานกับกำลังไมโครเวฟของเตาไมโครเวฟไม่มีความสัมพันธ์ต่อกัน ในขณะที่ปริมาณรังสีรั่วมีความสัมพันธ์กับปริมาณกำลังไมโครเวฟ (ที่ระดับนัยสำคัญ <0.05) จากการวิเคราะห์ทางสถิติพบว่า ร้อยละ 97 ของเตาไมโครเวฟมีรังสีรั่วน้อยกว่าขีดจำกัดทั่วไป (1 mW/cm^2) และร้อยละ 0.68 มีรังสีรั่วสูงกว่าค่าจำกัดเฉพาะงาน (5 mW/cm^2) จะเห็นได้ว่าเตาไมโครเวฟที่สำรวจได้ในพื้นที่ดังกล่าวส่วนใหญ่อยู่ในระดับที่ปลอดภัย และไม่พบว่าเป็นอันตรายต่อผู้ใช้ อย่างไรก็ตามประเทศไทยควรมีการกำหนดมาตรฐานและเกณฑ์ในการจำกัดปริมาณรังสีรั่วสำหรับเตาไมโครเวฟที่ใช้กันในประเทศในลำดับต่อไป

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CONTENT

CONTENT (continued)

LIST OF TABLES

LIST OF TABLES (continued)

TABLE **Page**

LIST OF FIGURE

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS AND ABBREVIA	TERM
σ^2	Variance
A	Ampere
ANSI	American National Standards Institute
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency Standard
CCIR	International Radio Consultative Committee
cm	Centimeter
EHF	Extremely high frequency
ELF	Extremely low frequency
EM	Electromagnetic radiation
f	Frequency
FCC	Federation Communications Commission
FDA	Food and Drug Administration
GHz	Gigahertz
H_2O	Hydrogen dioxide
HF	High frequency
hr.	Hour
Hz	Hertz
ICNIRP	International Commission on Nonionizing Radiation Protection
IEEE	Institute of Electrical and Electronic Engineer
IRPA	International Radiation Protection Association
ISM	Industrial scientific medical
ITU	International Telecommunications Union
kHz	Kilohertz
LF	Low frequency
MAX	Maximum
MF	Medium frequency

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

SYMBOLS AND ABBREVIA	TERM
MHz	Megahertz
min	Minute
Min	Minimum
ml	Milliliter
mm	Millimeter
mW/cm^2	Milliwatts per square centimeter
mW/g	Milliwatts per gram
NCRP	National Council on Radiation Protection and Measurement
n	Number (count)
nm	Nanometer
No.	Number
RED	Radiation emitting device
RF	Radiofrequency
SAR	Specific absorption rate
SD	Standard deviation
SHF	Super high frequency
TV	Television
UHF	Ultra high frequency
UK	United Kingdom
US	United State of America
V	Volt
VHF	Very high frequency
VLF	Very low frequency
W	Watt
W/kg	Watts per kilogram
WHO	World Health Organization
y	Years

CHAPTER I
INTRODUCTION

The practical uses of electromagnetic energy at microwave and radiofrequencies is in providing telecommunication services, e.g., radio and television broadcasting, cellular telephone, satellite communication, etc. Microwave energy is also applicable in non-communicable uses such as microwave diathermy or microwave heating. Microwave oven represents the most universal connection of microwave technology to the every life of people worldwide.

Usage of microwave ovens has increased significantly over the last decade. As a result, public concern about the possible harmful effects of microwave ovens has become an issue. In particular, the effects of leakage of electromagnetic radiation (EMR) from microwave ovens have been raised.

In Thailand, due to the high increase of the use of microwave ovens in households, offices and restaurants, it was necessary to control the radiation of each installed oven. Till now there is no law or regulation by the Thai Government.

Many countries have proposed the specific standard controlling product design of microwave ovens before marketing or import & export, including before or after services. The standard also covers the limit or the maximum allowable of radiation leakage from the microwave ovens. The general consensus from authorities around the world concerned is that leakage levels from ovens in good working order are low and that they do not pose a health hazards.

The Food and Drug Administration (FDA) in USA has determined Radiation leakage acceptable at a maximum level of 1 mW/cm^2 at the distance of 5 cm for new ovens and not more than 5 mW/cm^2 at the distance of 5 cm for the oven in present use. The prescription of these rules and regulations lead to product development.

In Thailand, microwave oven has been used for more than 20 years, but there is currently no adopted emission standard and regulation for their proper use and maintenance. This demonstrated the need for field assessment of electromagnetic leakage from microwave ovens used in Thailand.

In This study visits to households and restaurants were carried out to investigate the oven leakage and the dependence of measured leakage on parameter such as oven operating power and oven age.

CHAPTER II
OBJECTIVE

The objectives in this study

1. To survey and measure radiation leakage of domestic and restaurant microwave ovens in Bangkok area.
2. To investigate the dependent parameters on measured leakage, such as oven age and operating power.

Research Scope

1. Measurements are to be carried out by visiting households, restaurants and convenient stores in Bangkok (Rama 4 Citycort apartment Silom, Lalanee village Bangpakok, Srinakarintwirot University Demonstration School Patumwan, restaurants and convenient store and other houses)
2. The survey is to be conducted using a microwave leakage detector model no. MD-2000 that rated for a maximum power density of 9.99 mW/cm^2 and a minimum sensitivity of 0.01 mW/cm^2. (Warning Value : 5.0 mW/cm^2)
3. The emission limits is set at $\leq$ 1 mW/cm^2 at 5 cm for new ovens and $\leq$ 5 mW/cm^2 at 5 cm for use ovens.

Useful results that tend to receive in future

1. Users recognize the effect of radiation leakage from microwave ovens and are able to monitor radiation leakage from their own microwave oven.
2. The levels of leakage in compliance with acceptable limits.
3. Safe microwave operation and safety precautions for used.
4. Availability of statistical information for national authority to establish emission standard and regulations.

CHAPTER III

LITERTURE REVIEW

3.1 Radiation

Radiation is energy that travels through space or matter, displaying the properties of either particles or waves, depending on how it is measures and how it interacts with matter.

3.1.1 Electromagnetic Radiation (EM)

Visible light, radio waves, and X-rays are different types of EM radiation. EM radiation is characterized by wavelength (λ), frequency (υ) and energy per photon (E). Categories of EM radiation (including radiant heat; radio, TV, and microwaves; infrared, visible and ultraviolet light; and X-rays and gamma rays) comprise the electromagnetic spectrum (Figure 3-1).

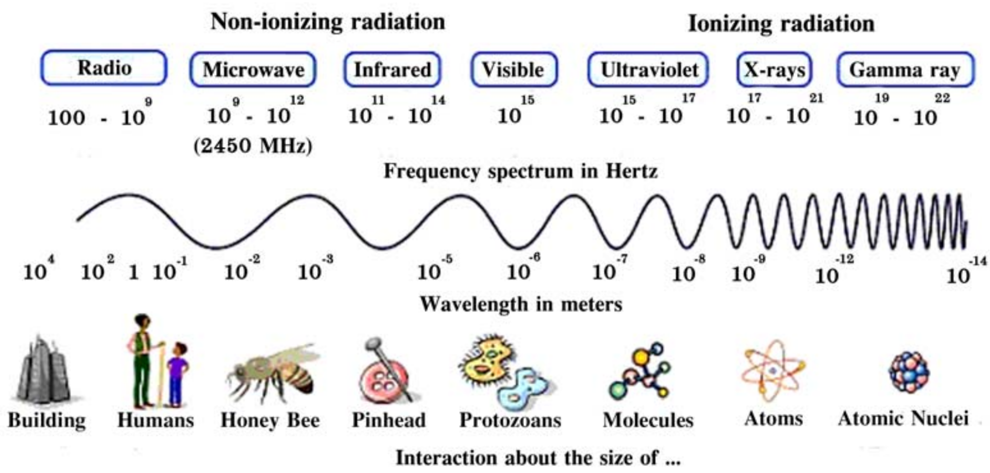

Figure 3-1 Electromagnetic spectrum

Some practical application EM radiation include: (a) gamma rays, which emanate from within the nuclei of radioactive atoms and are used for radionuclide imaging; (b) X-rays which are produced outside the nuclease and are used in radiography; (c) radiofrequency EM radiation, the most important use is for processing of information or communication and used to interact with materials for some benefit such as heating.

3.1.2 Ionizing vs. Non-ionizing radiation

EM radiation of higher frequency than the near-ultraviolet region of the spectrum carried sufficient energy per photon to remove bound electron from atomic shells, thus producing ionizing atoms and molecules is called ionizing radiation. EM radiation with energy below the far-ultraviolet region is called non-ionizing radiation. (14,24,26)

Ionizing radiation

The frequency of ionizing radiation is measured in millions of trillions of hertz (cycles per second). The energy contained in a given photon is proportional to its frequency, which means that the higher the frequency, the higher the energy. The tremendous photon energy of X-rays and gamma rays (because of their extremely high frequencies) is capable of changing the internal structure of atoms and molecules, as well as being immensely penetrating. This is the sort of radiation we associate with radioactive substances such as uranium, radium, and radiation emitted during atomic and thermonuclear explosions. Ionizing radiation has sufficient energy to cause actual chemical changes to take place within the molecular structure of matter, damaging the cells of living tissues by creating electrically charged, or “ionized,” molecules, and causing genetic mutations. These deadly rays are particularly dangerous because they are initially imperceptible, causing little or no temperature rise within the exposed matter, and since their damaging effects are cumulative, even slight exposure is hazardous.

Non-ionizing radiation

Non-ionizing radiation covers all of the lower-frequency radiation. Because of their significantly lower frequencies, and therefore lower energy, they do not have the same damaging and cumulative properties as ionizing radiation. Microwave radiation is non-ionizing, and in sufficient intensity will simply cause the molecules in matter to vibrate, causing friction, which produces heat. The danger from microwave radiation, then, exists in the cooking or heating effect.

Microwaves, like visible light, are a part of the electromagnetic radiation spectrum. They are extremely high frequency radio waves. As the frequency of radiation increases, its wavelength decreases, so very high frequencies correspond to very short wavelengths; hence the name microwaves. Infrared radiation, ultraviolet light and X-rays are also electromagnetic radiation, but have even shorter wavelengths than microwaves.

Microwaves may be reflected, transmitted or absorbed by matter in their path. Metallic materials totally reflect microwaves. Most non-metallic materials such as glass and plastics are partially transparent to microwaves. Material containing moisture, such as food and even people, absorbs microwave energy. If energy is absorbed at a rate greater than the rate at which the material looses energy (i.e. rate of cooling), its temperature will increase. In the Modern world is full of devices which, either directly or indirectly, acts as source of non-ionizing radiation. These sources produce non-ionizing radiation in electromagnetic spectrum of wavelengths/ frequencies ranging from 100 nm to static fields.

In general, non-ionizing radiation tends to be less hazardous to humans than ionizing radiation (ionizing radiation has a wavelength less than 100 nm or a photon energy greater than 12.4 electron Volts). However, depending on the wavelength/ frequency and the irradiant (or power density) value, non-ionizing radiation source may present a human health hazard.

3.2 Radiofrequency and microwave radiation

Radiofrequency (RF) radiation spans the frequency range from 3 kHz to 300 MHz. Microwave radiation occurs at higher frequency from 300 MHz to 300 GHz. Radiation below 3 kHz is referred to as extremely low frequency (ELF). The bands of radiofrequency and microwaves are show in Table III-1

Table III-1 Band of radiofrequency and microwave radiation.

Frequency Range	**Wavelength Range**	**Name**
>300 GHz	<1 mm	Infrared
30 GHz – 300 GHz	10 mm – 1 mm	Extremely high frequency (EHF)
>3 GHz – 30 GHZ	10 cm – 1 cm	Super high frequency (SHF)
300 MHz – 3 GHz*	1 m – 10 cm	Ultra high frequency (UHF)
30 MHz – 300 MHz	10 m – 1 m	Very high frequency (VHF)
3 MHz – 30 MHz	100 m – 10 m	High frequency (HF)
300 kHz – 3 MHz	1 km – 100 m	Medium frequency (MF)
30 kHz – 300 kHz	10 km – 1 km	Low frequency (LF)
3 kHz – 30 kHz	100 km – 10 km	Very low frequency (VLF)
300 Hz – 3 kHz**	1000 km – 100 km	Voice frequency
>0 Hz***– 300 Hz	>1000 km	Extremely low frequency (ELF)
0 Hz	-	Static

* Frequencies >300 MHz up to 300 GHz are referred to “Microwave waves”

** Frequencies >3000 kHz up to 300 MHz are referred to as “Radiofrequencies”.
Lower frequencies are referred to as “Subradiofrequencies”.

*** A traditional definition of extremely low frequencies was frequencies between 30 Hz and 300 Hz

Human-made source of RF and microwave radiation are generated by a variety of device. These include power grid tubes, linear beam tubes such as klyptrons, cross-field device including magnetron and amplitrons, and solid state device. Once microwave energy is generated, it can transmit to an antenna through a waveguide or coaxial transmission line. Radiating antennas including reflectors are used to transmit microwave energy through free space or dielectric materials. The transmitted energy can be used directly as in a communication system or converted to other energy from such as heat via a microwave oven. Examples of other applications are summarized in Table III-2.

Table III-2 Applications of RF and Microwave Radiation

Application	Frequency Range
Video display units	ELF – 300 kHz
Industrial dielectric heaters	kHz – 27 MHz
Industrial welders	kHz – 27 MHz
Communication/broadcasting transmitters for radio and television	
High frequency (HF)	3 – 30 MHz
Very high frequency (VHF)	30 – 300 MHz
Ultra high frequency (UHF)	0.3 – 3 GHz
Medical applications	
Microwave blood warmers	27 MHz – 2.45 GHz
Electrosurgical devices	27 MHz – 2.45 GHz
Microwave ovens	2.45 GHz

Authorities, who regulate the use of the spectrum, the Federation Communications Commission (FCC), and the International Telecommunications Union (ITU), set aside specific bands of frequency, i.e., industrial-scientific-medical (ISM) for these uses. Table III-3 list the primary ISM bands available today.

Table III-3 Frequency allocation of ISM application

Frequency (MHz)	Region	Condition
6.765 – 6.795	Worldwide	Special authorization with CCIR* limits both in band and out of band
13.533 – 13.567 26.957 – 27.283 40.66 – 40.70	Worldwide	Free radiation bands
433.05 – 434.79	Select countries in region 1**	Free radiation bands
433.05 – 434.79	Rest of region 1**	Special authorization with CCIR* limits in band
886 – 906	U.K. only	Free radiation bands
902 – 928	Region 2***	Free radiation bands
2.40 – 2.50 x 10^3	Worldwide	Free radiation bands
5.725 – 5.875	Worldwide	Free radiation bands
24.0 – 24.25	Worldwide	Free radiation bands
61.0 – 61.5 122 – 123 244 – 246	Worldwide	Special authorization with CCIR* limits both in band and out of band

* CCIR = **International Radio Consultative Committee** of the International Telecommunications Union (ITU)

** Region 1 comprises Europe and Parts of Asia; the selected countries are the Federal Republic of Germany, Austria, Liechtenstein, Portugal, Switzerland and Yugoslavia

*** Region 2 comprises the Western hemisphere

3.3 Hazards of non-ionizing radiation

The properties and hazards of non-ionizing radiation can best be understood by considering the electromagnetic spectrum as three broad categories:

- Optical radiation (100 nm to 1 mm)
- Microwave radiation (300 GHz to 300 MHz)
- Radiofrequency and lower frequency radiation (300 MHz to static fields)

Basic characteristic of optical radiation (Ultraviolet, Visible light, Infrared):

- Process small wavelengths, large frequencies, and substantial energy (Extreme UV approaches the photon energy of ionizing radiation).
- Both thermal and photochemical (biological) effects are possible from exposures depending on wavelength.
- Exposures normally occur in the far field where the electric fields and magnetic fields are strongly coupled.
- The inverse square law applies to any analysis of the radiation field.
- Only power density measurements are normally considered in hazard analysis.
- The radiation interacts readily with surfaces and can easily deposit energy in human tissues.

Basic characteristic of microwave radiation:

- Process intermediate wavelengths, low frequencies, and moderate photon energy
- Both thermal and induced current (biological) effects are possible from exposures.
- Exposures may occur in the near field and far fields.
- The hazard analysis, both electrical field and magnetic field measurements must be considered in addition to the power density measurements.
- This type of radiation resonates from standing waves in tissue dimensions with multiples of 1/2 wavelength that depending on tissue orientation to the wave plane.

***Basic characteristics of radiofrequency and lower frequency fields*:**

- Possess large wavelengths (>1 m), small frequencies, and very low energy.
- Circuit theory can be applied to an analysis of the radiation field.
- In general there is poor energy deposition in human tissue but thermal and induced current (biological) effects are possible.
- Exposures usually occur in the near field where the electric fields and magnetic fields are not coupled.
- The inverse square law may not apply.

- The electric fields and magnetic fields measurements must be considered separately for a hazard analysis.
- At radiofrequency and lower frequency fields and static fields, the magnetic field dominates the hazard analysis.
- This type of radiation can easily penetrate, but rarely deposit energy in tissue.

3.3.1 Factors Affecting Exposure to Microwave/RF Radiation

The hazards from exposure to microwave/RF radiation are related to the following parameters:

- Frequency of the source
- Power density at the point of exposure
- Accessibility to the radiation field
- Does the exposure occur in the near or far field
- Orientation of the human body to the radiation field

This combination of factors is used in both evaluating and mitigating the hazard.

3.3.2 Biological effects

Non-ionizing radiation is not normally quantified in terms of dose because of the difficulty in calculating energy absorption per unit mass. With non-ionizing radiation, deposition is normally quantified in terms of energy or power absorption per unit area (mW/cm^2).

Because of the complexity and limited understanding of the detailed nature of microwave absorption, a dose unit analogous to the rad or Gy, expressing a specific absorption rate is not feasible. The quantity used to measure how much RF energy is absorbed in the body is called the specific absorption rate (SAR). It is usually expressed in emits of watts per kilogram (W/kg) or milliwatts per gram (mW/g).

The primary physical effect of microwave or radiofrequency electromagnetic radiation is heating. Heating mechanism include joule heating due to ionic current induced by electric field or polar molecular vibration induced by oscillating electric fields.

Thermal effects occur for exposure great than 10 mW/cm^2 and include hypothermia or increases in body temperature. Common temperature induced effects are cataract formation in the lens of the eye and loss of fertility as a result of temperature changes in testicles.

Non-thermal effects, which may occur at a below 10 mW/cm^2, are not clearly understood , and the data are less definitive. The more common non-thermal effects include increased fatigue, headaches, irritability, sleepiness and decreases in olfactory sensitivity.

3.3.3 Potential Bioeffects of Exposure to Microwave/RF Radiation

In general, most biological effects of exposure to microwave/RF radiation are related to the direct heating of tissues (thermal effects) or the flow of current through tissue (induced current effects). Non-thermal effects resulting in carcinogenesis, teratogenesis, etc. have been demonstrated in animals but have not been proven by epidemiological studies on humans. The following biological effects have been demonstrated in humans:

- Cataract formation (from eye exposure).
- RF (induction) burns.
- Burns from contact with metal implants, spectacles, etc.

