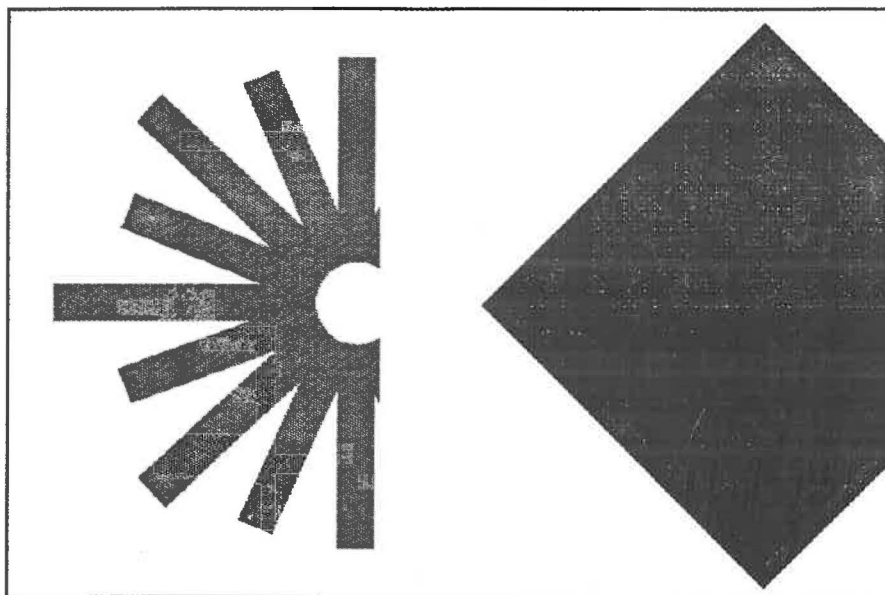


R2354

NIOSH

583

Nonionizing Radiation



Division of Training and Manpower Development



*U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health*

NONIONIZING RADIATION (583)

**Conducted by
Division of Training and Manpower Development**

**U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health**

Cincinnati, Ohio 45226

March 1979

NIOSH LOCATIONS

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Rockville, Maryland 20857

CINCINNATI LABORATORY

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Robert A. Taft Laboratories
4676 Columbia Parkway
Cincinnati, Ohio 45226

APPALACHIAN LABORATORY

Appalachian Laboratory for Occupational Safety & Health
National Institute for Occupational Safety & Health
944 Chestnut Ridge Road
Morgantown, West Virginia 26505

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Regional Consultant, NIOSH
DHEW Region I
Government Center (JFK Fed. Bldg.)
Boston, Massachusetts 02203
617/223-6868

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DHEW Region II — Federal Bldg.
26 Federal Plaza
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REGION III—Philadelphia

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215/596-6716

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DHEW Region IV
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Room 1700-A
Dallas, Texas 75202
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REGION VII—Kansas City

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Regional Consultant, NIOSH
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601 East 12th Street
Kansas City, Missouri 64106
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REGION VIII—Denver

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Regional Consultant, NIOSH
DHEW Region VIII
11037 Federal Building
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REGION IX—San Francisco

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Regional Consultant, NIOSH
DHEW Region IX
50 United Nations Plaza
Room 231
San Francisco, California 94102
415/556-3781

REGION X—Seattle

(Alaska, Idaho, Oregon and Washington)
Regional Consultant, NIOSH
DHEW Region X
1321 Second Avenue (Arcade Bldg.)
Seattle, Washington 98101
206/442-0530

**LABORATORY
NUMBER**

TOPIC

5	INSTRUMENTATION LABORATORY
6	MICROWAVE LABORATORY
7	ULTRAVIOLET RADIATION
8	LASERS

INSTRUMENTATION LABORATORY
NO. 5

COURSE OUTLINE

V. INSTRUMENTATION

A. INTRODUCTION

1. Objectives
2. Overview
3. Equipment
4. Precautions

B. INSTRUCTOR'S DEMONSTRATION - LECTURE

1. Introduction
2. Photon Devices
 - a. Photoelectric
 - b. Photoconductive
 - c. Photovoltaic
3. Thermal Devices
 - a. Calorimeters
 - b. Bolometers
 - c. Thermocouple
4. Summary
5. Detection Accessories
6. Detector Requirements and Commercially Available Detectors
 - a. Microwave
 - b. Ultraviolet
 - c. Laser

C. STUDENTS' LABORATORY EXERCISE

1. Introduction
2. Phase I. Familiarization to Radiation Detectors
 - a. Microwave
 - b. Ultraviolet
 - c. Laser
3. Phase II. Sensing Elements

L5	INSTRUMENTATION LAB	1
OBJECTIVES 1. TO KNOW THE DIFFERENT GENERAL TYPES OF RADIATION DETECTORS. 2. TO KNOW BASIC REQUIREMENTS FOR RADIATION DETECTORS. 3. TO REVIEW INSTRUMENTS COMMERCIALY AVAILABLE. 4. TO BE INTRODUCED TO THE INSTRUMENTS TO BE USED IN THE SUCCEEDING LABS. 5. TO EXAMINE THE ACTUAL DETECTING ELEMENTS OF DIFFERENT TYPES OF DETECTORS.		

A. INTRODUCTION

1. Objectives

1. To know the different general types of radiation detectors.
2. To know the basic requirements for radiation detectors.
3. To review instruments commercially available.
4. To be introduced to the instruments to be used in the succeeding labs.
5. To examine the actual detecting elements of different types of detectors.

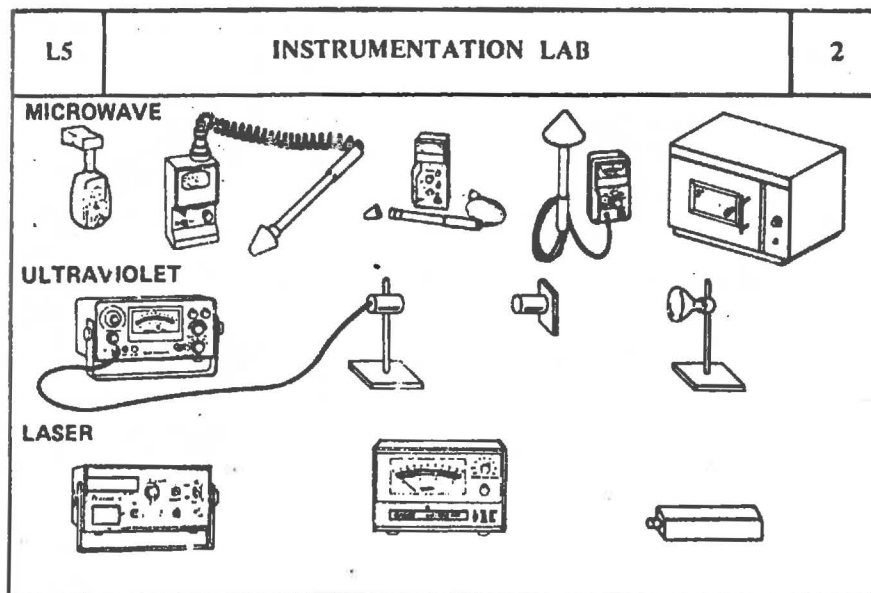
2. Overview

The instructor will review and explain the different types of radiation detectors and explain the basic concepts of their operation. The requirements for radiation detectors will be discussed, and a compilation of manufacturers specifications will be examined.

The students during their laboratory exercise will use the instruments that are available in the lab to look at a single radiation source. For example the microwave instruments will be used to measure the output of a microwave signal source, the laser instruments will be used to measure the output of a laser, etc. Thus, the response of the different detectors can be compared.

Next the students will look at the detecting elements from various detectors. The detecting elements will be cross-sectioned or removed from their holders so that they can easily be examined. The students will sketch the elements and record what parameter varies with incident radiation.

The lab exercise will be turned in at the end of the lab.



3. Equipment

1. Microwave

- a. Waveline 1200B Densimeter
- b. Naeda 8200
- c. Naeda 8100
- d. Haladay HI1500
- e. Microwave Oven
- f. Microwave Hazard Signs

2. Ultraviolet

- a. IL600 Photometer, PT100D with ACT270
- b. IL700 Research Radiometer
- c. Sunlamp
- d. UV Hazard Signs

3. Laser

- a. IL700 Photometer, PT200A/203A
- b. Scientech 362
- c. HeNe Laser
- d. Laser Hazard Signs

L5	INSTRUMENTATION LAB	2A
SENSING ELEMENTS		
PHOTOTUBE	BARETTER	
PHOTOMULTIPLIER	CALORIMETER	
PHOTOCONDUCTOR	THERMOCOUPLE	
PHOTOCELL	THERMOPILE	
THERMISTOR	DIODE	

4. Sensing Elements*

- a. Phototube
- b. Photomultiplier
- c. Photoconductor
- d. Photocell
- e. Thermistor
- f. Baretter
- g. Calorimeter
- h. Thermocouple
- i. Thermopile
- j. Hot Carrier Diode

* Sensing elements are mounted on wood panels and are cross sectioned to expose interior.

L5	INSTRUMENTATION LAB	3
1. FOLLOW INSTRUCTIONS WHEN USING THE VARIOUS DETECTORS. 2. AVOID PROLONGED EXPOSURE AROUND THE VARIOUS RADIATION SOURCES. 3. DO NOT ENTER AREAS DESIGNATED AS HAZARDOUS BY THE INSTRUCTOR. 4. BE CAREFUL WHEN HANDLING THE FRAGILE SENSING ELEMENTS		

4. Precautions

The above precautions will be followed during the demonstration - lecture and students' laboratory exercise.

L5	INSTRUMENTATION LAB	4
TWO CLASSIFICATIONS OF DETECTORS PHOTON DEVICES THERMAL DEVICES		

B. INSTRUCTOR'S DEMONSTRATION-LECTURE

1. Introduction

A variety of light detectors have been utilized and can be classified under one of two general categories: photon devices and thermal devices. These two classifications of light detectors are based on the two ways in which light interacts with matter. Photon devices interact via the photoelectric effect, photoconductive effect, and photovoltaic effect. Thermal devices utilize the heating effect and corresponding temperature rise caused by energy absorption.

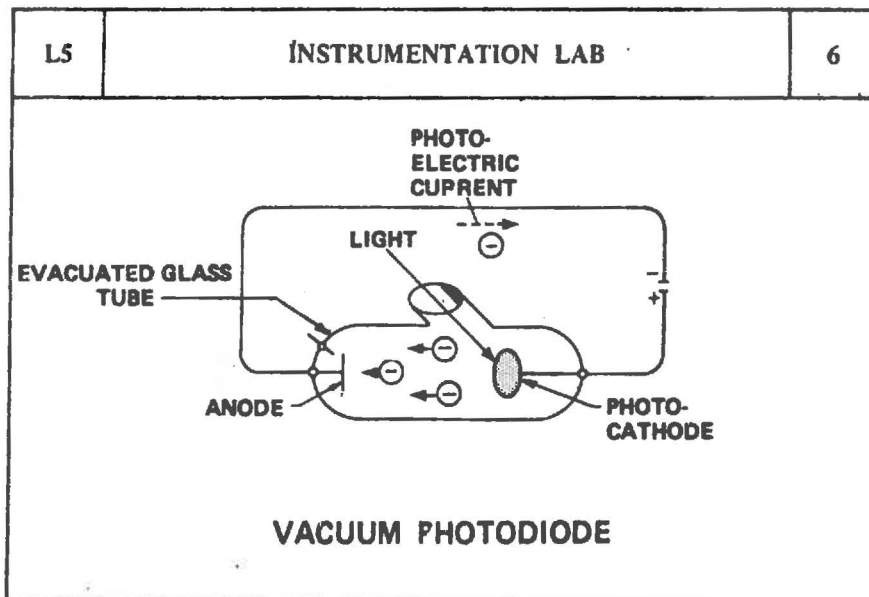
Microwave detectors incorporate the thermal devices since microwave photon energy is insufficient to activate the photon devices. Some microwave detectors measure the current produced in an antenna by the RF field.

L5	INSTRUMENTATION LAB	5
PHOTON DEVICES PHOTOELECTRIC PHOTOCONDUCTIVE PHOTOVOLTAIC		

2. Photon Devices

Photon devices measure the rate at which light quanta are absorbed. The response at any particular wavelength is proportional to the rate at which photons of that wavelength are absorbed. These detectors have a strong wavelength dependence.

There are three ways to categorize photon devices: photoelectric, photoconductive, and photovoltaic. Electrons in a material may absorb energy from incident light quanta. When the electron is ejected or completely removed from the metal upon absorption of a light photon, the photoelectric effect has occurred. If, however, the electron is liberated from a particular atom but is not ejected from the metal, this is termed the photoconductive effect. When the photoconductive effect occurs at the P-N boundary of semiconductors or at the boundary between a metal and a semiconductor, a potential difference will develop. This is classified as the photovoltaic effect.

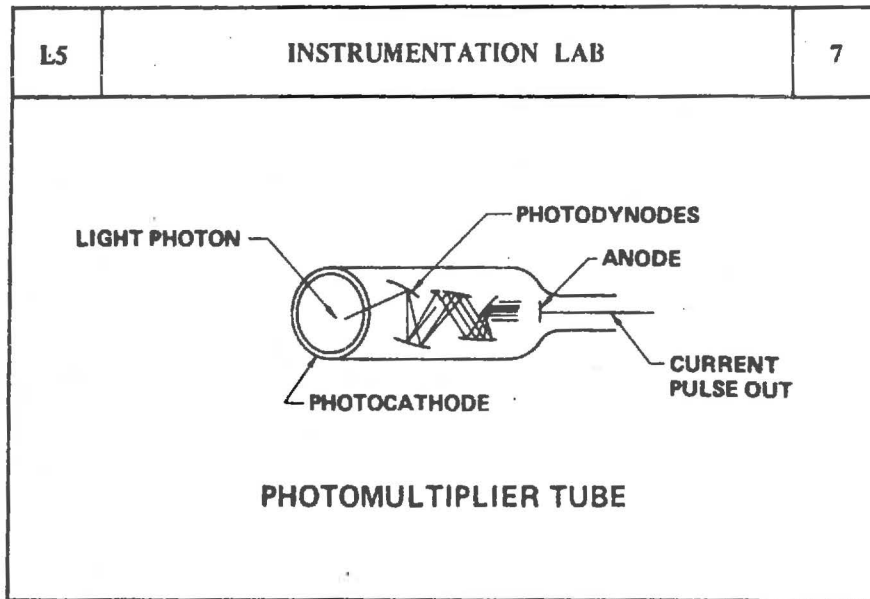


2. Photon Devices (contd.)

a. Photoelectric

A single light photon is absorbed by a photocathode and a photoelectron is emitted. This electron is then attracted to a positive anode. As a light beam consists of many photons, numerous electrons will be emitted from the photocathode and attracted to the anode. The resulting current or voltage can then be measured.

The light-sensitive photocathode is usually placed inside an evacuated glass tube. This is called a vacuum photodiode. It has good stability and good range (linearity over large intensity range).

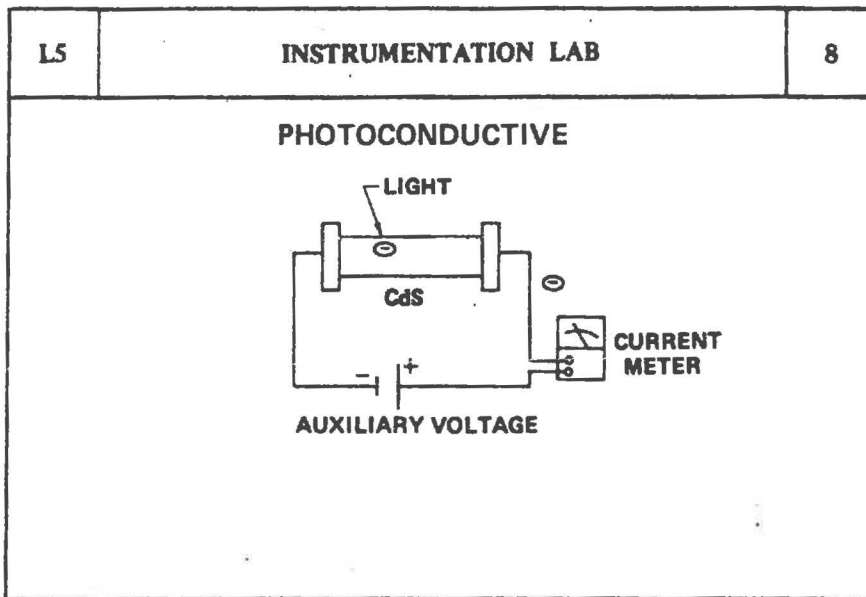


2. Photon Devices

a. Photoelectric (contd.)

The most sensitive of all the light-detectors is the photomultiplier tube (PMT). Similar to the vacuum photodiode, the PMT consists of a photocathode and a positive anode. In addition, however, it contains accelerating photodynodes which amplify the number of electrons emitted from the photocathode.

Since the photocathode is so sensitive, it can only be used to detect very low power levels (around 10^{-5} watts or less). (There are photomultiplier tubes which are able to detect one photon.) The sensitivity derives from the high gain or amplification that comes from the dynodes, with 13 stages, gains of 10^6 to 10^7 can be realized. There are two major disadvantages: different photocathodes have different spectral responses (dependence on the incident wavelength), and PMT's tend to lack linearity over wide intensity ranges.



2. Photon Devices (contd.)

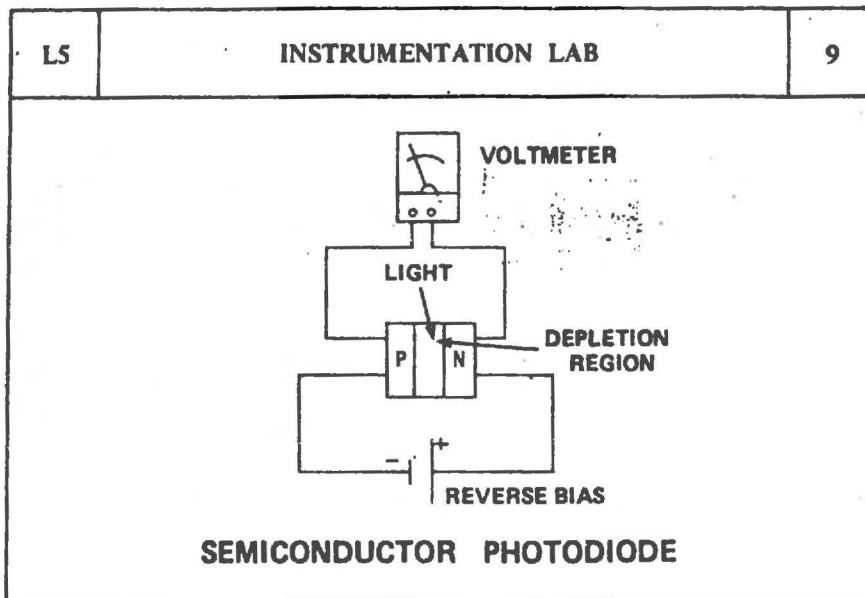
b. Photoconductive

Photoconductive materials do not generate electricity (electron current) as do the photoelectric devices. Instead, these detectors possess the very useful characteristic of changing resistance when absorbing light. This resistance change may be on the order of millions between light and dark exposures. Characteristic photoconductive cells are cadmium sulphide and cadmium selenide.

The photoconductive effect is the simplest photon effect. When this occurs in a semiconductor the electron is not removed from the material but merely liberated from a particular atom (electrons are moved from the valence band or "doped" electron energy level into the conduction band). The resistance to electron flow is then greatly reduced, and the conductivity greatly increased. This change in resistance or conductivity can be easily measured.

Note that an auxiliary voltage supply is required for the photoconductive detectors. They can be used to measure powers 10^{-5} to 0.5 watts; they also are wavelength-dependent.

Although CdS is used for photometric applications with diffuse white light, it is not satisfactory for measuring laser power quantitatively.



2. Photon Devices

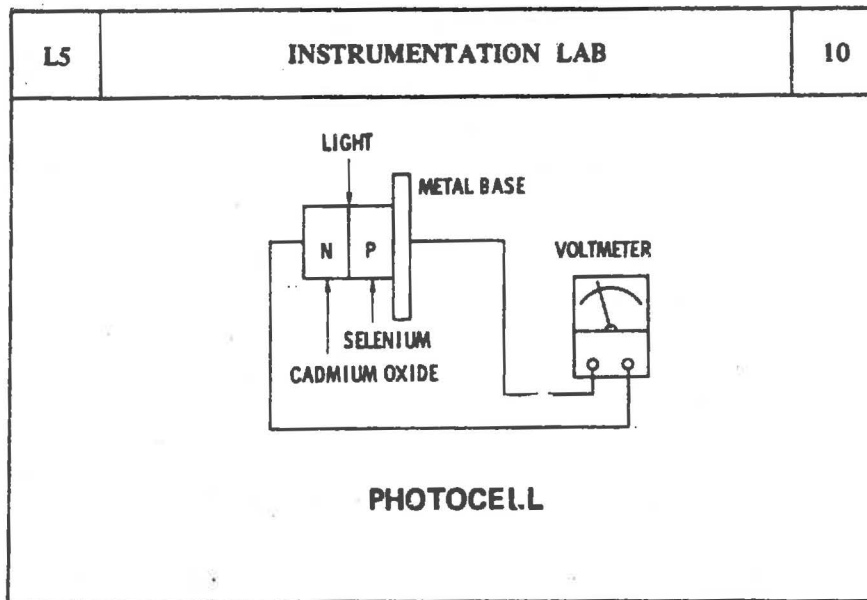
b. Photoconductive (contd.)

The silicon semiconductor photodiode is another popular detector. The semiconductor silicon acts as a current generator, with the current dependent on the incident light. When a semiconductor is "back-biased" it operates in the photoconductive mode.

The semiconductor photodiodes are operated with an applied reverse bias (voltage) so that a very low concentration of charge carriers exist at the interface between the two semiconductor regions. When a light photon is absorbed, the charge from the electron hole pair creation is separated by the applied electric field. This effect produces a measurable voltage across the interface, called the depletion region. Measuring this voltage change gives an indication of the power or energy of the incident light.

Semiconductor photodiodes have many characteristics that make them useful in measuring small output powers of 10^{-5} to 0.5 watts. Some of the advantages are: 1) good linearity over seven orders of magnitude; 2) reasonable spectral response, though not good in the ultraviolet region; 3) fast response time with a 4 to 5 nsec rise time and a 10 nsec decay time. The semiconductor photodiode's small size can be advantageous in monitoring small beam areas or fields.

Some disadvantages are the wavelength dependence and the small area of the detector. For large power densities, filters, gratings, or beam splitters can be used to attenuate the beam (or sample a smaller area) and then calculate the actual power level from the sampled portion.

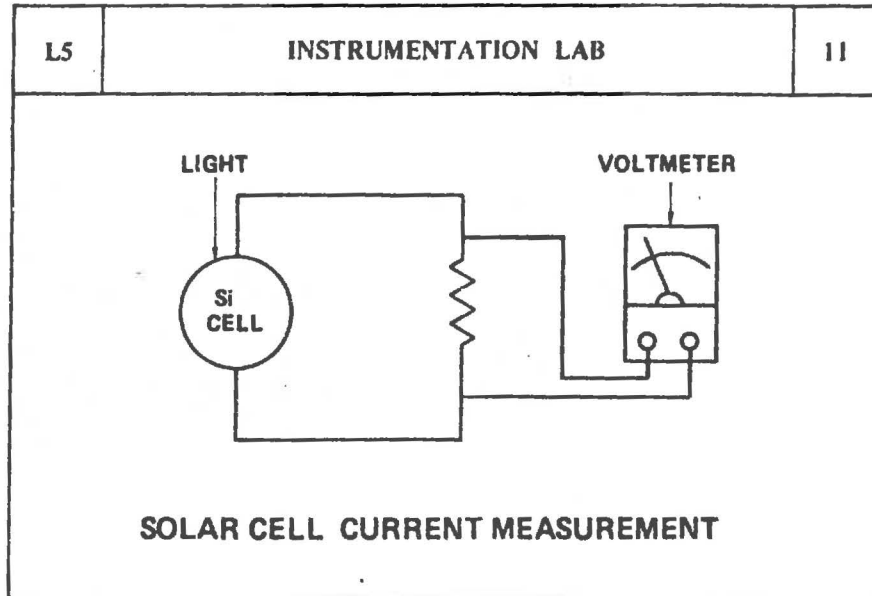


2. Photon Devices (contd.)

c. Photovoltaic Detectors

All practical photovoltaic cells consist of a junction between two dissimilar semiconductor materials. When light is absorbed at this boundary, an electron will be liberated from an atom, but not ejected from the material (photoconductive effect). There will also be a potential difference arising which can be detected (photovoltaic effect). No battery or electrical power supply is necessary. Photovoltaic detectors may be classified in two ways: photocells and solar cells.

Photocell or selenium cells have found widespread application as light meters in cameras and as automatic exposure devices. Cadmium oxide is usually coated on a selenium base, fastened to a metal baseplate. As light is absorbed, a potential difference arises between the cadmium oxide and baseplate which can be measured, as in Figure 10. The response of the selenium cell to light is similar to that of the human eye.



2. Photon Devices

c. Photovoltaic Detectors (contd.)

Another type of cell, used as a source of electrical power for satellites, is the solar cell. This is made of the most common element found on our planet, silicon. In actuality, this can be classified as a photoelectric device since an electron current is generated when light is absorbed. However, since no external voltage supply is necessary, this is usually classified as photovoltaic. The current can be measured directly or as a voltage across a load resistor.

The silicon photovoltaic cell is a very popular laser detector. Having ranges from 0.1 mW to 100 mW, it has found much use in He-Ne laser power meters.

L5	INSTRUMENTATION LAB	12
THERMAL DEVICES CALORIMETERS BOLOMETERS THERMOCOUPLES		

3. Thermal Devices

Thermal devices measure the effect of heat and temperature changes on materials when absorbing light energy. There are three general categories: calorimeters, bolometers and thermocouples.

L5	INSTRUMENTATION LAB	13
CALORIMETERS 1. ABSORB THE TOTAL LIGHT ENERGY. 2. TEMPERATURE RISE INDICATES THE AMOUNT OF ENERGY ABSORBED. 3. SLOW RESPONSE TIME. 4. WAVELENGTH DEPENDENCE DETERMINED BY ABSORBING MEDIUM.		

3. Thermal Devices (contd.)

a. Calorimeters

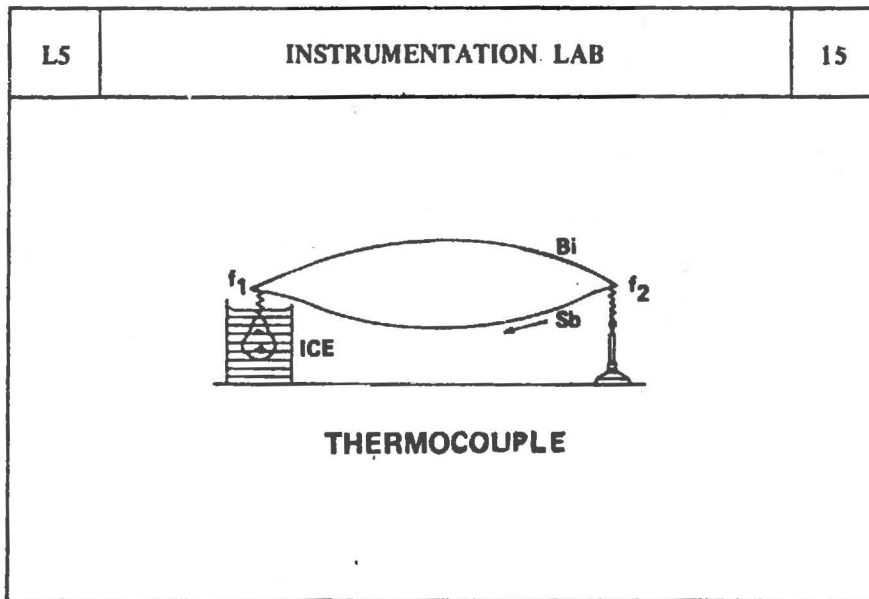
Calorimeters absorb the total light energy, and the corresponding temperature rise indicates the amount of energy absorbed. They are useful in measuring pulsed laser outputs from 10^{-3} to 100 joules per pulse. The response time is slow; they should not be used for measurement of rapid trains of pulses since it takes some time for the calorimeters to equilibrate to ambient temperature. The energy supply to the calorimeters can be compared with energy supplied from an accurately known source (i.e., an electric heater). Calorimeters can also be used to measure C W outputs greater than 0.1 watts. Wavelength dependence is determined by the absorbing medium. They are also used as conventional standards in photometry and radiometry.