3.4 Protection Standards

Many different government agencies and professional societies have developed recommendations and standards for exposure to electromagnetic radiation. These include:

The International Radiation Protection Association (IRPA)

The International Commission on Nonionizing Radiation Protection (ICNIRP)

The World Health Organization (WHO)

The American National Standards Institute (ANSI)

The Institute of Electrical and Electronic Engineer (IEEE)

The National Council on Radiation Protection and Measurement (NCRP)

and etc.

Prior to the industrial revolution, the natural background radiation of electric and magnetic field is quite low. However, the advancement and proliferation of technology have resulted in the exposure to increasing levels and varieties of EMR. The most significant contributors to increasing levels of EMR include the growth of electric power generation and transmission systems, and the proliferation of EM field generating devices in industrial facilities, homes, public transit systems and office areas. These devices include electric motors, computer and common application such as microwave ovens, hair dryers and electric blank etc.

Because of the fundamentally different nature of the interaction of the interaction of different radiofrequecy, the standards for exposure are expressed in different forms.

3.4.1 Radiofrequency Standard

Most radiofrequency field standards are based on a limiting SAR (W/kg) for frequency above about 1 MHz and extending up to several GHz. For lower frequencies, extending down to 300 Hz, more emphasis is placed on electrostimulation by induced currents (mA/m^2). For frequency above 10 GHz, the incident energy is absorbed essentially at the surface, and the heating is limiting expressed in the units of energy per unit area (W/m^2) is the quantity that relates best to biological effects.

The initial safety standard for exposure to radiofrequency radiation was a single value, a power density of 10 milliwatts per square centimeter (mW/cm^2). It was independent of the frequency. In 1982, new limits were developed by the ANSI (C95) committee, which included dependence on the frequency. The occupational limits were still based on limiting the SAR in the body. The limit chosen was 0.4 W/kg (average) and it applied to whole-body exposure either from continuous wave on pulsed radiation over any 0.1 hour period.

The safety criterea are based on reported threshold SARs at frequencies between approximately 100 kHz and 6 GHz for most sensitive biological endpoints that can be related to human health. The whole-body average SARs in human limit to 0.4 W/kg in the working environment is also recommended for the general public.

In 1984, NCRP published recommendation on exposure criteria for radiofrequency electromagnetic field as given in Table III-4 (2). The occupational limits were similar to those published by ANSI (C95) in 1982, based on the fundamental SARs exposure criterion of 0.4 W/kg and set the averaged exposure criterion for the general public at one-fifth that of the occupationally exposed individual, at 0.08 W/kg. The 1982 C95 ANSI was revised by IEEE in 1991 and adopted by ANSI in 1992.

Table III-4 Radiofrequency protection guides from National Council on Radiation Protection are Measurement, 1986.

Frequency range	Occupational*			Public**
	Equivalent Power density (mW/cm^2)	Electric field (V/m)	Magnetic field (A/m)	Equivalent Power density (mW/cm^2)
300 kHz – 3 MHz	100	632	1.58	20
3 MHz – 30 MHz	$900/f^2$	63.2 (30/f)	0.158	$180/f^2$
30 MHz – 300 MHz	1.0	63.2	0.158	0.2
300 MHz – 1.5 GHz	f/300	3.65 (f/17.3)	0.0091f	f/1500
1.5 GHz – 100 GHz	5.0	141	0.354	1

Source : NCRP,1986 (21)

* Measured 5 cm or greater from any object in the field and average for any 0.1 hr. (6min)

** The protection guide for the publish was set at one-fifth the occupational exposure criterion

Note : f , frequency (MHz); both f and are used to denote frequency.

3.4.2 Microwave Ovens Safety Standards

U.S. FDA: Food and Drug Administration

The U.S. Food and Drug Administration between 1971 and 1980 promulgated special standards for microwave ovens. The regulation was issued under authority granted in the Radiation Control for Health and Safety Act of 1968. Limits were set for ovens prior to sale and increased to allow for same leakage as the oven became older. They were:

< 1 mW/cm^2 at 5 cm from external surface prior to sale

< 5 mW/cm^2 thereafter

Measurements were to be made with the oven loaded with 275 ml H_2O in a glass beaker centered in the oven.

International Standards (ICNIRP 1998)

ICNIRP, 1998 (21), limit exposure of the general public to RF power to 1 mW/cm^2 at 2,450 MHz. These standards are designed to protect against the thermal effect of the microwave power. Although the 1 mW/cm^2 limit is below the maximum permissible emission of 5 mW/cm^2, the expected exposure for a microwave oven user is generally below the 1 mW/cm^2 limit because of the diverging nature of the microwave radiation.

Canadian Safety Limits

The Canadian Regulation dealing with microwave ovens were promulgated under the Radiation Emitting Devices (RED) in 1974 (21). The microwave radiation leakage at 5 cm from the outer surface of the oven must not exceed 1 mW/cm^2 with a test load in a cavity and 5 mW/cm^2 without a test load. In the case of an oven that is designed for cooking and that has a total microwave power generating capacity not greater than 1.5 kW, the test load shall be 275 ± 15 ml of water at an initial temperature of 20 ± 5 ^oC.

Australian Radiation Protection and Nuclear Safety Agency Standard (ARPANSA)

The ARPANSA sets recommended limits of maximum exposure levels to radiofrequency fields 3 kHz to 300 GHz (4). At the microwave frequency of 2,450 MHz, the whole-body exposures limit when average over a six-minute period is 10 W/m^2. The SAR of 0.08 W/kg will be created by a whole-body exposure in 10 W/m^2 power density field. This limits the body temperature increase to no less than 0.02 ^oC. The 5 mW/cm^2 at 5-cm exposure limit was written in an Australian Standard.

The emission limit of 1 mW/cm^2 at 5 cm at manufacture and 5 mW/cm^2 at 5 cm after sale is still in use in the U.S., Canada and Australia. Similar standards are used in many countries; some countries also require that microwave ovens be checked every 3 years.

The SAR at 5 cm from the oven where the emission was 5 mW/cm^2 was found to be 0.256 W/kg. When measured as close as practical to the door (<1-mm) the SAR was 7.95 W/kg. Based on the inverse square of the distance, this would result in an estimated SAR of 0.0056 W/kg at a distance of 30 cm from the oven (5)

3.5 Microwave Oven

3.5.1 Source of Microwave Power

The most successful tube for power applications is the magnetron. Currently available magnetrons include the cooker magnetron for microwave ovens and its derivatives (300 – 3000 W) and the high power (25 – 100 kW and even more) magnetron at 915 MHz (or 896 MHz for UK).

The cooker magnetron is the remarkable breakthrough that was key to the microwave oven revolution. The cooker magnetron typically provides approximately 800 – 1000 W into a matched load at 2.45 GHz with and efficiency of approximately 70% (Figure 3-2)

An inexpensive cooker magnetron exists only for powers at approximately 500 – 1000 W at 2.45 GHz. Suppliers exist in Japan, Korea, Thailand, Russia and China. The estimated worldwide production of this magnetron and its derivatives is between 30 – 40 million tubes per year. It is used in consumer microwave ovens, commercial microwave ovens and most of the industrial application of microwaves.

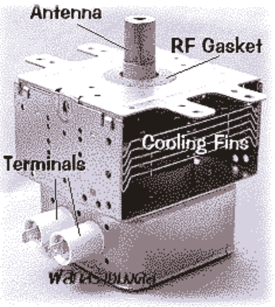

Figure 3-2 Magnetron

3.5.2 Microwave Oven

Microwave ovens use microwave radiation to cook food, either in the home or in commercial or other premises. There is no evidence to suggest that microwave ovens when used according to the manufacturer's instructions and maintained in good working order will be a radiation hazard. Some features of microwave ovens and precautions in their use are described.

In the microwave oven, an electronic device called a magnetron is used to produce the microwaves. These microwaves have a frequency of 2,450 MHz. The microwaves then pass into the enclosed metal oven cavity where they are reflected around the oven walls and absorbed in food or drink placed in the oven. Uneven absorption may cause localized "hot spots". (Figure 3-3)

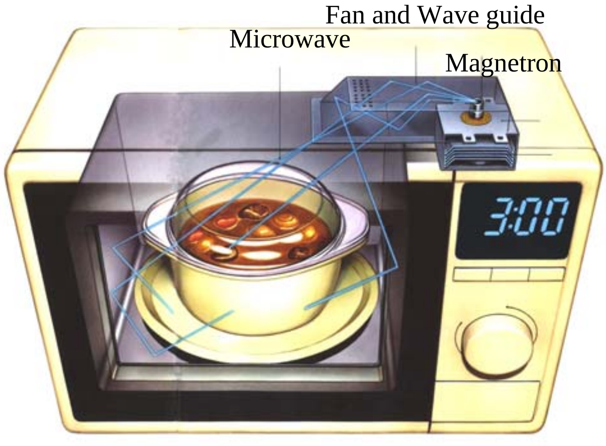

Figure 3-3 Microwave Oven

The microwaves penetrate the food or liquid and agitate the water molecules within. This causes molecular friction, which produces heat and results in a rapid rise in temperature. Cooking time is usually much shorter than in a conventional oven. The rate of heating depends on the moisture content, shape, volume and mass of food present. Uneven heating can occur in some foods where the outside may be only warm while the inside may be close to boiling (jam filled donuts or meat pies are examples). In other foods, some parts will be cooked, while others are not. Some parts of frozen food may remain frozen if insufficient time is allowed for the heating process.

The oven walls and most non-metallic cooking utensils are not directly heated by microwaves because they do not absorb microwave energy. However, the inside of the oven will feel warm due to the presence of the hot food and heat from the electrical circuits.

Exposure to sufficiently high levels of microwaves will cause heating. In the case of human tissue, excessive heating could have serious health effects, such as deep tissue burns and even death. Extensive research has provided no conclusive evidence that microwave exposure, at any level, either causes or promotes cancer

Microwaves generated in microwave ovens cease to exist once the electrical power to the magnetron is turned off (like visible light from light globes). They do not remain in the food when the power is turned off. Neither can they make the food or the oven radioactive. Therefore, food cooked in a microwave oven is not a radiation hazard.

All microwave ovens have at least two safety interlock switches which stop the generation of microwaves immediately the door is opened. The design of modern microwave ovens is such that the microwaves should be contained within the oven, but it is still possible for some leakage to occur around the doors of certain microwave ovens.

The Standard specifies a test to assess the level of microwave leakage and states that 'The microwave leakage at any point 50 millimeters or more from the external surface of the appliance shall not exceed 50 watts per square meter. This Standard applies to ovens designed for domestic applications, even if used in a workplace. The recommended limit is conservative and includes significant safety factors, so that even leakage levels marginally above the limit will have no effect on human health.

Surveys by testing authorities have shown that microwave oven leakage levels in excess of the recommended limits are rare and an oven in good condition and used correctly is safe. If an oven appears to have deteriorated or is damaged, it should not be used until a qualified service inspector has tested the oven and checked that the leakage does not exceed the recommended limit. Routine testing of microwave oven leakage is not considered necessary.

Even when very close to a microwave oven, modern pacemakers are not likely to be susceptible to interference where leakage levels are within the recommended limits. Persons with pacemakers should obtain and rely on their own medical advice in this respect.

3.5.2.1 Microwave Cooking and Nutrition

The majority of reports published on the nutritive value of foods cooked in microwave ovens indicate that food prepared in this manner is at least as nutritious as comparable food cooked by conventional methods.

Most of these studies have concentrated on vitamin retention and indicate that cooking in minimal water for a reduced time, as occurs with microwaving, promotes the retention of the water-soluble vitamins particularly of vitamin C and thiamine. Microwave cooking is preferable to boiling to minimize the leaching of vitamins into the cooking water; in this regard, it is similar to steaming. Far less information is currently available on the effect of microwave cooking on other food components such as carbohydrates, lipids and fat-soluble vitamins. For the same reasons given for vitamin C, microwave cooking enhances mineral retention in vegetables.

The quality of protein is higher in microwave than in conventionally cooked food as far less oxidation occurs in meat cooked in a microwave. Lack of browning is visible evidence that heating is gentler, and makes it likely that vitamins A and E are better retained than in conventional cooking. However these differences are likely to be slight and of little nutritional significance.

Reheating food quickly in a microwave retains more nutrients than holding food hot for long periods; this is significant in institutions and hospitals where food may be held hot for several hours in traditional catering systems.

The nutritional value of food does not depend only on the way in which it is cooked. Just as important are shopping wisely for quality products, correct temperature control during storage and preparation and serving food promptly after it is prepared. Leaching effects aside there seems to be little difference to the retention of nutrients between foods cooked by microwaves or by conventional means, providing cooking time and temperature guidelines are carefully followed.

3.5.2.2 Microwaves and Food

Effect on Food

All food undergoes changes when heated; there is no solid evidence that microwaves cause any effect on food other than those due to rapid heating. Care should be taken to avoid overcooking.

Radiation and Food

Food cooked in a microwave oven does not present a radiation risk. Microwaves cease to exist as soon as the power to the magnetron of a microwave oven is switched off. They do not remain in the food and are incapable of making either it or the oven radioactive.

Chemical Changes in Foods

Consumer concern has been caused by media coverage of isolated reports, which suggest that microwave heating produces chemical changes in foods with the formation of potentially toxic compounds. The most widely reported of these was a letter which appeared in the reputable journal 'The Lancet' in 1989. This work was reviewed by an expert committee of the National Health and Medical Research Council which concluded that the results obtained in the experiment were not relevant to the way food is prepared and consumed. A second more recent report in a little known Swiss journal also appears to be irrelevant to domestic use of microwave ovens.

3.5.2.3 Microwave Ovens and Uneven Heating

Food cooked in a microwave oven does not heat uniformly and unwanted microorganisms may survive in portions of poorly heated food.

Manufacturers use stirrer fans and turntables and recommend standing times to help alleviate the problem of uneven heating. Many microwavable meal packs carry the instruction to stir the food part way through the cooking process. Items such as lasagna that cannot be stirred should be allowed standing time to allow the whole product to reach a uniform temperature. How far microwaves are able to penetrate into the food will also depend on the thickness of portions and on the composition and moisture content of the food. When heating large quantities of food it is more effective to divide it into smaller portions for reheating than it is to heat a large amount for longer. Care should be taken that frozen food has been completely thawed. Water absorbs microwaves far more easily than ice does; incomplete thawing will result in uneven cooking and the potential survival of undesirable microorganisms in those parts of the food, which have been insufficiently heated. A positive feature of microwave ovens with regard to food safety is that food can be taken from the freezer, thawed quickly, cooked and served without it spending long periods of time in the danger temperature zone between 4^{o}C and 60^{o}C, which provides favorable conditions for the growth of dangerous microorganisms.

3.5.2.4 Microwave Ovens and Burns

Microwave ovens are less likely to cause burns than are conventional ovens. However, the potential hazard of burns associated with microwave cooking is not often considered, and many people allow young children to operate these appliances unsupervised.

Burns have occurred from the steam emitted from microwaveable popcorn bags and similar closed packages and from the boiling portions of foods, which heat unevenly. An example of this is a jam-filled donut; the jam centre may exceed the boiling point of water while the donut itself is only warm. Frozen macaroni cheese is another example as the cheese reaches a high temperature more quickly and retains more heat than the macaroni. Severe scalding has also occurred when babies have been given milk heated in a microwave oven. When using new crockery for the first time in a microwave oven, use oven gloves to remove the item after heating, until you are aware of its heating characteristics. There have been instances when some types of crockery mugs have absorbed more heat than the liquid they contained causing unexpected burns.

3.5.2.5 Containers and Films for Microwave Cooking

Only utensils designed for the purpose should be used in a microwave oven. However, as there are no standards currently available for claims such as 'microwave-safe,' any concerns about the safety of such products should be referred to the manufacturer. Some additives used in the manufacture of plastics, particularly those that make it pliable, may migrate into food, especially at high temperatures. Only those plastic containers, which have been specifically designed for microwave cooking, should be used, and they should be discarded when the surface shows any signs of breaking down.

When plastic films are used in microwave ovens, it is preferable that they are not in direct contact with the food they cover. Meals to be reheated on a plate may be covered with clean white absorbent kitchen paper to prevent spatter. It is very important that food containers, which have been designed to package frozen or chilled foods such as ice cream or margarine, are not exposed to high temperatures in a microwave oven. The low melt temperatures of these plastics may result in migration of undesirable contaminants into the food or in physical disintegration of the containers themselves. As migration is more likely to occur into hot fatty foods, glass containers are preferred to plastic for heating them.

Container shape may also influence the way a food reacts to reheating. Circular or oval containers help prevent edges of the food burning because energy absorption occurs evenly around the edges. Square containers tend to encourage burning on the edges of a product. Shallow containers, because they provide a large surface area, are a good choice for heating foods.

Packaging for microwavable meals has been especially designed for use at high temperatures. This sophisticated packaging may incorporate susceptors (surface layers) to compensate for some of the limitations of microwave cooking. Susceptors consist of a plastic film metallised usually with aluminum and laminated to paper or paperboard to hold the required shape. They are designed to enhance browning and crisping of a product and to improve its texture. For example without the use of susceptors, pizzas heated in a microwave oven would be soggy.

Susceptors absorb microwave energy and heat food mainly by direct contact. Suspected materials have been tested for both migration levels of undesirable chemicals and the release of any volatiles, but tests have not revealed that they pose any threat to consumer safety. However, because manufacturers of microwavable foods and packaging materials are continually looking at new ways of improving their products by improving the design of susceptors, it is essential that surveillance of high temperature packaging materials be sustained. The packaging industry recognizes the problems of potential migration from packaging into food, constantly monitors, and improves manufacturing processes.

3.5.2.6 Radiation and Leakage

Microwave oven doors are designed with at least two features, which ensure that power is cut off immediately the door is opened. However, it is possible for microwaves to leak out around the edges of a badly fitting or damaged door. If a door does not fit squarely and operate smoothly or if it shows signs of corrosion or damage, the oven should be inspected by a qualified technician.

3.6 Radiation Leakage Detector

Of the several instruments manufactured to measure microwave power density, only a few are satisfactory for determining compliance with the microwave oven standard. The proper procedures for use that described below.

NARDA 8100 System:

This instrument covers the two frequency bands used for microwave cooking, 915 and 2450 MHz. It utilizes interchangeable probes to provide four full-scale measurement ranges.

NARDA 8200:

This is a single frequency instrument usually cover the 2450 MHz band. However, some 8200's have been produced that cover 915 MHz rather than 2450 MHz.

Holaday HI 1500:

The HI 1500 is the single frequency instrument operating at 2450 MHz. (9)

3.7 Research Review

Tongruang and Parisanyakul (28) determined radiation leakage from 98 microwaves from October 1991-September 1994, they used radiation leakage detector-Narda Microwave Corporation model 8100B with probe and spacer. In this survey 96.94% of the microwave ovens was found, to have radiation leakage not exceed 1 mW/cm^2 at 5 cm from the external surface of the oven, 2.04% and 1.02% of the ovens have radiation leakage 1-2 mW/cm^2 and 2-5 mW/cm^2 respectively. None of the surveyed ovens have the leakage greater than 5 mW/cm^2.

Wasutarayaroen et al. (33) surveyed the radiation leakage from used microwave ovens in Khon Kaen using a Holday radiation leakage detector model HI 1501. In this survey a total of 125 microwave ovens, both commercial and household models, from 31 different manufactures were measured. The age of surveyed ovens varied from less than 6 months to 13 years. None of surveyed ovens emitted radiation in excess of the maximum allowed leakage specified in the U.S. FDA and Canadian regulations. They concluded that the survey results agreed with those reported by the Canadians (7), and the adverse health effects are not expected to occur as a result of radiation exposure during cooking with these microwave ovens.

Thanasandote et al. (22) reported the leakage of radiation from microwave ovens using a NARDA 8120A radiation leakage detector in greater Ottawa area. A survey of a total of 60 before-sale ovens was carried out to determine their compliance with the requirements of Canadian Radiation Emitting Devices Regulation for microwave ovens. Similarly, over 100 used ovens were also inspected to determine their microwave leakage level and compare them to the maximum allowed leakage given in the regulation. None of before-sale ovens were found to emit microwave radiation in excess of the maximum allowed leakage, and only one used oven leaked in excess of the before-sale ovens from three different manufactures were found to be noncompliant with the labeling requirements.

CHAPTER IV
MATERIALS AND METHODS

Materials

Microwave Oven

A total 738 of microwave ovens from different national and international manufacturers were inspected and measured, which were from 3 locations:

Number of Microwave ovens

Microwave Power (watt)		700	800	850	900	1000
Household	676 ovens	45	301	169	154	7
Convenient store	34 ovens	1	20	7	6	0
Restaurant	28 ovens	1	9	7	11	0

Microwave Leakage Detector (LCD Digital Readout) Model NO. MD-2000:

The MD-2000 is a single instrument for detecting microwave leakage from microwave oven and should not be connected to other detecting units or attempt to apply out of microwave oven detecting. This detector should be installed with its mounting holder on the wall in the kitchen near or beside the microwave oven.

Figure 4-1 Microwave Leakage Detector Model No. MD-2000

Water load:

In order to provide uniform test condition, the standard requires that all emission tests be performed with a specific method by using 275 ± 15 milliliter of tap water, centered on the load carrying surface of the oven cavity. The water should have an initial temperature of 20 ± 5 degrees Celsius. Its container should be made of nonconductive material, e.g., glass or plastic (for microwave oven) with the inside diameter of approximately 8.5 centimeters, such as a low from beaker. Each load must be use for all compliance measurements or microwave emission form a microwave oven.

Methods

Survey Procedures:

1. Enter the survey date, the two – letter code for the division/section controlling the oven, as well as the property location codes and room where the oven located.
2. Visually inspect the oven for signs of a compromised seal. Whether the door loose, there are dented or broken components. There are burn marks from arcing.
3. Prepare the test instrument. Set detector to zero point. Empty oven cavity, and measure the microwave leaking from microwave oven, to be keeping two inches distance from the door seals or the front glass of microwave oven.
4. Fill a beaker with 275 ml of water and place it in the center of load bearing surface. During the test, change the water as necessary to minimize boiling. Measure the microwave leaking from microwave oven.
5. If selectable, set the power to the maximum power output. Activate the oven and begin the closed-door test. Record the values and locations of maximum reading.

   Door Frame – Probe the entire periphery of the door frame with the tip of the detector in contact with oven.

   Door Screen – Probe the entire surface of the door screen with the tip of the detector in contact with the screen.

   Control Panel – Probe the display window and operation bottom.
6. Record data in microwave oven survey form

Figure 4-2 Position of microwave oven survey

Measurement process

- Record data from Manufacturer detail behind microwave oven.
- Set power level at high level (Power 100%). Set Timer at 3-5 minutes.
- For Water load test : Fill a beaker with 275 ml of water and place it in the center of load bearing surface (Figure 4-3a).

Manufacturer detail behind microwave oven.

Micro wave Oven (front view)

Microwave with water load

Figure 4-3a Location of microwave oven

- Probe the entire periphery of the oven with side of oven (Figure 4-3b).

Figure 4-3b Location of microwave oven.

- **Door Frame** – Probe the entire periphery of the door frame with the tip of the detector in contact with oven (Figure 4-3b and c). (top, right, left and bottom)

Figure 4-3c Location of microwave oven.

- **Door Screen** – Probe the entire surface of the door screen with the tip of the detector in contact with the screen (Figure 4-3d).

Figure 4-3d Location of microwave oven.

- **Control Panel –** Probe the display window and operation bottom

Figure 4-3e Location of microwave oven.

The radiation leakages in each position were measure 3 times and average value. The maximum radiation leakage from recorded data was analyzed.

CHAPTER V
RESULTS

A total of 738 used microwave ovens of national and international manufacturers were inspected and measured to verify their compliance with the ICNRP, NCRP, US FDA and Canadian regulations. The microwave operating power was between 700 to 1000 watt (Appendix III). The results of measurement are shown on the scatter plot in Figure 5.1 for an empty oven cavity and Figure 5.2 for the cavity loaded with 275 ml H_2O.

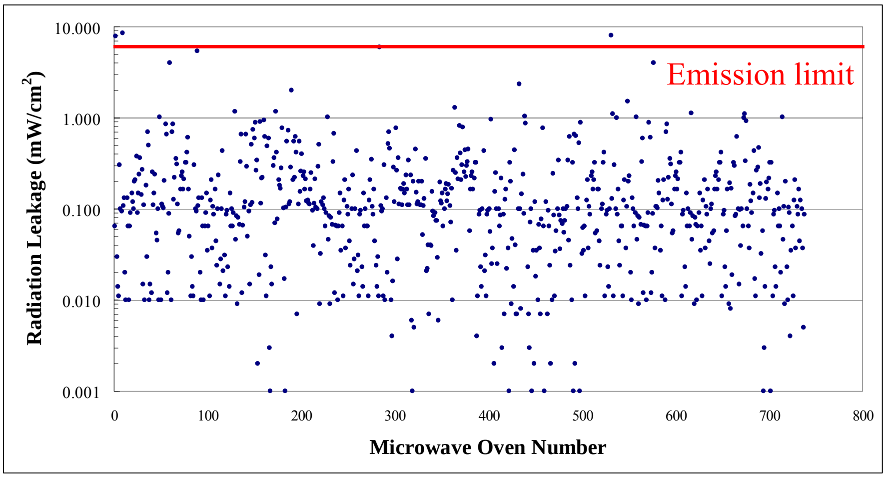

Figure 5-1 Distribution of radiation leakage from 738 microwave ovens (without load)

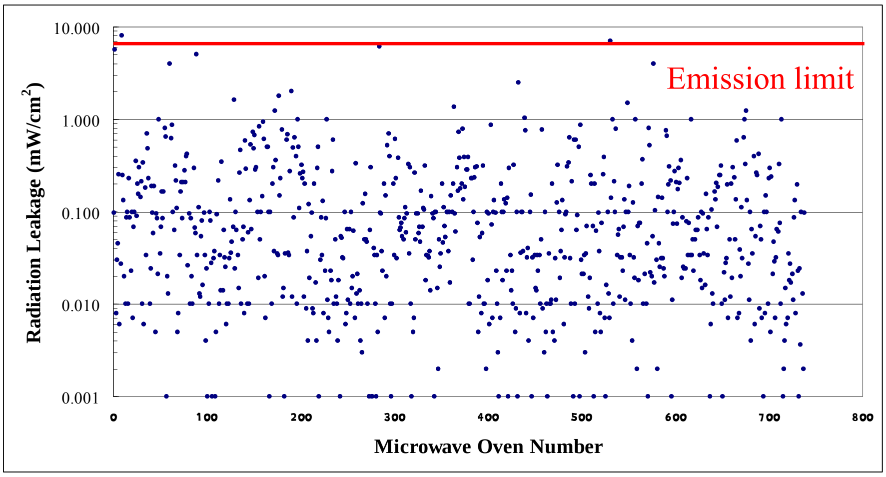

Figure 5-2 Distribution of radiation leakage from 738 microwave ovens (loaded with water).

The ovens were between 1 to more than 10 years old. Most of the survey ovens were found to comply with the 5 mW/cm^2 leakage limits at 5 cm from oven. Five ovens (0.68%) were found to leak more than 5 mW/cm^2 limit specified in the standard, both without load and with water test load. Seventeen other ovens (2.30%) without load and 15 ovens (2.03%) with water test load, were found to leak 1 mW/cm^2 or more with the remaining ovens (97.02% and 97.29% respectively) leak lower than 1 mW/cm^2 (Table V-1 and V-2). The average leakage level was 0.235 mW/cm^2 when operated without load and 0.196 mW/cm^2 with loaded water (Table V-3).

Table V-1 Average measured leakage from the survey ovens without load.

Radiation leakage (mW/cm^2)	Microwave Power (watt)						
	700 W	800 W	850 W	900 W	1000 W	Total	%
<1	47	327	182	159	1	716	97.02
1-5	0	3	1	11	2	17	2.30
>5	0	0	0	1	4	5	0.68
Total	47	330	183	171	7	738	

Table V-2 Average measured leakage from the survey ovens with loaded water.

Radiation leakage (mW/cm^2)	Number of microwave oven (ovens)						
	700 W	800 W	850 W	900 W	1000 W	Total	%
<1	47	326	183	161	1	718	97.29
1-5	0	4	0	9	2	15	2.03
>5	0	0	0	1	4	5	0.68
Total	47	330	183	171	7	738	

Table V-3 Average measured leakage from 738 ovens.

Case	Radiation leakage (mW/cm^2)			95% Confidence Interval
	Max	min	average	
Without load	8.513	0.001	0.235 ± 0.662	less than 1.559
With load	8.004	0.001	0.196 ± 0.607	less than 1.410

Table V-4 shows position of radiation leakage around the surveyed ovens expressed in percentage of ovens. The maximum leakage was detected in 2%, 97% and 1% of the ovens at the door frame, door screen and control panel respectively. In a highest percentage of ovens (78%), a measured leakage at the center of the door screen was 0.098 ± 0.103 mW/cm^2 without load and 0.075 ± 0.129 mW/cm^2 with load. In 13% at the right (open) of door screen the leakage was 0.862 ± 1.507 mW/cm^2 without load and 0.773 ± 1.374 mW/cm^2 with load.

Table V-4 Position of maximum leakage around the surveyed ovens expressed in percentage of ovens.

Leakage Position		Number and Percentage of Ovens (%)			
		Without Load		With Load	
Door Frame	Right	8	1.08	7	0.95
	Left	2	0.27	2	0.27
	Top	3	0.41	3	0.41
	Bottom	2	0.27	0	0
Door Screen	Right (Open)	98	13.28	96	13.01
	Left (Close)	17	2.30	18	2.44
	Top	12	1.63	15	2.03
	Center	576	78.05	583	79.00
	Bottom	12	1.63	7	0.94
Control Panel	Display window	6	0.81	3	0.41
	Operation bottom	2	0.27	4	0.54

The maximum measured leakage from each oven against its operating power is shown in Table V-5 and Figure 5-3 without load and in Table V-6 and Figure 5-4 with loaded water. It is apparently that there is some correlation between measured leakage and operating power. There are 4 microwave ovens operated at 1000 watt release radiation leakage more than acceptable limit (7.950, 8.513, 5.355 and 8.022 mW/cm^2). The remaining ovens operated between 700 to 900 watt leaking less than 5 mW/cm^2 with only one 900 watt-oven from 171 ovens exceeds the 5 mW/cm^2 emission limit (6.002 mW/cm^2).

Table V-5 Leakage of microwave ovens in relation to their maximum output power in without load case.

Microwave power (Watt)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
		Max	Min	Average		
700	47	0.771	0.001	0.128	0.163	0.027
750	-	-	-	-	-	-
800	330	4.011	0	0.142	0.280	0.078
850	183	1.000	0.001	0.121	0.135	0.018
900	171	6.002	0.004	0.364	0.562	0.315
950	-	-	-	-	-	-
1000	7	8.513	0.995	5.137	3.223	10.38
Total	738	-	-	-	-	-

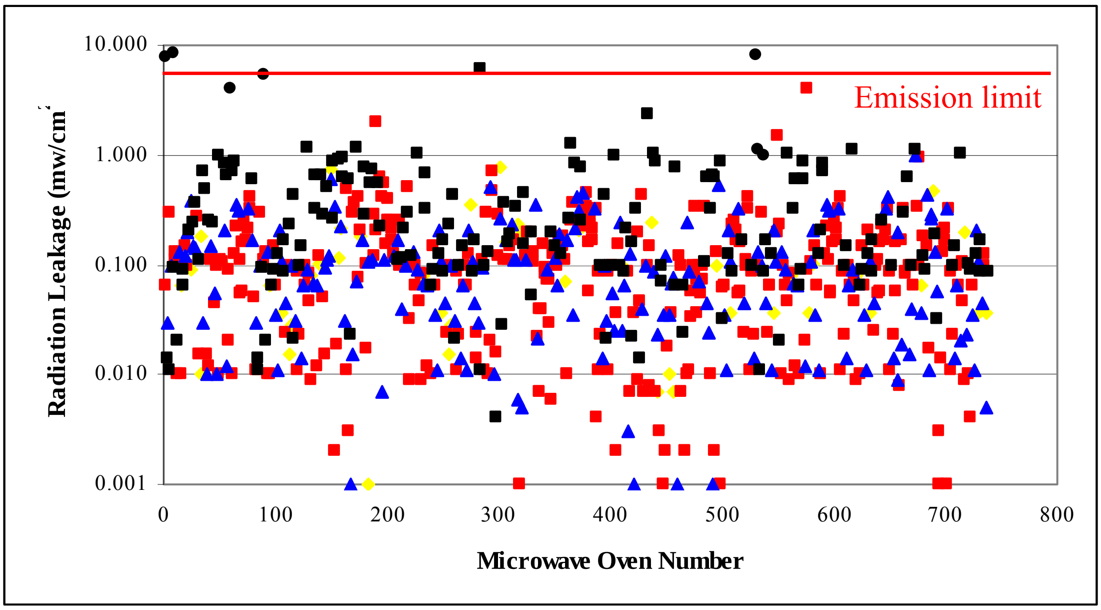

Figure 5-3 Radiation leakage data of microwave ovens (without load)

Microwave Power ● : 1000 Watt ■ : 900 Watt

▲ : 850 Watt ■ : 800 Watt

♦ : 700 Watt

Table V-6 Leakage of microwave ovens in relation to their maximum output power in Water loaded case.

Microwave power (Watt)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
		Max	Min	Average		
700	47	1.800	0.001	0.127	0.291	0.085
750	-	-	-	-	-	-
800	330	4.000	0	0.114	0.281	0.079
850	183	1.000	0	0.095	0.133	0.017
900	171	6.120	0.001	0.320	0.581	0.338
950	-	-	-	-	-	-
1000	7	8.004	0.789	4.512	2.797	7.828
Total	738	-	-	-	-	-

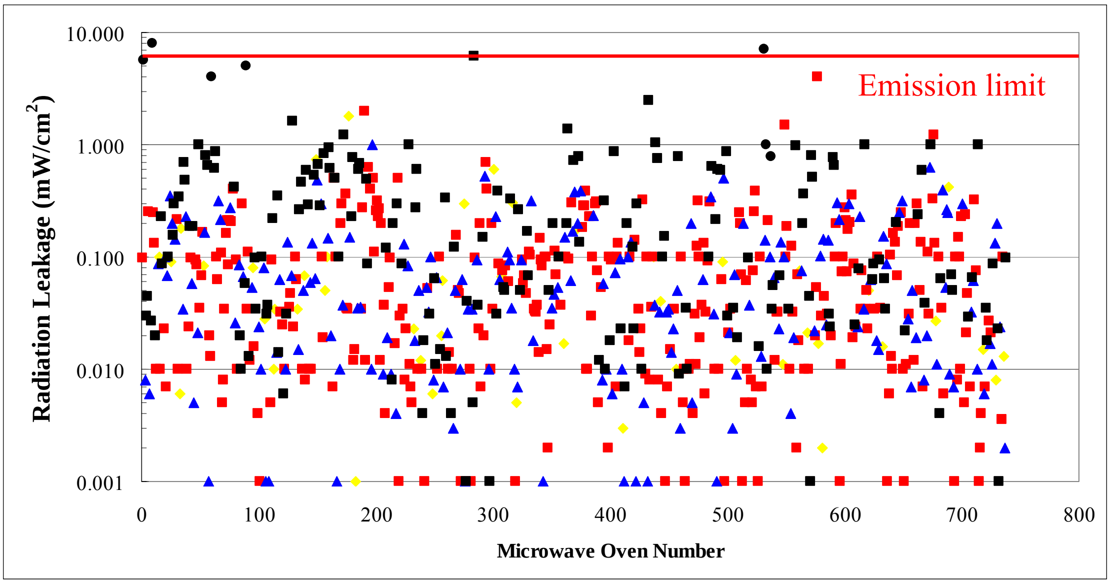

Figure 5-4 Radiation leakage data of microwave ovens (with load)

Microwave Power ● : 1000 Watt ■ : 900 Watt

▲ : 850 Watt ■ : 800 Watt

◆ : 700 Watt

The distribution of numbers of ovens grouped by usage time and operating power is tabulated in Table V-7. Only 5.5% of the surveyed ovens have been in used for more than 7 years. The mean oven age is 3.76 years. Among the survey of 738 ovens, the popular range of operating power is 800 to 900 watt (92.7%). These include 624 domestic, 33 convenient stores and 27 restaurants.

Table V-7 Microwave ovens grouped by age and operating power.

Usage time (years)	**Number of ovens**					**Total**	**%**
	Microwave power (watt)						
	700	**800**	**850**	**900**	**1000**		
1	2	38	27	25	0	92	12.5
2	5	87	37	17	0	146	19.8
3	0	58	52	48	0	158	21.4
4	4	47	5	16	0	72	9.7
5	13	56	40	42	1	152	20.6
6	11	19	18	9	0	57	7.7
7	2	12	2	5	0	21	2.8
8	1	8	0	4	3	16	2.2
9	1	1	0	2	1	5	0.7
10	8	3	2	1	2	16	2.2
>10	0	1	0	2	0	3	0.4
Total	47	330	183	171	7	738	100
%	6.4	92.7			0.9		

Table V-8 and Table V-9 show maximum and average measured leakage as a function of oven age. In these tables, the average emission is found to comply with the 5 mW/cm^2 leakage limit. It can be seen that there is no apparent correlation between measured leakage and age of ovens.

Table V-8 Measured leakage of microwave ovens grouped by age in without load case.

Usage time (years)	Number of ovens	Radiation leakage (mW/cm^2)			SD	σ^2
		Max	Min	Average		
1	92	1.173	0	0.140	0.204	0.042
2	146	1.129	0.001	0.126	0.187	0.035
3	158	1.040	0.001	0.149	0.198	0.039
4	72	1.025	0.001	0.174	0.181	0.032
5	152	5.355	0.004	0.236	0.494	0.244
6	57	1.183	0.001	0.178	0.251	0.063
7	21	2.011	0.023	0.247	0.427	0.182
8	16	8.513	0.097	1.848	2.485	6.173
9	5	1.111	0.218	0.624	0.350	0.122
10	16	8.022	0.007	1.273	2.636	6.952
> 10	3	0.905	0.253	0.548	0.468	0.219

Table V-9 Measured leakage of microwave ovens grouped by age in with loaded water case.

Usage time (years)	Number of ovens	Radiation leakage (mW/cm^2)			SD	σ^2
		Max	Min	Average		
1	92	1.638	0.001	0.126	0.228	0.052
2	146	1.000	0	0.105	0.191	0.036
3	158	1.036	0.001	0.113	0.179	0.032
4	72	0.986	0.001	0.128	0.185	0.034
5	152	5.004	0	0.197	0.476	0.226
6	57	1.800	0.001	0.178	0.328	0.107
7	21	2.000	0.007	0.222	0.429	0.184
8	16	8.004	0.001	1.764	2.442	5.966
9	5	0.700	0.100	0.557	0.356	0.126
10	16	7.100	0.012	1.063	2.123	4.507
> 10	3	0.834	0.187	0.507	0.433	0.187

The distribution of the surveyed ovens in relation to user type, age and operating power is shown in Table V-10.