L5	INSTRUMENTATION LAB	14
BOLOMETERS 1. THERMISTOR INCREASE IN TEMPERATURE DECREASES RESISTANCE 2. BARETTER INCREASE IN TEMPERATURE INCREASES RESISTANCE		

3. Thermal Devices (contd.)

b. Bolometers

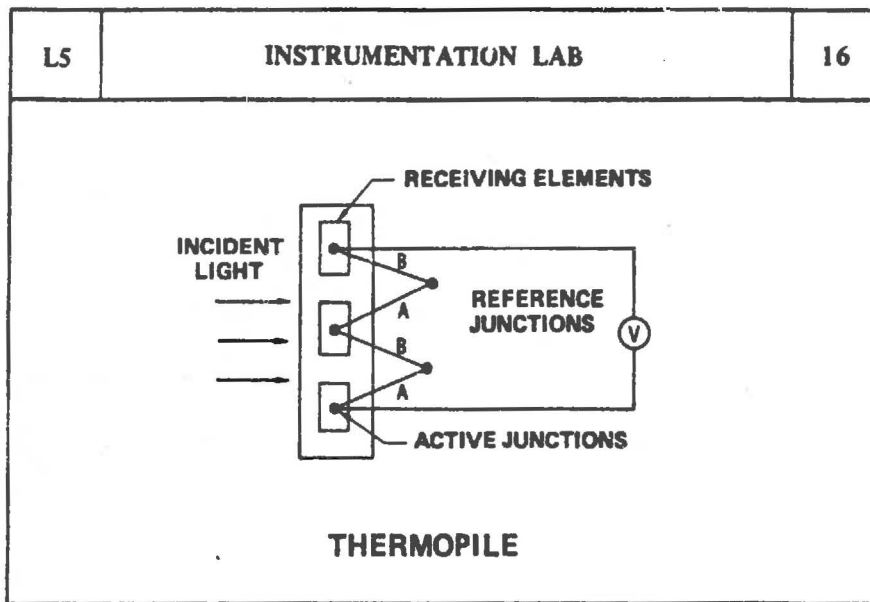
Bolometers are detectors whose resistance changes when heated. Measuring this change in resistance provides a means of determining the incident power of the absorbed radiation. The most common bolometer is the thermistor. A thermistor consists of a short length of fine wire and a small bead of semiconducting metal at the end. As radiation impinges on the bead, the temperature rises, and resistance (caused by heating the thermistor) is an indication of the incident light energy. The advantages of a thermistor are its uniform response to all wavelengths of light and its simplicity of operation. The major disadvantage is its very slow response time. Another device similar to the thermistor is the baretter. In a baretter, an increase of temperature causes an increase in resistance.



3. Thermal Devices (contd.)

c. Thermocouple

Another thermal device to measure temperature rise is the thermocouple. A thermocouple consists of a pair of junctions between two different metals, such as antimony and bismuth. Since the two metals have different thermal properties a small voltage difference can be produced when their junctions are at different temperatures. If a closed loop of two dissimilar metals is made, current will be observed to flow around the loop when the junctions are kept at different temperatures. The current will flow across the hot junction, and will depend on the thermal properties of the metals used. In figure 15, the current flows from bismuth to antimony. Depending upon the two materials used, the direction of flow follows the order: bismuth, nickel, cobalt, platinum, copper, lead, zinc, cadmium, iron, and antimony. Any pair of these metals is called a thermocouple.



3. Thermal Devices

c. Thermocouple (contd.)

The thermally generated voltages in a thermocouple can be quite small, and a larger net voltage can be obtained by connecting several thermocouples in series. This is called a thermopile. The total thermally produced voltage across the output terminals is the sum of the individual thermocouple voltages. As the receiving elements absorb incident radiation, the temperature of each junction is increased and the thermopile voltage increases accordingly.

Since the receiver element is quite sensitive, and high levels of 1 watt/cm^2 or greater will deteriorate the surface. (Common receiver coatings are goldblack, lampblack, and Parson's black.)

Thermopiles are generally unaffected by the beam orientation, the wavelength of the incident light, the pulse length, or the beam diameter. However, they are not as sensitive as the photon devices.

L5	INSTRUMENTATION LAB					17
Detector	Intensity Range	Response Time	Output	Sensitivity	Wavelength Range	Comments
Vacuum Photodiode	1 μ W-10W	1 μ sec	I	Medium	150-1500nm	Best Stability, Wavelength - Dependent
Photomultiplier Tube	10 μ W	1 μ sec	I	High	200-1000nm	Most Sensitive, Wavelength - Dependent, Lack of Linearity
Photoconductor (back biased)	1 μ W -10W	10 μ sec	R	Medium	350-4000nm	Good Linearity, Wavelength - Dependent, Requires Power Source
Photovoltaic	.03 mW-1W	10 μ sec	V	Medium	350-750nm	Self-powered
Calorimeter	0-10 ⁴ W	msec	T	Medium		Air, Water, Oil, Cooled Laboratory Standard, Range Depends on Absorber.
Bolometer		1 msec	R	Low	100 nm-40 μ m	
Thermopile	.25W	10 msec	V	Low	100 nm-40 μ m	Can be Water Cooled, Not as Sensitive as Photon Devices

4. Summary

The intensity range, response time, output, sensitivity, wavelength range and general comments regarding different sensing elements are summarized in Figure 17. Note that photodiodes, photomultipliers, photoconductors and photovoltaic devices are not used in the long wavelength regions. In the long wavelength region bolometers and thermocouples are used.

L5	INSTRUMENTATION LAB	18
DETECTION ACCESSORIES 1. FILTERS 2. GRATINGS 3. DIFFUSERS 4. BEAM SPLITTERS 5. MULTIPLE APERTURE DISH 6. AMBIENT LIGHT COMPENSATOR		

5. Detection Accessories

Several laser detection accessories are very useful for versatile measurements. (1) Filters can be used to select specific wavelengths of the operating laser; they also attenuate the beam so the full energy of the laser does not damage the detector (such as the photodiode detector). (2) Gratings also are wavelength selectors which prove to be more exact than filters. (3) When the beam is small compared to the active detector area, diffusers spread the beam over the entire detector surface. (4) Measuring high-power lasers calls for a beam sampler to split the beam and select only a fraction to be incident on the detector. This percentage can then be extrapolated to the total power. (5) A multiple-aperture dish is utilized to vary the power level falling on the detector. It is simply a dish with numerous holes. (6) Another handy accessory is the ambient light-compensator which permits ambient light to be electronically dialed out.

L5	INSTRUMENTATION LAB	19
MICROWAVE DETECTOR REQUIREMENTS 1. SMALL ANTENNA PROBE 2. ISOTROPIC RESPONSE AND POLARIZATION INSENSITIVITY } ± 1 db 3. RESPONSE TIME, 0-90% 3 SEC. 4. WIDE RANGE FREQUENCY RESPONSE 5. ACCURACY $< \pm 2$ db		

6. Detector Requirements and Commercially Available Detectors

a. Microwave

The following list is a summary of the basic requirements for any field-survey instrument, used in microwave-hazard work:

- 1.) The antenna probe must be sufficiently small (or the impedance matched well enough) to produce insignificant back scatter and/or interference of the probe to the source.
- 2.) The receiver system should have both isotropic response and polarization-insensitivity at the ± 1 db level.
- 3.) The response time should meet the 0-90% (3-second) criteria required by the bureau of Radiological Health for oven-hazard measurements.
- 4.) It is important that the frequency response cover as wide a range as practical. In particular, direct reading at 925 and 2450 MHz is essential, since these are the two most common frequencies in oven and industrial applications.
- 5.) Instrument accuracy should be less than ± 2 db over the quoted range for calibration by using a plane wave.

L5	INSTRUMENTATION LAB	20
MICROWAVE DETECTOR REQUIREMENTS (CONTD.) 6. SEVERAL RANGES OF SENSITIVITY 7. OVERLOAD 300% FULL SCALE 1000% FOR 1 SEC. 8. 5 CM. SPACER		

6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

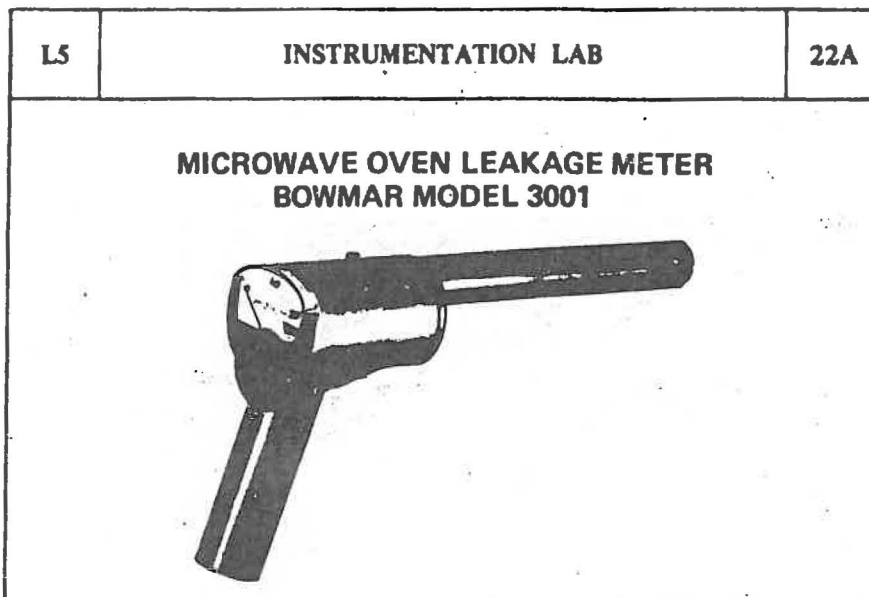
- 6) Several ranges of sensitivity should be available, (for example, 0-2, 0-20, 0-200 mW/cm²).
- 7) The instrument should be able to withstand a continuous exposure of at least 300% of full scale, using an unmodulated signal, and a one-second exposure of 1000% of full scale. A burn-out proof probe is desirable.
- 8) A 2-inch (5 cm) spacer should be provided to enable positioning of the probe at the correct distance from an oven to meet federal measurement standards.

L5	INSTRUMENTATION LAB.	21
MICROWAVE DETECTOR REQUIREMENTS (CONTD.) 9. POWER SOURCE { INTERNAL RECHARGABLE LOW VOLTAGE INDICATOR 10. RELIABLE CALIBRATION 11. SENSITIVITY TO MEASURE $\frac{.1 \text{ mW}}{\text{cm}^2}$		

6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

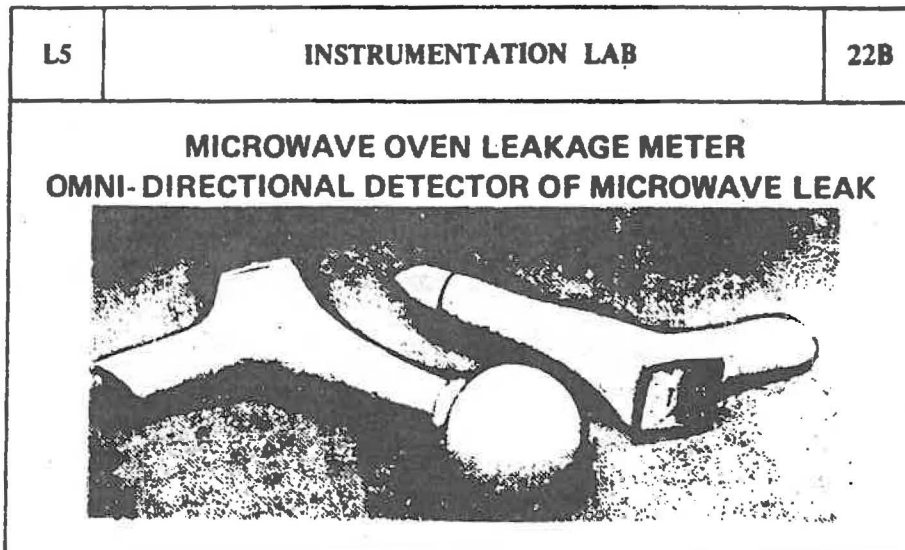
- 9) The power source should be by an internal rechargeable or easily replaceable battery. The instrument should indicate when an error of $\pm 5\%$ of full scale occurs due to low power.
- 10) Some reliable calibration must be available, and it must be simple to operate.
- 11) The instrument should have sufficiently high sensitivity to measure accurately a flux of 0.1 mW/cm^2 .



6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

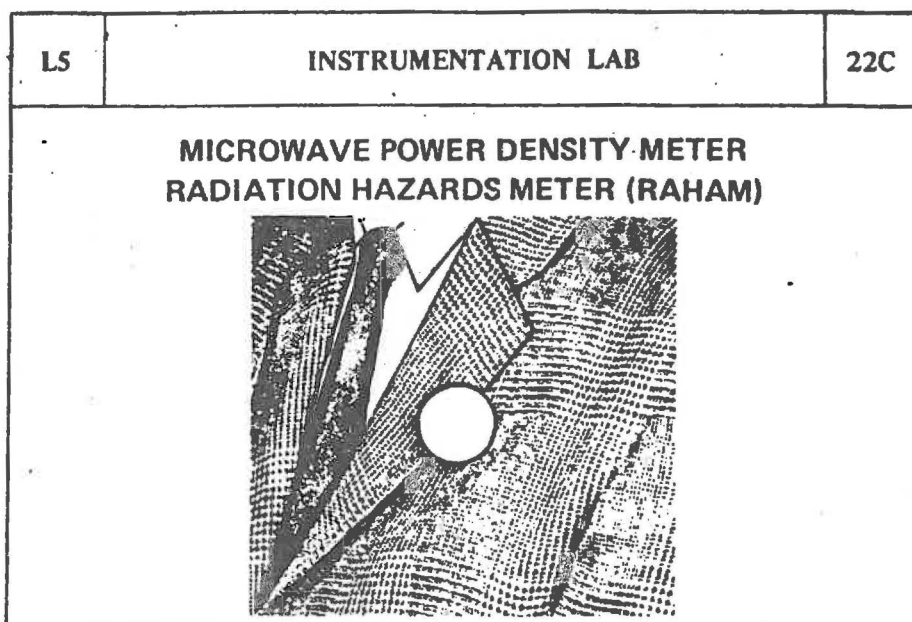
Class	Portable, hand-held oven leakage meter
Principle of Operation	Antenna, diode, meter readout
Sensitivity and Range	Operation: 2450 MHz Two Full-scale Ranges: 0-5 and 0-50 mW/cm ² Maximum Permissible flux: 200 mW/cm ² Minimum Measurable Flux: 0.1 mW/cm ²
Sampling	Continuous
Performance	Accuracy: ± 1 db Response Time: 90% of steady-state reading within 3 sec.
Requirements	Power: Microwave energy being detected Size: 27 cm long (11") Weight: 0.3 Kg (0.8 lb)
Features	Antenna is 5 cm from end of barrel, factory calibrated, no fail-safe circuit
Reference	Manufacturer's specification
Cost	\$ 89.50
Address	Bowmar/TIC, Oven Systems Division 850 Lawrence Drive Newburg Park, California 91320 (805) 498-2161 Attention: Mr. Arthur Parnes



6. Detector Requirements and Commercially Available Detectors

a. Microwave (Cont'd)

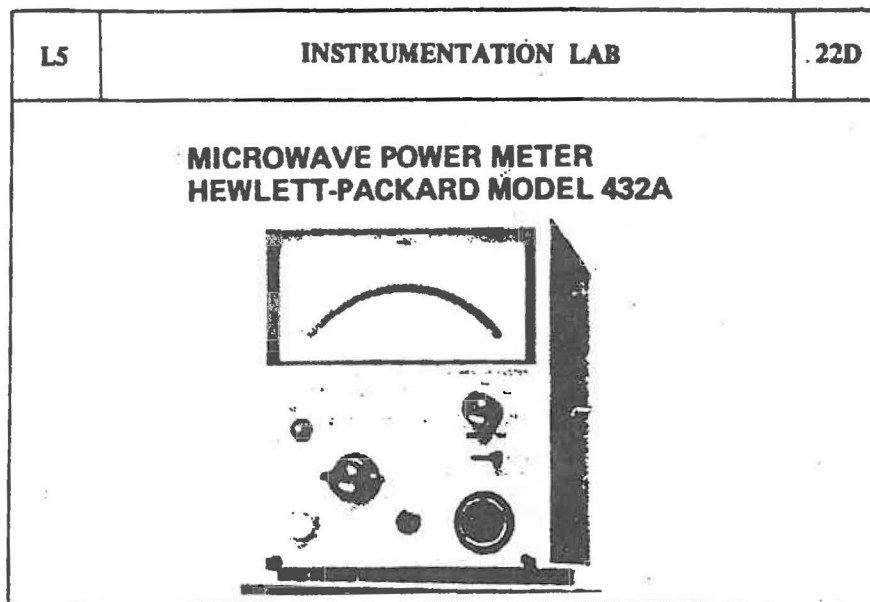
Class	Portable, hand held oven leakage monitor
Stage of Development	First prototypes have been built at General Electric and are being evaluated.
Principle of Operation	Antenna is a small tetrahedral structure with six crystal-diode detectors on the six edges. Meter measures E^2 with read-out in mW/cm^2
Sensitivity and Range	Frequency range: 925 to 2450 GHz Dynamic range: 1 to 20 mW/cm^2 Maximum permissible flux: (Burnout) 1 watt/ cm^2 Minimum measurable flux: 1 milliwatt/ cm^2
Sampling	Continuous
Performance	Antenna sensitivity designed to be uniform within about $\pm 20\%$ over entire range of possible orientations.
Requirements	Power: microwave energy being detected Space: 3" x 6" x 26" Weight: 8 oz.
Features	Inputs microwave radiation Outputs to a 1 milliamper meter
References	C.L. Andrews, "Microwave Probes for Electric Fields Near Metal Surfaces", I.E.E.E. Trans. on Antennas and Propagation, Vol. AP-16, No. 4, July 1968.
Cost	Unknown
Remarks	Potentially valuable instrument, General Electric seeks licensee.
Address	General Electric Company Corporate Research and Development Schenectady, New York 12301 Attn: Dr. C.L. Andrews (518) 346-8771 Mr. F. P. Hession (518) 374-2211



6. Detector Requirements and Commercially Available Detectors

a. Microwave (Cont'd)

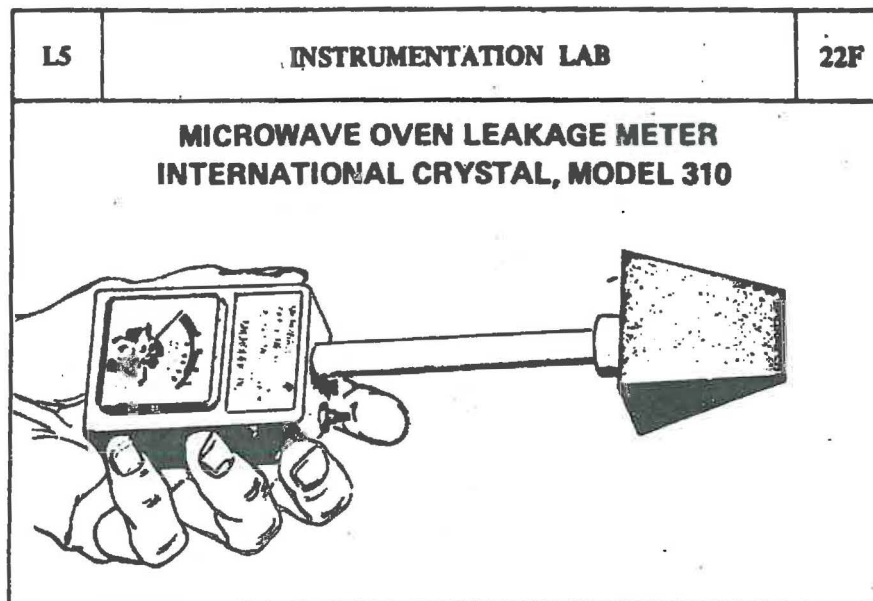
Class	Portable, two models (hand-held and lapel)
Principle of Operation	Antenna made of an array of thin film nichrome-bismuth thermocouples followed by amplifier and threshold gate.
Sensitivity and range	Frequency Range: 20 KHz to 12.3 GHz Hand-held Model Ranges: 0 - 0.2 mW/cm ² 0 - 2 mW/cm ² 0 - 20 mW/cm ² 0 - 200 mW/cm ² Maximum Permissible Power Density: 1 W/cm ² Minimum Measurable Flux: 0.02 mW/cm ²
Sampling	Continuous
Performance	Accuracy: ± 1 db Stability: Unknown Calibration: At rf or audio Results: Continuously available, audible or meter
Requirements	Power: Battery Size: About 3 cm x 5 cm x 8 cm (1" x 2" x 3") Weight: About 1 Kg (2 to 3 lb for hand-held model)
Features	One antenna, circular polarization insensitive to orientation in the plane of the probe. Pocket-size electronic package, audible fail-safe alarm, audible hazard alarm.
References	Developed under contract with USAF Rome Air Development Center, Rome, New York. Attention: J. Scherer
Cost	Approximately \$350
Remarks	Measures power density levels from 0.02 to 200 mW/cm ² over the tremendous frequency range of 20 KHz to 12.4 GHz with ± 1 db, very compact electronic
Address	General Microwave Corporation 155 Marine Street Farmingdale, Long Island, New York 11735 (516) 694-3600 Attention: Mr. Moe Wind



6. Detector Requirements and Commercially Available Detectors

a. Microwaves (contd.)

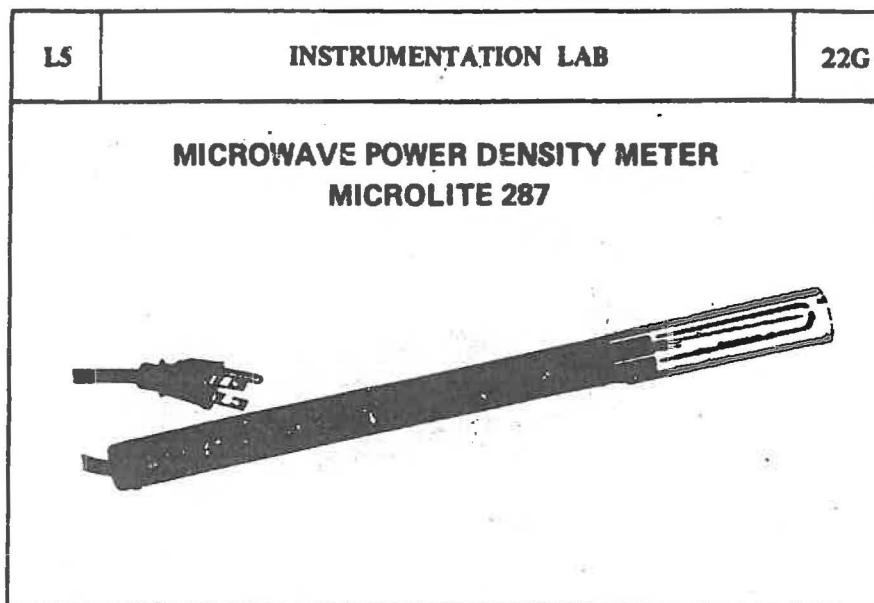
Class	Lab standard, portable
Principle of Operation	External temperature-compensation thermistors feed ac/dc bridge, amplifier, meter read-out
Sensitivity and range	Frequency Range: 10 MHz to 40 GHz Power Levels: Seven ranges from 1 μ W to 10 mW Maximum sensitivity: $\pm$ 0.5 μ W
Sampling	Continuous
Performance	Accuracy: $\pm$ 1% Temperature range: 0 $^{\circ}$ to 55 $^{\circ}$ C
Requirements	Power: 115 or 230V ac, 50 to 400 Hz, 2.5 watts, optional battery pack, 24 hours lifetime, \$100 Weight: 3.6 Kg (7.9 lbs) Size: 13 cm W, 15.5 cm H, 28 cm D (5.1"W, 6.2" H, 11" D)
Features	Automatic zero by pressing a switch, recorder output, Meter indicates Power level (in watts). To obtain power density (in watts/cm 2) user must provide area measurement over which the energy is being collected. Waveguide flanges available, bolometer sensors available.
Cost	Model 432A - \$495 Power meter calibrator, Model 8477A - \$450
Remarks	Supercedes model 431C, "The data supplied with each thermistor mount are traceable to the National Bureau of Standards." Not an electromagnetic field monitor for survey use. It is included since it is a widely used reference instrument for calibrating survey instruments.
Address	Hewlett-Packard 1101 Embarcadero Road Palo Alto, California 94303 (415) 327-6500 TWX 373-1280



6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

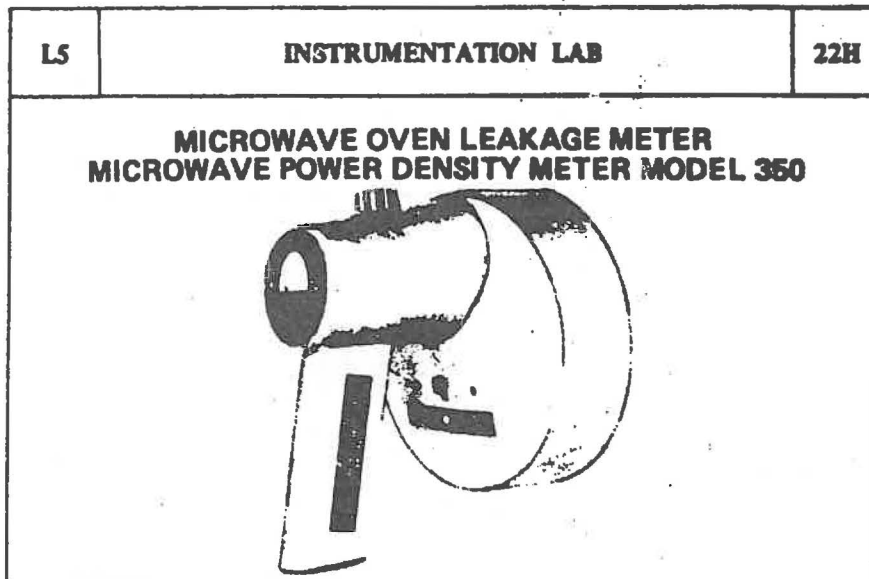
Class	Portable, hand-held oven leakage monitor for 2450 MHz.
Principle of Operation	Microwave energy induced on a shaped dipole antenna is rectified using a Hewlett Packard series 2800 hot-carrier diode, the rectified current drives a 100 μ A meter.
Sensitivity and Range	Calibrated at 2450 MHz Two ranges 0.4 mW/cm ² to 6 mW/cm ² 1.0 mW/cm ² to 23 mW/cm ² Maximum permissible flux 500 mW/cm ² Minimum measurable flux 0.25 mW/cm ²
Performance	± 1 db at 2450 MHz ± 20 MHz at 2 inches from source Rotational error for single polarized signal is 1 db at 30°
Requirements	Power: Operates on the detected microwave energy Size: 24 cm L, 5 cm W, 5 cm H (9" x 2" x 2") Weight: 0.3kg (13 oz)
Features	The total power density at any point is the sum of two readings taken with the probe rotated 90° between readings. No fail-safe mechanism
References	Manufacturer's data sheet
Cost	\$75
Address	International Crystal Manufacturing Company 10 North Lee Oklahoma City, Oklahoma Attention: R. R. Freeland, Jr. (405) 236-3741