Table V-10 Survey data grouped by type of use.

Type of use	**n**	**%**	**Average power (Watt)**	**Average age (years)**	**Average leakage (mW/cm²)**	
					Without load	**With load**
Household	676*	91.6	830.69	3.73 ± 2.12 (1-10 y)	0.239 ± 0.686	0.201 ± 0.628
Convenient store	34	4.61	825.0	3.41 ± 1.68 (1-8 y)	0.233 ± 0.353	0.176 ± 0.355
Restaurant	28	3.79	848.21	4.25 ± 1.43 (2-6 y)	0.133 ± 0.162	0.100 ± 0.162

* There are 5 ovens (0.7%) emitted radiation leakage more than acceptable limit (> 5 mW/cm^2).

This table shows that none of the used oven in convenient stores and restaurants emitted microwave radiation exceeding a power density of 5 mW/cm^2 at a distance of 5 cm from the surface. This table also shows that ovens in private household tend to leak more than those used in convenient stores and restaurant 0.239 VS 0.233 and 0.133 mW/cm^2 respectively. Ovens used in restaurant are older than those used in private household and convenient stores, 4.25 years VS 3.73 and 3.41 years and have a higher operating power, 848 watt VS 831 and 825 watt. With 95% probability the upper limit of expected leakage will be less than 1.611, 0.918 and 0.463 mW/cm^2 for ovens used in private households, convenient stores and restaurants respectively.

The distribution of measured leakage of ovens without and with load grouped by oven ages or operating power are show in Table V-11, V-12, V-13 and V-14.

Table V-11 Radiation leakage without load at different operating power grouped by oven age.

Usage time (y)	Microwave power (Watt)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
1	700	2	0.470	0.010	0.240	0.325	0.105
	800	38	0.321	0	0.089	0.079	0.006
	850	27	0.320	0.001	0.080	0.093	0.008
	900	25	1.173	0.004	0.275	0.325	0.105
2	700	5	0.037	0.015	0.025	0.009	0.00008
	800	87	0.420	0.001	0.090	0.008	0.00006
	850	37	0.532	0.003	0.089	0.121	0.014
	900	17	1.129	0.052	0.420	0.376	0.141
3	800	58	0.440	0.007	0.091	0.102	0.010
	850	52	1.000	0.001	0.134	0.155	0.024
	900	48	1.040	0.011	0.236	0.283	0.080
4	700	4	0.101	0.001	0.053	0.056	0.003
	800	47	0.420	0.001	0.123	0.095	0.009
	850	5	0.600	0.070	0.292	0.212	0.044
	900	16	1.025	0.032	0.316	0.282	0.079
5	700	13	0.240	0.037	0.116	0.064	0.004
	800	56	0.454	0.004	0.167	0.126	0.015
	850	40	0.520	0.005	0.142	0.125	0.015
	900	42	2.341	0.014	0.332	0.438	0.191
	1000	1	5.355	-	-	-	-

Table V-11 (continue) Radiation leakage without load at different operating power grouped by oven age.

Usage time (y)	Microwave power (Watt)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
6	700	11	0.350	0.010	0.088	0.099	0.009
	800	19	0.618	0.001	0.104	0.153	0.023
	850	18	0.344	0.011	0.096	0.104	0.010
	900	9	1.183	0.113	0.611	0.322	0.103
7	700	2	0.237	0.164	0.201	0.051	0.002
	800	12	2.011	0.023	0.251	0.566	0.320
	850	2	0.200	0.114	0.157	0.060	0.003
	900	5	0.550	0.125	0.292	0.157	0.024
8	700	1	0.207	-	-	-	-
	800	8	4.011	0.097	0.932	1.319	1.739
	900	4	6.002	0.210	2.098	2.641	6.974
	1000	3	8.513	0.995	4.506	3.783	14.311
9	700	1	0.218	-	-	-	-
	800	1	0.700	-	-	-	-
	900	2	0.733	0.360	0.547	0.264	0.069
	1000	1	1.111	-	-	-	-
10	700	8	0.771	0.007	0.236	0.321	0.103
	800	3	0.931	0.154	0.546	0.389	0.151
	850	2	0.380	0.150	0.265	0.150	0.022
	900	1	0.339	-	-	-	-
	1000	2	8.022	7.950	7.986	0.051	0.002
>10	800	1	0.487	-	-	-	-
	900	2	0.905	0.253	0.579	0.461	0.212

Table V-12 Radiation leakage with load at different operating power grouped by oven age.

Usage time (y)	Microwave power (Watt)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
1	700	2	0.421	0.006	0.214	0.293	0.085
	800	38	0.300	0.001	0.056	0.063	0.003
	850	27	0.298	0.001	0.056	0.077	0.005
	900	25	1.638	0.001	0.266	0.384	0.147
2	700	5	0.062	0.010	0.029	0.020	0.0004
	800	87	0.357	0	0.062	0.076	0.005
	850	37	1.000	0.001	0.109	0.193	0.037
	900	17	1.000	0.023	0.344	0.381	0.145
3	800	58	0.321	0.001	0.069	0.085	0.007
	850	52	0.634	0.001	0.090	0.120	0.014
	900	48	1.036	0.001	0.190	0.270	0.072
4	700	4	0.084	0.001	0.024	0.040	0.001
	800	47	0.400	0.001	0.090	0.092	0.008
	850	5	0.487	0.037	0.212	0.187	0.034
	900	16	0.986	0.001	0.239	0.322	0.103
5	700	13	0.180	0.005	0.055	0.050	0.002
	800	56	0.400	0.001	0.132	0.117	0.013
	850	40	0.520	0	0.111	0.117	0.013
	900	42	2.500	0.001	0.297	0.460	0.211
	1000	1	5.004	-	-	-	-
6	700	11	1.800	0.003	0.208	0.534	0.285
	800	19	0.632	0.001	0.085	0.151	0.022
	850	18	0.300	0.003	0.071	0.076	0.005
	900	9	1.230	0.120	0.553	0.356	0.126

Table V-12 (continue) Radiation leakage with load at different operating power grouped by oven age.

.Usage time (y)	Microwave power (Watt)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
7	700	2	0.304	0.067	0.186	0.167	0.027
	800	12	2.000	0.007	0.243	0.563	0.316
	850	2	0.068	0.035	0.052	0.023	0.0005
	900	5	0.497	0.068	0.254	0.158	0.024
8	700	1	0.177	-	-	-	-
	800	8	4.000	0.001	0.875	1.345	1.809
	900	4	6.120	0.100	2.065	2.753	7.579
	1000	3	8.004	0.789	4.264	3.614	13.060
9	700	1	0.100	-	-	-	-
	800	1	0.700	-	-	-	-
	900	2	0.687	0.300	0.494	0.273	0.074
	1000	1	1.000	-	-	-	-
10	700	8	0.734	0.012	0.205	0.290	0.084
	800	3	1.230	0.110	0.613	0.568	0.322
	850	2	0.350	0.058	0.204	0.206	0.042
	900	1	5.687	-	-	-	-
	1000	2	7.100	5.687	6.394	0.999	0.998
>10	800	1	0.500	-	-	-	-
	900	2	0.834	0.187	0.511	0.457	0.208

Table V-13 Radiation leakage without load at different usage times grouped by operating power.

Microwave power (Watt)	Usage time (y)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
700	1	2	0.470	0.010	0.240	0.325	0.105
	2	5	0.037	0.015	0.025	0.009	0.00008
	3	0	-	-	-	-	-
	4	4	0.101	0.001	0.053	0.056	0.003
	5	13	0.240	0.037	0.116	0.064	0.004
	6	11	0.350	0.010	0.088	0.099	0.009
	7	2	0.237	0.164	0.201	0.051	0.002
	8	1	0.207	-	-	-	-
	9	1	0.218	-	-	-	-
	10	8	0.771	0.007	0.236	0.321	0.103
	>10	0					
800	1	38	0.321	0	0.089	0.079	0.006
	2	87	0.420	0.001	0.090	0.008	0.00006
	3	58	0.440	0.007	0.091	0.102	0.010
	4	47	0.420	0.001	0.123	0.095	0.009
	5	56	0.454	0.004	0.167	0.126	0.015
	6	19	0.618	0.001	0.104	0.153	0.023
	7	12	2.011	0.023	0.251	0.566	0.320
	8	8	4.011	0.097	0.932	1.319	1.739
	9	1	0.700	-	-	-	-
	10	3	0.931	0.154	0.546	0.389	0.151
	>10	1	0.487	-	-	-	-

Table V-13 (continue) Radiation leakage without load at different usage times grouped by operating power.

Microwave power (Watt)	Usage time (y)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
850	1	27	0.320	0.001	0.080	0.093	0.008
	2	37	0.532	0.003	0.089	0.121	0.014
	3	52	1.000	0.001	0.134	0.155	0.024
	4	5	0.600	0.070	0.292	0.212	0.044
	5	40	0.520	0.005	0.142	0.125	0.015
	6	18	0.344	0.011	0.096	0.104	0.010
	7	2	0.200	0.114	0.157	0.060	0.003
	8	0	-	-	-	-	-
	9	0	-	-	-	-	-
	10	2	0.380	0.150	0.265	0.150	0.022
	>10	0	-	-	-	-	-
900	1	25	1.173	0.004	0.275	0.325	0.105
	2	17	1.129	0.052	0.420	0.376	0.141
	3	48	1.040	0.011	0.236	0.283	0.080
	4	16	1.025	0.032	0.316	0.282	0.079
	5	42	2.341	0.014	0.332	0.438	0.191
	6	9	1.183	0.113	0.611	0.322	0.103
	7	5	0.550	0.125	0.292	0.157	0.024
	8	4	6.002	0.210	2.098	2.641	6.974
	9	2	0.733	0.360	0.547	0.264	0.069
	10	1	0.339	-	-	-	-
	>10	2	0.905	0.253	0.579	0.461	0.212
1000	5	1	5.355	-	-	-	-
	8	3	8.513	0.995	4.506	3.783	14.311
	9	1	1.111	-	-	-	-
	10	2	8.022	7.950	7.986	0.051	0.002

Table V-14 Radiation leakage with load at different usage times grouped by operating power.

Microwave power (Watt)	Usage time (y)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
700	1	2	0.304	0.067	0.186	0.167	0.027
	2	5	0.062	0.010	0.029	0.020	0.0004
	3	0	-	-	-	-	-
	4	4	0.084	0.001	0.024	0.040	0.001
	5	13	0.180	0.005	0.055	0.050	0.002
	6	11	1.800	0.003	0.208	0.534	0.285
	7	2	0.304	0.067	0.186	0.167	0.027
	8	1	0.177	-	-	-	-
	9	1	0.100	-	-	-	-
	10	8	0.734	0.012	0.205	0.290	0.084
	>10	0	-	-	-	-	-
800	1	38	0.300	0.001	0.056	0.063	0.003
	2	87	0.357	0	0.062	0.076	0.005
	3	58	0.321	0.001	0.069	0.085	0.007
	4	47	0.400	0.001	0.090	0.092	0.008
	5	56	0.400	0.001	0.132	0.117	0.013
	6	19	0.632	0.001	0.085	0.151	0.022
	7	12	2.000	0.007	0.243	0.563	0.316
	8	8	4.000	0.001	0.875	1.345	1.809
	9	1	0.700	-	-	-	-
	10	3	1.230	0.110	0.613	0.568	0.322
	>10	1	0.500	-	-	-	-

Table V-14 (continue) Radiation leakage with load at different usage times grouped by operating power.

Microwave power (Watt)	Usage time (y)	Number of Ovens	Radiation leakage (mW/cm^2)			SD	σ^2
			Max	Min	Average		
850	1	27	0.298	0.001	0.056	0.077	0.005
	2	37	1.000	0.001	0.109	0.193	0.037
	3	52	0.634	0.001	0.090	0.120	0.014
	4	5	0.487	0.037	0.212	0.187	0.034
	5	40	0.520	0	0.111	0.117	0.013
	6	18	0.300	0.003	0.071	0.076	0.005
	7	2	0.068	0.035	0.052	0.023	0.0005
	8	0	-	-	-	-	-
	9	0	-	-	-	-	-
	10	2	0.350	0.058	0.204	0.206	0.042
	>10	0	-	-	-	-	-
900	1	25	1.638	0.001	0.266	0.384	0.147
	2	17	1.000	0.023	0.344	0.381	0.145
	3	48	1.036	0.001	0.190	0.270	0.072
	4	16	0.986	0.001	0.239	0.322	0.103
	5	42	2.500	0.001	0.297	0.460	0.211
	6	9	1.230	0.120	0.553	0.356	0.126
	7	5	0.497	0.068	0.254	0.158	0.024
	8	4	6.120	0.100	2.065	2.753	7.579
	9	2	0.300	0.494	0.273	0.074	
	10	1	5.687	-	-	-	-
	>10	2	0.834	0.187	0.511	0.457	0.208
1000	5	1	5.004	-	-	-	-
	8	3	8.004	0.789	4.264	3.614	13.060
	9	1	1.000	-	-	-	-
	10	2	7.100	5.687	6.394	0.999	0.998

Statistical analysis of the radiation leakage from microwave ovens in relation to oven age and microwave operating power was performed by two-way ANOVA. Because of some missing data outside the popular range of operation power (800 to 900 watt) and small number of ovens aging more then 7 years, these observations were not included in the statistical analysis. Scatter plot of the maximum leakage of each oven at operating power between 800 to 900 watt grouped by oven age 1, 2, 3 and 5 years are shown in Figure 5.5 a, b, c and d.

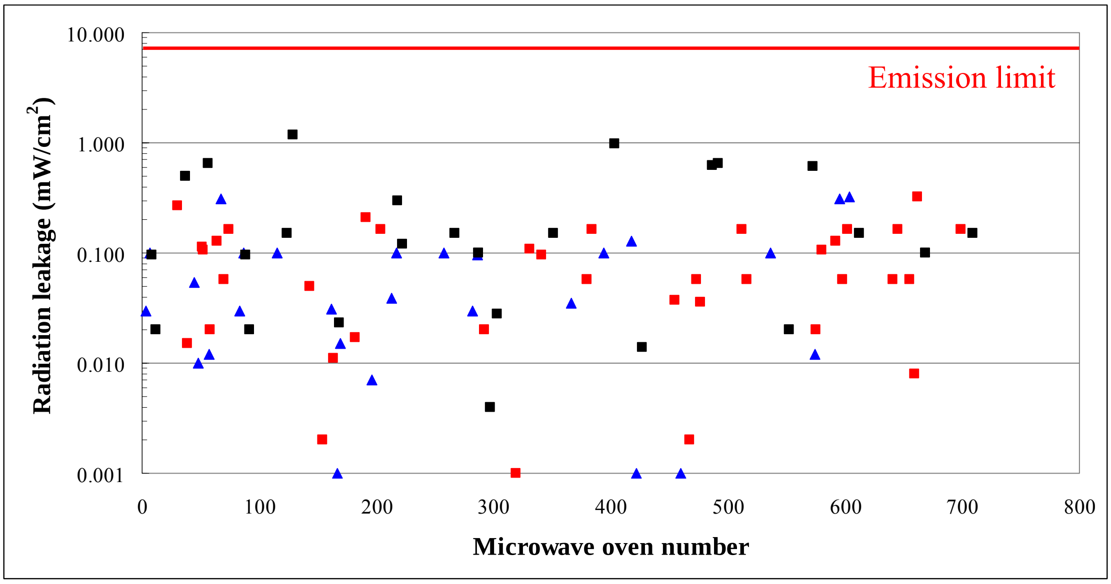

Figure 5-5a Radiation leakage data of microwave ovens grouped by oven age 1 year. (without load case)

Microwave Power ■ : 900 Watt ▲ : 850 Watt ■ : 800 Watt

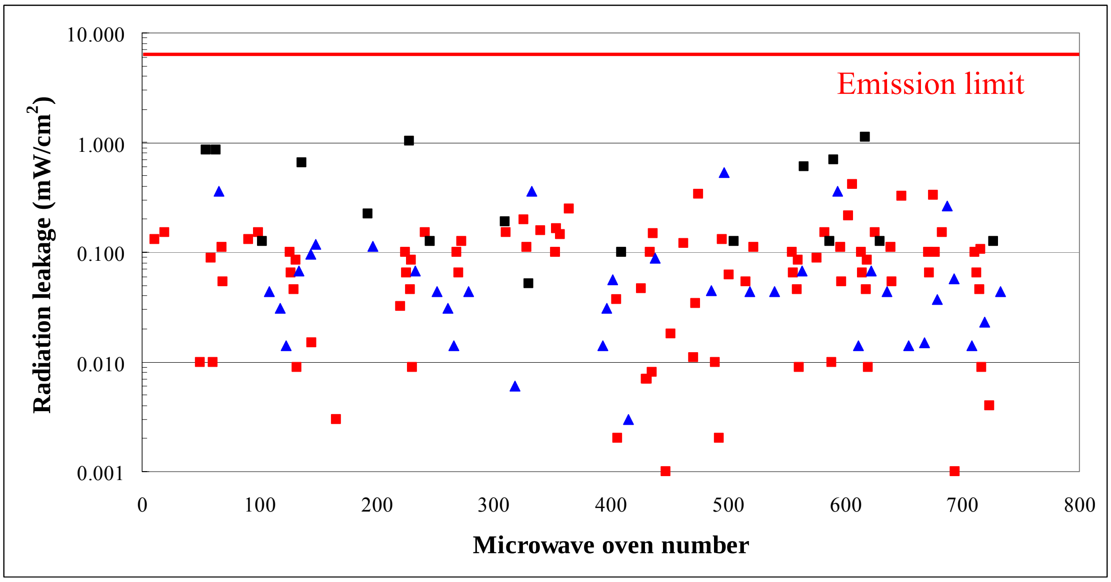

Figure 5-5b Radiation leakage data of microwave ovens grouped by oven age 2 years. (without load case)

Microwave Power ■ : 900 Watt ▲ : 850 Watt ■ : 800 Watt

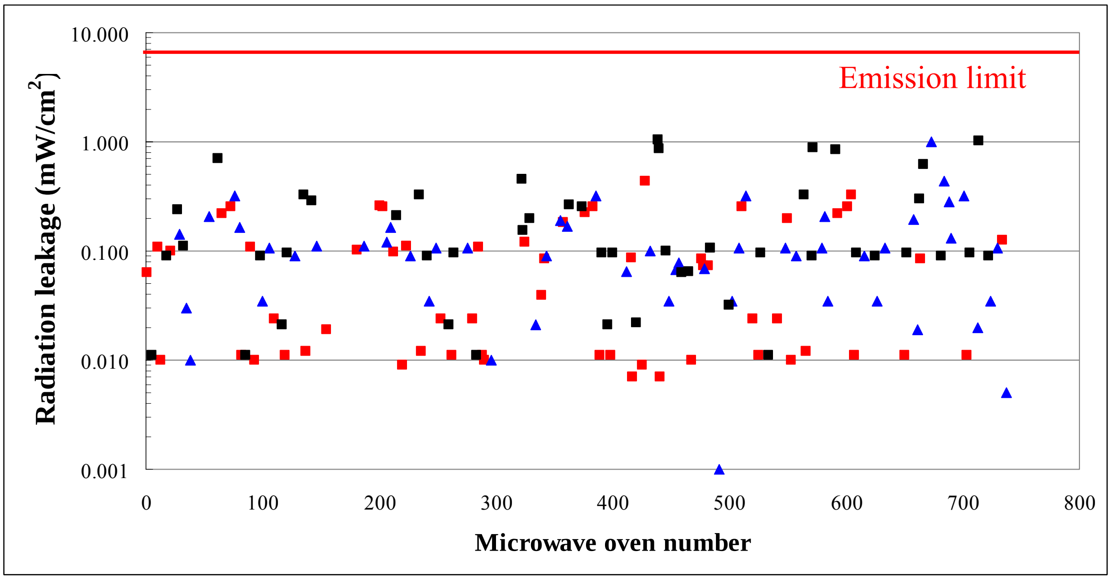

Figure 5-5c Radiation leakage data of microwave ovens grouped by oven age 3 years. (without load case)