6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

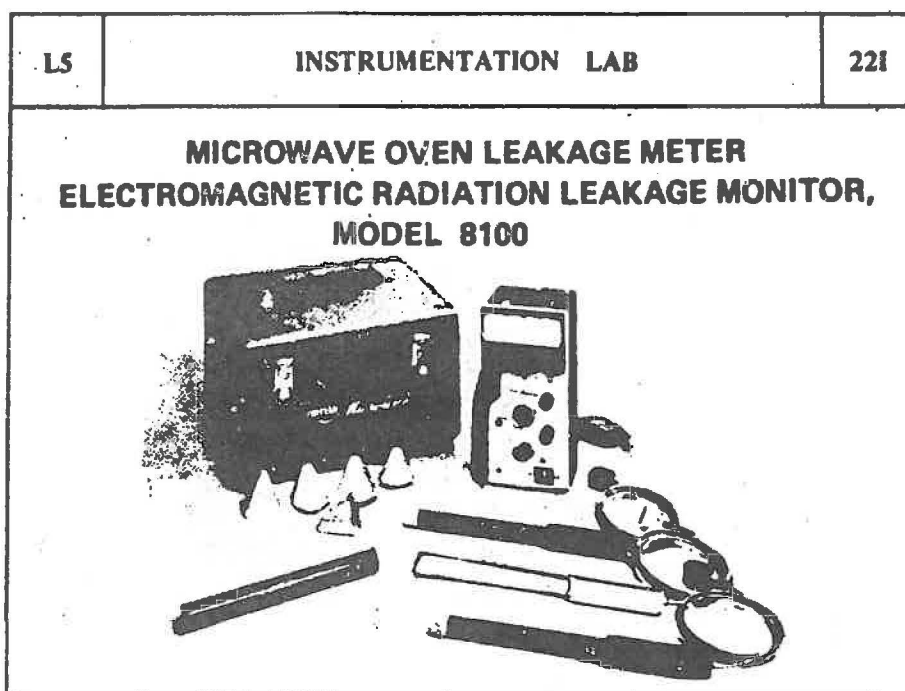
Class	Portable microwave survey instrument
Principle of Operation	Pre-ignited glow tube
Sensitivity and Range	Frequency response: 2450 MHz only Dim glow occurs at 5-6 mW/cm ² , full glow at 10 mW/cm ² or greater
Sampling	Continuous
Performance	Accuracy: extremely variable device (Reference 1) Stability: poor; threshold fluctuations are severe (Reference 1)
Requirements	Power: 115 VAC Size: pen-sized Weight: less than 6.oz.
Features	Small in size
References	1. P. Crapuchettes, Journal of Microwave Power 4, 138 (1969) 2. USPHS Bureau of Radiological Health Report BRH/DEP 70-20 (August 1970)
Cost	\$29.50
Address	International Crystal Mfg. Co., Inc. 10 North Lee Oklahoma City, Oklahoma 73102 (405) 236-3741



6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

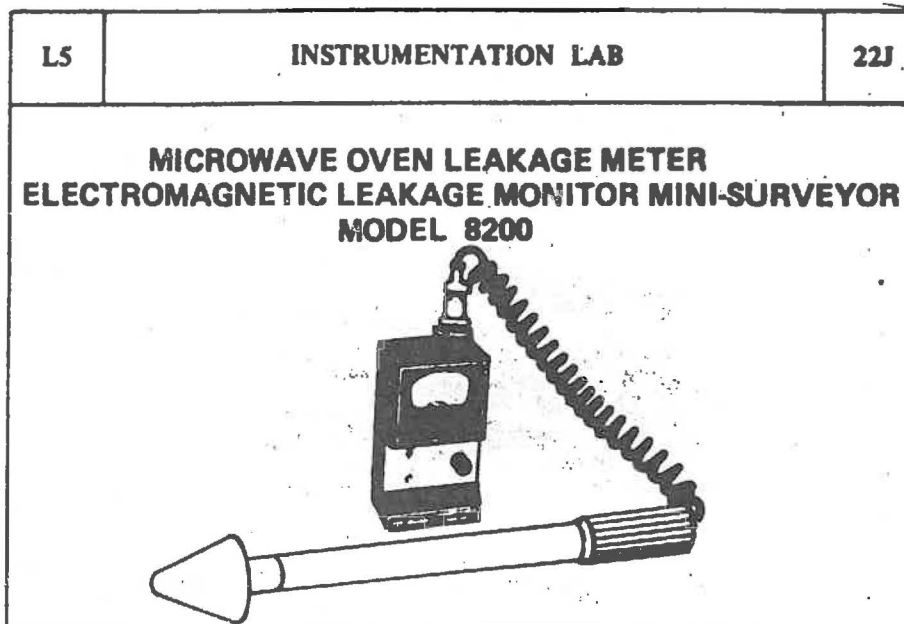
Class	Portable, hand-held radar and oven leakage monitor
Principle of Operation	Thermistor heating by absorbed electromagnetic energy from two perpendicular broad-band antennas, bridge circuit, meter read-out.
Sensitivity and Range	Frequency range: 1 to 10 GHz Midscale readings 2 mW/cm ² and 10 mW/cm ² Minimum sensitivity: .5 mW/cm ²
Sampling	Continuous
Performance	Accuracy: ± 2db Temperature range: - 20°C to +40°C Calibration: Factory calibrated. Direct reading in mW/cm ² Drift: Compensated by zero-setting via control knob Ready to read-out after a few seconds warm-up time.
Requirements	Power: 120 mW from internal battery or from an external battery Space: Transport case 245 x 210 x 200 cm supplied together with a pocket-size case for external battery Weight: 3.4 Kg
Features	Ready to read-out after a few seconds warm-up time.
References	Manufacturer's specifications
Cost	\$600 (U.S.)
Remarks	Reading depends on the orientation of the probe, must balance the bridge before use
Address	Magnetic AB, Manufacturing Division Gardsfogdev 18 Bromma, Sweden



b. Detector Requirements and Commercially Available Detectors

a. Microwave (Cont'd)

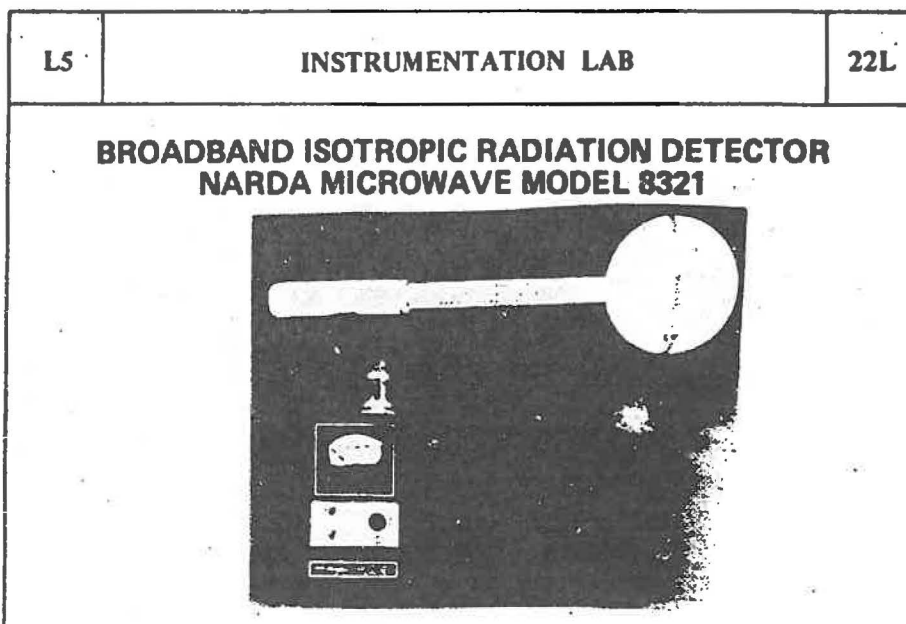
Class	Portable, hand-held oven leakage monitor.
Principle of Operation	Three different probes each having a dynamic range of 23 db which use thermocouples as the sensing elements, battery operated, meter readout.
Sensitivity and Range	Operated at either 915 or 2450 MHz Full scale (two ranges) Probe Model 8120A, 200 $\mu\text{W}/\text{cm}^2$ to 2 mW/cm^2 Probe Model 8121A, 2 mW/cm^2 to 20 mW/cm^2 Probe Model 8122A, 20 mW/cm^2 to 200 mW/cm^2 Maximum permissible flux = 5 db above full scale Minimum measurable flux = 23 db below highest full scale
Sampling	Continuous, settling time to obtain reading is from .75 sec (min) (35 ms with 8120A) to 3 sec (max) selected by front panel switch
Performance	Manufacturer's specifications Probe accuracy $\pm .75$ db Instrument accuracy $\pm 3\%$ of full scale Stability 0.5% of full scale Stability 0.5%/°C max zero offset, 0.05%/°C temperature sensitivity Calibration of probes by manufacturer is at 2 mW/cm^2 for Models 8120A and 8121A, and 20 mW/cm^2 for Model 8122A
Requirements	Power: Rechargeable Ni-Cad battery, 2:1 use to charge ratio, 20 hr use time Size: Probe, 11.5" long x .75" diameter Meter, 10" x 4.5" x 4" Weight: 12.5 lb with case
Features	Color coded probes, 5 ft cable, recorder output 100 mV full scale into 100 Ω min, fast/slow response to check instantaneous peak or average leakage. Adjustable, audible alarm, insensitive to polarization
References	a.) Manufacturer's data sheet b.) Only instrument recommended by R. H. Groom, Chairman, Radiation Hazards Subcommittee, A. T. and T., 295 Broadway, New York, New York 10007, (Nov. 1970) c.) Only instrument recommended by Dr. Robert Elder, Director of Electronics Products Div. HEW during a Bureau of Radiological Health committee meeting, (1970) d.) Edward E. Aslan, "Electromagnetic Radiation Survey Meter", IEEE Trans. on Instrumentation and Measurement, Vol IM-19, No. 4, (Nov. 1970)
Cost	Three probes and a zero power density simulator \$960
Remarks	Best sensitivity and accuracy currently available, fail-safe circuit
Address	Narda Microwave Corporation Plainville, New York 11803 Attention: Edward E. Aslan (516) 433-9000



6. Detector Requirements and Commercially Available Detectors

a. Microwave (Cont'd)

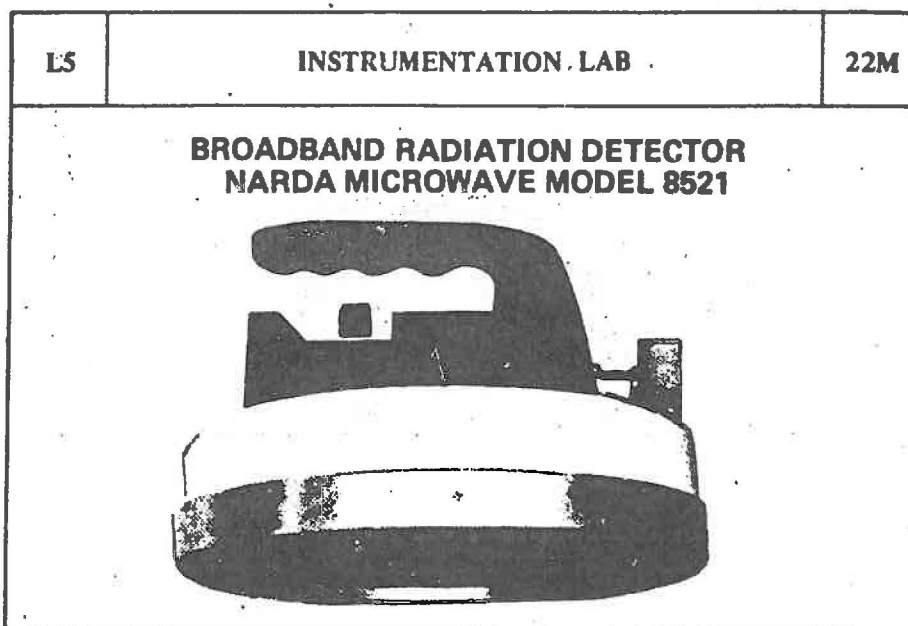
Class	Portable, hand-held oven leakage monitor	
Principle of Operation	Three different probes, each having a dynamic range of 23 db which use a thermocouple (as the sensing element), amplifier, and meter.	
Sensitivity and Range	Operation: 2450 MHz Probe Model 8223: 10 mW/cm ² and 100 mW/cm ² Probe Model 8221: 2 mW/cm ² and 20 mW/cm ² Maximum Permissible Flux: 5 db above full scale Minimum Measurable Flux: 23 db below highest full scale	
Sampling	Continuous, 1.2 sec to obtain reading	
Performance	Manufacturer's specifications Meter Accuracy: $\pm 3\%$ of full scale Probe Accuracy: $\pm .75$ db Stability: 0.5%/°C max zero offset; 0.05%/°C temperature sensitivity Calibration of Probes: 20 mW/cm ² Maintenance: Available Response Time: 1.2 sec typical	
Requirements	Power: 9V expendable battery Size: Probe 28 cm long, 2 cm dia (11" L, 3/4" D) Meter 12 cm L, 7 cm W, 4 cm H (4.6"x2.6"x1.7") Weight: 0.6 kg (1.3 lb)	
Features	Color coded probes for different ranges, battery test switch, furnished with one probe	
References	Manufacturer's data sheet	
Cost	Model 8200 including case	\$335
	Each additional probe	105
Address	Narda Microwave Corporation Plainview, New York 11803 (516) 433-9000 Attention: Edward E. Aslan	



6 Detector Requirements and Commercially Available Detectors

a. Microwave (Contd)

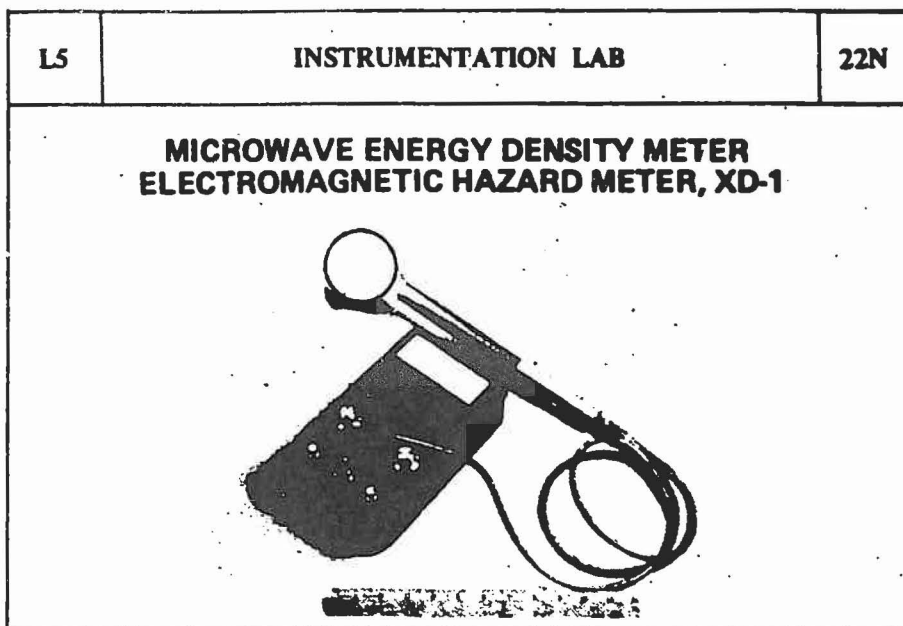
Class	Portable, hand held, broadband, isotropic	
Principle of Operation	Array of dipole antennas using thin film thermocouples as sensing elements. Amplifier and metering, Narda Model 8310 or 8315	
Sensitivity and range	Operates from 300 MHz to 18 GHz Two full scale ranges: 2 and 20 mW/cm ² Maximum permissible flux: 200 mW/cm ² Minimum measurable flux: 0.1 mW/cm ²	
Sampling	Continuous time to obtain reading: 1.2 seconds with 8310 0.75 or 3 seconds with 8315	
Performance	Calibration accuracy: ± 0.5 db (RMS) Frequency Sensitivity: ± 1.0 db from 850 MHz to 16 GHz Maximum frequency sensitivity: 3 db from 300 MHz to 18 GHz Instrument accuracy: $\pm 3\%$ full scale Stability: 0.5%/°C max zero offset, 0.05%/°C temperature sensitivity	
Features	Instrumentation similar to 8210 and 8110 Responds to all polarizations and directions of incidence	
Requirements	Power: None required for detector Size: 10 cm dia., 36 cm overall length (4" dia., 14" long) Weight: 0.2 kg (0.44 lbs)	
Reference	Manufacturer's specifications	
Cost	8321 detector alone	\$1,250
	8321/8310 metering instrument	\$1,570
	8321/3815 metering instrument	\$1,970
Address	The Narda Microwave Corporation Plainview, New York 11803 Attn: Edward E. Aslan (516) 433-9000	



6. Detector Requirements and Commercially Available Detectors

a. Microwave (Contd)

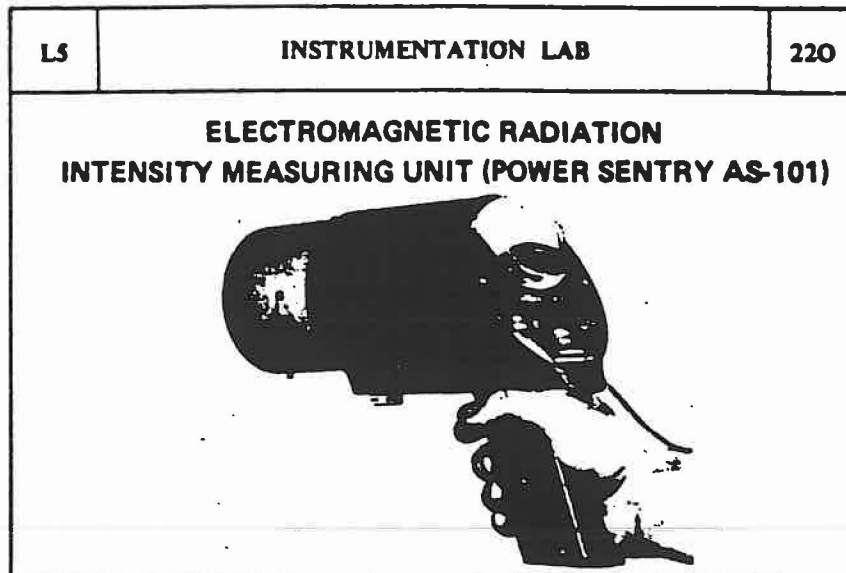
Class	Portable, hand-held broadband radiation detector
Principle of Operation	Array of multiple slot antennas using thin film thermocouples as sensing elements. Amplifier and metering same as Narda Model 8200 or 8100
Sensitivity and range	Operates from 915 MHz to 13.8 GHz Two full scale ranges: 2 and 20 mW/cm ² Maximum permissible flux = 60 mW/cm ² Minimum measurable flux = 0.1 mW/cm ²
Sampling	Continuous time to obtain reading: 1.2 seconds with 8200 0.75 or 3 seconds with 8100
Performance	Manufacturer's specifications Calibration accuracy = ± 0.5 dB (RMS) Calibration at 915, 1500, 2450, 4000, 6000, 8200, 9000, 10,000, 11,000, 12,400 MHz, 13,800 Frequency sensitivity = +1.5 dB from 2,500 MHz to 10 GHz Maximum frequency sensitivity = 6 dB from 915 MHz to 13.8 GHz Instrument accuracy $\pm 3\%$ of full scale Stability 0.5%/°C max zero offset, 0.05%/°C temperature sensitivity
Requirements	Power: None required for detector Size: 20 cm dia, 8 cm thick (7.8 in dia., 3 in thick) Weight: 0.7 Kg (1.5 lb)
References	Manufacturer's specifications
Cost	8521 detector alone - \$550 8521/8200 metering instrument - \$775 8521/8100 metering instrument - \$1,085
Address	The Narda Microwave Corporation Plainview, New York 11803 Tel. (516) 433-9000 Attention: Edward F. Aslan



6. Detector Requirements and Commercially Available Detectors

a. Microwave (Contd)

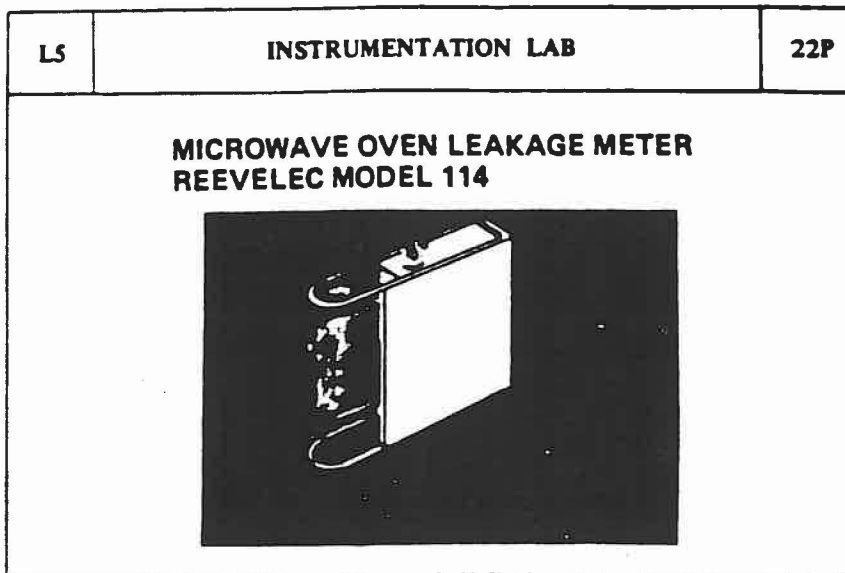
Class	Portable, hand-held field survey instrument
Stage of Development	Several prototypes have been built at NBS and are in the testing stage.
Principle of Operation	Measures either electric-field energy density or $ E ^2$ for a three-dimensional electromagnetic-field configuration. The antenna consists of three mutually orthogonal dipoles, with diode detectors, followed by three separate buffer amplifiers, whose signals are then summed and scaled electronically.
Sensitivity and Range	Frequency response from perhaps 25 MHz to 2500 MHz (lower limit not yet determined). Output is read directly in mW/cm^2 (EPE), meaning "equivalent plane-wave energy flow". Dynamic range goes over 4 decades, from 0.2 to 200 mW/cm^2 (EPE)
Performance	Battery-operated, with lifetime of 50 hours. Stability claimed to be within "a few percent". Accuracy probably within 2 db over entire range. Meter read-out.
References	1.) R. R. Bowman, et al, "Second Progress Report, Electromagnetic Hazards Project," unpublished NBS Report, Sept. 1970. 2.) P. F. Wacker and R. R. Bowman, "Quantifying Hazardous Electromagnetic Fields: Scientific Basis and Practical Considerations", IEEE Trans. on Microwave Theory and Techniques, Vol. MIT-19, No. 2, p. 178, MIT-19, No. 2, p. 178, Feb. 1971.
Cost	Unknown
Remarks	Device has the important design feature of measuring the parameter $ E ^2$ which is what is required in the near-field hazard problem. It is $ E ^2$ which is what is required in the near-field hazard problem. It is designed to be insensitive to orientation of the (hand-held) meter, and to cover a substantial portion of the microwave and RF spectrum.
Address	Mr. Ronald R. Bowman National Bureau of Standards Boulder, Colorado 80302 (303) 447-1000



Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

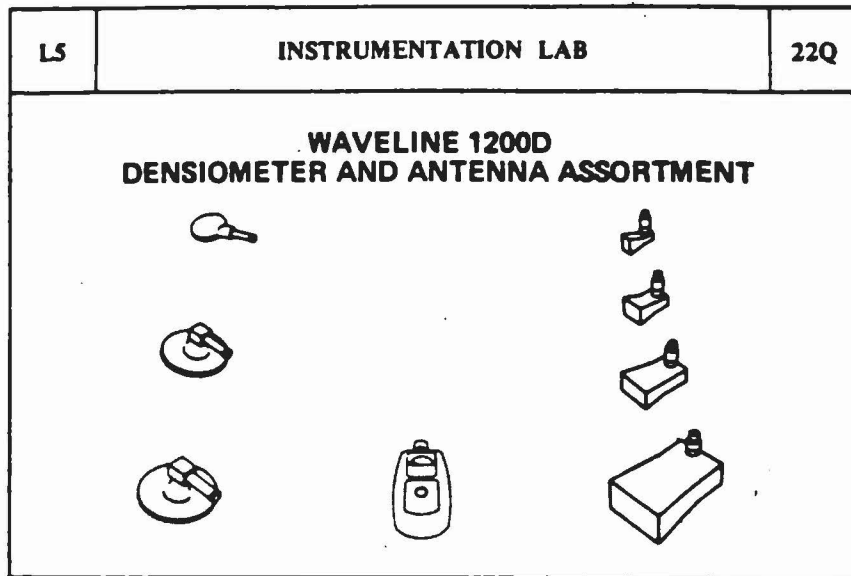
Class	Portable, hand-held
Principle of Operation	The measuring head contains two orthogonally mounted thermistors which are compared by means of a bridge circuit with another thermistor which is shielded from RF power. The out-of-balance is shown on the meter which is calibrated in milliwatts/cm ² .
Sensitivity and Range	Frequency: 2450 MHz Range: 0-20 mW/cm ² linear Minimum measurable flux: 1mW/cm ² Maximum measurable flux: 20mW/cm ² Overload capability: 200mW/cm ²
Sampling	Continuous
Performance	Accuracy (plane wave): -0, +2 db Time constant: 1 to 3 seconds
Requirements	Power: one 9 volt battery, 216 series, draws 4 mA Size: 30.5 cm, 10 cm, 20 cm (12", 4", 8") Weight: 1.13 Kg (2.6lbs)
Features	Remote operation up to 12 feet, battery test circuit
Cost	\$375
Address	Rank Precision Industries, Inc. 411 Jarvis Avenue Des Plaines, Ill. 60018 (312) 297-7720



Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

Class	Portable, fits in shirt pocket
Principle of Operation	Glow lamp changes color to incident energy
Sensitivity and Range	Frequency: 2450 MHz Ranges: not applicable Minimum measurable flux: 1 mW/cm^2 Maximum measurable flux: at least 100 mW/cm^2
Sampling	Continuous, when button is held down
Performance	Response time: about one second
Requirements	Power: One 9 V battery Size: 9 cm, 7 cm, 2 cm (3.6", 2.6" x 0.8") Weight: 0.12 Kg (4 oz.)
Cost	\$69.50
Remarks	No meter for quantitative read-out, sensitive to orientation
Address	Reevelec, Inc. 609 West Lake Street Chicago, Illinois 60606 Attn: William J. Madeley (312) 726-9755



6. Detector Requirements and Commercially Available Detectors

a. Microwave (contd.)