Microwave Power ■ : 900 Watt ▲ : 850 Watt ■ : 800 Watt

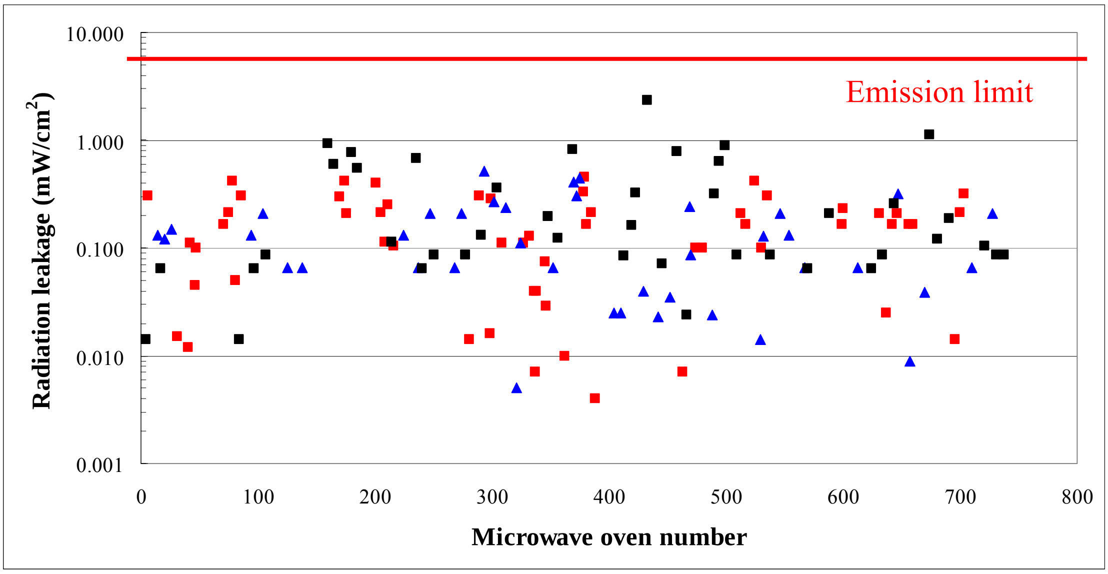

Figure 5-5c Radiation leakage data of microwave ovens grouped by oven age 3 years. (without load case)

Microwave Power ■ : 900 Watt ▲ : 850 Watt ■ : 800 Watt

It is noticed that maximum leakage at higher operating power are found more often at maximum leakage region. Two-way ANOVA shows that there is no relationship between the quantity of radiation leakage and oven age (Appendix V).

Significant relationship was observed between measured leakage and operating power ($p<0.05$). It is evidenced from the scatter plot between measured leakage and its operating power in Figure 5-6 a, b, c and d that radiation leakage tends to increase with operating power especially when the usage time is longer.

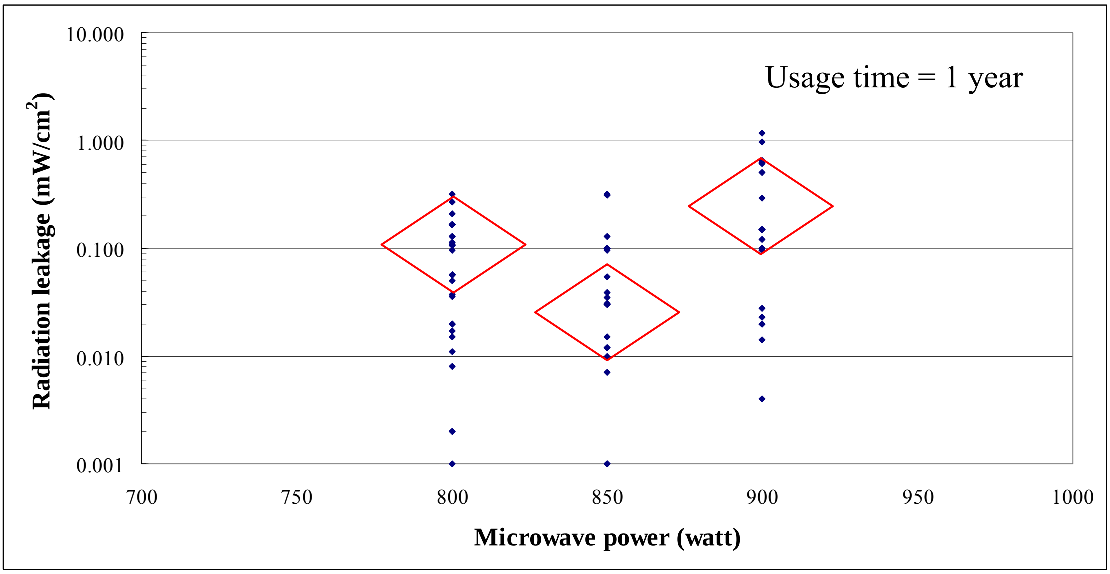

Figure 5-6a Radiation leakage data of microwave ovens in relation to microwave power.

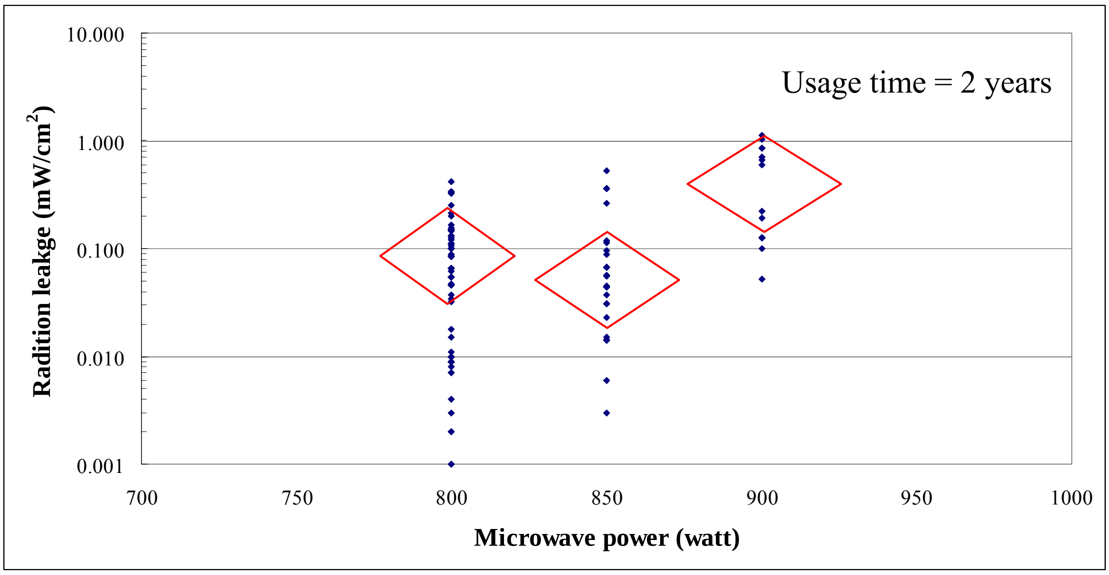

Figure 5-6b Radiation leakage data of microwave ovens in relation to microwave power.

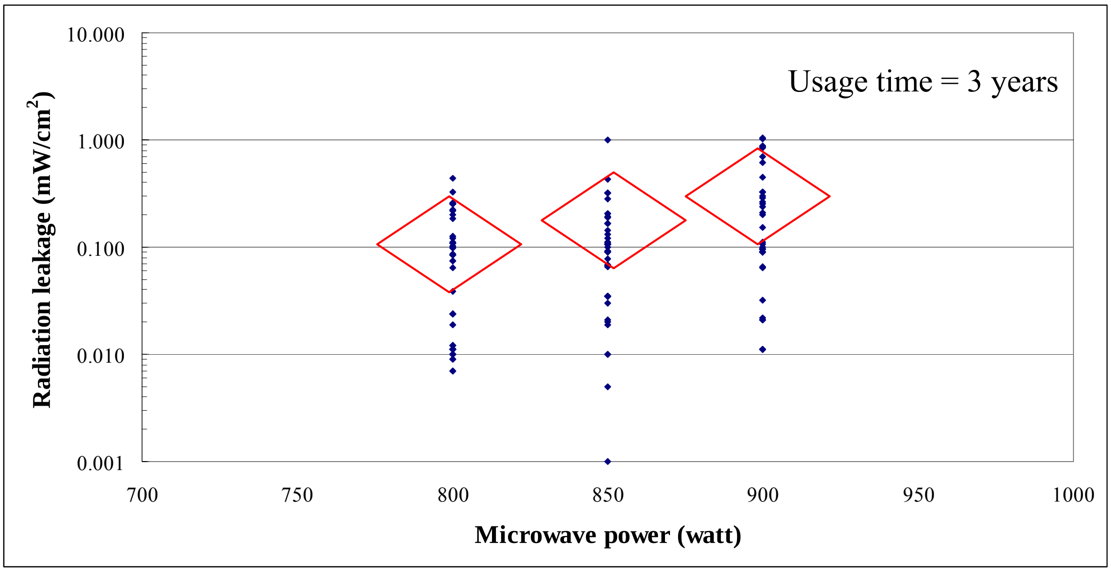

Figure 5-6a Radiation leakage data of microwave ovens in relation to microwave power.

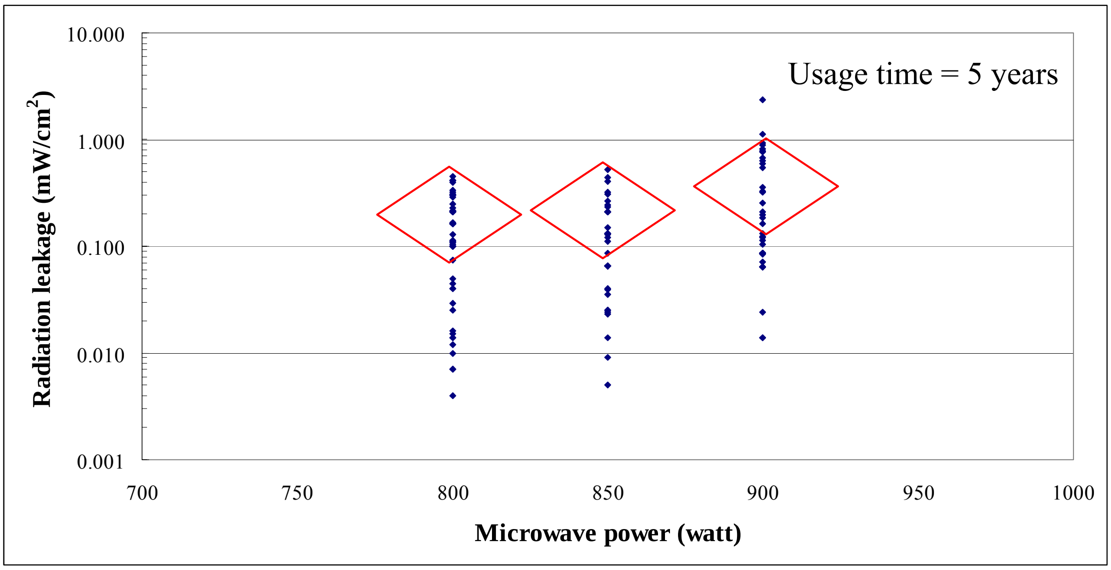

Figure 5-6a Radiation leakage data of microwave ovens in relation to microwave power.

CHAPTER VI
DISCUSSION

Over the last 50 years, the microwave oven was an unexpected success and this device is now become a standard device in modern technology. Most microwave ovens operate at 2450 MHz with operating power ranging from 0.5 to 2 kW. Microwave ovens commonly available for the domestic market have a full power capacity between 600 to 1000 watts. In our study, the most popular operating power ranged from 800 to 900 watts in 92.7% of the surveyed ovens.

Various organizations and countries have developed exposure standard for radiofrequency energy. Most of the standards specified the maximum amount of leakage from microwave ovens at distance of 5 cm from the oven to be 1 mW/cm^2 before used and 5 mW/cm^2 throughout its operating life. These standards are designed to protect against the thermal effect of microwave power. In this study a total of 738 microwave ovens, 676 household, 34 convenient store and 28 restaurant ovens were investigated and measured for radiation leakage. The data were statistically analyzed and compared with established international standards. The results of the measurements showed that only 5 household ovens (0.68%) were found to leak more than 5 mW/cm^2, the remaining 716 ovens (97.02%) and 17 ovens (2.3%) was found to leak less than 1 mW/cm^2 and between 1 to 5 mW/cm^2 respectively. These agreed with other study reported by Tongruang and Pasisanyakul in Thailand in 1994 where 96.94% of the 98 ovens supplied for testing was found to leak less than 1 mW/cm^2 and the remaining 3% were between 1 to 5 mW/cm^2 (28). Another study by Wasuntharajaroen et al. (33) in Khon Kaen in 1998 reported that none of the 125 surveyed ovens was found to leak more than the allowed limit specified by the US and the Canadian regulation. The average leakage from the convenient store and household ovens were 0.14 and 0.12 mW/cm^2 respectively. These were in the same magnitude when compared with results in our study, 0.201, 0.176 and 0.10 mW/cm^2 from household, convenient store and restaurant ovens respectively. The averages of all surveyed ovens with and without water test load were 0.196 and 0.235 mW/cm^2. Several other studies concerning leakage from microwave ovens have been conducted. Matthes in

1992 measured radiation leakage from 130 microwave ovens in domestic used and reported that none of the checked ovens emitted microwave radiation exceeding a power density of 1 mW/cm^2 at a distance of 5 cm from the surface of the device (23). He also suggested that 50% of operating ovens emit less than 0.062 mW/cm^2 and the probability of emitting more than 5 mW/cm^2 is less than 0.05%.

Thanasandote et al. (22) reported the results of radiation leakage of the before-sale and used microwave ovens in Ottawa, Canada in 2000. They concluded that none of the before-sale ovens was found to leak more than 1 mW/cm^2 and none of used ovens was found to leak more than 5 mW/cm^2. The average leakage of 0.17 mW/cm^2 from used ovens in the report agreed with results in present study. A more recent survey report of 106 domestic and restaurant microwave ovens in Saudi Arabia by Alhekail in 2001 (1) showed that only one oven was found to leak more than the 5 mW/cm^2 emission limit. He reported that 14% of the surveyed ovens leakage 1 mW/cm^2 or more while in our study only 2.3% was found to leak 1 mW/cm^2 or more. He also reported a correlation between measured leakage and age of ovens and no apparent correlation was found between measured leakage and operating power. This is different from our findings; we can observe a correlation with operating power and no correlation with age of oven. This indicated that there was no clear dependence of measurement leakage on parameter such as oven operating power and age.

Based on the findings in this study and other studies, the conclusion is that domestic microwave ovens are not considered to leak microwave radiation in excess of 5 mW/cm^2. To date there is no evidence to support the claim that leakage from a microwave oven has caused harm to any person. However, because of the diverging nature of the microwave radiation, it can be concluded that leakage from most of our surveyed ovens is relatively low when compared with thermally harmful densities (21). Most of ovens emitted microwave radiation less than 1 mW/cm^2 and the 1 mW/cm^2 limit is below the maximum permissible emission of 5 mW/cm^2 at points very close to oven. It is certain that at the distance where user usually stands, the leakage is even less than the specified safe limit.

There is no adopted electromagnetic exposure standard in Thailand. This demonstrated the necessary to control the radiation of each installed oven and to work out our own limit for occupational exposure and exposure for member of the public Although there is no law or regulations by the Thai Government, it is suggested that periodical leakage testing from domestic microwave ovens is required. Ovens following repair or if damage is suspected should be tested for leakage. The specified limit of 1 mW/cm^2 at 5 cm at manufacture and 5 mW/cm^2 at 5 cm after sale is still in place in the US, Canada and Australia. At the present time these standards are used in Thailand as well as in other countries.

CHAPTER VII
CONCLUSION

All surveyed microwave ovens in Bangkok area, except for five (0.68%), were found to comply with the 5 mW/cm^2 leakage limits at 5 cm from the oven. The maximum leakage but within the acceptable limit was found at the door screen. None of the convenient store and restaurant ovens was found to leak more than 5 mW/cm^2. Most of the surveyed ovens (97%) were found to leak less than 1 mW/cm^2, and the remaining 2% leak between 1 – 5 mW/cm^2. Statistical analysis suggests that with 95% probability, the upper limit of the leakage is expected to be less than 1.611, 0.918 and 0.463 mW/cm^2 for household, convenient store and restaurant ovens respectively.

Correlation was observed between measured leakage and operating power of the oven and no apparent correlation was found between measured leakage and age of the oven.

Since the radiated power density decreased with distance, it is reasonable to assume that the exposure of a person which will occur at about the arm distance, 30 to 40 cm from the oven is much less than the specified general public exposure limit (1 mW/cm^2). Therefore, no detrimental health effects are expected at the location where a person is exposed. Based on the finding in this study, and studies in other countries, one can concluded that leakage from microwave ovens during cooking should not expose people to power densities more than the specified limit for the general public, if properly operated.

REFERENCES

1. Alhekail Z. *Electromagnetic Radiation From Microwave Ovens*. J Radiol Prot, 2001; 21: 251-258
2. ANSI/IEEE, *Standard for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz (IEEE Std. C95.1-1991)***.** New York: Institute of Electrical and Electronic Engineers.
3. Australian Radiation Protection and Nuclear Safety Agency. 1999 [on line]. Available: http://www.arpansa.gov.au/is_mwave.html
4. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), *Radiation Protection Standard : Maximum Exposure Levels to Radio-frequency Fields – 3 kHz to 300 GHz*. Radiation Protection Series Publication No.3, ARPANSA, 2002, Yallambie Australia.
5. Bangay M and Zomboias C, *Advance Measurements of Microwave Oven Leakage*. Australian Radiation Protection and Nuclear Safety Agency, p.1-4. Commonwealth of Australia, 2004.
6. Bray JH and Maxwell SE, *Multivariate Analysis of Variance*. Sara Miller McCune, Sage Publications, London, 1986.
7. Canadian Center for Occupational Health & Safety. 1997-2001 [on line]. Available: http://www.ccons.ca/oshanswers/phys_agents/microwave_ovens.html
8. Center for Devices and Radiological Health. *Microwave Radiation*. [On line]. Available: http://www.tda.gov/cdrh/consumer/microwave.html
9. Food and Drug Administration. *Procedures for Field Testing Microwave Ovens*. Department of Health, Education, and Welfare, Public Health Service, 1977, p.8-26
10. Food and Drug Administration, *Performance Standard for Microwave and Radiofrequency emitting products. Paragraph 1030.10 Microwave Ovens 21 CFR Ch.I (4-1-92 edition), Part 1030***.** 1992, p.496-9

11. Gallawa CJ. *Basic Principle of Microwave Energy*. 2000, p.1-3.

12. Gallawa CJ. 1989-99 [on line]. Available:
http://www.gallawa.com/microtech/howcook.html
http://www.gallawa.com/microtech/mwave.html
http://www.gallawa.com/microtech/how_work.html
http://www.gallawa.com/microtech/Ch3.html.