Class	Portable, Hand-held
Principle of Operation	Thermistor
Sensitivity and Range	Power: 2dB above 10mW/cm ² 10 dB below 10mW/cm ²
Sampling	Continuous
Performance	
Requirements	2 1.5 V Batteries
Features	dB above and below mW/cm ² meter readout
References	Manufacturers Spec.
Cost	
Remarks	
Address	Waveline, Inc. P.O. Box 718 West Caldwell New Jersey 07006

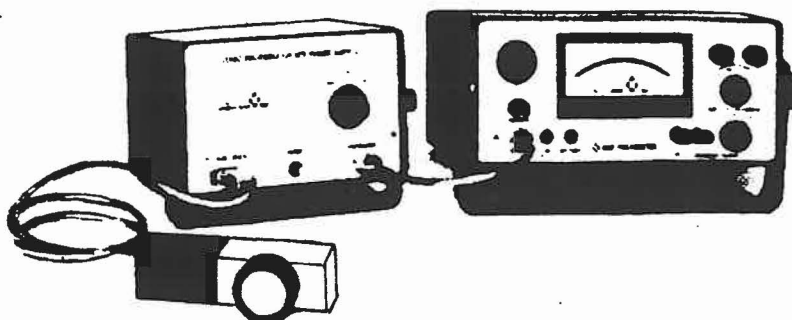
L5	INSTRUMENTATION LAB	23
ULTRAVIOLET DETECTOR REQUIREMENTS 1. SENSITIVITY RANGE OF $.1\mu\text{W}/\text{cm}^2$ 2. BIOLOGICAL WEIGHTING OF SPECTRAL INFORMATION 3. HAND-HELD, PORTABLE 4. METER-READ-OUT, FAIL-SAFE INDICATOR		

6. **Detector Requirements and Commercially Available Detectors (contd.)**

b. **Ultraviolet**

- 1.) UV instruments are required with sensitivities in the range of $0.1\mu\text{W}/\text{cm}^2$.
- 2.) Some way of introducing the biologically-weighted spectral information (actinic) into the instrumentation is valuable: In cases where the UV exposure is over a broad-band region it is essential.
- 3.) The device should be a hand-held meter which can measure both absolute flux in units of W/cm^2 using a flat frequency response, and a biologically-weighted flux.
- 4.) The device should have a meter-read-out-fail-safe indication.

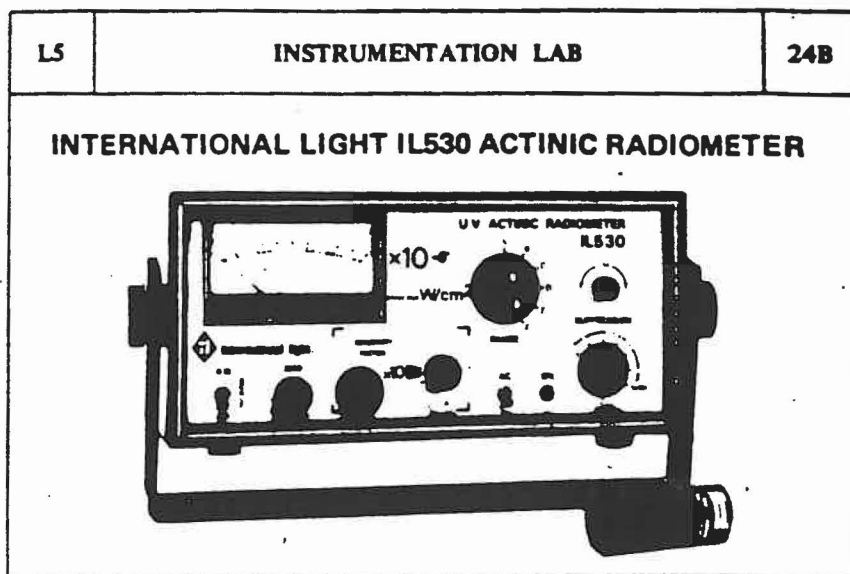
ULTRAVIOLET MONITOR IL 600/IL 660 RESEARCH PHOTOMETER



6. Detector Requirements and Commercially Available Detectors

b. Ultraviolet Control

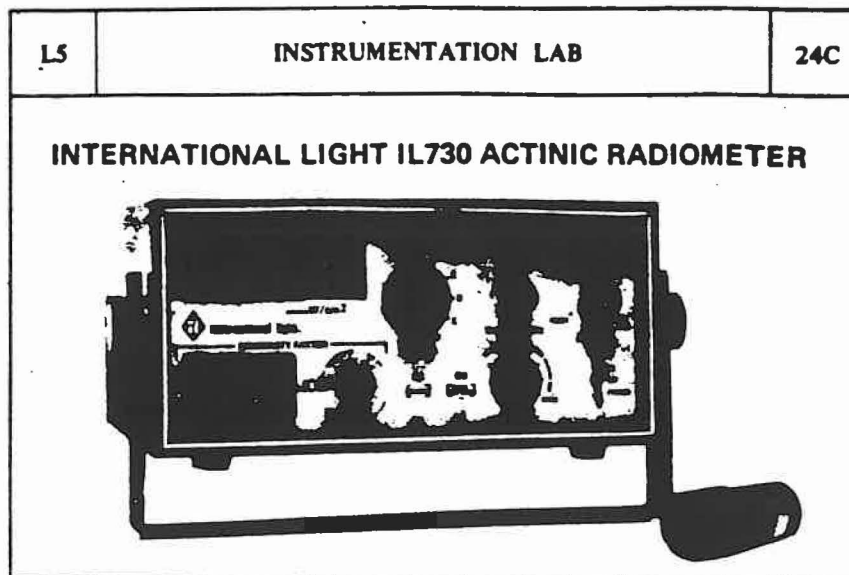
Class	Laboratory-standard research instrument
Principle of Operation	Uses a photomultiplier coupled to the UV source through one of several filters. Reads intensity in microamps; a calibration factor must then be used to convert to flux density ($\mu\text{W}/\text{cm}^2$).
Sensitivity and Range	Nine overlapping ranges from 0.01 to 100 μA . Fullscale minimum sensitivity down to $4 \times 10^{-6} \mu\text{W}/\text{cm}^2$. Sensor S4: Spectral range - 320-660 nm Peak response - 400 nm Sensor S5: Spectral range - 220-660 nm Peak response - 340 nm
Sampling	Continuous
Performance	Measurement accuracy 1% on all ranges Effective aperture - 17.6
Requirements	Power: 115 VAC or rechargeable Ni-Cd battery with 8-hour lifetime Size: 11" wide x 5" high x 7" deep (27 cm x 13 cm x 18 cm) Weight: 10 lb (4.5 Kg)
Features	1. Diffusion attachments: collects and collimates diffuse light 2. Iris: to reduce sensitive area if desired 3. Attenuators and filters: supplied as required 4. Meter read-out; recorder-oscilloscope read-out also available 5. Digital integrator accessory (IL-620 dosimeter) is available for determination of total energy overtime ($\mu\text{W-seconds}/\text{cm}^2$)
Remarks	This is an extremely sensitive laboratory research instrument, not designed for field-survey use. However, it is used for survey purposes by the U.S.P.H.S. National Institute of Occupational Safety and Health, Cincinnati, Ohio (D. Dobbin, private communication).
References	Lape, B.F. and Ryer, D.V. "How to Measure Light", International Light, Inc.
Cost	IL-600: Research photometer \$948 IL-660: Photomultiplier power supply \$479 PM-200: BUS4) or C(S-5) series PM assembly \$345 IL-620: Digital photodosimeter \$993
Address	International Light, Inc. Dexter Industrial Green Newburyport, Mass. 01950 (617) 465-5923



6. Detector Requirements and Commercially Available Detectors

b. Ultraviolet (contd.)

Class	Laboratory-Standard Research Instrument
Principle of Operation	Uses a vacuum photodiode coupled to the UV radiation through a filter
Sensitivity	Spectral sensitivity 235 to 340 nm peak at 270nm. Minimal detectable level 1×10^{-8} $\frac{\text{watts full scale}}{\text{cm}^2}$
Sampling	Continuous
Performance	Measurement accuracy 1% (electrical, all ranges)
Requirements	Power: External 115 AC or 230 AC 50-60 Hz Size: 11" x 7 1/2" x 5" Weight: 6 1/4 lbs.
Features	Meter Readout, Ambient Light Compensation, W/cm^2 Readout, Recorder-Oscilloscope Output
References	Manufacturer's specification sheet
Cost	\$834
Remarks	The detector head spectral sensitivity closely matches the present NIOSH values.
Address	International Light, Inc. Dexter Industrial Green Newburyport, Mass. 01950 Tel: (617) 465-5923



6. Detector Requirements and Commercially Available Detectors

b. Ultraviolet (contd.)

Class	Laboratory-Standard Research Instrument
Principle of Operation	Uses a vacuum photodiode coupled to the UV source through a filter
Sensitivity and Range	Spectral sensitivity 235 to 340 nm peak at 270 Minimal detectable level $1 \times 10^{-9} \frac{\text{watts}}{\text{cm}^2}$
Sampling	Continuous
Performance	$\pm 2\%$ spectrally - $\pm 1\%$ linearity
Requirements	Power: External 115 AC or 230 AC 50-60 Hz Size: 11" x 5" X 7" Weight: 15 lbs.
Features	Digital readout, ambient light compensation W/cm^2 readout, recorder-oscilloscope output, integrate mode.
References	Manufacturer specification sheet
Cost	\$1334.00
Remarks	The detector head spectral sensitivity closely matches the present NIOSH values.
Address	International Light, Inc. Dexter Industrial Green Newburyport, Mass. 01950 (617) 465-5923

ULTRAVIOLET MONITOR BLAK RAY UV INTENSITY METER



6. Detector Requirements and Commercially Available Detectors

b. Ultraviolet Content

Class	Hand-held, portable meter
Principle of Operation	An optical filter and photovoltaic cell sensitive to ultraviolet radiation drives a meter, read-out calibrated in $\mu\text{W}/\text{cm}^2 \times 100$
Sensitivity and Range	Spectral Range: Model J-221 300 nm - 400 nm with main peak @ 365 nm Model J-225 220 nm - 280 nm with main peak @ 254 nm Sensitivity Range A: 0-200 $\mu\text{W}/\text{cm}^2$ Range B: 1000-6000 $\mu\text{W}/\text{cm}^2$ Minimum measurable flux: 20 $\mu\text{W}/\text{cm}^2$ Maximum measurable flux: about 24,000 $\mu\text{W}/\text{cm}^2$
Sampling	Continuous
Performance	Tracking precision $\pm 5\%$ when readings are greater than 200 $\mu\text{W}/\text{cm}^2$ $\pm 10\%$ when readings are less than 200 $\mu\text{W}/\text{cm}^2$ Absolute accuracy J-221 $\pm 15\%$ @ 365 nm J-225 $\pm 15\%$ @ 254 nm Infrared sensitivity: less than 5% to energy peaks without contact filter Visible sensitivity: none up to 40 foot candles
Requirements	Power: none required, operated on UV radiation Size: 8 cm cube (3" cube) Net weight: 0.5 Kg (11lb)
Features	The sensor cell can be used remotely with extension cord. A snap-on contrast filter absorbs all ultraviolet which allows measuring the visible and infrared interferences.
References	Manufacturer's specifications
Cost	Model J-221 \$124.50 Model J-225 \$124.50
Remarks	This instrument is useful mainly for industrial applications, such as to measure intensities under germicidal lamps. It lacks sufficient sensitivity to be a useful survey meter at the low (0-5 $\mu\text{W}/\text{cm}^2$) levels where environmental hazards exist.
Address	Ultra-Violet Products, Inc. 5114 Walnut Grove Avenue San Gabriel, Calif. 91778 (213) 285-1124 Attention: Lee W. Davey

L5	INSTRUMENTATION LAB.	25
LASER DETECTOR REQUIREMENTS 1. SENSITIVITY - $1\mu\text{W}/\text{cm}^2$ 2. RANGE - ULTRAVIOLET, VISIBLE, NEAR INFRARED 3. AMBIENT LIGHT COMPENSATOR - REQUIRED 4. SOLID ANGLE SENSITIVITY - COMPARABLE TO HUMAN EYE		

6. Detector Requirements and Commercially Available Detectors (contd.)

c. Laser

A variety of instruments are available that measure the power of laser beams. However, the problems encountered in measuring the environmental or industrial hazard due to dispersed and reflected beams require an instrument to meet more stringent design specifications. The following list of items needs to be considered when buying a laser hazard monitor.

- 1.) **Sensitivity:** The instrument should be sensitive to at least $1\mu\text{W}/\text{cm}^2$ for low-level occupational exposure to continuous wave lasers.
- 2.) **Bandwidth:** The instrument should cover the ultraviolet, visible, and near infrared regions. A variety of easily mounted optical filters would provide selective sensitivity to different wavelengths.
- 3.) **Ambient Light:** If the instrument has the required sensitivity and bandwidth, then it will respond to room lamps, sunlight, and specular reflections. Two measurements, with and without the optical filter, will provide the user with both the total intensity and the contribution from one wavelength.
- 4.) **Geometric Acceptance:** The solid angle of sensitivity should be similar to the human eye. If the acceptance is too narrow then a significant reflection may not be detected; if it is too broad then it is difficult to find the source.

L5	INSTRUMENTATION LAB	26
LASER DETECTOR REQUIREMENTS (CONTD.) 5. DYNAMIC RANGE - HIGH 6. MODULATION - AVERAGE AND PEAK 7. PEAK FREQUENCY RESPONSE AND DUTY CYCLE — GRAPHICALLY DESCRIBED 8. ACCURACY - $\pm 15\%$		

6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

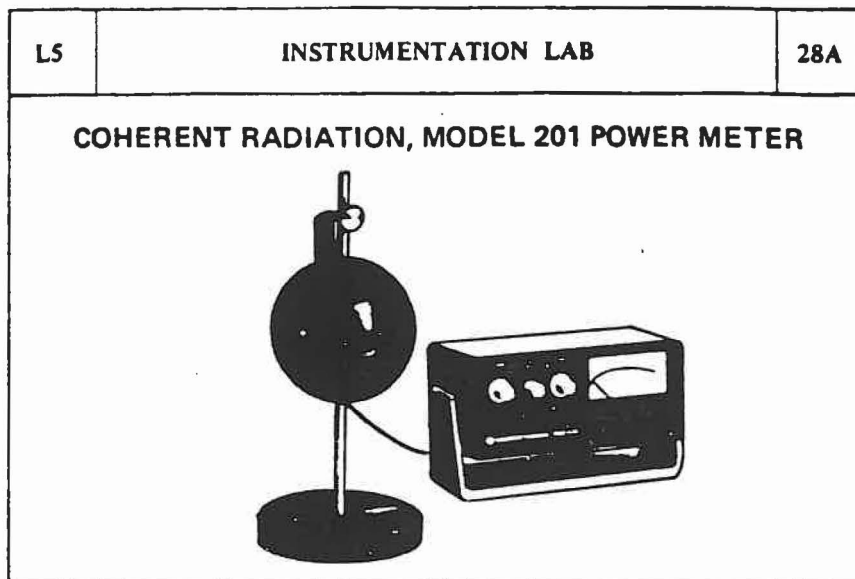
- 5) **Dynamic Range:** Since a specular reflection may be 10% (or more) of the energy in the beam, the instrument should be able to measure high doses without burning out.
- 6) **Modulation:** Continuous wave and pulsed lasers may be modulated, which will affect the temporal rate of deposition of energy. Both average (for CW) and peak (for Q-switched) readings should be provided:
- 7) **Frequency Response:** The peak frequency response (maximum repetition rate) and the highest measurable duty cycle should be graphically described, illustrating the 1 db and 3 db points.
- 8) **Accuracy:** Since the difference between "safe" and "unsafe" is not a precise discontinuity, the instrument does not require extremely high accuracy (e.g. $\pm 15\%$)

LS	INSTRUMENTATION LAB	27
LASER DETECTOR REQUIREMENTS (CONTD.)		
9.	FEATURES:	RUGGED, COMPACT, LIGHT WEIGHT RECHARGEABLE ETC.
10.	CALIBRATION - INDEPENDENT SOURCE	
11.	APERATURE STOPS - 7MM & 1 MM	
12.	SENSITIVITY/AREA - CONSTANT $\pm 10\%$	

6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

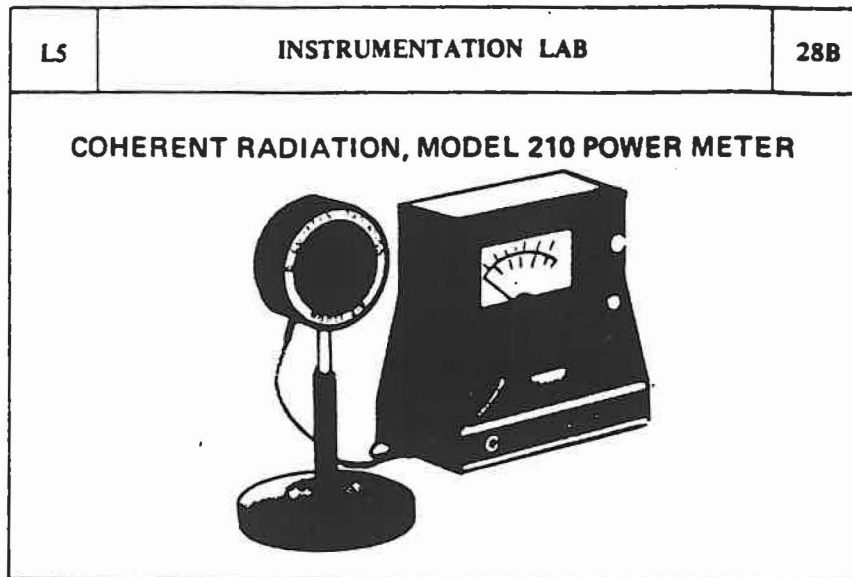
9. **Engineering Features:** The usual objectives of all survey instruments (e.g., lightweight, rugged, compact rechargeable, inexpensive) should be provided. Options (e.g., audible alarms, and recorders) may be usefull for some applications.
10. **Calibration:** An independent calibrated source should be available to allow a complete check of the instrument's operation from sensor to the readout, for fail-safe operation.
11. **Aperture Stop:** The aperture stop should be similar to a fully dilated human eye (7mm dia.) over the visible light range (400 to 1400). For wavelengths from 0.1 to 400 nm and from 1400 to 10^6 nm the stop should be 1 nm in diameter.
12. **The relative sensitivity per unit area should be constant within $\pm 10\%$ across the aperture stop when mapped with a 1 nm diameter beam.**



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

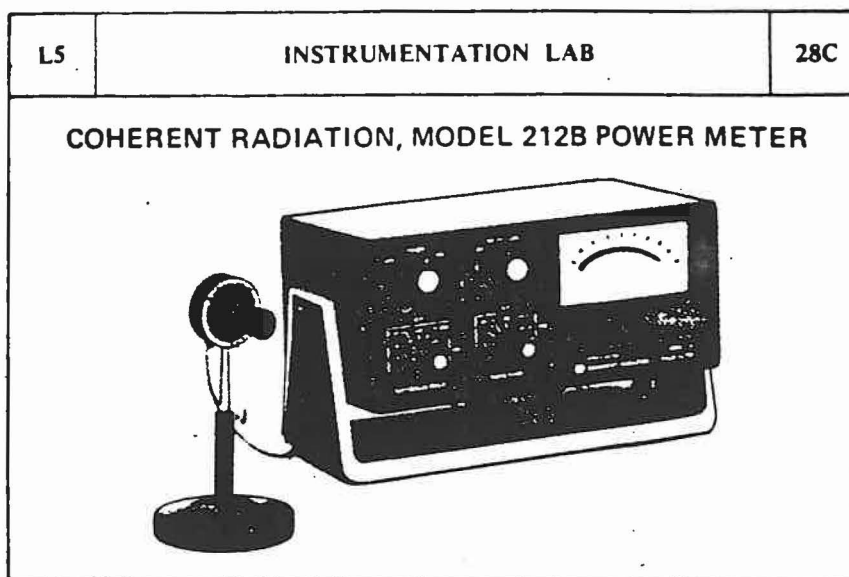
Class	Portable
Principle of Operation	Thermal Disc/ Thermopile
Sensitivity and Range	Power Range: 1 - 100 W Wavelength Range: 300 nm - 30 μ m
Sampling	Continuous
Performance	Response Time 1 sec, $\pm$ 5% accuracy
Requirements	115/230 VAC or 2 Mallory 12.6 V batteries
Features	Manufacturer's specification sheet
Cost	
Remarks	
Address	Coherent Radiation 3210 Porter Drive Palo Alto, California 94304 (415) 493-2111



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

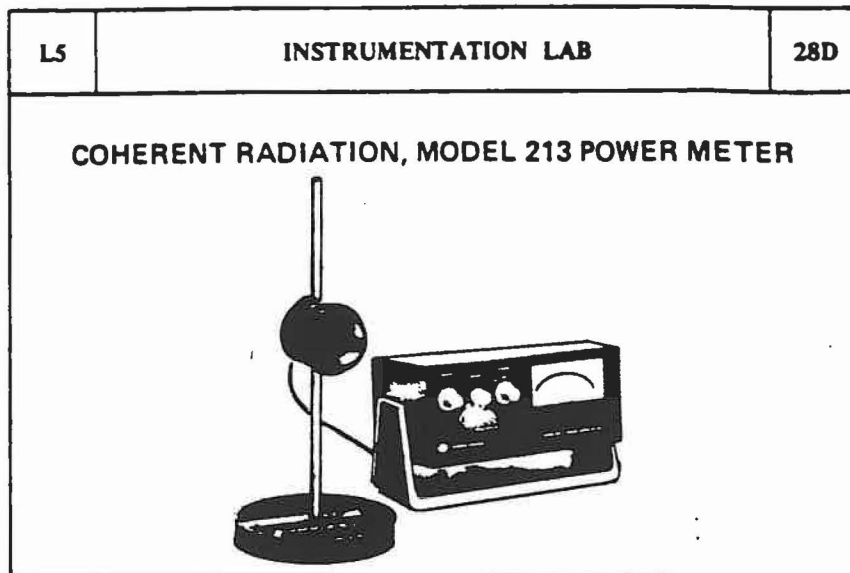
Class	Portable
Principle of Operation	Thermal Disc/Thermopile
Sensitivity and Range	Power Range: .3 - 10. W Wavelength Range: 300 nm - 30 μ m
Sampling	Continuous
Performance	Response time 1 sec, $\pm$ 5% accuracy
Requirements	4 RCA 9 V batteries
Features	Adjustable stand, battery-operated, control indicator unit, variable aperture attachment available
References	Manufacturer's specification sheet
Remarks	
Address	Coherent Radiation 3210 Porter Drive Palo Alto, California 94304 (514) 493-2111



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

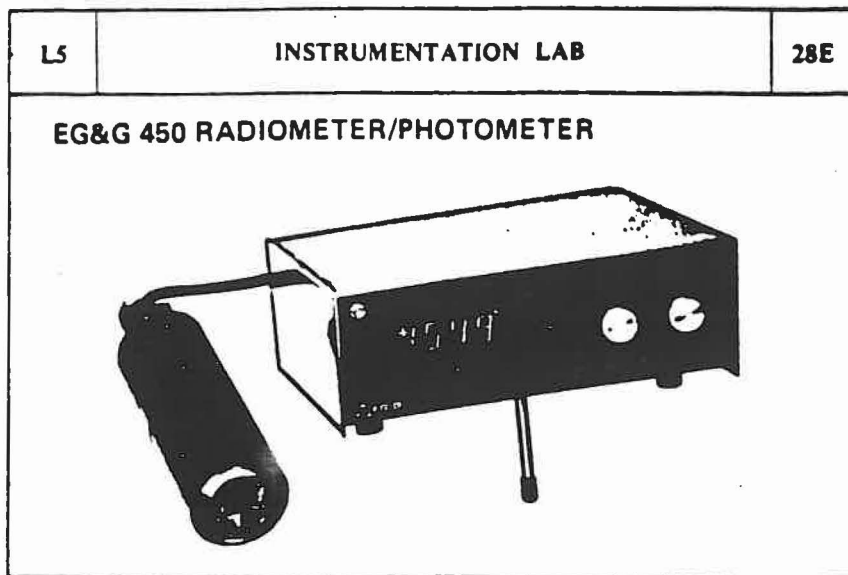
Class	Portable
Principle of Operation	Silicon Cell
Sensitivity	Power Range: .1 - 100 μ W or 1 - 100mW with attenuator Wavelength Range: 440 - nm - 1100 nm
Sampling	Continuous
Performance	Response time 200 μ s (min) $\pm$ 5% accuracy
Requirements	4 Mallory 8.1 V batteries
Features	Tubular light shield to restrict ambient light, illuminated meter readout, zero suppression control, battery operated.
References	Manufacturer's specification sheet
Cost	
Remarks	
Address	Coherent Radiation 3210 Porter Drive Palo Alto, California 94304 (415) 493-2111



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

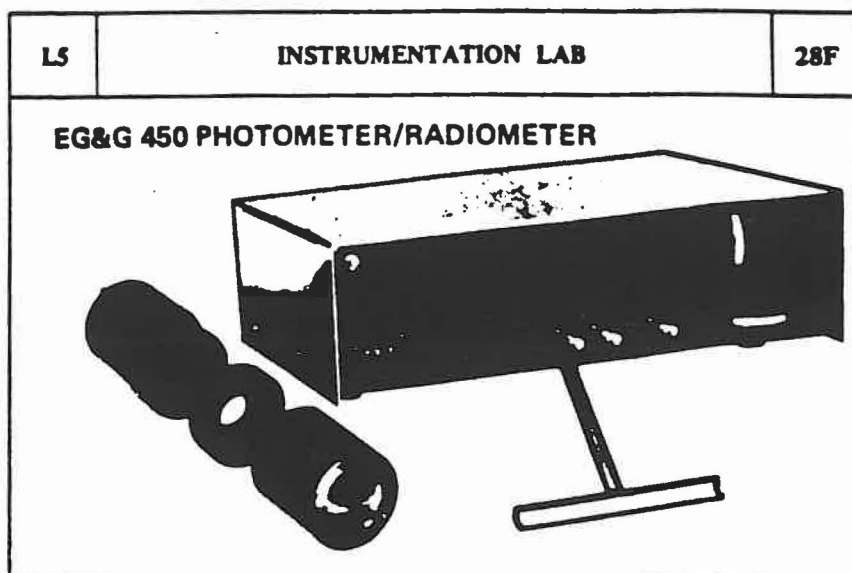
Class	Lab Standard
Principle of Operation	Thermal Disc/Thermopile
Sensitivity and Range	Power Range: 100 W - 1000 W Wavelength Range: 300 nm - 30 μ m
Sampling	Continuous
Performance	Response Time/Sec, $\pm$ 5% accuracy
Requirements	115 V/230 V AC
Features	Water cooled broad band sensor, adjustable table top stand, illuminated readout meter, automatic ambient temperature compensation, output jack.
References	Manufacturer's specification sheet
Cost	
Remarks	
Address	Coherent Radiation 3210 Porter Drive Palo Alto, California 94304 (415) 493-2111



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

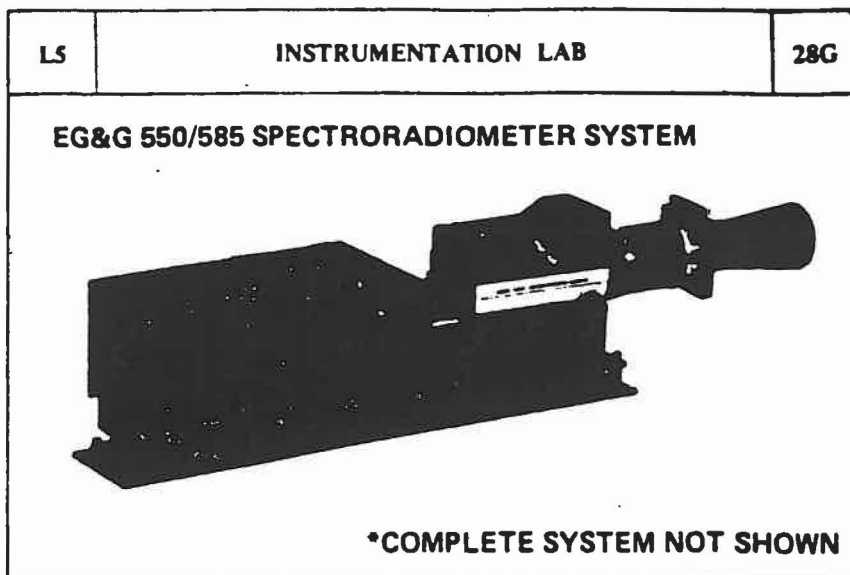
Class	Portable
Principle of Operation	Silicon Photovoltaic Detector
Sensitivity and Range	Sensitivity: 10^{-11} W/cm ² Power Range: 2×10^8 W/cm ² - 2×10^{-3} W/cm ² Wavelength Range: 200 nm - 1150 nm
Sampling	Continuous (Integrator Optional)
Requirements	115V or 220V 4 Watts 50/60 Hz 8 1/4" x 3" x 7 1/2" - 4 lbs.
Features	Digital Readout, Zero Ambient Compensation Readout in 4 Optical Units.
References	Manufacturer's specification sheets
Cost	
Remarks	Accessories Available
Address	EG&G, Inc. Electro-Optics Division 35 Congress Street Salem, Mass. 01970 (617) 745-3200



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

Class	Portable
Principle of Operation	Silicon Photovoltaic Detector
Sensitivity and Range	Sensitivity: 10^{-12} W/cm ² Power Range: 2×10^{-9} - 2×10^{-3} W/cm ² Wavelength Range: 200 - 1150 nm
Sampling	Continuous (Integration Module Optional)
Performance	$\pm$ 5% accuracy response time $\leq$ 3 sec.
Requirements	115V or 220 V 50/60 Hz 12 Watts 11" x 3" x 9" - 7 lbs.
Features	Zero/Ambient Compensation, Analog Output, Unit Selection - 10 Optical Units, 2 Electrical Digital Readout, Autoranging
References	Manufacturer's specification sheet
Cost	
Remarks	Accessories Available
Address	EG&G, Inc. Electro-Optics Division 35 Congress Street Salem, Mass. 01970 (617) 745-3200



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

The Model 580/585 Spectroradiometer Systems is a flexible system.