13. Health Canada, *Radiation Emitting Devices Regulation*, 1994

14. Heimler CH, Jack Price. *Focus on Physical Science*. Marrill Publishing co.: USA, 1989, p. 439-448.

15. ICNIRP, *Guidelines for Limiting exposure to time-varying electric, Magnetic, and electromagnetic fields (up to 300 GHz)*. Health Phys, 1998, p. 74: 494-522.

16. Miller TM. *Results of Microwave Oven Radiation Leakage Surveys at Fermi lab*. American Ind Hyg Assoc J, 1987; 48: 77-80.

17. Moseeley H, Davison M. *Radiation Leakage Levels from Microwave Ovens*. Annals of Occupational Hyg, 1989; 33 (4): 653-654.

18. NCRP, *Biological Effect and Exposure Criteria for Radiofrequency Electromagnetic Field: Recommendation of the National Council on Radiation Protection and Measurements. NCRP Report 86*. Bethesda, MD: NCRP Publication, 1986.

19. NCRP, *Radiofrequency Electromagnetic Fields-Properties, Quantities and Units, Biophysical Interaction, and Measurements, NCRP Report No.67*. Betherda, MD: NCRP Publications, 1981.

20. Osepchuk JM., *A history of Microwave heating application*, IEEE Trans. Microwave Theory Tech, 1984, 32: 1200-1224.

21. Osepchuk JM., *The cooker magnetrons as a standard in crossed-field Research, in Proc*. 1st Int Crossed-field Device Workshop, Aug 15-16, 1995, p.159-177.

22. Partnering Thansandote, Lecuyer DW and Gajda GB**.** *Radiation Leakage of Before-Sale and Used Microwave Ovens*. International Microwave Power Institute: USA, 2000, p.4-8.

23. Matthes R. *Radiation Emission from Microwave Ovens*. J Radiol Prot, 1992; 12 (3): 167-172.

24. Servey RA. Physics for Scientists & Engineer with Modern Physics. 3rd edition, Update Printing: USA, 1990, p.1435-1436

25. Stuchly MA, Repacholi MH and Lecuyer DW. *The Impact of Regulation on Microwave Ovens in Canada*. Health Physics, 1978; 37: 137-144
26. Yong HD, Freedman RA. *University Physics*. 9th edition. Addison-Wesley Publishing co.: USA, 1996, p.593: 1394.
27. Raymond A. Serway. *Physics for Scientists & Engineers with Modern Physics*. 3rd edition. Updated Printing: USA, 1990, p.1435-1436.
28. การไฟฟ้านครหลวง. *เตาไมโครเวฟ คืออย่างไร*. ข่าวการไฟฟ้า 2542: การไฟฟ้านครหลวง กรุงเทพฯ, ฉบับที่ 315, หน้า 67-68.
29. จินดา ทองเรือง, สุรศักดิ์ ปริสัญญกุล. *การศึกษาปริมาณรังสีรั่วจากเตาไมโครเวฟ*. วารสารกรมวิทยาศาสตร์การแพทย์ 2538: กรมวิทยาศาสตร์การแพทย์ กระทรวงสาธารณสุข, นนทบุรี, ปีที่ 37, ฉบับที่ 3, หน้า 197 –202.
30. ธีรศักดิ์ อุรัจนานนท์, *ความน่าจะเป็นและสถิติประยุกต์*. กรุงเทพฯ: สกายบุ๊กส์, 2546.
31. บุญถึง แน่นหนา. *คนเก่าเล่าเรื่อง เตาไมโครเวฟ*. UPDATE 2544, หน้า 82 – 88.
32. สืบพงษ์ โลจนานนท์, วิบูรณ์ ภัทรพิทยาสิน และ วิบูรณ์ ลิมปนุสสรณ์, *การสร้างเตาอบไมโครเวฟ*. เอกสารวิชาการภาควิชาวิทยาศาสตร์ฟิสิกส์ นิทรรศการเทคโนโลยี 2525: สถาบันเทคโนโลยีพระจอมเกล้าธนบุรี, หน้า 3.1-3.13
33. Ira Flatow, ศราวุธ เหมพันธุ์พิรุฬห์, แปลและเรียบเรียง. *จากแท่งช็อกโกแลตที่ละลายสู่เตาไมโครเวฟ (From a Melted Candy Bar to Microwave)*. วารสาร MTEC เทคโนโลยีวัสดุ 2542: ศูนย์เทคโนโลยีโลหะและวัสดุแห่งชาติ สนง.พัฒนาวิทยาศาสตร์และเทคโนโลยีแห่งชาติ, ฉบับที่ 14, หน้า 24-25.
34. ศิริวัฒน์ วสุนธราเจริญ, ดร.บุญยิ่ง เจริญ, ดร.อาจณรงค์ ฐานสันโดษ และ พูลสุข พงษ์พัฒน์. *การสุ่มสำรวจวัดคลื่นรั่วจากเตาไมโครเวฟในจังหวัดขอนแก่น (Survey of Radiation Leakage from Microwave Ovens in Khon Kaen)*. วิศวกรรมสาร ฉบับ ว.ส.ท.เทคโนโลยี 2543: ปีที่ 53, เล่มที่ 1, หน้า 68-72.

APPENDIX

APPENDIX A

Microwave Leakage Detector (LCD Digital Readout) Model NO. MD-2000

Features:

- LCD Digital Readout
- Leakage volume in dangerous zone will sound “Beeping” and a red lamp flashing
- Low leakage volume display for warning
- Human factor engineering design is suitable for the operation of both hands.
- Battery operates for more than one year
- Never need to recalibrate
- High sensitivity to the microwave
- Excellent reliability and high precision

Specification:

- Calibrated at 2450 MHz
- Range : 0 – 9.99 mW/cm^2
- Warning Value : 5.0 mW/cm^2
- Accuracy : 1 ± dB
- Power Source : 9 V Alkaline or Carbon Zinc Battery
- Battery Life : 1 year minimum for routine checking once a mouth
- Dimension : H 120 * W 55 * D 24

Operation & Battery Replacement

Operation: The MD-2000 can not be operation without holding down the button, therefore when you take the detector to measure microwave leakage while you should always hold down the button except stopping the measurement. When you release the button, the detector will be stopped its operation.

Battery Replacement: The MD-2000 has built in the low voltage detecting circuit itself. If the display field appears “BAT” during the measurement, it indicates the battery is in the status of low power. Notice that does not replace the battery immediately and let the measurement continued. This is caused by the different characteristics from different kinds of batteries. If the next time to use the MD-2000 to do the measurement and still shows the sign “BAT”, it is the time we suggest replacing the battery. One 9 V (DC) battery will be operate for more than one year if in normal condition.

APPENDIX B

Microwave Oven Survey Form

Date of Test/Survey ……………………..

Band Name ……………………………………

Model Number …………………………………. Serial ……………………………

Location of Oven [ ] Home [ ] Restaurants

[ ] Convenient store [ ] Other ………………………………

Microwave Frequency ……………… MHz Microwave Power ……………… kW

Operation time …………………… (Frequency of use)

Age of Using ………………………

Size of oven [ ] Large [ ] Medium [ ] Small

Result

1. No Load

Position		Microwave radiation leakage (mW/cm^2)			Average
		1	2	3	
Door frame	Right				
	Left				
	Top				
	Bottom				
Door screen	Right				
	Left				
	Top				
	Bottom				
	Center				
Control Panel	Display window				
	Operation bottom				
Maximum radiation leakage (mW/cm^2)					

2. Water Load

Position		Microwave radiation leakage (mW/cm^2)			Average
		1	2	3	
Door frame	Right				
	Left				
	Top				
	Bottom				
Door screen	Right				
	Left				
	Top				
	Bottom				
	Center				
Control Panel	Display window				
	Operation bottom				
Maximum radiation leakage (mW/cm^2)					

Note …………………………………………………………………………………………..
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APPENDIX C

Record data of surveyed and measurement radiation leakage from microwave ovens. (No load case)

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
1	800	3	0.064	56	900	1	0.653
2	1000	10	**7.950**	57	850	1	0.012
3	850	1	0.030	58	800	1	0.020
4	900	5	0.014	59	800	2	0.089
5	900	3	0.011	60	1000	8	**4.011**
6	800	5	0.304	61	800	2	0.010
7	850	1	0.100	62	900	3	0.700
8	900	1	0.095	63	900	2	0.861
9	1000	8	**8.513**	64	800	1	0.128
10	800	3	0.109	65	800	3	0.220
11	800	2	0.132	66	850	2	0.357
12	900	1	0.020	67	850	1	0.311
13	800	3	0.010	68	800	2	0.112
14	850	5	0.132	69	800	2	0.054
15	700	10	0.064	70	800	1	0.057
16	800	6	0.010	71	800	5	0.164
17	900	5	0.064	72	800	4	0.230
18	900	3	0.090	73	800	3	0.256
19	800	2	0.150	74	800	1	0.165
20	850	5	0.120	75	800	5	0.214
21	800	3	0.100	76	850	3	0.321
22	850	7	0.200	77	800	4	0.324
23	900	8	0.210	78	800	5	0.415
24	850	10	0.380	79	900	6	0.613
25	700	5	0.090	80	850	3	0.165
26	850	5	0.150	81	800	5	0.050
27	900	3	0.240	82	800	3	0.011
28	900	9	0.360	83	850	1	0.030
29	850	3	0.143	84	900	5	0.014
30	800	1	0.270	85	900	3	0.011
31	800	5	0.015	86	800	5	0.304
32	900	3	0.110	87	850	1	0.100
33	700	1	0.010	88	900	1	0.095
34	700	5	0.180	89	1000	5	**5.355**
35	850	3	0.030	90	800	3	0.109
36	900	4	0.700	91	800	2	0.132
37	900	1	0.500	92	900	1	0.020
38	850	3	0.010	93	800	3	0.010
39	800	1	0.015	94	850	5	0.132
40	800	5	0.012	95	700	10	0.064
41	900	12	0.253	96	800	6	0.010
42	800	5	0.110	97	900	5	0.064
43	850	10	0.150	98	900	3	0.090
44	900	7	0.240	99	800	2	0.150
45	850	1	0.054	100	850	3	0.035
46	800	5	0.045	101	800	4	0.065
47	800	5	0.100	102	850	6	0.011
48	850	1	0.010	103	900	2	0.125
49	900	6	**1.010**	104	850	5	0.210
50	800	2	0.010	105	700	6	0.037
51	800	1	0.113	106	850	3	0.106
52	800	1	0.107	107	900	5	0.087
53	700	4	0.101	108	900	4	0.165
54	850	3	0.205	109	850	2	0.044
55	900	2	0.850	110	800	3	0.024

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
111	800	6	0.100	176	800	5	0.210
112	900	4	0.235	177	700	6	0.181
113	700	2	0.015	178	850	4	0.167
114	700	2	0.028	179	900	7	0.282
115	850	1	0.100	180	900	5	0.766
116	900	6	0.435	181	800	3	0.103
117	900	3	0.021	182	800	1	0.017
118	850	2	0.031	183	700	4	0.001
119	800	3	0.011	184	850	6	0.105
120	800	4	0.087	185	900	5	0.550
121	900	3	0.096	186	900	9	0.733
122	800	7	0.023	187	850	3	0.112
123	850	2	0.014	188	800	4	0.120
124	900	1	0.150	189	800	8	0.288
125	850	5	0.065	190	800	7	**2.011**
126	800	2	0.100	191	800	1	0.210
127	800	2	0.065	192	900	7	0.550
128	850	3	0.090	193	900	2	0.222
129	900	1	**1.173**	194	800	6	0.618
130	800	2	0.046	195	800	4	0.420
131	800	2	0.084	196	850	1	0.007
132	800	2	0.009	197	850	2	0.113
133	700	5	0.081	198	800	10	0.552
134	850	2	0.067	199	800	10	0.154
135	900	3	0.328	200	800	3	0.257
136	900	2	0.660	201	800	5	0.401
137	800	3	0.012	202	800	4	0.230
138	850	5	0.066	203	800	3	0.256
139	700	6	0.104	204	800	1	0.165
140	800	4	0.119	205	800	5	0.214
141	900	6	0.654	206	850	3	0.121
142	900	3	0.290	207	800	4	0.124
143	800	1	0.050	208	800	5	0.114
144	850	2	0.095	209	900	6	0.113
145	800	2	0.015	210	850	3	0.165
146	850	3	0.111	211	800	5	0.250
147	900	4	0.507	212	800	3	0.097
148	850	2	0.118	213	850	1	0.039
149	700	10	0.737	214	900	5	0.114
150	850	4	0.600	215	900	3	0.211
151	900	8	0.888	216	800	5	0.104
152	900	7	0.265	217	850	1	0.100
153	850	6	0.344	218	900	1	0.295
154	800	1	0.002	219	800	8	0.513
155	800	3	0.019	220	800	3	0.009
156	900	11	0.905	221	800	2	0.032
157	700	10	0.115	222	900	1	0.120
158	700	9	0.218	223	800	3	0.110
159	850	6	0.222	224	850	5	0.132
160	900	5	0.935	225	800	2	0.100
161	900	6	0.621	226	800	2	0.065
162	850	1	0.031	227	850	3	0.090
163	800	1	0.011	228	900	2	**1.023**
164	800	11	0.487	229	800	2	0.046
165	900	5	0.596	230	800	2	0.084
166	800	2	0.003	231	800	2	0.009
167	850	1	0.001	232	700	5	0.081
168	900	1	0.023	233	850	2	0.067
169	850	1	0.015	234	900	3	0.328
170	800	5	0.300	235	900	5	0.673
171	800	8	0.365	236	800	3	0.012
172	850	4	0.070	237	850	5	0.066
173	900	6	**1.183**	238	700	10	0.064
174	800	5	0.416	239	800	6	0.010
175	800	4	0.077	240	900	5	0.064

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
241	900	3	0.090	306	850	6	0.166
242	800	2	0.150	307	700	7	0.164
243	850	3	0.035	308	800	5	0.110
244	800	4	0.065	309	900	4	0.164
245	850	6	0.011	310	900	2	0.190
246	900	2	0.125	311	800	2	0.150
247	850	5	0.210	312	850	5	0.235
248	700	6	0.037	313	800	4	0.165
249	850	3	0.106	314	850	6	0.111
250	900	5	0.087	315	900	10	0.339
251	900	4	0.165	316	850	6	0.110
252	850	2	0.044	317	700	7	0.237
253	800	3	0.024	318	850	2	0.006
254	800	6	0.100	319	800	1	0.001
255	900	4	0.235	320	700	5	0.201
256	700	2	0.015	321	850	5	0.005
257	700	2	0.028	322	900	3	0.450
258	850	1	0.100	323	900	3	0.153
259	900	6	0.435	324	850	5	0.112
260	900	3	0.021	325	800	3	0.120
261	850	2	0.031	326	800	2	0.199
262	800	3	0.011	327	800	5	0.111
263	800	4	0.087	328	800	2	0.110
264	900	3	0.096	329	900	3	0.199
265	800	7	0.023	330	900	2	0.052
266	850	2	0.014	331	800	1	0.108
267	900	1	0.150	332	800	5	0.129
268	850	5	0.065	333	850	2	0.357
269	800	2	0.100	334	850	3	0.021
270	800	2	0.065	335	800	4	0.022
271	800	4	0.065	336	800	5	0.040
272	850	6	0.011	337	800	5	0.007
273	800	2	0.125	338	800	5	0.040
274	850	5	0.210	339	800	3	0.039
275	700	6	0.350	340	800	2	0.156
276	850	3	0.106	341	800	1	0.095
277	900	5	0.087	342	800	3	0.084
278	900	4	0.165	343	850	3	0.091
279	850	2	0.044	344	800	4	0.074
280	800	3	0.024	345	800	5	0.074
281	800	5	0.014	346	800	5	0.029
282	850	1	0.030	347	800	4	0.006
283	900	3	0.011	348	900	5	0.196
284	900	8	**6.002**	349	800	6	0.123
285	800	3	0.109	350	850	7	0.114
286	850	1	0.095	351	900	1	0.150
287	900	1	0.100	352	850	5	0.065
288	800	3	0.011	353	800	2	0.100
289	800	5	0.305	354	800	2	0.165
290	800	3	0.010	355	850	3	0.190
291	900	5	0.132	356	900	5	0.123
292	800	1	0.020	357	800	2	0.146
293	850	5	0.520	358	800	3	0.184
294	800	9	0.700	359	800	4	0.109
295	800	8	0.465	360	700	5	0.071
296	850	3	0.010	361	850	3	0.167
297	900	1	0.004	362	800	5	0.010
298	800	5	0.016	363	900	3	0.264
299	800	5	0.288	364	900	8	**1.290**
300	800	4	0.119	365	800	2	0.250
301	700	10	0.771	366	850	1	0.035
302	850	5	0.267	367	800	6	0.365
303	900	1	0.028	368	850	6	0.211
304	900	5	0.360	369	900	5	0.825
305	800	6	0.112	370	850	5	0.410

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
371	700	8	0.207	436	800	2	0.147
372	850	5	0.306	437	700	5	0.240
373	900	4	0.787	438	850	2	0.088
374	900	3	0.255	439	900	3	**1.040**
375	850	5	0.444	440	900	3	0.870
376	800	3	0.224	441	800	3	0.007
377	800	7	0.300	442	850	5	0.023
378	800	5	0.332	443	700	10	0.007
379	800	5	0.454	444	800	6	0.003
380	800	1	0.057	445	900	5	0.071
381	800	5	0.164	446	900	3	0.100
382	800	4	0.230	447	800	2	0.001
383	800	3	0.256	448	850	3	0.035
384	800	1	0.165	449	800	4	0.002
385	800	5	0.215	450	850	6	0.120
386	850	3	0.321	451	800	2	0.018
387	800	4	0.324	452	850	5	0.035
388	800	5	0.004	453	700	6	0.010
389	800	3	0.011	454	850	3	0.067
390	800	4	0.087	455	800	1	0.037
391	900	3	0.096	456	700	4	0.007
392	800	7	0.023	457	850	3	0.078
393	850	2	0.014	458	900	5	0.777
394	850	1	0.100	459	900	3	0.064
395	900	6	0.435	460	850	1	0.001
396	900	3	0.021	461	800	1	0.000
397	850	2	0.031	462	800	2	0.120
398	800	3	0.011	463	800	5	0.007
399	800	4	0.087	464	800	8	0.097
400	900	3	0.096	465	900	3	0.065
401	800	7	0.100	466	900	5	0.024
402	850	2	0.056	467	800	1	0.002
403	900	1	0.970	468	800	3	0.010
404	850	5	0.025	469	850	5	0.244
405	800	2	0.037	480	850	5	0.086
406	800	2	0.002	481	800	2	0.011
407	800	4	0.156	482	800	2	0.034
408	850	6	0.247	483	800	1	0.057
409	900	2	0.100	484	800	5	0.100
410	850	5	0.025	485	800	2	0.340
411	700	6	0.100	486	800	3	0.085
412	850	3	0.065	487	800	1	0.036
413	900	5	0.085	488	800	3	0.074
414	900	4	0.215	489	850	3	0.069
415	850	2	0.003	490	800	5	0.100
416	800	3	0.087	491	800	4	0.055
417	800	3	0.007	492	800	3	0.074
418	850	1	0.128	493	800	4	0.100
419	900	5	0.163	494	900	3	0.106
420	900	3	0.022	495	800	7	0.345
421	800	4	0.037	496	850	2	0.045
422	850	1	0.001	497	900	1	0.620
423	900	5	0.325	498	850	5	0.024
424	800	8	0.200	499	800	2	0.010
425	800	3	0.009	500	900	5	0.320
426	800	2	0.047	501	850	3	0.001
427	900	1	0.014	502	900	1	0.653
428	800	3	0.440	503	800	2	0.002
429	850	5	0.040	504	900	5	0.632
430	800	2	0.007	505	800	2	0.132
431	800	2	0.007	506	700	5	0.100
432	850	3	0.100	507	850	2	0.532
433	900	5	**2.341**	508	800	6	0.001
434	800	2	0.100	509	900	5	0.885
435	800	2	0.008	510	900	3	0.032