Features and Capabilities:

Measures CW and pulsed sources

Eleven - Decade dynamic range

Spectral range from .2 to 3.2 μm

Usable as a photometer and radiometer

Autoranging, digital, recorder, BCD and oscilloscope readouts

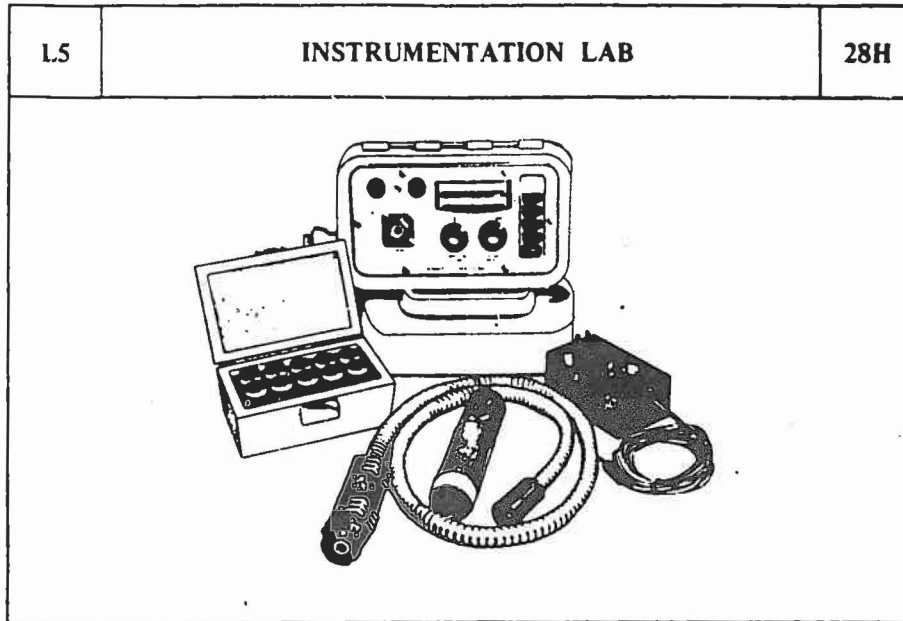
Portable for use in field, laboratory production line, and inspection stations

Digital grating monochromator

Telescope, microscope, and fiber optic accessories

For complete details on entire system write:

EG&G, Inc.
Electro-Optics Division
35 Congress Street
Salem, Mass. 01970
(617) 745-3200

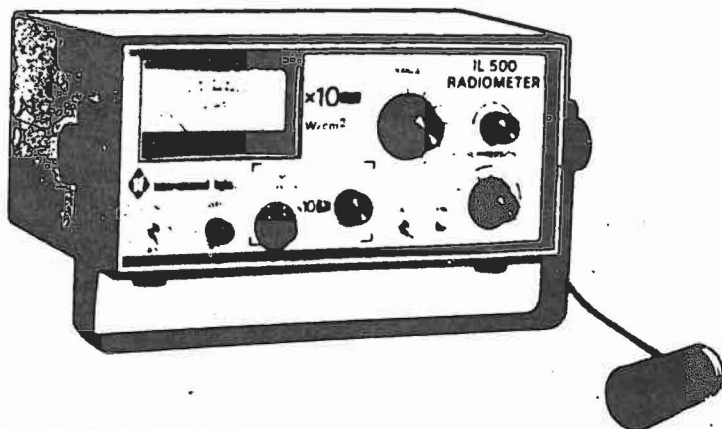


6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

Class	Portable
Stage of development	Prototype being evaluated by U.S. Bureau of Radiological Health
Principle of Operation	Optical input has four fiber-optic bundles which feed four detectors. Detectors are silicon PIN photosensitive diodes, each connected to a separate temporal range. Each of the four each connected to a separate integrator channels has a different response characteristic with a flat response over a separate temporal range (10^{-8} to 10^{-6} sec; 10^{-6} to 10^{-4} sec; 10^{-4} to 10^{-2} sec; 10^{-2} to 10^{-1} sec). The read-out is in terms of a biologically-weighted "hazard factor", (defined as the ratio of level being measured to threshold). The biological weighting is accomplished within the electronics.
Sensitivity	(1) Basic spectral sensitivity is from 400 to 1100 nm, spectrally corrected from the human eye's spectral sensitivity. (2) Aperture has diameter of 7.5 mm which simulates a fully dilated human eye. (3) Unit is capable of integrating laser pulses or pulse trains of duration from 10^{-8} seconds to CW. (4) Normal angular field of view is about 60 degrees; narrow field adapter and sun-shield is provided as an accessory. (5) Sensitivity is over range of "hazard factor" from 0.1 to 1000 (where 1000, for example, would be the very hazardous condition in which the measured level exceeds the threshold-damage level of by a factor of 1000).
Cost	\$10,800 plus \$250 per calibrated wavelength channel
Address	International Laser Systems, Inc. 3404 N. Orange Blossom Trail Orlando, Florida 32804 (305) 295-4010 Attn: Mr. Graham Flint

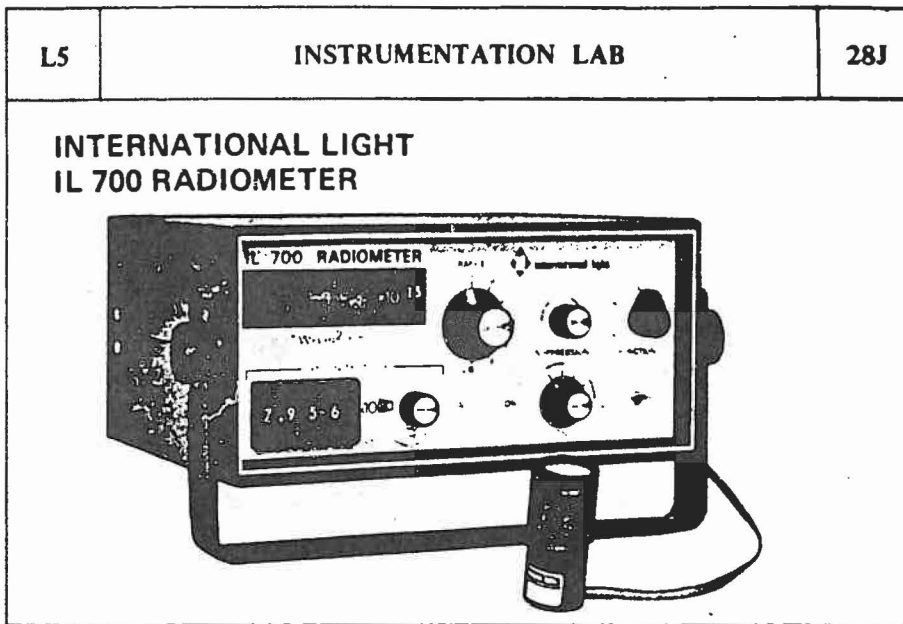
INTERNATIONAL LIGHT IL 500 RADIOMETER



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

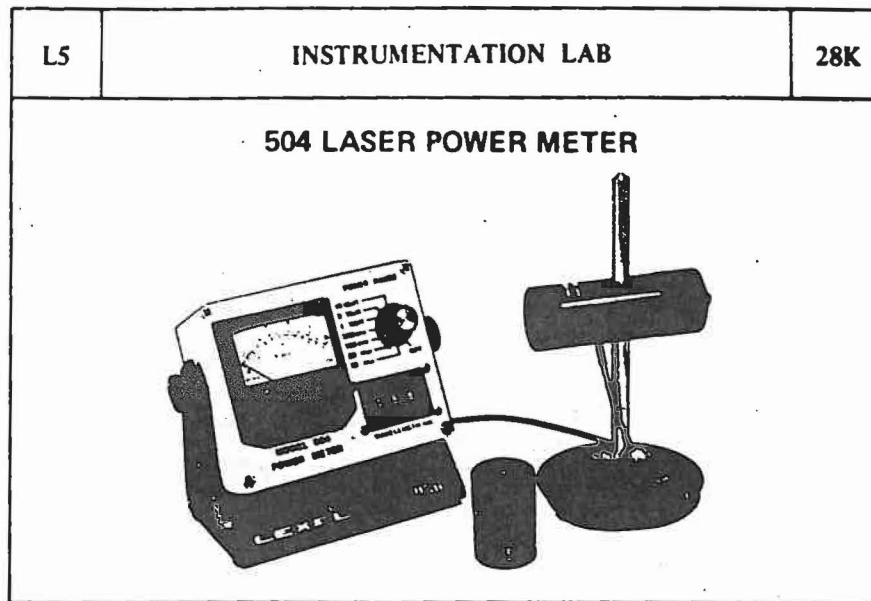
Class	Portable
Principle of Operation	Vacuum photodiode or photomultiplier
Sensitivity	Sensitivity: $3.6 \times 10^{-9} \frac{\text{watts}}{\text{cm}^2}$ with vac photodiodes $3.6 \times 10^{-13} \frac{\text{watts}}{\text{cm}^2}$ with photomultiplier Wavelength Range: 220 nm - 1200 nm detector
Sampling	Continuous
Performance	Better than $\pm 1\%$ accuracy on all ranges
Requirements	55-135 or 270 VAC 50-60 Hz or 10-28 VDC Battery
Features	Meter readout, ambient light compensation, recorder output.
References	
Cost	\$495.00 (excluding detector)
Remarks	Full line of accessories available
Address	International Light Inc. Dexter Industrial Green Newburyport, Mass. 01950 Tel. (617) 465-5923



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

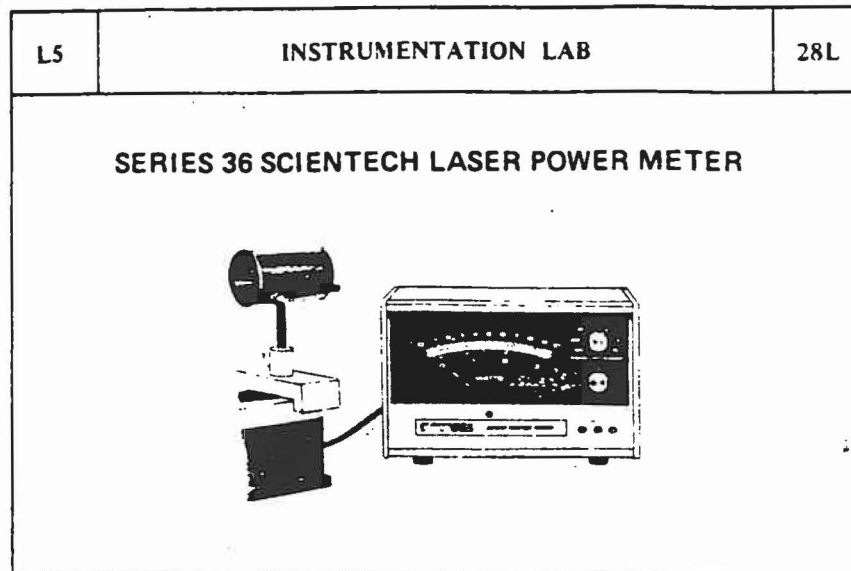
Class	Portable
Principle of Operation	Vacuum Photodiode
Sensitivity and Range	Sensitivity: 1×10^{-13} watts/cm ² Wavelength Range: 240 nm - 1100 nm Power Range: 20 decades
Sampling	Continuous or pulsed
Performance	Better than $\pm 1\%$ accuracy
Requirements	95-135 or 190-270VAC, 50-60 Hz or 10-28 VDC from self-contained battery
Features	Digital readout, continuous and pulsed modes, illuminated exponent, indicator, chart recorder output
References	Manufacturer's Spec Sheet
Costs	
Remarks	
Address	International Light, Inc. Dexter Industrial Green Newburyport, Mass. 01950 Tel. (617) 465-5923



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

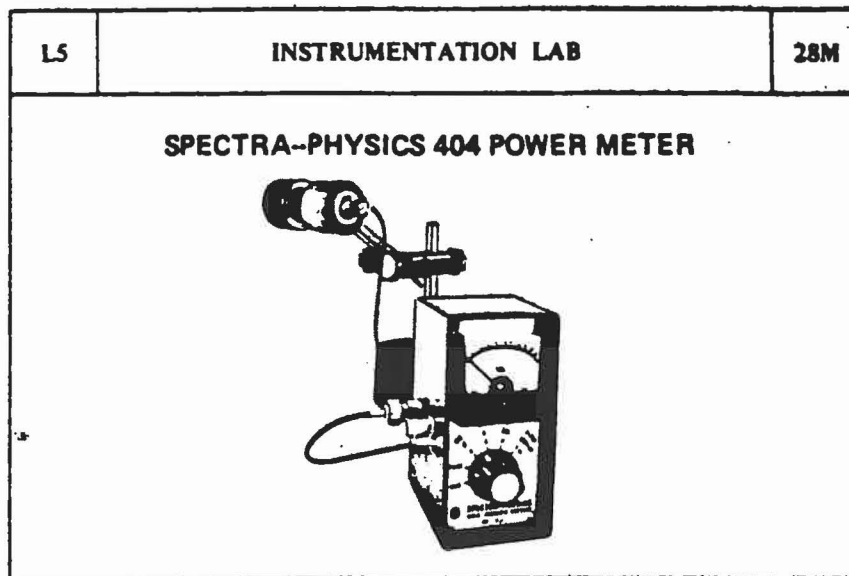
Class	Portable
Principle of Operation	Silicon Cell
Sensitivity	Power Range: .2 mW -10 watts (with optional attenuator) λ Range: 400 nm - 1100 nm Calibrated Wavelengths: 440 nm - 680 nm
Sampling	Continuous
Performance	Accuracy: ± 5% full scale at 488 nm
Requirements	Self Powered - no batteries required 5.8" x 4.7" x 3.5" 3.3 lbs
Features	Dial-in wavelength calibration over visible range, 0-50 mv recorder output, no zeroing adjustment, indicator unit is trunnion mounted
References	
Cost	\$495.00
Remarks	
Address	Lexel Corporation 928 East Meadow Drive Palo Alto, Calif. 94303 Tel. (415) 328-3466



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

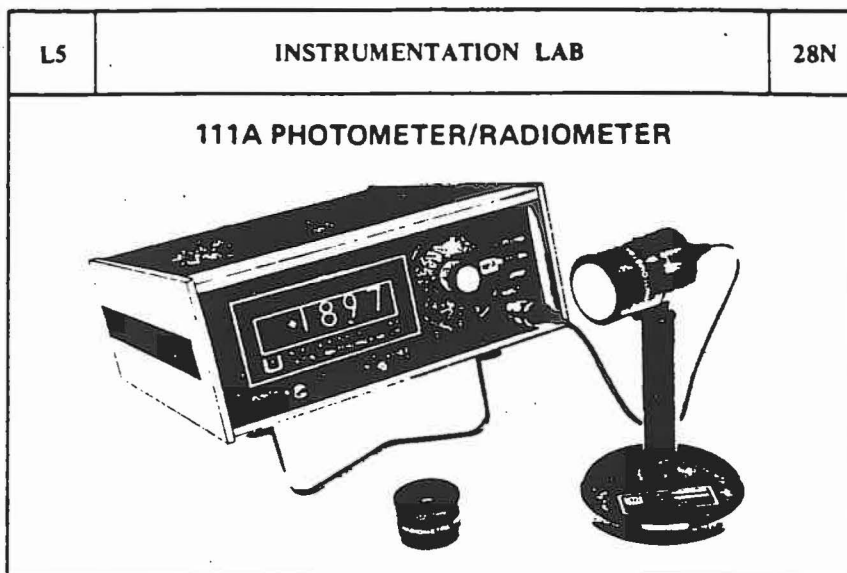
Class	Laboratory
Principle of Operation	Disc Calorimeter, thermopile
Sensitivity and Range	Sensitivity: 10 μ w Power Range: 10 μ w - 10W (300W using beam sampler) Wavelength Range: Flat from 250 nm - 35000 nm
Sampling	CW or pulse energy
Performance	$\pm$ 3% Accuracy, time constant 14 sec
Requirements	Calorimeter: 2.5" Dia 4" long 1.8 lbs
Features	Meter Readout, Manganin heater calibration, recorder output, precision integrator.
References	Manufactures Specifications Sheet
Cost	1" Disc Calorimeter \$375.00 Power Indicator for 1" Disc Calorimeter (9 ranges) \$575.00 Isoperibol Enclosure \$175.00 Beam Sampler \$325.00
Remarks	4" Disc Calorimeter available, economy readouts available, accessories available
Address	Scientech, Inc. 1724 14th Street Boulder, Colorado 80302 Tel. 303/44-1361



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

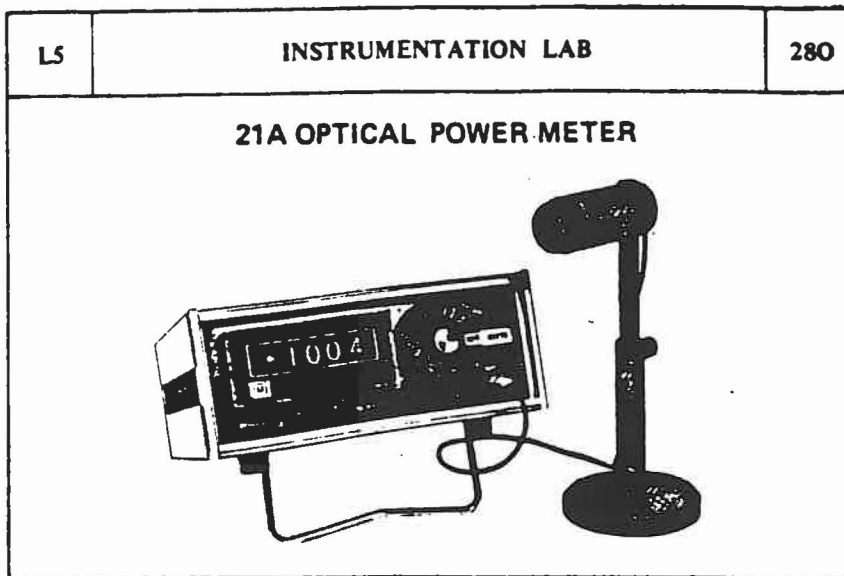
Class	Portable
Principle of Operation	
Sensitivity and Range	Power Range: 1 mw - 200 W (with attenuators) Sensitivity: 1 ma/mw Wavelength Range: 450 nm - 900 nm Frequency Response: 30 KH Least sensitive scale 5 KH Most sensitive scale
Sampling	Continuous
Performance	Response $\pm 15\%$ 450-900 nm
Requirements	2 1-1/2 volt batteries
Features	Meter Readout, recorder/oscilloscope output jack
References	Manufactures specificaitons sheet
Cost	
Remarks	
Address	Spectra-Physics 1250 West Middlefield Road Mountain View, Calif. 94042 Tel. (415) 961-2550



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

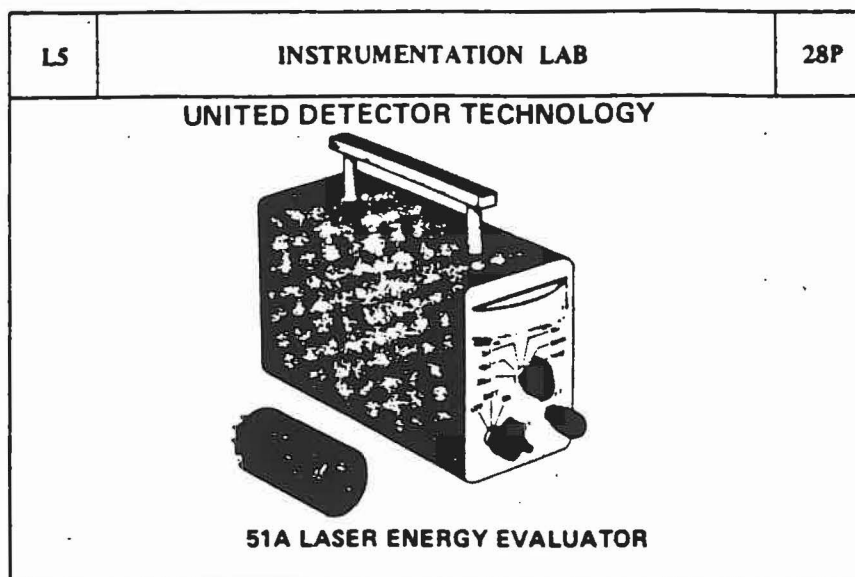
Class	Laboratory Standard														
Principle of Operation	Silicon Photodiode														
Sensitivity and Range	Sensitivity 10^{-11} watts Ranges $10^{-3} - 10^3 \mu\text{w}$, 100% overranging, 200-1100 nm depending on sensor														
Sampling	<table> <tr> <th>Hertz</th><th>μ watts</th></tr> <tr> <td>0.17</td><td>10^{-3}</td></tr> <tr> <td>1.1</td><td>10^{-2}</td></tr> <tr> <td>230</td><td>10^{-1}</td></tr> <tr> <td>1700</td><td>10^0</td></tr> <tr> <td>1000</td><td>10^2</td></tr> <tr> <td>1000</td><td>10^3</td></tr> </table>	Hertz	μ watts	0.17	10^{-3}	1.1	10^{-2}	230	10^{-1}	1700	10^0	1000	10^2	1000	10^3
Hertz	μ watts														
0.17	10^{-3}														
1.1	10^{-2}														
230	10^{-1}														
1700	10^0														
1000	10^2														
1000	10^3														
Performance	1% linearity, $\pm 2\%$ stability for 6 mo. $\pm 2\%$ calibration														
Requirements	Power: 115/230 volts, 50/60 Hz, 8 watts Weight: 6 lbs Size: 8-1/2" x 4" x 11"														
Features	Digital Readout, ambient light compensation, analog and BCD output, remote sample and hold control														
References	Manufacturers Specifications Sheet														
Cost	\$1295.00														
Remarks	The 111A is furnished with a manual and carrying case. Various sensing heads and filters are available.														
Address	United Detector Technology, Inc. 1732 21st Street Santa Monica, CA 90404 Tel. (213) 829-3557														



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

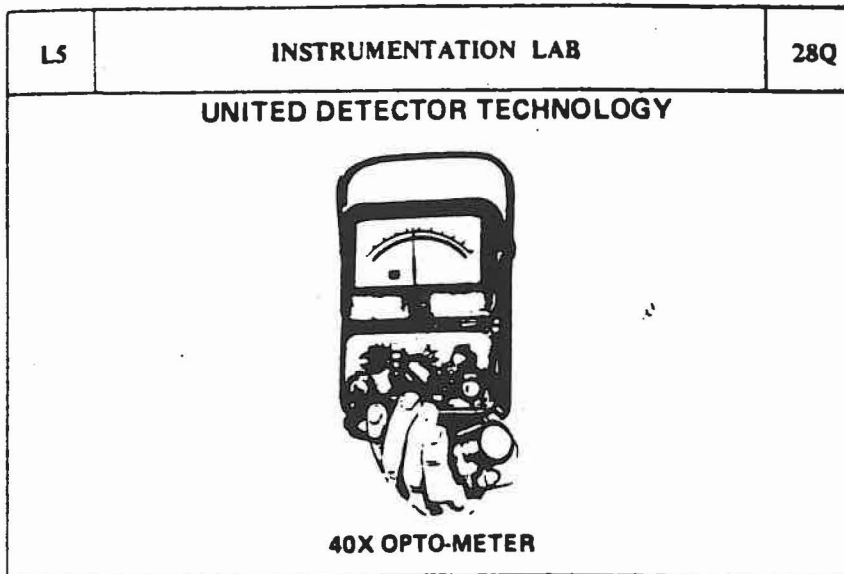
Class	Laboratory Standard
Principle of Operation	Silicon Photodiode
Sensitivity and Range	10^{-10} watts resolution on most sensitive range Ranges 10^{-10} watts - 1 watt (10 watts with optional accessories) 380 nm - 1150 nm Standard 250 nm - 900 nm Optional UV (10^{-9} w - 1 mw) 450 nm - 950 nm Optional Flat Response
Sampling	Continuous
Performance	1% linearity $\pm 2\%$ stability for 6 mo. $\pm 2\%$ calibration accuracy
Requirements	115/230 volts 50/60 Hz, 8 watts 3-1/2"x8-1/2"x10" 6 lbs.
Features	Digital readout, direct power readout, analog and BCD outputs, ambient light compensation
References	Manufacturers Specification Sheet
Cost	\$895.00
Remarks	The UDT 21A is furnished with a manual and carrying case. Various sensing heads and filters are available.
Address	United Detector Technology, Inc. 1732 21st Street Santa Monica, CA 90404 Tel. (213) 829-3357



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

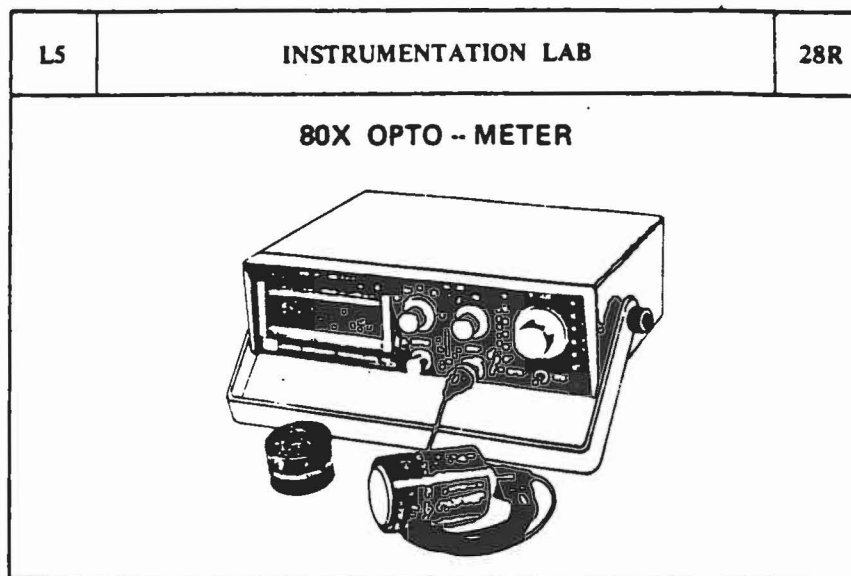
Class	Portable
Principle of Operation	Seven mm diameter aperture, subtractive filter, silicon photodiode, amplifier, meter readout.
Sensitivity and Range	Sensitivity: 350 to 1150 nm - flat response 450 to 980 nm with mult. for 1060 nm Energy Range: .02 to 30 microjoules and .06 to 10 milliwatts
Sampling	Pulsed: Up to 150 pulses/sec, displays max. Continuous: Displays max. value
Performance	Accuracy: $\pm 10\%$ absolute to N.B.S., continuous and pulse Stability: Silicon sensor $\pm 2\%$ per six months Temperature: 0 to 40°C
Requirements	Power: Cells; 50 hours min. Size: 25 cm x 10 cm x 7.5 cm Weight: 1.35 kg (3 lb.)
Features	N.B.S. standard calibration
References	Manufacturer's specifications
Cost	\$1450.
Address	United Detector Technology 1732 21st Street Santa Monica, CA 90404 Attn: Mr. George Richardson Tel. (213) 829-3517



Detector Requirements and Commercially Available Detectors (contd.)