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
511	800	3	0.256	576	800	2	0.089
512	800	1	0.165	577	800	8	**4.011**
513	800	5	0.210	578	700	2	0.037
514	850	3	0.321	579	850	3	0.106
515	800	2	0.054	580	800	1	0.107
516	800	1	0.057	581	700	4	0.101
517	800	5	0.164	582	850	3	0.205
518	900	4	0.165	583	800	2	0.150
519	850	2	0.044	584	850	3	0.035
520	800	3	0.024	585	800	4	0.065
521	800	6	0.100	586	850	6	0.011
522	800	2	0.112	587	900	2	0.125
523	800	4	0.324	588	900	5	0.210
524	800	5	0.414	589	800	2	0.010
525	800	3	0.011	590	900	2	0.700
526	800	4	0.087	591	900	3	0.852
527	900	3	0.096	592	800	1	0.128
528	800	7	0.023	593	800	3	0.220
529	850	5	0.014	594	850	2	0.357
530	800	5	0.100	595	850	1	0.311
531	1000	10	**8.022**	596	800	2	0.112
532	850	5	0.130	597	800	2	0.054
533	1000	9	**1.111**	598	800	1	0.057
534	900	3	0.011	599	800	5	0.164
535	800	5	0.304	600	800	5	0.230
536	850	1	0.100	601	800	3	0.256
537	1000	8	0.995	602	800	1	0.165
538	900	5	0.087	603	800	2	0.214
539	900	4	0.165	604	850	1	0.320
540	850	2	0.044	605	800	3	0.325
541	800	3	0.024	606	800	2	0.420
542	800	4	0.065	607	800	3	0.011
543	800	4	0.065	608	800	4	0.087
544	850	6	0.011	609	900	3	0.096
545	900	7	0.125	610	800	7	0.023
546	850	5	0.210	611	850	2	0.014
547	700	6	0.037	612	900	1	0.150
548	850	3	0.106	613	850	5	0.065
549	800	8	**1.513**	614	800	2	0.100
550	800	3	0.199	615	800	2	0.065
551	800	4	0.232	616	850	3	0.090
552	900	1	0.020	617	900	2	**1.129**
553	800	3	0.010	618	800	2	0.046
554	850	5	0.132	619	800	2	0.084
555	800	2	0.100	620	800	2	0.009
556	800	2	0.065	621	700	5	0.081
557	850	3	0.090	622	850	2	0.067
558	900	4	**1.025**	623	800	6	0.010
559	800	2	0.046	624	900	5	0.064
560	800	2	0.084	625	900	3	0.090
561	800	2	0.009	626	800	2	0.150
562	700	5	0.081	627	850	3	0.035
563	850	2	0.067	628	800	4	0.065
564	900	3	0.328	629	850	6	0.011
565	900	2	0.600	630	900	2	0.125
566	800	3	0.012	631	800	5	0.210
567	850	5	0.066	632	700	6	0.037
568	700	10	0.064	633	850	3	0.106
569	800	6	0.010	634	900	5	0.087
570	900	5	0.064	635	900	4	0.165
571	900	3	0.090	636	850	2	0.044
572	900	3	0.884	637	800	5	0.025
573	900	1	0.614	638	800	6	0.100
574	850	1	0.012	639	800	2	0.112
575	800	1	0.020	640	800	2	0.054

No.	**Microwave Power (watt)**	**Usage time (years)**	**Maximum radiation leakage (mW/cm^2)**	**No.**	**Microwave Power (watt)**	**Usage time (years)**	**Maximum radiation leakage (mW/cm^2)**
641	800	1	0.057	706	900	3	0.096
642	800	5	0.164	707	800	7	0.023
643	800	4	0.230	708	850	2	0.014
644	900	5	0.256	709	900	1	0.150
645	800	1	0.165	710	850	5	0.065
646	800	5	0.210	711	800	2	0.100
647	850	5	0.321	712	800	2	0.065
648	800	2	0.324	713	850	3	0.020
649	850	4	0.414	714	900	3	**1.023**
650	800	3	0.011	715	800	2	0.046
651	800	4	0.087	716	800	2	0.107
652	900	3	0.096	717	800	2	0.009
653	800	7	0.023	718	700	5	0.200
654	850	2	0.014	719	850	2	0.023
655	800	1	0.057	720	800	6	0.010
656	800	5	0.164	721	900	5	0.104
657	850	5	0.009	722	900	3	0.090
658	850	3	0.194	723	800	2	0.004
659	800	1	0.008	724	850	3	0.035
660	800	5	0.167	725	800	4	0.065
661	850	3	0.019	726	850	6	0.011
662	800	1	0.321	727	900	2	0.125
663	900	3	0.300	728	850	5	0.210
664	800	3	0.084	729	700	6	0.037
665	800	4	0.087	730	850	3	0.106
666	900	3	0.620	731	900	5	0.087
667	800	7	0.100	732	900	4	0.165
668	850	2	0.015	733	850	2	0.044
669	900	1	0.099	734	800	3	0.125
670	850	5	0.039	735	800	6	0.100
671	800	2	0.100	736	700	6	0.037
672	800	2	0.065	737	850	3	0.005
673	850	3	**1.000**	738	900	5	0.087
674	900	5	**1.112**				
675	800	2	0.333				
676	800	10	0.931				
677	800	2	0.100				
678	700	5	0.064				
679	850	2	0.037				
680	800	6	0.184				
681	900	5	0.122				
682	900	3	0.090				
683	800	2	0.150				
684	850	3	0.432				
685	800	4	0.017				
686	850	6	0.011				
687	850	2	0.263				
688	850	3	0.284				
689	700	1	0.470				
690	850	3	0.132				
691	900	5	0.187				
692	900	4	0.032				
693	850	2	0.057				
694	800	2	0.001				
695	800	6	0.003				
696	800	5	0.014				
697	800	4	0.130				
698	800	4	0.198				
699	800	1	0.165				
700	800	5	0.215				
701	850	3	0.321				
702	800	4	0.001				
703	800	5	0.320				
704	800	3	0.011				
705	800	4	0.087				

Record data of surveyed and measurement radiation leakage from microwave ovens. (Water load case)

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
1	800	3	0.098	56	900	1	0.653
2	1000	10	**5.687**	57	850	1	0.001
3	850	1	0.008	58	800	1	0.020
4	900	5	0.030	59	800	2	0.013
5	900	3	0.045	60	1000	8	**4.000**
6	800	5	0.254	61	800	2	0.000
7	850	1	0.006	62	900	3	0.621
8	900	1	0.027	63	900	2	0.865
9	1000	8	**8.004**	64	800	1	0.100
10	800	3	0.250	65	800	3	0.063
11	800	2	0.132	66	850	2	0.316
12	900	1	0.020	67	850	1	0.216
13	800	3	0.010	68	800	2	0.109
14	850	5	0.087	69	800	2	0.005
15	700	10	0.100	70	800	1	0.008
16	800	6	0.010	71	800	5	0.034
17	900	5	0.230	72	800	4	0.164
18	900	3	0.086	73	800	3	0.210
19	800	2	0.023	74	800	1	0.085
20	850	5	0.100	75	800	5	0.210
21	800	3	0.007	76	850	3	0.277
22	850	7	0.068	77	800	4	0.209
23	900	8	0.100	78	800	5	0.400
24	850	10	0.350	79	900	6	0.423
25	700	5	0.090	80	850	3	0.026
26	850	5	0.200	81	800	5	0.095
27	900	3	0.156	82	800	3	0.010
28	900	9	0.300	83	850	1	0.085
29	850	3	0.143	84	900	5	0.020
30	800	1	0.214	85	900	3	0.010
31	800	5	0.010	86	800	5	0.296
32	900	3	0.340	87	850	1	0.067
33	700	1	0.006	88	900	1	0.058
34	700	5	0.180	89	1000	5	**5.004**
35	850	3	0.034	90	800	3	0.034
36	900	4	0.695	91	800	2	0.111
37	900	1	0.486	92	900	1	0.013
38	850	3	0.230	93	800	3	0.012
39	800	1	0.010	94	850	5	0.054
40	800	5	0.024	95	700	10	0.080
41	900	12	0.187	96	800	6	0.016
42	800	5	0.098	97	900	5	0.098
43	850	10	0.058	98	900	3	0.034
44	900	7	0.187	99	800	2	0.004
45	850	1	0.005	100	850	3	0.024
46	800	5	0.095	101	800	4	0.001
47	800	5	0.085	102	850	6	0.010
48	850	1	0.021	103	900	2	0.100
49	900	6	**1.000**	104	850	5	0.080
50	800	2	0.035	105	700	6	0.028
51	800	1	0.068	106	850	3	0.001
52	800	1	0.165	107	900	5	0.031
53	700	4	0.084	108	900	4	0.037
54	850	3	0.165	109	850	2	0.001
55	900	2	0.796	110	800	3	0.005

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
111	800	6	0.094	176	800	5	0.034
112	900	4	0.218	177	700	6	0.180
113	700	2	0.010	178	850	4	0.150
114	700	2	0.034	179	900	7	0.231
115	850	1	0.014	180	900	5	0.765
116	900	6	0.349	181	800	3	0.012
117	900	3	0.014	182	800	1	0.015
118	850	2	0.063	183	700	4	0.001
119	800	3	0.032	184	850	6	0.035
120	800	4	0.025	185	900	5	0.600
121	900	3	0.006	186	900	9	0.687
122	800	7	0.010	187	850	3	0.036
123	850	2	0.010	188	800	4	0.034
124	900	1	0.031	189	800	8	0.275
125	850	5	0.135	190	800	7	**2.000**
126	800	2	0.036	191	800	1	0.012
127	800	2	0.047	192	900	7	0.497
128	850	3	0.068	193	900	2	0.087
129	900	1	**1.638**	194	800	6	0.632
130	800	2	0.024	195	800	4	0.400
131	800	2	0.100	196	850	1	0.010
132	800	2	0.063	197	850	2	0.100
133	700	5	0.034	198	800	10	0.500
134	850	2	0.015	199	800	10	0.110
135	900	3	0.264	200	800	3	0.257
136	900	2	0.463	201	800	5	0.318
137	800	3	0.010	202	800	4	0.230
138	850	5	0.050	203	800	3	0.270
139	700	6	0.068	204	800	1	0.012
140	800	4	0.008	205	800	5	0.200
141	900	6	0.587	206	850	3	0.009
142	900	3	0.290	207	800	4	0.037
143	800	1	0.010	208	800	5	0.004
144	850	2	0.059	209	900	6	0.120
145	800	2	0.010	210	850	3	0.019
146	850	3	0.132	211	800	5	0.054
147	900	4	0.534	212	800	3	0.098
148	850	2	0.064	213	850	1	0.009
149	700	10	0.734	214	900	5	0.008
150	850	4	0.487	215	900	3	0.200
151	900	8	0.671	216	800	5	0.017
152	900	7	0.287	217	850	1	0.004
153	850	6	0.300	218	900	1	0.295
154	800	1	0.100	219	800	8	0.500
155	800	3	0.019	220	800	3	0.001
156	900	11	0.834	221	800	2	0.030
157	700	10	0.050	222	900	1	0.087
158	700	9	0.100	223	800	3	0.034
159	850	6	0.146	224	850	5	0.130
160	900	5	0.937	225	800	2	0.008
161	900	6	0.614	226	800	2	0.023
162	850	1	0.020	227	850	3	0.084
163	800	1	0.007	228	900	2	0.990
164	800	11	0.500	229	800	2	0.011
165	900	5	0.500	230	800	2	0.007
166	800	2	0.100	231	800	2	0.005
167	850	1	0.001	232	700	5	0.023
168	900	1	0.100	233	850	2	0.018
169	850	1	0.010	234	900	3	0.276
170	800	5	0.200	235	900	5	0.598
171	800	8	0.300	236	800	3	0.010
172	850	4	0.037	237	850	5	0.050
173	900	6	**1.230**	238	700	10	0.012
174	800	5	0.361	239	800	6	0.010
175	800	4	0.035	240	900	5	0.004

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
241	900	3	0.018	306	850	6	0.063
242	800	2	0.001	307	700	7	0.067
243	850	3	0.054	308	800	5	0.075
244	800	4	0.052	309	900	4	0.054
245	850	6	0.032	310	900	2	0.050
246	900	2	0.031	311	800	2	0.084
247	850	5	0.100	312	850	5	0.111
248	700	6	0.006	313	800	4	0.060
249	850	3	0.008	314	850	6	0.095
250	900	5	0.064	315	900	10	0.327
251	900	4	0.011	316	850	6	0.035
252	850	2	0.065	317	700	7	0.304
253	800	3	0.010	318	850	2	0.010
254	800	6	0.100	319	800	1	0.001
255	900	4	0.015	320	700	5	0.005
256	700	2	0.020	321	850	5	0.007
257	700	2	0.062	322	900	3	0.264
258	850	1	0.007	323	900	3	0.050
259	900	6	0.333	324	850	5	0.095
260	900	3	0.013	325	800	3	0.095
261	850	2	0.021	326	800	2	0.058
262	800	3	0.010	327	800	5	0.068
263	800	4	0.014	328	800	2	0.047
264	900	3	0.004	329	900	3	0.169
265	800	7	0.010	330	900	2	0.068
266	850	2	0.003	331	800	1	0.110
267	900	1	0.123	332	800	5	0.104
268	850	5	0.050	333	850	2	0.317
269	800	2	0.156	334	850	3	0.018
270	800	2	0.050	335	800	4	0.034
271	800	4	0.047	336	800	5	0.033
272	850	6	0.010	337	800	5	0.032
273	800	2	0.001	338	800	5	0.037
274	850	5	0.063	339	800	3	0.014
275	700	6	0.300	340	800	2	0.147
276	850	3	0.001	341	800	1	0.095
277	900	5	0.001	342	800	3	0.084
278	900	4	0.040	343	850	3	0.001
279	850	2	0.034	344	800	4	0.100
280	800	3	0.010	345	800	5	0.100
281	800	5	0.001	346	800	5	0.015
282	850	1	0.034	347	800	4	0.002
283	900	3	0.005	348	900	5	0.050
284	900	8	**6.120**	349	800	6	0.025
285	800	3	0.098	350	850	7	0.035
286	850	1	0.095	351	900	1	0.200
287	900	1	0.037	352	850	5	0.046
288	800	3	0.023	353	800	2	0.112
289	800	5	0.200	354	800	2	0.070
290	800	3	0.007	355	850	3	0.053
291	900	5	0.150	356	900	5	0.100
292	800	1	0.020	357	800	2	0.100
293	850	5	0.520	358	800	3	0.037
294	800	9	0.700	359	800	4	0.100
295	800	8	0.400	360	700	5	0.017
296	850	3	0.010	361	850	3	0.150
297	900	1	0.001	362	800	5	0.100
298	800	5	0.010	363	900	3	0.200
299	800	5	0.200	364	900	8	**1.370**
300	800	4	0.034	365	800	2	0.096
301	700	10	0.605	366	850	1	0.061
302	850	5	0.231	367	800	6	0.301
303	900	1	0.031	368	850	6	0.168
304	900	5	0.384	369	900	5	0.723
305	800	6	0.086	370	850	5	0.379

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
371	700	8	0.177	436	800	2	0.100
372	850	5	0.200	437	700	5	0.099
373	900	4	0.787	438	850	2	0.037
374	900	3	0.136	439	900	3	**1.036**
375	850	5	0.387	440	900	3	0.759
376	800	3	0.184	441	800	3	0.008
377	800	7	0.287	442	850	5	0.032
378	800	5	0.287	443	700	10	0.040
379	800	5	0.387	444	800	6	0.004
380	800	1	0.010	445	900	5	0.100
381	800	5	0.010	446	900	3	0.153
382	800	4	0.230	447	800	2	0.001
383	800	3	0.231	448	850	3	0.032
384	800	1	0.030	449	800	4	0.007
385	800	5	0.100	450	850	6	0.034
386	850	3	0.234	451	800	2	0.015
387	800	4	0.300	452	850	5	0.014
388	800	5	0.310	453	700	6	0.034
389	800	3	0.075	454	850	3	0.023
390	800	4	0.005	455	800	1	0.034
391	900	3	0.012	456	700	4	0.010
392	800	7	0.053	457	850	3	0.050
393	850	2	0.008	458	900	5	0.777
394	850	1	0.058	459	900	3	0.009
395	900	6	0.317	460	850	1	0.003
396	900	3	0.010	461	800	1	0.100
397	850	2	0.010	462	800	2	0.005
398	800	3	0.002	463	800	5	0.010
399	800	4	0.100	464	800	8	0.001
400	900	3	0.018	465	900	3	0.035
401	800	7	0.095	466	900	5	0.010
402	850	2	0.006	467	800	1	0.010
403	900	1	0.862	468	800	3	0.011
404	850	5	0.072	469	850	5	0.200
405	800	2	0.007	480	850	5	0.005
406	800	2	0.100	481	800	2	0.004
407	800	4	0.134	482	800	2	0.031
408	850	6	0.097	483	800	1	0.011
409	900	2	0.023	484	800	5	0.124
410	850	5	0.010	485	800	2	0.319
411	700	6	0.003	486	800	3	0.100
412	850	3	0.001	487	800	1	0.019
413	900	5	0.007	488	800	3	0.037
414	900	4	0.200	489	850	3	0.063
415	850	2	0.100	490	800	5	0.134
416	800	3	0.018	491	800	4	0.006
417	800	3	0.100	492	800	3	0.032
418	850	1	0.135	493	800	4	0.093
419	900	5	0.123	494	900	3	0.100
420	900	3	0.023	495	800	7	0.307
421	800	4	0.140	496	850	2	0.340
422	850	1	0.001	497	900	1	0.637
423	900	5	0.298	498	850	5	0.031
424	800	8	0.034	499	800	2	0.010
425	800	3	0.014	500	900	5	0.214
426	800	2	0.023	501	850	3	0.001
427	900	1	0.010	502	900	1	0.600
428	800	3	0.321	503	800	2	0.010
429	850	5	0.005	504	900	5	0.597
430	800	2	0.009	505	800	2	0.063
431	800	2	0.100	506	700	5	0.091
432	850	3	0.001	507	850	2	0.500
433	900	5	**2.500**	508	800	6	0.001
434	800	2	0.008	509	900	5	0.864
435	800	2	0.036	510	900	3	0.030

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
511	800	3	0.200	576	800	2	0.054
512	800	1	0.070	577	800	8	**4.000**
513	800	5	0.001	578	700	2	0.017
514	850	3	0.200	579	850	3	0.102
515	800	2	0.005	580	800	1	0.030
516	800	1	0.062	581	700	4	0.002
517	800	5	0.010	582	850	3	0.144
518	900	4	0.098	583	800	2	0.045
519	850	2	0.037	584	850	3	0.025
520	800	3	0.008	585	800	4	0.031
521	800	6	0.005	586	850	6	0.140
522	800	2	0.076	587	900	2	0.031
523	800	4	0.254	588	900	5	0.024
524	800	5	0.387	589	800	2	0.020
525	800	3	0.007	590	900	2	0.764
526	800	4	0.001	591	900	3	0.657
527	900	3	0.016	592	800	1	0.100
528	800	7	0.100	593	800	3	0.198
529	850	5	0.013	594	850	2	0.305
530	800	5	0.007	595	850	1	0.217
531	1000	10	**7.100**	596	800	2	0.001
532	850	5	0.140	597	800	2	0.011
533	1000	9	**1.000**	598	800	1	0.074
534	900	3	0.010	599	800	5	0.100
535	800	5	0.213	600	800	5	0.276
536	850	1	0.100	601	800	3	0.210
537	1000	8	0.789	602	800	1	0.074
538	900	5	0.034	603	800	2	0.175
539	900	4	0.056	604	850	1	0.298
540	850	2	0.065	605	800	3	0.204
541	800	3	0.012	606	800	2	0.357
542	800	4	0.032	607	800	3	0.019
543	800	4	0.032	608	800	4	0.087
544	850	6	0.023	609	900	3	0.025
545	900	7	0.068	610	800	7	0.024
546	850	5	0.136	611	850	2	0.024
547	700	6	0.011	612	900	1	0.078
548	850	3	0.100	613	850	5	0.230
549	800	8	**1.489**	614	800	2	0.034
550	800	3	0.100	615	800	2	0.075
551	800	4	0.187	616	850	3	0.034
552	900	1	0.034	617	900	2	**1.000**
553	800	3	0.010	618	800	2	0.034
554	850	5	0.004	619	800	2	0.050
555	800	2	0.124	620	800	2	0.023
556	800	2	0.032	621	700	5	0.050
557	850	3	0.019	622	850	2	0.063
558	900	4	0.986	623	800	6	0.001
559	800	2	0.002	624	900	5	0.063
560	800	2	0.070	625	900	3	0.087
561	800	2	0.018	626	800	2	0.034
562	700	5	0.075	627	850	3	0.018
563	850	2	0.075	628	800	4	0.100
564	900	3	0.200	629	850	6	0.015
565	900	2	0.365	630	900	2	0.095
566	800	3	0.010	631	800	5	0.035
567	850	5	0.000	632	700	6	0.016
568	700	10	0.021	633	850	3	0.154
569	800	6	0.010	634	900	5	0.064
570	900	5	0.045	635	900	4	0.034
571	900	3	0.001	636	850	2	0.087
572	900	3	0.800	637	800	5	0.001
573	900	1	0.517	638	800	6	0.006
574	850	1	0.022	639	800	2	0.105
575	800	1	0.020	640	800	2	0.013

No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)	No.	Microwave Power (watt)	Usage time (years)	Maximum radiation leakage (mW/cm^2)
641	800	1	0.010	706	900	3	0.029
642	800	5	0.164	707	800	7	0.007
643	800	4	0.136	708	850	2	0.032
644	900	5	0.203	709	900	1	0.065
645	800	1	0.068	710	850	5	0.061
646	800	5	0.186	711	800	2	0.325
647	850	5	0.250	712	800	2	0.075
648	800	2	0.250	713	850	3	0.010
649	850	4	0.315	714	900	3	**1.000**
650	800	3	0.010	715	800	2	0.001
651	800	4	0.001	716	800	2	0.002
652	900	3	0.022	717	800	2	0.004
653	800	7	0.011	718	700	5	0.015
654	850	2	0.028	719	850	2	0.006
655	800	1	0.031	720	800	6	0.007
656	800	5	0.198	721	900	5	0.035
657	850	5	0.007	722	900	3	0.018
658	850	3	0.050	723	800	2	0.027
659	800	1	0.012	724	850	3	0.017
660	800	5	0.200	725	800	4	0.021
661	850	3	0.019	726	850	6	0.011
662	800	1	0.300	727	900	2	0.086
663	900	3	0.236	728	850	5	0.132
664	800	3	0.050	729	700	6	0.008
665	800	4	0.135	730	850	3	0.198
666	900	3	0.587	731	900	5	0.023
667	800	7	0.007	732	900	4	0.001
668	850	2	0.008	733	850	2	0.024
669	900	1	0.039	734	800	3	0.004
670	850	5	0.020	735	800	6	0.100
671	800	2	0.111	736	700	6	0.013
672	800	2	0.031	737	850	3	0.002
673	850	3	0.634	738	900	5	0.098
674	900	5	**1.000**				
675	800	2	0.326				
676	800	10	**1.230**				
677	800	2	0.134				
678	700	5	0.027				
679	850	2	0.011				
680	800	6	0.100				
681	900	5	0.004				
682	900	3	0.064				
683	800	2	0.035				
684	850	3	0.398				
685	800	4	0.006				
686	850	6	0.054				
687	850	2	0.263				
688	850	3	0.250				
689	700	1	0.421				
690	850	3	0.009				
691	900	5	0.069				
692	900	4	0.050				
693	850	2	0.007				
694	800	2	0.001				
695	800	6	0.100				
696	800	5	0.008				
697	800	4	0.150				
698	800	4	0.100				
699	800	1	0.010				
700	800	5	0.230				
701	850	3	0.297				
702	800	4	0.005				
703	800	5	0.237				
704	800	3	0.021				
705	800	4	0.047				

APPENDIX D

Record data for statistic analysis:

Usage time (years)	Microwave power (Watt)											
	800				850				900			
1	0.270	0.011	0.037	0.057	0.030	0.001	0.128		0.095	0.120	0.020	
	0.015	0.017	0.000	0.165	0.100	0.015	0.001		0.020	0.150	0.614	
	0.113	0.210	0.002	0.057	0.054	0.007	0.001		0.500	0.100	0.150	
	0.107	0.165	0.057	0.165	0.010	0.039	0.100		0.653	0.004	0.099	
	0.020	0.020	0.036	0.057	0.012	0.100	0.012		0.095	0.028	0.150	
	0.128	0.001	0.165	0.008	0.311	0.100	0.311		0.020	0.150		
	0.057	0.108	0.057	0.321	0.030	0.030	0.320		0.150	0.970		
	0.165	0.095	0.020	0.165	0.100	0.095			1.173	0.014		
	0.050	0.057	0.107		0.100	0.035			0.023	0.620		
	0.002	0.165	0.128		0.031	0.100			0.295	0.653		
2	0.132	0.150	0.120	0.100	0.357	0.044			0.850			
	0.150	0.100	0.011	0.065	0.044	0.044			0.861			
	0.010	0.065	0.034	0.046	0.031	0.067			0.125			
	0.089	0.125	0.340	0.084	0.014	0.357			0.660			
	0.010	0.150	0.010	0.009	0.067	0.014			0.222			
	0.112	0.199	0.002	0.150	0.095	0.067			1.023			
	0.054	0.110	0.132	0.112	0.118	0.044			0.125			
	0.132	0.156	0.062	0.054	0.113	0.014			0.190			
	0.150	0.100	0.054	0.324	0.067	0.015			0.052			
	0.100	0.165	0.112	0.100	0.044	0.037			0.100			
	0.065	0.146	0.100	0.065	0.031	0.263			0.125			
	0.046	0.250	0.065	0.333	0.014	0.057			0.600			
	0.084	0.037	0.046	0.100	0.044	0.014			0.125			
	0.009	0.002	0.084	0.150	0.006	0.023			0.700			
	0.015	0.047	0.009	0.001	0.357	0.044			1.129			
	0.003	0.007	0.089	0.100	0.014				0.125			
	0.032	0.007	0.150	0.065	0.031				0.125			
	0.100	0.100	0.010	0.046	0.056							
	0.065	0.008	0.112	0.107	0.003							
	0.046	0.147	0.054	0.009	0.088							
	0.084	0.001	0.214	0.004	0.045							
	0.009	0.018	0.420		0.532							
3	0.064	0.256	0.224	0.011	0.143	0.106	0.035	0.284	0.011	0.096	0.065	0.096
	0.109	0.097	0.256	0.024	0.030	0.106	0.106	0.132	0.090	0.011	0.106	1.023
	0.010	0.009	0.011	0.199	0.010	0.010	0.321	0.321	0.240	0.450	0.032	0.090
	0.100	0.110	0.011	0.010	0.205	0.021	0.106	0.020	0.110	0.153	0.096	
	0.220	0.012	0.087	0.012	0.321	0.091	0.090	0.035	0.700	0.199	0.011	
	0.256	0.024	0.007	0.220	0.165	0.190	0.106	0.106	0.011	0.264	0.328	
	0.011	0.011	0.009	0.256	0.035	0.167	0.205	0.005	0.090	0.255	0.090	
	0.109	0.024	0.440	0.325	0.106	0.321	0.035		0.021	0.096	0.884	
	0.010	0.109	0.007	0.011	0.090	0.065	0.090		0.096	0.021	0.852	
	0.024	0.011	0.010	0.011	0.111	0.100	0.035		0.328	0.096	0.096	
	0.011	0.010	0.085	0.084	0.112	0.035	0.106		0.290	0.022	0.090	
	0.012	0.120	0.074	0.011	0.121	0.067	0.194		0.211	1.040	0.096	
	0.019	0.039	0.074	0.125	0.165	0.078	0.019		0.328	0.870	0.300	
	0.103	0.084	0.256		0.090	0.069	1.000		0.090	0.100	0.620	
	0.257	0.184	0.024		0.035	0.001	0.432		0.021	0.064	0.090	
5	0.304	0.401	0.040	0.414	0.132	0.235	0.024		0.014	0.132	0.885	
	0.015	0.214	0.074	0.100	0.120	0.005	0.014		0.064	0.360	0.087	
	0.012	0.114	0.029	0.304	0.150	0.112	0.130		0.014	0.196	0.087	
	0.110	0.250	0.010	0.164	0.132	0.065	0.210		0.064	0.123	0.064	
	0.045	0.104	0.332	0.230	0.210	0.410	0.132		0.087	0.825	0.210	
	0.100	0.014	0.454	0.210	0.065	0.306	0.066		0.935	0.085	0.064	
	0.164	0.305	0.164	0.025	0.066	0.444	0.065		0.596	0.163	0.087	
	0.214	0.016	0.215	0.164	0.132	0.025	0.321		0.766	0.325	0.256	
	0.415	0.288	0.004	0.210	0.066	0.025	0.009		0.550	2.341	1.112	
	0.050	0.110	0.007	0.164	0.210	0.040	0.039		0.114	0.071	0.122	
	0.304	0.111	0.100	0.167	0.065	0.023	0.065		0.673	0.777	0.187	
	0.300	0.129	0.100	0.014	0.210	0.035	0.210		0.064	0.024	0.104	
	0.416	0.040	0.210	0.215	0.520	0.244			0.087	0.320	0.087	
	0.210	0.007	0.164	0.320	0.267	0.086			0.087	0.632	0.087	

APPENDIX E

Statistic :Two-way analysis of variance

The two-way analysis of variance is simply multiple regression analysis with two categorical explanatory variables (or factors). We will primarily use the Two-Way ANOVA approach for initial model assessment, testing for interaction and/or individual factor effects. After an appropriate (general) model is found, we can answer specific questions about the factor effects using a multiple regression approach.

Variables and Notation

Variables: Y: the response

X1: factor 1 with I levels (FACTOR1)

X2: factor 2 with J levels (FACTOR2)

Calculation value

SS - Sum of square

df - Level of freedom

Ms - Unbiased estimator

F - F-distribution test

SST - Total sum of square

$$SST = \sum_{j=1}^{k}\sum_{i=1}^{n}\left(\bar{x}_{ij} - \bar{x}_{**}\right)^2 = \sum_{j=1}^{k}\sum_{i=1}^{n} x_{ij}^2 - \frac{T_{**}^2}{nk}$$

SSTr - Total sum of square (Process)

$$SSTr = \sum_{i=1}^{a}\sum_{j=1}^{b}\frac{T_{ij*}^2}{n} - \frac{T_{***}^2}{abn}$$

SSA - Sum of square among treatments mean or Treatment sum of square (factor a)

$$SSA = \sum_{j=1}^{k}\sum_{i=1}^{n}\left(\bar{x}_{i*} - \bar{x}_{**}\right)^2 = \sum_{i=1}^{n}\frac{T_{i*}^2}{k} - \frac{T_{**}^2}{nk}$$

SSC - Sum of square among treatments mean or Treatment sum of square (factor c)

$$SSC = \sum_{j=1}^{k}\sum_{i=1}^{n}\left(\bar{x}_{*j} - \bar{x}_{**}\right)^2 = \sum_{j=1}^{k}\frac{T_{*j}^2}{n} - \frac{T_{**}^2}{nk}$$

SSAC - Interaction sum of square among treatments mean (factor a and c)

$$SSAC = SSTr - SSA - SSC$$

SSW or SSE - Sum of square within treatments or Error sum of square

$$SSE = \sum_{j=1}^{k}\sum_{i=1}^{n}\left(x_{ij} - \overline{x}_{i*} - \overline{x}_{*j} + \overline{x}_{**}\right)^2 = SST - SSA - SSB$$

MSB - Unbiased estimator of variance

MSA - Unbiased estimator of variance (factor a)

$$MSA = \frac{SSA}{c-1}$$

MSC - Unbiased estimator of variance (factor c)

$$MSC = \frac{SSC}{c-1}$$

MSAC - Unbiased estimator of variance (Interaction factors a and c)

$$MSAC = \frac{SSAC}{k-1}$$

MSW or MSE - Error unbiased estimator of variance

$$MSE = \frac{SSE}{ac(n-1)}$$

Variables: Radiation Leakage response

a: factor 1 (Usage time) has levels numbered i=1, ... a

c: factor 2 (Microwave power) has levels numbered j=1, ...c

and each combination has k=1, ... n replications.

Statistical analysis

The data could be laid out as follows Table above:

Table A Average radiation leakage in relation to age and operating power

		Radiation leakage (mW/cm^2) (No load)				
		Microwave power				
		j = 1 (800 W)	j = 2 (850 W)	j = 3 (900 W)	Total	Mean
Usage time	i = 1 (1 y)	0.089	0.080	0.275	0.444	0.148
	i = 2 (2 y)	0.090	0.089	0.420	0.599	0.199
	i = 3 (3 y)	0.091	0.134	0.236	0.461	0.461
	i = 4 (5 y)	0.167	0.142	0.332	0.641	0.641
	Total	0.437	0.445	1.263	2.145	
	Mean	0.109	0.111	0.315		

Hypothesis test format:

1) $H_0 : \mu_a = \mu_c$

H_1 : Not all μ_j are equal

2) $F = \dfrac{MSAC}{MSE}$, $\nu_1 = k - 1 = 4 - 1 = 3$, $\nu_2 = (n-1)(k-1) = (4-1)(3-1) = 6$

Critical region $F > f_{0.05\,(3,6)} = 4.76$

3) $\alpha = 0.05$

4) If $F_{calculation} \leq F_{t-1,n-t,\alpha}$ Do Not Reject H_0.

If $F_{calculation} > F_{t-1,n-t,\alpha}$ Reject H_0.

Calculate statistic value as follow appendix E:

$$SSA = \sum_{i=1}^{n} \frac{T_{i*}^2}{n} - \frac{T_{**}^2}{nk} = \frac{0.444^2 + 0.599^2 + 0.461^2 + 0.641^2}{3} - \frac{(2.145)^2}{12} = 0.009$$

$$SSB = \sum_{j=1}^{k} \frac{T_{*j}^2}{n} - \frac{T_{**}^2}{nk} = \frac{0.437^2 + 0.445^2 + 1.263^2}{4} - \frac{(2.145)^2}{12} = 0.112$$

$$SST = \sum_{j=1}^{k} \sum_{i=1}^{n} x_{ij}^2 - \frac{T_{**}^2}{nk} = 0.089^2 + 0.080^2 + 0.275^2 + ... + 0.332^2 - \frac{(2.145)^2}{12} = 0.139$$

$$SSE = SST - SSA - SSB = 0.139 - 0.009 - 0.112 = 0.018$$

$$SSTr = \sum_{i=1}^{a} \sum_{j=1}^{b} \frac{T_{ij*}^2}{n} - \frac{T_{***}^2}{abn} = \frac{0.089^2 + 0.080^2 + 0.275^2 + ... + 0.332^2}{3} - \frac{(2.145)^2}{(4)(3)(3)} = 0.163$$

$$SSAC = SSTr - SSA - SSB = 0.163 - 0.112 - 0.009 = 0.042$$

Table B Calculated statistic value in ANOVA

Source of Variation	SS	df	Ms	F
Factor a	SSA = 0.009	3	MSA = 0.003	1
Factor c	SSC = 0.112	2	MSC = 0.056	18.66
AC interaction	SSAC = 0.042	6	MSAC = 0.007	2.33
Error	SSE = 0.018	6	MSE = 0.003	
Total	SST = 0.139	11		

Summary:

In factor 1: Oven age

$F_{calculation} \leq F_{t-1,n-t,\alpha}$ - There is no relationship between the quantity of radiation leakage and the oven age.

In factor 2: Operating power

$F_{calculation} > F_{t-1,n-t,\alpha}$ - The quantity of radiation leakage is significantly related to the microwave operating power at $\alpha = 0.05$. .

APPENDIX F

Microwave Oven Safety Guidelines

- Do not operate the oven if it is damaged or does not operate properly. It is imperative that the oven door seals properly and that there is no damage to the door seal, hinges, latches, or oven surfaces.
- Ovens used for food preparation must be cleaned on a regular basis to prevent biological contamination, fire potential, and door seal damage.

Ovens used for laboratory applications cannot be used for food preparation.

Conversely, food preparation ovens should never be used for other applications.

Do not use aluminum foil or any metal containers, metal utensils, metal objects, or objects with metal or foil trim in the oven. Such items can cause arcing, damaging the oven and creating a fire or burn hazard. A classic item, which is often overlooked, is the metal handle on the paper Chinese food box.

Do not heat objects that are sealed as they may explode, damaging the oven and blowing off the door. Never heat any flammable or combustible liquid in the oven. A fire and/or explosion may result.

Is careful when removing containers from the microwave. Containers or their contents may be very hot, resulting in burns or spills of hot materials.

If a fire should start inside the oven, leave the door closed, disconnect the power cord and call the fire department at 191.

Never make adjustments to or tamper with any component of the oven. Do not try to perform repairs on your own. The oven operates on high voltage and amperage that can be lethal if improperly handled.

Generally speaking, commercially available microwave ovens are very safe and reliable, regardless of the manufacturer. All ovens produced for sale in the United States must meet a strict FDA/CDRH product performance requirement that limits their microwave leakage during service to <5 mW/cm2 at 5 cm from any oven surface.

If your oven is damaged or you have a reason to believe it may be leaking,please contact ORS at 3-8414 to arrange a survey of the oven.

BIOGRAPHY

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