Laser

Class	Portable field survey meter
Principle of Operation	7 mm diameter aperture (simulates fully dilated human eye) backed by a photo-diode circuit.
Sensitivity and Range	Spectral Response: 350-100 nm (flat from 420 to 940 nm) Minimum Sensitivity: About 0.1 μ J pulsed Ranges: Pulsed 0-1 μ J, 0-3 μ J, 0-10 μ J Continuous Wave 0-3 mW, 0-10 mW
Sampling	For pulsed laser unit samples up to 100 pulses/sec. For continuous wave lasers, unit gives watts into 7 mm diameter aperture.
Performance	Accuracy: $\pm 10\%$ Stability: 2%
Requirements	Power: Two replaceable mercury batteries 50 hr operation (minimum) Size: 3"x4"x7" (approximate) Weight: 3 lbs
References	a) Developed under contract with U.S.A.F. School of Aerospace Medicine, San Antonio, Texas. Attention: Capt. Donald Marston b) Meets U.S.A.F. regulation AFM-161-8, April 1, 1969
Cost	Meter about \$1000 LED calibration source about \$200
Remarks	Light emitting diode calibration source provides fail-safe circuit
Address	United Detector Technology 1732 21st Street Santa Monica, California Attn: Mr. George Richardson Tel. (213) 829-3517



6. Detector Requirements and Commercially Available Detectors

c. Laser (contd.)

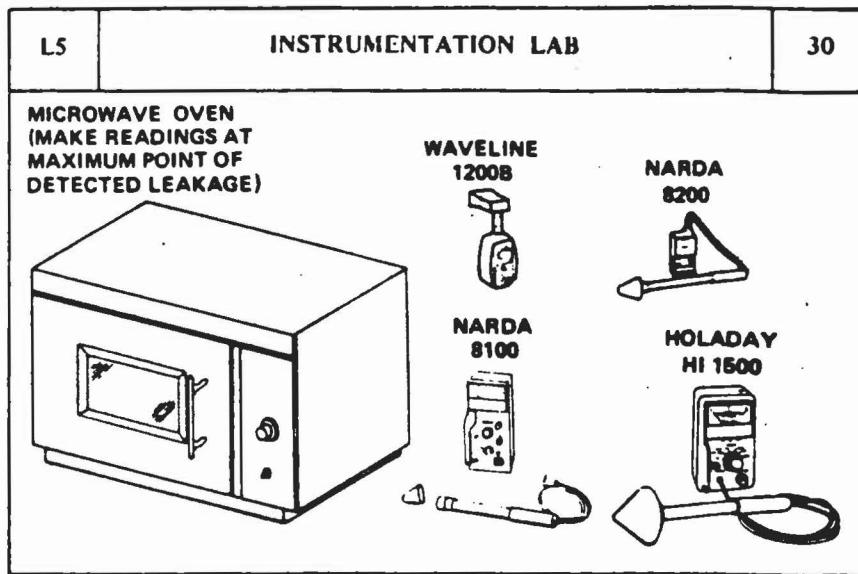
Principle of Operation	Silicon Photodiode
Sensitivity and Range	Sensitivity: 10^{-10} watt Ranges: $.01 \mu\text{w} - 10^4 \mu\text{w}$ (15 watt/cm ² with optional accessories) 350 nm - 1100 nm Standard 250 nm - 1100 nm Optional
Sampling	Continuous
Performance	1% linearity $\pm 2\%$ stability for 6 mo. $\pm 5\%$ calibration accuracy
Requirements	4 1.25 V Size D NICAD Batteries 115/230 V 50/60 Hz 10" x 6-1/2 x 2-1/2" 5 lbs.
Features	Digital readout, analog and BCD output, battery or line powered, external gain control.
References	Manufacturers Specification Sheets
Cost	\$975.00
Remarks	UDT 80X includes manual and carrying case. Additional accessories available.
Address	United Detector Technology, Inc. 1732 21st Street Santa Monica, CA 90404 Tel. (213) 829-3357

L5	INSTRUMENTATION LAB	29
PHASE I. FAMILIARIZATION TO RADIATION DETECTORS MICROWAVE ULTRAVIOLET LASER PHASE II. SENSING ELEMENTS		

C. STUDENTS' LABORATORY EXERCISE

1. Introduction

The students laboratory exercise will be conducted in two phases. During Phase I the students will use the microwave detectors to monitor a microwave signal source, the UV detectors to monitor a sunlamp and the laser detectors to monitor a laser. Comparisons of the detectors for a given source will then be made. During Phase II the students will have the opportunity to handle and observe the detecting elements from various types of detectors. They will make sketches of the sensing elements and record what parameter varies with incident radiation.



2. Phase I. Familiarization with Radiation Detectors

a. Microwave

- (1) The instructor will set up the equipment and detectors as shown in Figure 30. The microwave signal source and detectors will be turned on, zeroed and will be ready for use.

L5	INSTRUMENTATION LAB				31
LOCATION OF READING	WAVELINE 1200B	NARDA 8100	NARDA 8200	HOLADAY HI 1500	

2. Phase I. Familiarization with Radiation Detectors

a. Microwave (contd.)

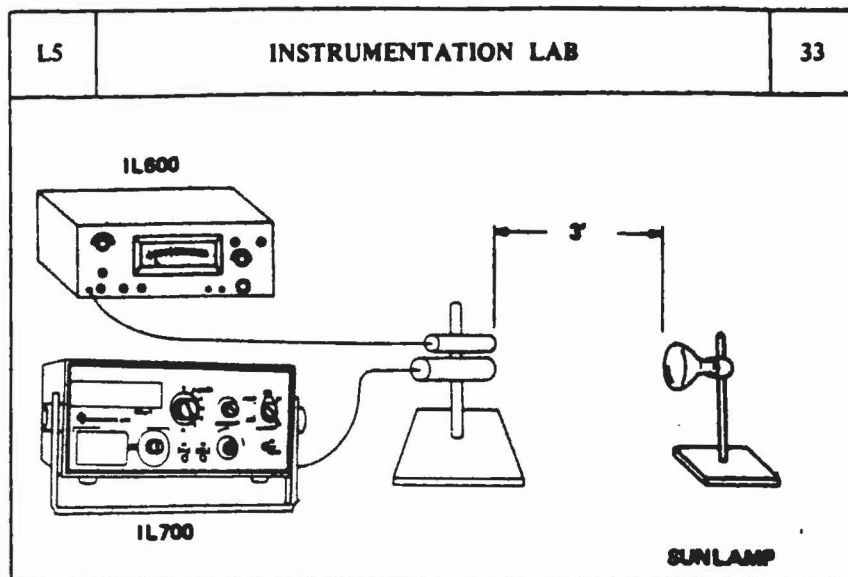
- (2) Make measurements with the 1200B Densimeter, the Narda 8100 and 8200, the Holaday HI 1500. Record values on Figure 31.

LS	INSTRUMENTATION LAB				32
MICROWAVE INSTRUMENTS					
INSTRUMENT	SENSOR TYPE	POWER RANGE	WAVE LENGTH RANGE	ACCURACY	COMMENT
WAVELINE 1200B					
NARDA 8100					
NARDA 8200					
HOLADAY HI 1500					

2. Phase I. Familiarization with Radiation Detectors

a. Microwave (contd.)

- (3) Record in Figure 32 the specifications of the instruments used in step 2. Use the information provided in the Manufacturers Specifications section.



2. Phase I. Familiarization with Radiation Detectors (contd.)

b. Ultraviolet

- (1) The instructor will set-up the equipment and detectors as shown in Figure 33. All equipment will be turned on, zeroed and will be ready for use.

L5	INSTRUMENTATION LAB			34								
<table border="1"> <thead> <tr> <th>DISTANCE TO SOURCE</th> <th>IL600</th> <th>IL700</th> <th>COMMENT</th> </tr> </thead> <tbody> <tr> <td>3'</td> <td>$\mu A \times 90.8 =$ $\frac{\mu W}{cm^2}$</td> <td></td> <td></td> </tr> </tbody> </table>					DISTANCE TO SOURCE	IL600	IL700	COMMENT	3'	$\mu A \times 90.8 =$ $\frac{\mu W}{cm^2}$		
DISTANCE TO SOURCE	IL600	IL700	COMMENT									
3'	$\mu A \times 90.8 =$ $\frac{\mu W}{cm^2}$											

2. Phase I. Familiarization with Radiation Detectors

b. Ultraviolet (contd.)

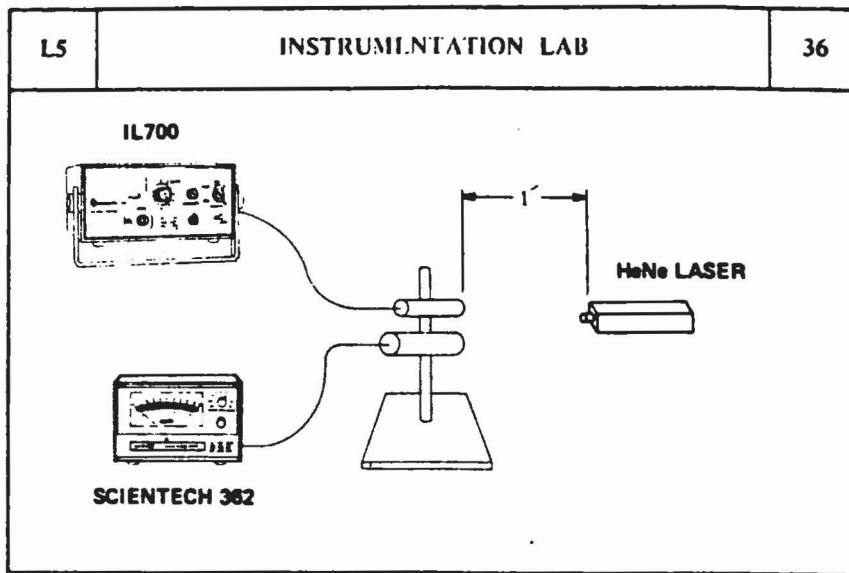
- (2) Make measurements using the IL600 Photometer and IL700 Radiometer.
Record data in Figure 34.

L5	INSTRUMENTATION LAB				35
ULTRAVIOLET DETECTORS					
INSTRUMENT	SENSOR TYPE	POWER RANGE	WAVELENGTH RANGE	ACCURACY	COMMENT
IL800					
IL700					

2. Phase I. Familiarization with Radiation Detectors

b. Ultraviolet (contd.)

- (3) Record in Figure 35, the specifications, of the instruments used in step 2. Use the information provided in the Manufacturers specifications section.



2. Phase I. Familiarization with Radiation Detectors (contd.)

c. Laser

- (1) The instructor will set-up the equipment and detectors as shown in Figure 36. The laser and detectors will be turned on, zeroed and will be ready for use.

LS	INSTRUMENTATION LAB		37								
<table border="1"> <tr> <th>DISTANCE TO SOURCE</th> <th>IL700</th> <th>362</th> <th>COMMENT</th> </tr> <tr> <td>1</td> <td></td> <td></td> <td></td> </tr> </table>				DISTANCE TO SOURCE	IL700	362	COMMENT	1			
DISTANCE TO SOURCE	IL700	362	COMMENT								
1											

2. Phase I. Familiarization with Radiation Detectors

c. Laser (contd.)

- (2) Make measurements using the Scientech 362 and IL700. Record values on Figure 37.

LS	INSTRUMENTATION LAB				38
LASER DETECTORS					
INSTRUMENT	SENSOR TYPE	POWER RANGE	WAVELENGTH RANGE	ACCURACY	COMMENT
SCIENTECH 352					
IL700					

2. Phase I. Familiarization with Radiation Detectors

c. Laser (contd.)

- (3) Record in Figure 38, the specifications of the instruments used in step 2. Use the information provided in the Manufacturers specifications section.

L5	INSTRUMENTATION LAB	39
SENSING ELEMENT _____ WAVELENGTH RANGE _____ OUTPUT _____		

2. Phase II. Sensing Elements

- a. Examine and make sketches of the phototube, photomultiplier, photoconductor, photocell, thermistor, varetter, calorimeter, hot carrier diode thermocouple and thermopile.
- b. Make your sketches on Figures 39 to 48. Fill in the information required .

**MICROWAVE LABORATORY
NO. 6**

COURSE OUTLINE

VI. MICROWAVE LAB

A. INTRODUCTION

1. Objectives
2. Overview
3. Equipment
4. Precautions

B. INSTRUCTOR'S DEMONSTRATION - LECTURE

1. Introduction
2. Detection of Microwaves
3. Laboratory Equipment
 - a. Microwave Source
 - b. The Waveline 1200 B Densiometer
 - c. Using the Waveline 1200 B Densiometer
 - d. The Narda Model 8200
 - e. Microwave Oven
4. Survey Technique
 - a. Introduction
 - b. General Information
 - c. Hazard Determination
 - d. Environment
 - e. Personnel
 - f. Personnel Protection
 - g. Certification
 - h. Comment

C. STUDENTS' LABORATORY EXERCISE

1. Introduction
2. Phase I. Survey of Microwave Sources
 - a. Microwave Oven Survey
 - b. Microwave Survey of a Signal Generator
3. Phase II. Properties of Microwaves
 - a. Polarization
 - b. Shielding

L6	MICROWAVE LAB	1
OBJECTIVES 1. TO REVIEW MICROWAVES AND MICROWAVE DETECTORS 2. TO BE ABLE TO PERFORM A MICROWAVE SURVEY 3. TO OBSERVE MICROWAVE POLARIZATION AND SHIELDING		

VI. MICROWAVE LAB

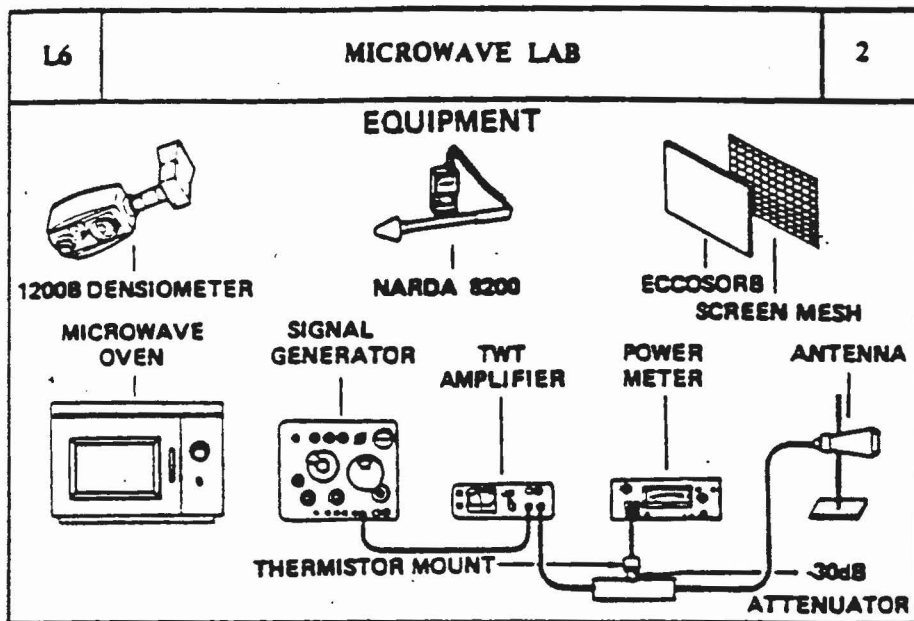
A. INTRODUCTION

1. Objectives
 - a. To review microwaves and microwave detectors
 - b. To be able to perform a microwave survey
 - c. To observe microwave polarization and shielding
2. Overview

The instructor will first review some basic points of microwaves, microwave sources and microwave detectors. He will then introduce the class to a microwave signal generating device. The students will observe the microwaves from the signal generator but they will not be required to operate the device. The instructor will next introduce and explain the use of a Waveline 1200B Densimeter. He will also discuss a Narda 8200 detector, a microwave oven, and the survey technique used in monitoring microwave sources.

The students will use the Narda 8200 to make a survey of an operating microwave oven. They will use the Densimeter to survey the signal generating device. Microwave polarization and shielding will also be observed using the signal generator and Densimeter.

At the conclusion of the lab, the students will submit the completed lab.



3. Equipment List

- a. Waveline 1200B Densiometer
- b. Narda 8200
- c. X-Band Signal Generator, TWT, -30 dB Attenuator, Power Meter and Thermistor Mount, X-Band Antenna
- d. Microwave Oven
- e. Eccosorb
- f. Screen Mesh
- g. Microwave Hazard Signs
- h. Lab Stands
- i. Graph Paper 3' x 3'

L6	MICROWAVE LAB	3
PRECAUTIONS 1. DO NOT ENTER AREAS DESIGNATED BY THE INSTRUCTOR AS BEING HAZARDOUS 2. DO NOT SPEND UNNECESSARY TIME IN CLOSE PROXIMITY TO THE MICROWAVE OVEN OR THE SIGNAL GENERATOR SET-UP 3. TURN MICROWAVE SOURCES OFF WHEN NOT IN USE		

4. Precautions

These precautions will be followed during the demonstration and during the students' laboratory exercise.

L6	MICROWAVE LAB	4
MICROWAVE REGION		
<u>BAND</u>	<u>MHz</u>	
MICROWAVE	100 - 300,000	
UHF	200 - 800	
L	800 - 1,800	
W	1,800 - 2,300	
S	2,300 - 3,950	
C	3,950 - 5,850	
J	5,850 - 8,200	
X	8,200 - 11,000	

B. INSTRUCTOR'S DEMONSTRATION - LECTURE

1. Introduction

As shown in Figure 4, the microwave region runs from 100 MHz to 300 GHz. This corresponds to a wavelength of 3 meters to 1 millimeter. This figure also shows the breakdown of bands within the microwave region. Although these are a convenient form of nomenclature, they have no official status and there is not always agreement as to the frequency limits associated with each band.

L6	MICROWAVE LAB	5
X-RAY HAZARDS FROM MICROWAVE TUBES 1. X-RAYS CAN BE PRODUCED IN: KLYSTRONS MAGNETRONS TWT TUBES HIGH VOLTAGE THYRATRONS 2. INSTRUMENTATION USED TO MONITOR THIS X RADIATION MUST BE RF INSENSITIVE		

1. Introduction (contd.)

The generation of adequate R-F power at the microwave frequencies has been accomplished by the development of several high power oscillator type tubes. The various tubes used for high power microwave frequency applications are magnetrons, klystrons and traveling-wave-tubes. These tubes although not designed specifically to generate x-radiation, radiate x-rays as an unwanted byproduct. Instrumentation used for detection and measurement of this unwanted x-radiation is essentially the same as standard x-ray survey meters with a few important exceptions. The microwave or radio frequency energy present does affect the circuitry of most standard x-ray survey meters and, therefore, this instrumentation must be shielded to protect it from this susceptibility which may cause erroneous readings.

L6	MICROWAVE LAB	6
DETECTION OF MICROWAVES ELECTRICAL DETECTOR SEMICONDUCTOR DIODE THERMAL DETECTORS 1. BOLOMETER THERMISTOR BARETTER 2. THERMOCOUPLE 3. AIR PRESSURE		

2. Detection of Microwaves

Detectors for microwaves can be divided into electrical detectors and thermal detectors. These two categories derive their names from the way in which electromagnetic energy interacts with the detectors.

The electrical approach to power density measurement is that of direct electrical energy conversion. The detected RF power directly activates the meter needle for measurement. This effect is accomplished by using a semiconductor diode or rectifier. This device, of the same type as used in early radio sets, rectifies the alternating RF current into direct current which may then be applied to a meter movement calibrated to indicate power. Knowing the effective antenna area, the power density may be calculated.

Thermal detectors act on the principle of producing a detectable physical change (temperature) in a thermally sensitive element. This change is then measured, usually by electrical means. There are three general types of thermally sensitive elements in use today.

The first is the thermistor. The resistance of the thermistor decreases when its temperature rises. The thermistor is heated by coupling it to the electromagnetic field. It is the radiofrequency current which causes the heating of the thermistor, but the detection of this heating is done by measuring the d.c. resistance of the thermistor.

Another device closely akin to the thermistor is the baretter which has a positive temperature coefficient of resistance rather than a negative one. Thermistors and baretters are both known as bolometer detectors, a term meaning any device which changes its resistance as it changes temperature.

L6	MICROWAVE LAB	6
DETECTION OF MICROWAVES ELECTRICAL DETECTOR 1. SEMICONDUCTOR DIODE THERMAL DETECTORS 1. BOLOMETER THERMISTOR BARETTER 2. THERMOCOUPLE 3. AIR PRESSURE		

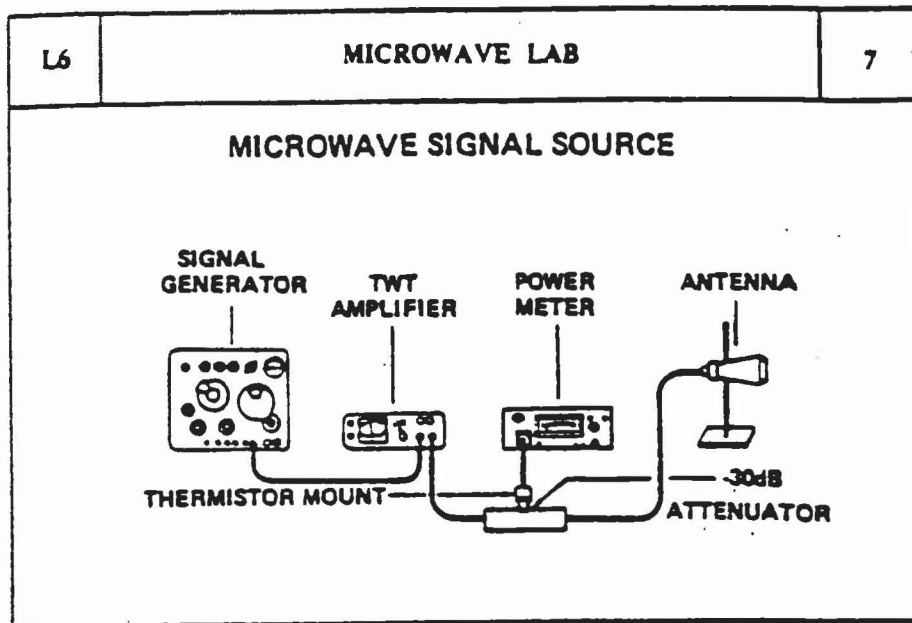
2. Detection of Microwaves (contd.)

Another type of temperature-sensitive device is the thermocouple. A thermocouple produces a voltage when heated. Therefore, all that is necessary to make a detection device from a thermocouple is an antenna and a current or voltage measuring device. Since voltage and current levels encountered when using these detectors are very small, a sensitive meter must be used, generally in conjunction with some type of direct-current amplifier.

A third approach to thermal microwave measurement is the air pressure system. This system involves measurement of a small pressure change in a confined gas when its container is heated slightly by absorbing some RF energy. The container for the gas is usually some sort of electrical insulator covered by a carbon compound which absorbs RF energy quite well. This system is used infrequently.

Thermal detection schemes have individual and common deficiencies. They all are ambient temperature dependent in their simple form. More sophisticated methods of measuring the difference in output from matched thermal detectors with only one exposed to RF heating have been developed, and such instruments are superior for general application. The Densimeter used in today's lab compensates for ambient heat by use of a balance control. The meter is zeroed outside the RF field and thus compensates for the ambient temperature effect.

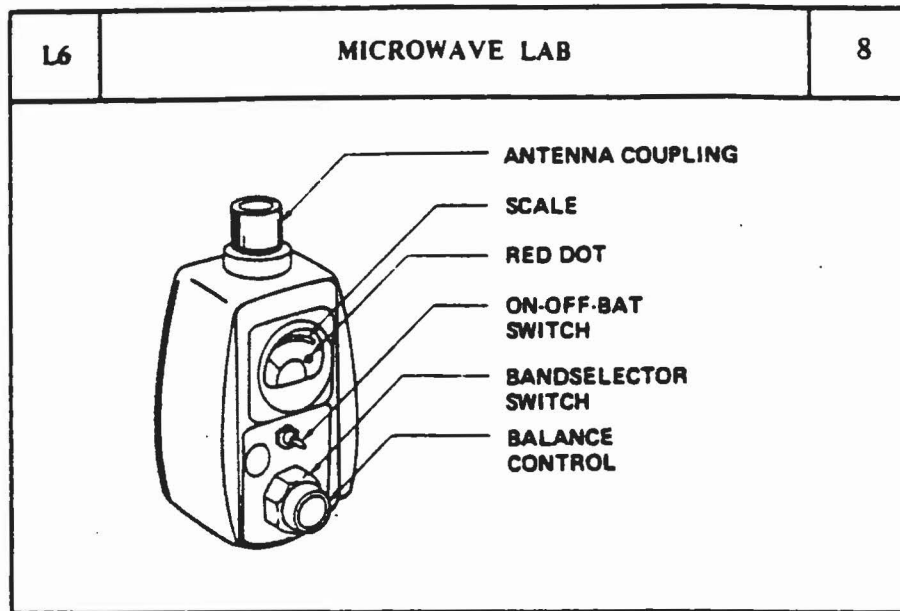
With the exception of the air-pressure detector, all detectors or sensors require an antenna to convert the propagating radiofrequency wave into wire-conducted radiofrequency currents which are then detected by either a thermistor, thermocouple, or diode. It is the antenna that determines the major characteristics of the measuring instrument. The Densimeter used in today's lab is polarization sensitive due to its antenna. Also, care must be exercised with the Densimeter to use the proper band antenna for the source being monitored.



3. Laboratory Equipment

- a. Microwave Source (Signal Generator, TWT, Power Meter, Attenuator Coupler and Antenna)

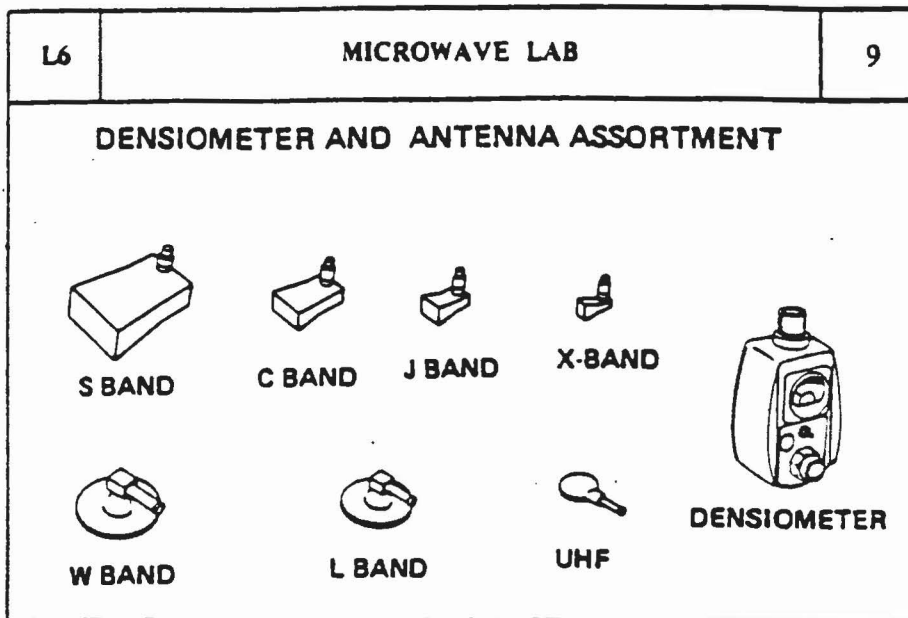
The x-band signal generator shown in Figure 8 will be used as one source of microwaves in today's lab. The signal generator output is connected to the TWT amplifier using a coaxial cable. A wave guide may be used to transfer the signal over greater distance than is practical with the coaxial cable. If wave guides and antennas are not properly attached, leakage can occur around their connecting joints. The TWT amplifies the signal from the signal generator. The power meter measures the output from the TWT. The antenna is coupled to the TWT through an attenuator coupling device (The students will not be required to operate this equipment).



3. Laboratory Equipment (contd.)

b. The Waveline 1200B Densimeter

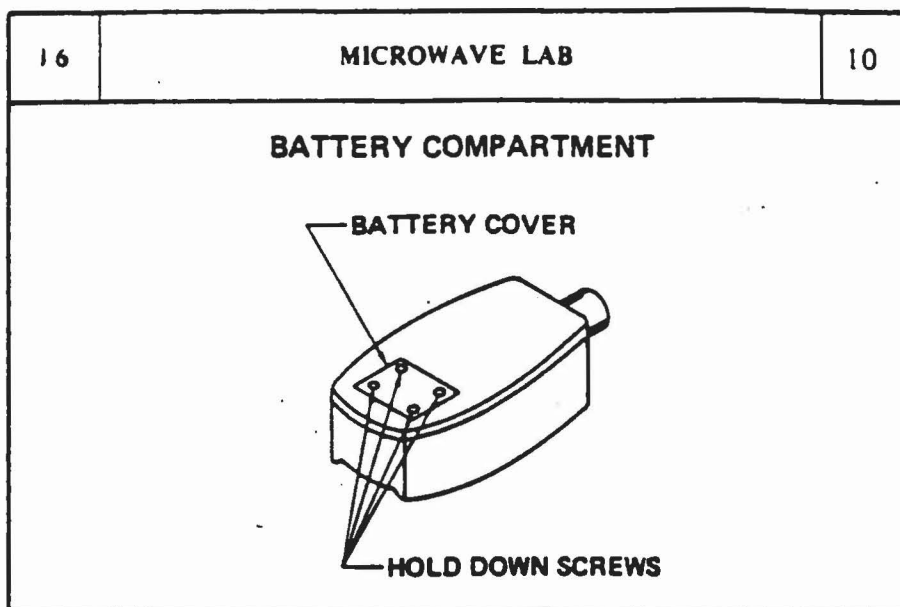
The Waveline 1200B Densimeter is a portable battery powered microwave detector that can be used to assess microwave health hazards. Figure 8 shows the meter removed from its protective leather carrying case. The on-off-battery switch turns the instrument on and off and checks the condition of the battery. Meter movement beyond the red dot indicates that the batteries are in good condition. The band selector switch selects the power frequency range to be used with the corresponding antenna. The balance control is used to zero the instrument with no RF power entering the antenna. The readout is provided on a scale indicating exposure levels above (red) and below (green) 10 mW/cm^2 in decibels. The antenna coupling allows any one of seven antennas to be connected to the instrument.



3. Laboratory Equipment

b. The Waveline 1200B Densimeter (contd.)

The antenna assortment is shown with the Densimeter in Figure 9. The antennas can be used to monitor microwave radiation from S band to UHF as denoted in the figure.



3. Laboratory Equipment

b. The Waveline 1200 B Densimeter (contd.)

The Densimeter should be kept clean and dry. Remember to turn the instrument off after each use to enhance battery life.

Batteries can be replaced by removing the four screws on the battery cover plate as shown in Figure 10. The old batteries may then be removed. The new batteries are inserted, making certain that the positive terminal of each battery is inserted in contact with the plus terminal indicated on the case. Finally, the battery cover is replaced.

L6	MICROWAVE LAB	11
USING THE WAVELINE 1200B DENSIOMETER 1. CHECK BATTERY 2. SELECT FREQUENCY AND BALANCE METER 3. CONNECT ANTENNA 4. ORIENT ANTENNA FOR MAXIMUM READING		

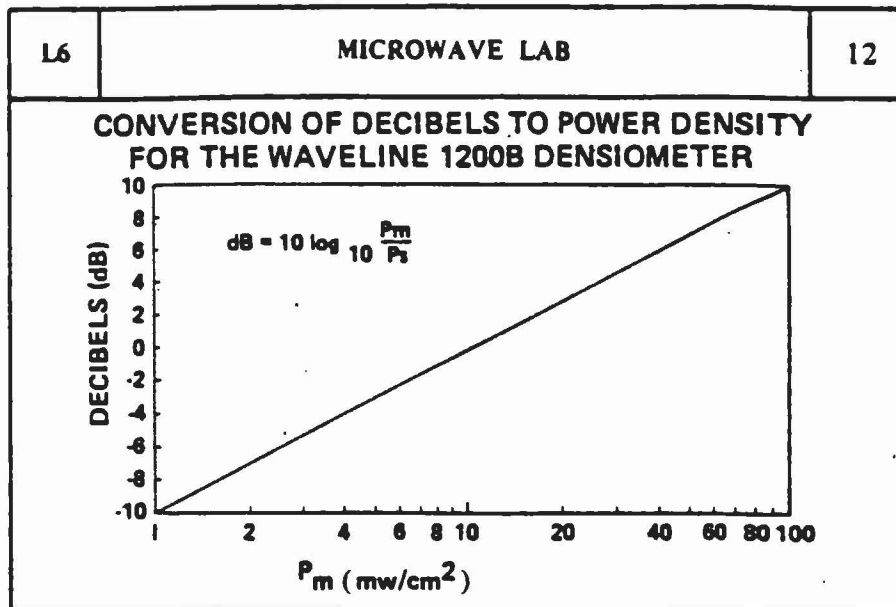
3. Laboratory Equipment (contd.)

c. Using the Waveline 1200B Densiometer

The instructor will demonstrate the use of the meter by covering the instructions outlined below.

- (1) Before connecting an antenna, set the selector switch to battery("BAT") position and press the "ON-OFF-BAT" toggle switch to the "BAT" position. The meter pointer should read at the "Red Dot," otherwise the batteries need replacement.
- (2) Select the proper frequency range to be measured. For example, set the "Selector Switch" to the x-band, turn the "ON-OFF-BAT" switch to "ON" and balance the meter with the "Balance Control." Proper balance is achieved when the meter pointer is at the extreme left edge of the green "Safe" scale. Proper balancing assures greater accuracy of the readings. To check the zero balance in the field, remove the antenna or completely shield it from RF energy. For optimum accuracy, the zero balance condition must be maintained.
- (3) Connect the x-band antenna to the Densiometer. To prevent damaging the sensing head mounted in the end of the case, remove and mount the antenna by turning the coupling nut. Do not use the antenna as a handle for removing it from the meter.
- (4) When using one of the waveguide horn antennas, the maximum reading will be obtained when the plane of the antenna aperture is normal to the direction of propagation of the RF energy. (When using the loop antennas, the maximum reading will be obtained when the plane of the major loop diameter is normal to the direction of propagation of the RF energy.)

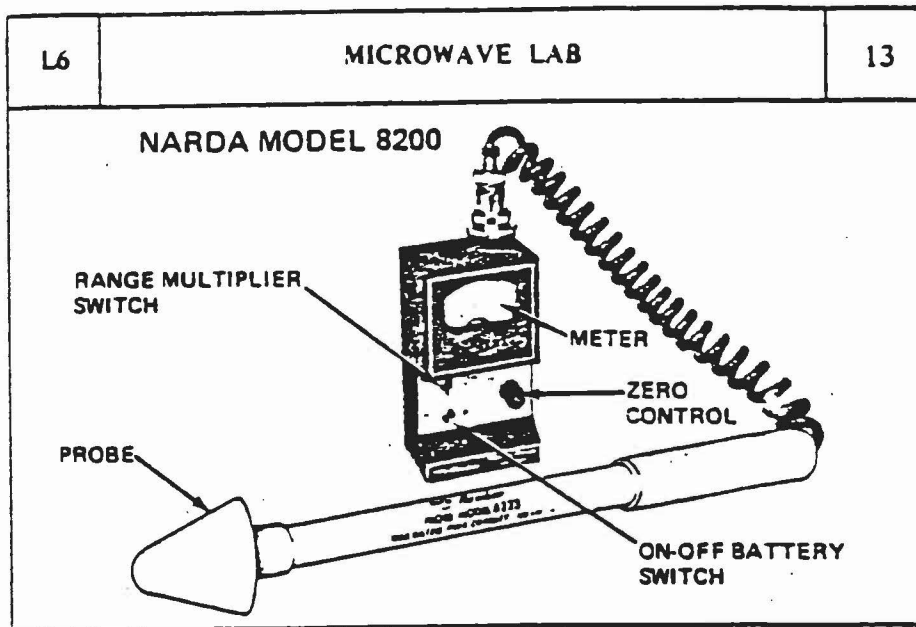
Rotation of the unit until the reading is maximized will provide optimum results and, therefore, optimum safety. This procedure aligns the antenna so as to achieve proper polarization alignment.



3. Laboratory Equipment

c. Using the Waveline 1200B Densiometer (contd.)

- (5) The readings obtained on the dB scale of the meter are referred to the maximum power density level to which personnel may be safely exposed. This level is 10 milliwatts/square centimeter. Thus, 0 dB at center scale represents that level. Above that level the red scale indicates danger. Below that level the green scale indicates safe exposure. Figure 12 provides a table which converts the dB scale readings obtained on the Densiometer to actual power density levels in milliwatts/square centimeter. Note that dB is a quantity that is related to the power density by $N(\text{dB}) = 10 \log_{10} P_m/P_s$. In Figure 12, P_s was taken as 10 mW/cm^2 and the values of P_m were substituted into the dB relation to relate dB to P_m for the 1200B densiometer.



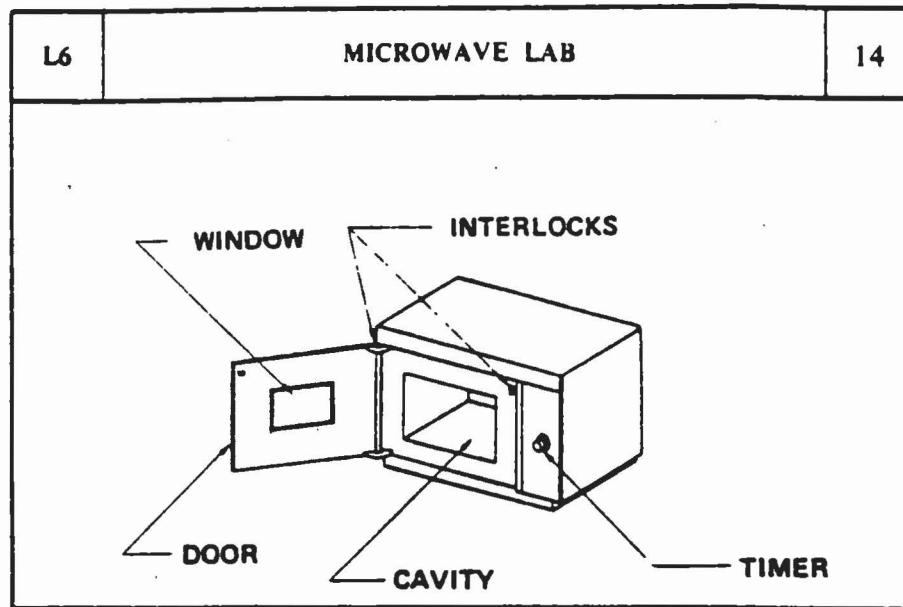
3. Laboratory Equipment (contd.)

d. The Narda Model 8200

The Narda Model 8200 was specifically developed as a small, inexpensive, completely portable, lightweight, battery-operated instrument to make accurate microwave oven measurements in the near field.

The Narda 8200 functions with either one of two probes at 2450 MHz only. The more sensitive probe has two full scale ranges of 2 and 20 mW/cm². The less sensitive probe has two full scale ranges of 10 and 100 mW/cm².

The range multiplier switch is used to select the proper range desired. The on-off-bat switch is used to turn the instrument on and off and check the battery. The meter is zeroed by using the zero control. The probe is equipped with a spacer to place the meter detector element two inches (~5 cm) from an oven surface.



3. Laboratory Equipment (contd.)

e. Microwave Oven

Microwave energy is widely used as a mechanism to heat, cook, and defrost food. The Federal Communications Commission has designated frequencies for unlicensed use in industrial, scientific, and medical equipment. Microwave ovens operate at either 915 or 2450 MHz. Most manufacturers use the 2450 MHz band for their ovens.

A typical microwave oven is illustrated in Figure 14. The source of microwaves in a microwave oven is usually a magnetron tube. The power supply provides energy to operate the magnetron and the control unit is a timer which operates the oven for a pre-determined interval. This interval depends upon the load to be processed. The cavity must be designed so as to process the load in the most efficient and desirable way. The stirrer is incorporated to prevent standing waves being set up in the cavity. The door and window hopefully seal the cavity against leakage of microwave energy and provide ready access and sight to the interior. Two interlocks must be provided to insure that the magnetron will cease generating microwave energy should the door be opened while the oven is operating. The oven should never be operated without a load in the cavity, since this could result in damage to or failure of the magnetron.

L6	MICROWAVE LAB				16
MICROWAVE SURVEY					
GENERAL INFORMATION	USING ORGANIZATION			ADDRESS	
	TYPE OF EQUIPMENT			INTENDED USAGE	
	MANUFACTURE	MODEL	SERIAL NUMBER	OTHER	

4. Survey Technique (contd.)

b. General Information

Different types of general information are recorded on the survey record in the block entitled General Information. The following information is required:

USING ORGANIZATION. In this space, the company or division of a company should be recorded. For example, if the survey is made on a radar at an airport, the name of the airport is recorded. If the survey is on a domestic microwave oven, the first and last name of the head of the household is recorded. **ADDRESS.** This is the address of the company, family, business place, etc. Enough information should be supplied so that someone unfamiliar with the location, could find the source. **TYPE OF EQUIPMENT.** This refers to whether the source is a radar, microwave oven, signal generator, etc. **INTENDED USAGE.** This is the purpose for which the equipment is used. For example the intended use could be cooking, research, product development, teaching, guidance, or communication. **MANUFACTURE-MODEL-SERIAL NUMBER-OTHER.** This information identifies the UV source as to manufacturer, the model number, the serial number, and any other general information unique to the source.

L6	MICROWAVE LAB						17
HAZARD DETERMINATION	FREQUENCY		FREQUENCY RANGE		PEAK POWER	AVE POWER	OTHER
	ANTENNA GAIN		STAT/SCAN	MONITORING INSTRUMENT		MONITORING CAL. DIST.	
	DISTANCE TO SOURCE		OR	SET	POWER DENSITY		MAXIMUM ALLOWABLE EXP TIME @ POWER DENSITY

4. Survey Technique (contd.)

c. Hazard Determination

FREQUENCY. This is the frequency at which the source was operating during the survey. For example, a microwave oven would operate at 2450 MHz. **FREQUENCY RANGE.** This is the range of frequencies over which the source is capable of operating. If more than one frequency is used, the power density at the different frequencies should be determined. **PEAK POWER-AVE POWER-OTHER.** This is the peak and average microwave power output of the source being measured. Other refers to information that might apply to only one particular type of source. **ANTENNA GAIN.** This is the gain of the antenna of the microwave source, for example 16.5 dB. (Gain does not apply to microwave ovens.) **STAT/SCAN.** This refers to whether the antenna is stationary (STAT) or scanning (SCAN). **MONITORING INSTRUMENT.** This is the instrument that is being used to make the survey. Examples might be, Waveline 1200B Densimeter, Microdek 310, Narda 8200, etc. The probe or antenna attachment should also be entered here.

L6	MICROWAVE LAB	18
10 mW/cm² CALCULATED DISTANCE $D = \sqrt{9.6 \times 10^{-4} G_t P_t}$ $D = 10 \frac{\text{mW}}{\text{cm}^2}$ - DISTANCE IN (YARDS) G_t - GAIN OF ANTENNA EXPRESSED AS A RATIO P_t - POWER INPUT TO ANTENNA IN WATTS		

4. Survey Technique

c. Hazard Determination (contd.)

10 mW/cm² CALC. DIST. This is the calculated distance (D) from the source at which a safe exposure level of 10 mW/cm² is expected. This distance in yards is given by

$$D = \sqrt{9.6 \times 10^{-4} G_t P_t}$$

G_t is the gain of the transmitting antenna taken as P_o/P_t , not in dB ($= 10 \log_{10} P_o/P_t$). Therefore, if G_t is given in dB it will be necessary to convert to a power ratio (P/P_t) using a graphic or calculational technique. P_t is the power input to the antenna by the transmitter. P_o is the power output of the antenna.

The survey in the field is usually started at 2D or 3D away from the antenna. The investigator then walks toward the antenna until 10 mW/cm² levels are reached. Obviously this calculated distance does not apply to microwave ovens.

L6		MICROWAVE LAB				19	
IDENTIFICATION	NAME OF SUBJECT		DATE OF MEASUREMENT		ADDRESS OF SUBJECT		
	FACILITY		FACILITY		FACILITY		
	FACILITY		FACILITY		FACILITY		
	FACILITY		FACILITY		FACILITY		
HAZARD DETERMINATION	FREQUENCY		FREQUENCY RANGE		PEAK POWER		AVE POWER
	ANTENNA GAIN		STAT/SCAN		MONITORING INSTRUMENT		MINIMUM CALC. DIST.
	DISTANCE TO SOURCE		D/R	KEY	POWER DENSITY		MAXIMUM ALLOWABLE
					dB		EXP TIME @ 10mW/cm ²
					mW/cm ²		

4. Survey Technique

c. Hazard Determination (contd.)

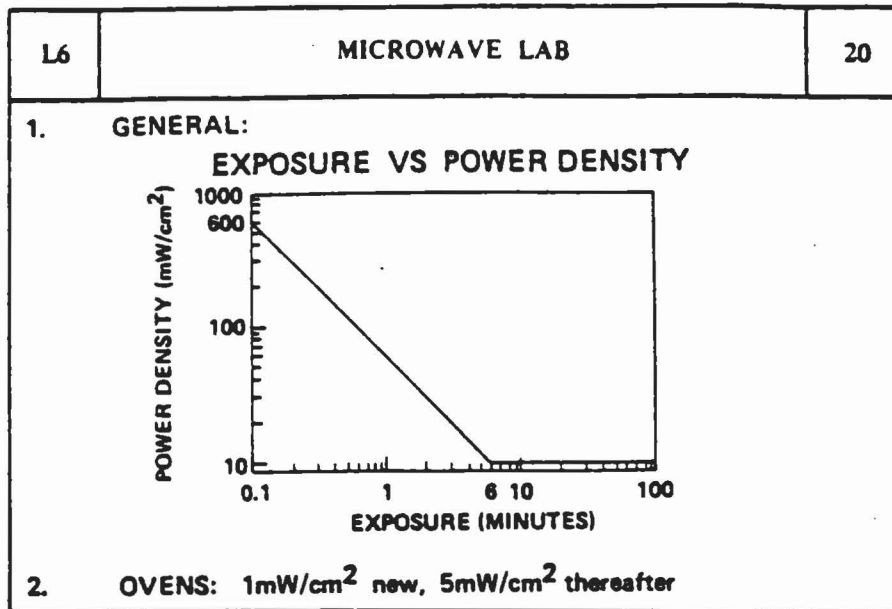
The next body of information pertains to the actual measurement made. The **DISTANCE TO SOURCE** is the distance to the source from the point of measurement. This can be a straight line distance or a given number of feet directly in front of the source with a given number of feet to the left or right of this centerline. Also, the distance to source could be to the left or right or from the top or bottom of a point on an oven.

The column labeled **D/R** refers to whether the reading was made looking directly (D) at the source or looking at a reflection (R). The **KEY** references these readings to a drawing of the microwave source area. For example, an A in the key column means that this measurement was taken in the area marked by A in the drawing. The **POWER DENSITY** can be recorded in dB or mW/cm². If the instrument used reads in dB, the dB reading should be converted to mW/cm².

Care must be exercised when obtaining measurements around a microwave source. If the microwaves are polarized and the detector is polarization sensitive, care must be taken to align the detector properly. It is possible in some cases where standing waves are being generated to obtain an erroneously low reading. For example the detector could be positioned at a location where the waves summed to zero or a low value. Usually these cases can be corrected for by taking several readings at slightly different positions and varying the orientation of the detector.

Measurements around antennas are made by starting at locations of low calculated power density which are usually far from the source. The investigator continues making measurements as he walks closer to the source until 10 mW/cm² levels are reached. This point is noted and necessary controls are instituted.

Measurements around microwave ovens are made at seams, openings, the door crack, the window screen, and the power cable. The interlocks and the amount of microwave leakage escaping from the door, as it is opened, is checked.

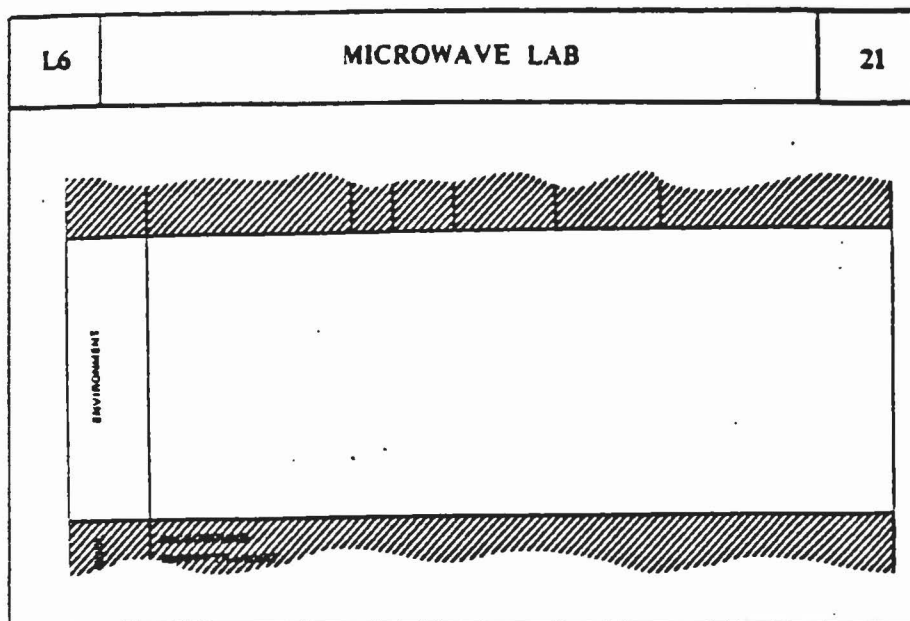


4. Survey Technique

c. Hazard Determination (contd.)

The measurements that are obtained are compared to exposure limits for safe operation. If the exposure is above 10 mW/cm² for microwave antennas, the **MAXIMUM ALLOWABLE EXPOSURE TIME** is recorded in the space provided. This is the time that a worker could be exposed to levels greater than 10 mW/cm² per 6 minute period. The exposure times for power densities above 10 mW/cm² can be obtained from Figure 20. It should be noted that this standard gives no upper limit as to power density. (An Air Force-Army standard allows no exposure above 100 mW/cm².)

The power density from a microwave oven shall not exceed 1 mW/cm² at any point 5 cm or more from the external surface of the oven, measured prior to the acquisition by a purchaser, and thereafter, 5 mW/cm² at any point 5 cm or more from the external surface of the oven. Measurements shall be made with the microwave oven operating at its maximum output and containing a load of 275 ± 5 ml of tap water initially at 20° ± 5° centigrade.



4. Survey Technique (contd.)

d. Environment

A freehand drawing of the area in which the microwave source is located is drawn in the block entitled environment. Top views and side views can be used to show pertinent features of the area. Letters (A,B,C, etc.) are located at given points in the sketch where measurements were made. These letters refer to the readings entered in the hazard determination block. Both direct and reflected measurements are shown. The number of people at a particular location with respect to the source are also entered on the sketch. For a microwave oven the front, back, top, bottom, left side and right are shown.

Non-UV hazards are also noted on the figure. Examples are electrical shock, fumes, explosion, fire, ventilation, etc.

L6	MICROWAVE LAB				22
PERSONNEL		BACKGROUND			
		SAFETY TRAINING			
PERSONNEL PROTECTION		UNAWARE ONLOOKER			
		OTHER			
PERSONNEL PROTECTION		SHIELDING	INTERLOCKS	LIGHT	CONTROLLED AREA
		SIGNS	FILM BADGE	SCREEN	
PERSONNEL PROTECTION		OTHER			
		RECOMMENDED			

4. Survey Technique (contd.)

e. Personnel

The **BACKGROUND** of the primary group or groups of people using the UV source is noted. They may be cooks, students, machinists, engineers, scientists, or a mix of these types of backgrounds. The amount of **SAFETY TRAINING** or safety awareness of the people using the source is also considered. The probability of an **UNAWARE ONLOOKER** being exposed to low or high exposure levels is noted. **OTHER** aspects of personnel which might have an effect on the hazard potential are also noted. For example, it might be noted that a particular individual was uncooperative in following or observing recommended safety practices.

f. Personnel Protection

The personnel protection block is divided into two parts; first those protective measures **IN USE**. And second, those protection measures **RECOMMENDED** after the hazard, environment, personnel and the current personnel protection measures have been evaluated.

The personnel protection measures in use could be shielding, signs, interlocks (2 are required by law for microwave ovens), film badge, lights, screens, controlled area access or some other form of safety measure. The safety measures recommended could be any one of the above or some other recommendation such as restricting people with pacemakers to enter a microwave source area.

L6	MICROWAVE LAB	23
		
CERT	PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE	

4. Survey Technique (contd.)

g. Certification

The certification entails obtaining the signature of the **PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION**. The safety monitor also signs the space marked **SURVEYED BY**, and finally the **DATE** of the survey is entered.

h. Comment

Additional information or drawings can be added to the back of the form if necessary. A check list might also be printed on the back of the form.

It should be pointed out that if a space required information which does not apply, the space can be marked **N.A.** (not applicable).

This general form presented is not intended to be a standard form. It merely points to various aspects which should be considered. Different forms can be developed as the need dictates.

L6	MICROWAVE LAB	24
STUDENTS' LABORATORY EXERCISE 1. PHASE I. SURVEY OF MICROWAVE SOURCES MICROWAVE OVEN SURVEY MICROWAVE SIGNAL GENERATOR SURVEY 2. PHASE II. PROPERTIES OF MICROWAVES POLARIZATION SHIELDING		

C. STUDENTS' LABORATORY EXERCISE

1. Introduction

The students' laboratory exercise will be conducted in two phases. In Phase I the students will make a survey of a microwave oven using a Narda 8200 detector. They will also make a survey of a microwave signal generator set-up using the Waveline 1200B Densimeter. For both the oven and signal generator sources, a situation will be assumed and a Microwave Survey Record will be completed.

In Phase II the students will observe some properties of microwaves using the signal generator as a source and the 1200B Densimeter for the detector. The properties to be studied are polarization and shielding.

2. Phase I. Survey of Microwave Sources

a. Microwave Oven Survey

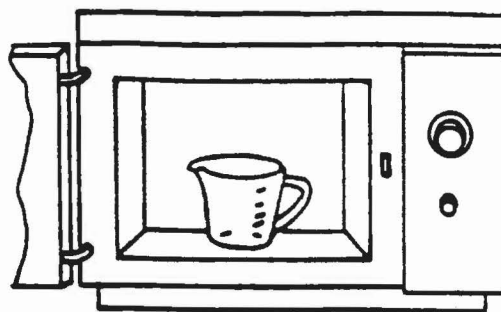
- (1) Set up the microwave oven and detector as shown in Figure 25. Record readings on Figures 25 and 26 as observed.
- (2) Place a 9 oz. measuring cup filled with tap water at room temperature in the oven at the center of the tray or shelf. Should the cup of water in the oven begin to boil during the measurement, stop and replace it with cool water.
- (3) Operate the oven and check the top edge of the door by moving the probe along the crack between the door and trim. If a reading is observed, stop at this point and rotate the meter slightly for maximum reading. Record the reading for future reference. Check each of the four edges of the door. The meter reading will vary with the rotation of the oven stirrer. This is normal, and the peak meter deflection should be noted for reference.
- (4) Move the probe element back and forth across the grill area. Rotate the element 45 degrees and repeat the scan. Where a reading is observed, rotate the meter for maximum reading.
- (5) Check all cracks and openings around the outside of the cabinet for any possible power leak. Also check for power cord leakage.
- (6) The "door burst" or door interlock check is made to insure proper adjustment of the interlock system. With the probe positioned in the right hand, grasp the handle with the fingers of the left hand. Place the left thumb against the timer panel to provide leverage. Slowly pull the door open while observing the meter. Note the level reached before the oven stops generating power. Make this test at arm's length and should the meter level reach 10 mW/cm^2 , immediately close the door and turn the power off before opening the door. Check the door burst level at several points around the edge.
- (7) Suppose that the microwave oven just surveyed was operating in a Boeing cafeteria located at 1420 S. Trenton, Seattle, Washington. The oven was a (*)model, *series. Its operating frequency is set at(*)

Mary Doe operates the oven and has read a few newspaper articles on the dangers of microwave ovens. She knows that you should not put your hand in the oven and that the oven should have safety locks. Many people use the cafeteria and some may have pace makers. The set-up of the cafeteria is shown in Figure 27.

Use the measurements of the microwave oven and Figure 27 to complete the Microwave Survey Form in Figure 28.

* Obtain information from oven just surveyed.

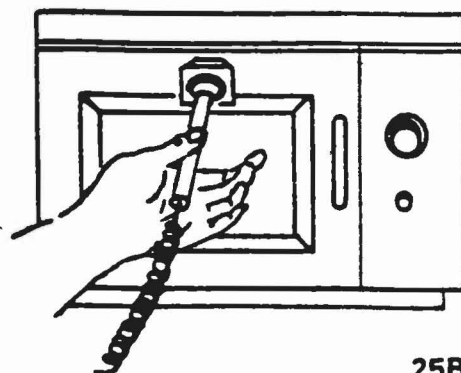
PLACE 9 OZ. CUP OF WATER
IN CENTER OF OVEN SHELF.



25A

HOLD EDGE OF PROBE ALONG OPENING
BEING CHECKED. MOVE BACK AND
FORTH ALONG TOP EDGE OF DOOR.

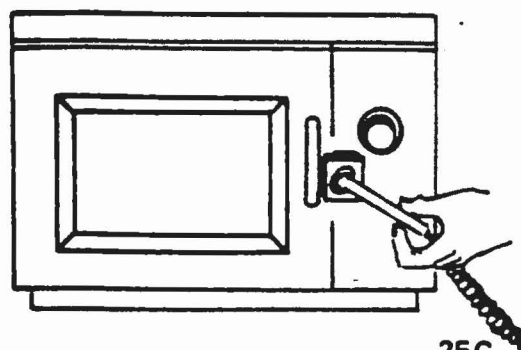
READING (mW/cm^2)					
DISTANCE FROM LEFT EDGE (INCHES)					



25B

CHECK RIGHT EDGE OF DOOR IN THE
SAME MANNER AS THE TOP EDGE.
MOVE METER BACK AND FORTH WITH
PROBE AGAINST DOOR CRACK.

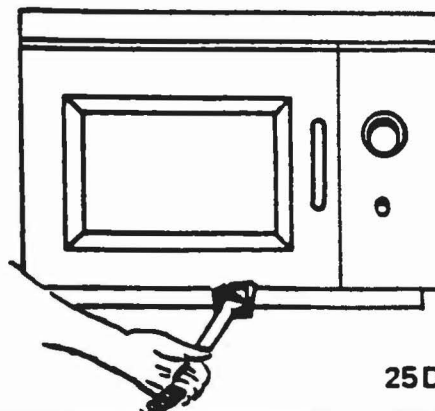
READING (mW/cm^2)					
DISTANCE FROM TOP (INCHES)					



25C

CHECK ALONG BOTTOM EDGE OF DOOR.

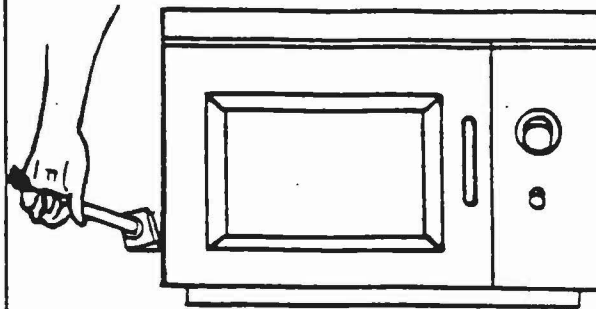
READING (mW/cm^2)					
DISTANCE FROM LEFT EDGE (INCHES)					



25D

CHECK ALONG LEFT EDGE OF DOOR OPENING.

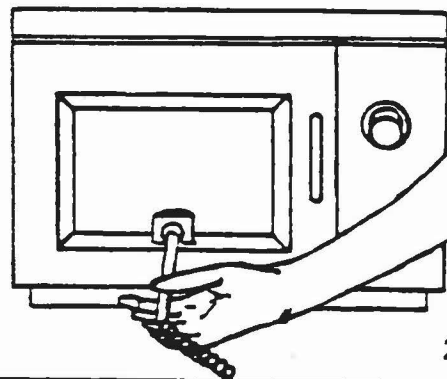
READING (mW/cm ²)					
DISTANCE FROM TOP (INCHES)					



26A

CHECK GRILL AREA IF READING IS FOUND. ROTATE METER FOR MAXIMUM INDICATION.

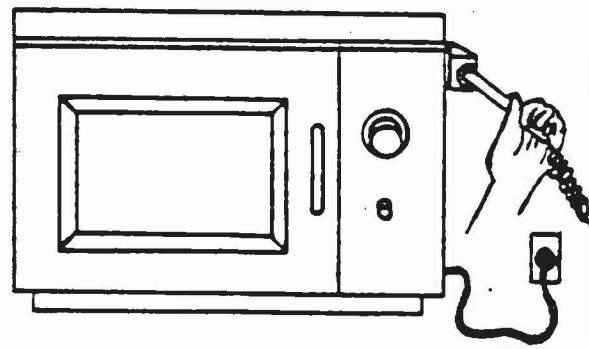
DISTANCE FROM WINDOW TOP					
DISTANCE FROM LEFT EDGE					
MAXIMUM READING (mW/cm ²)					



26B

PROBE ALONG ALL CABINET OPENINGS AND POWER CORD.

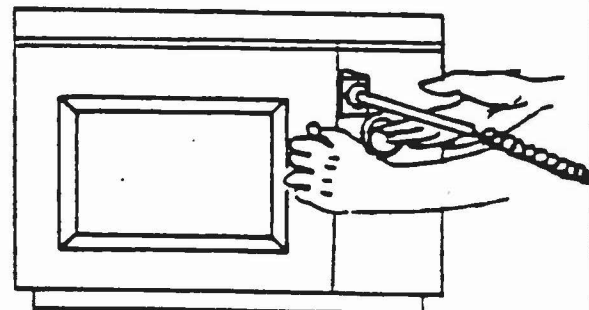
LOCATION					
READING (mW/cm ²)					



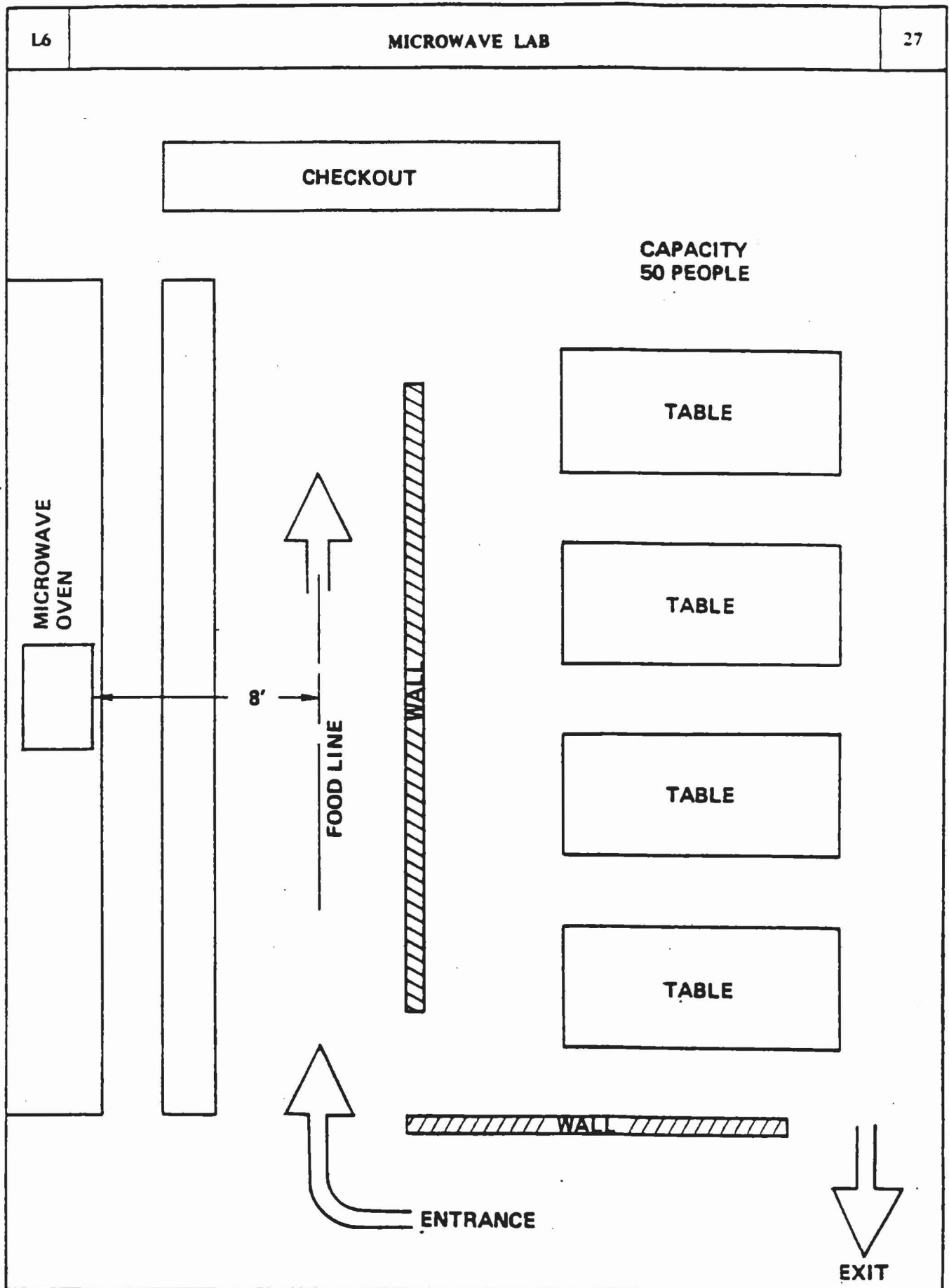
26C

CHECK FOR MAXIMUM POWER LEAKAGE AS DOOR IS PULLED OPEN. USE LEVERAGE OF THUMB AND FINGERS TO SLOWLY OPEN DOOR.

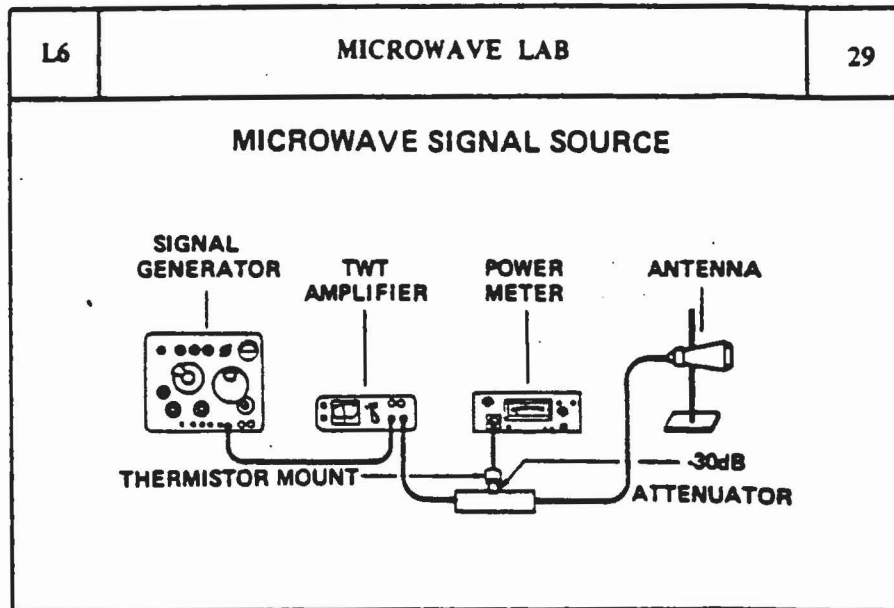
LOCATION					
READING (mW/cm ²)					



26D



GENERAL INFORMATION	USING ORGANIZATION				ADDRESS				
	TYPE OF EQUIPMENT				INTENDED USAGE				
	MANUFACTURE		MODEL	SERIAL NUMBER		OTHER			
HAZARD DETERMINATION	FREQUENCY		FREQUENCY RANGE		PEAK POWER		AVE POWER		OTHER
	ANTENNA GAIN		STAT/SCAN		MONITORING INSTRUMENT		10mW/CM ² CALC. DIST.		
	DISTANCE TO SOURCE		D/R	KEY	POWER DENSITY		MAXIMUM ALLOWABLE EXP TIME (> 10mW/CM ²)		
					dB		mW/CM ²		
ENVIRONMENT									
PERSONNEL	BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER								
PERSONNEL PROTECTION	IN USE	SHIELDING		INTERLOCKS		LIGHT		CONTROLLED AREA	
		SIGNS		FILM BADGE		SIREN			
	RECOMMENDED								
CERT	PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE								



2. Phase I. Survey of Microwave Sources (contd.)

b. Microwave survey of a signal generator

- (1) The equipment for the signal generator survey will be set up by the instructor as shown in Figure 29. (The instructor will adjust the power output at 10 GHz so that at 6" directly in front of the x-band source antenna, the Densimeter will read +2 dB.)
- (2) Before connecting an antenna to the Densimeter, set the selector switch to battery ("BAT") position and press the "ON-OFF-BAT" toggle switch to the "BAT" position. The meter pointer should read at the "Red Dot," otherwise the batteries need replacement.
- (3) Select the proper frequency range to be measured. Set the "Selector Switch" to the x-band, turn the "ON-OFF-BAT" switch to "ON" and balance the meter with the "Balance Control." Proper balance is achieved when the meter pointer is at the extreme left edge of the green "Safe" scale. Proper balancing assures greater accuracy of the readings. To check the zero balance in the field, remove the antenna or completely shield it from RF energy. For optimum accuracy, the zero balance condition must be maintained.

2. Phase I. Survey of Microwave Sources

b. Microwave survey of a Signal Generator (contd.)

- (4) Connect the x-band antenna to the Densimeter. To prevent damaging the sensing head mounted in the end of the case, remove and mount the antenna by turning the coupling nut. Do not use the antenna as a handle for removing it from the meter. Turn the x-band microwave generator on and place the detector about 6 inches from the x-band antenna. When using one of the waveguide horn antennas, the maximum reading will be obtained when the plane of the antenna aperture is normal to the direction of propagation of the RF energy. (When using the loop antennas, the maximum reading will be obtained when the plane of the major loop diameter is normal to the direction of propagation of the RF energy.) Rotation of the unit until the reading is maximized will provide optimum results, and therefore, optimum safety. This procedure aligns the antenna so as to achieve proper polarization alignment.
- (5) Make and record readings at 6" from the source antenna and on both sides of the antenna, as shown in Figure 30. Readings are made to the left and right of the centerline at 3" and 1".
- (6) Repeat step 5 using an 8" and a 10" source to detector distance. Record the readings in the spaces provided in Figure 30.
- (7) The readings on the dB scale of the meter refer to the maximum power density level to which personnel may be safely exposed. This level is 10 milliwatts/square centimeter. Thus, 0 dB at center scale represents a 10 mW/cm² level. Above the 10 mW/cm² level, the red scale indicates danger. Below 10 mW/cm² the green scale indicates safe exposure. Figure 12 provides a table which converts the dB scale readings obtained on the Densimeter to actual power density levels in milliwatts/square centimeter. Note that dB is a quantity that is related to the power density by $N(\text{dB}) = 10 \log_{10} \frac{P_m}{P_s}$.

In Figure 12, P_s was taken as 10 mW/cm² and the values of P_m were substituted into the dB relation to relate dB to P_m for the 1200B Densimeter. Convert the readings to power density.

2. Phase I. Survey of Microwave Sources

b. Microwave survey of a Signal Generator (contd.)

- (8) Suppose that the x-band source antenna just surveyed was a weather radar on an airplane.

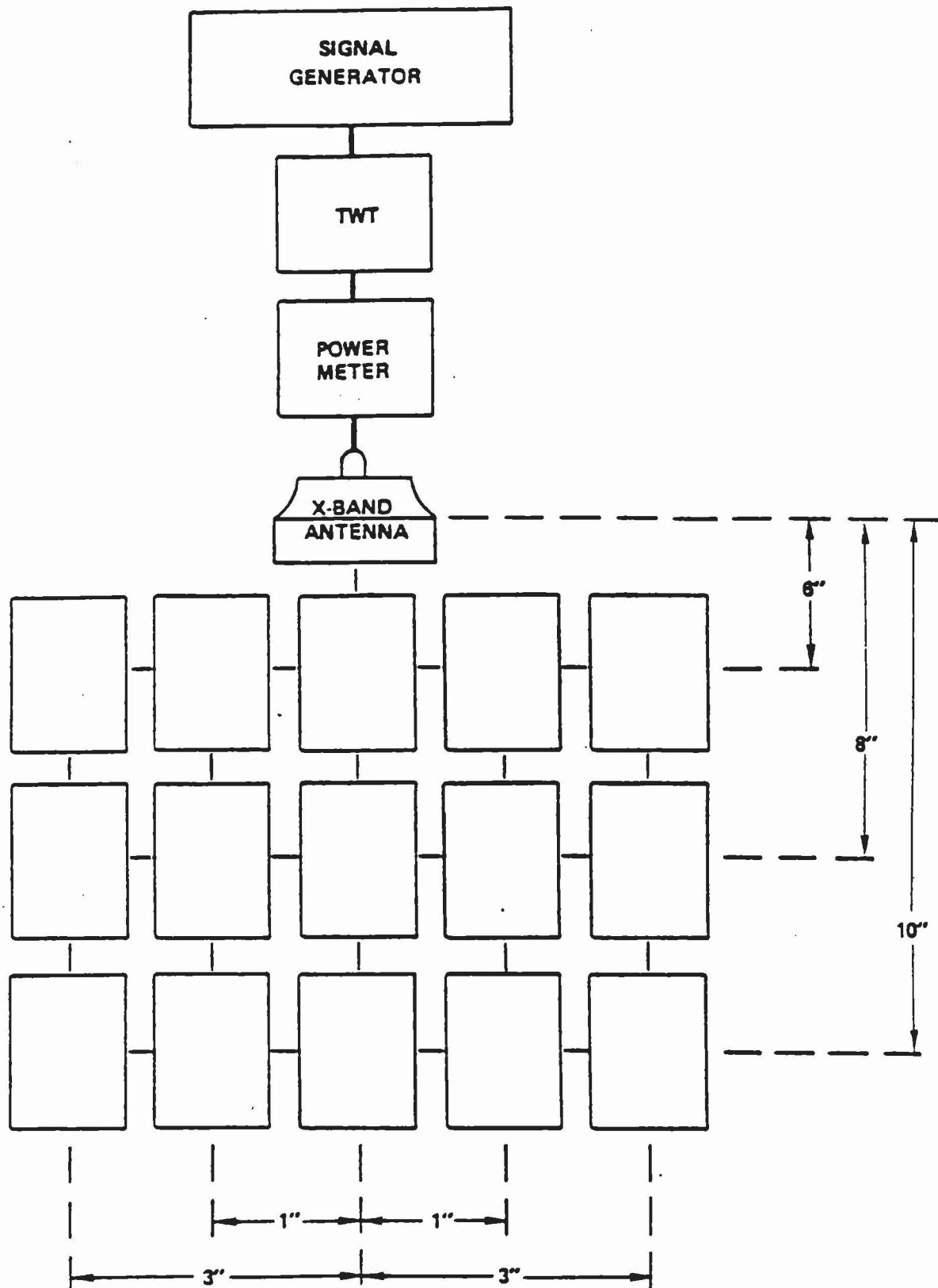
The jet, a Boeing 707, is located at Boeing Field, Seattle, Washington. The weather radar in the nose of the airplane is used to aid in predicting weather changes in the flight path. The microwave radar unit is a BENDIX model RDR-1 E series 1965.

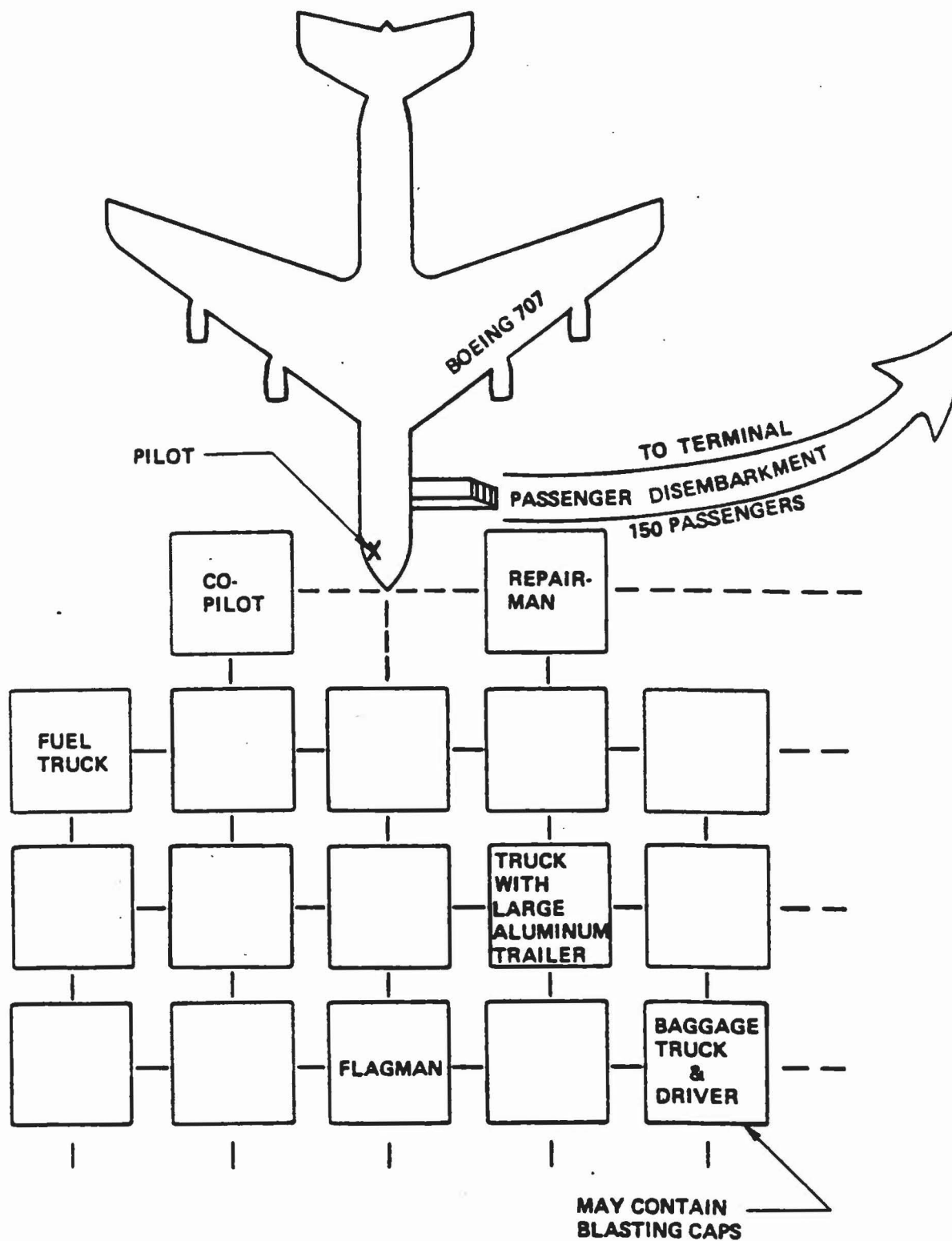
The frequency at which the radar is operating for your survey is $10 \text{ GHz} \pm 30 \text{ MHz}$. Suppose the peak power output of the radar is .8 watts and the antenna gain is + 16.5 dB. The antenna is ordinarily used as a scanning antenna but for your survey the pilot has fixed the antenna in its forward position. (You have observed that your monitoring instruments' response time is too slow to measure the power density when the antenna is scanning.)

The pilot, Bill Tower, has been flying 707's for 10 years, the co-pilot 5 years, and the repairman has 8 years experience with radar equipment. They are all aware that microwave radar can be harmful to humans and in some cases can cause flammable materials to ignite.

The passengers from the airplane are disembarking from the front door as shown. There are no signs indicating that the radar is being tested.

Use your measurements of Figure 30, the situation as shown in Figure 31, and complete the survey record form in Figure 32. Assume the measurements of Figure 30 corresponds to Figure 31 and that 1 inch in Figure 30 represents 10 feet in Figure 31. The 707 represented in Figure 31 corresponds to the x-band antenna in Figure 30. You have the authority to make measurements and recommendations only.





GENERAL INFORMATION	USING ORGANIZATION				ADDRESS				
	TYPE OF EQUIPMENT				INTENDED USAGE				
	MANUFACTURE		MODEL	SERIAL NUMBER		OTHER			
HAZARD DETERMINATION	FREQUENCY		FREQUENCY RANGE		PEAK POWER		AVE POWER		OTHER
	ANTENNA GAIN		STAT/SCAN		MONITORING INSTRUMENT		10mW/CM ² CALC. DIST.		
	DISTANCE TO SOURCE		D/R	KEY	POWER DENSITY		MAXIMUM ALLOWABLE EXP TIME (> 10mW/CM ²)		
					dB	mW/CM ²			
ENVIRONMENT									
PERSONNEL	BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER								
PERSONNEL PROTECTION	IN USE	SHIELDING		INTERLOCKS		LIGHT		CONTROLLED AREA	
		SIGNS		FILM BADGE		SIREN			
CERT	RECOMMENDED								
		PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE							

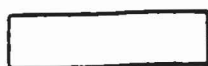
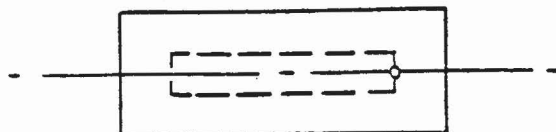
3. Phase II. Properties of Microwaves

a. Polarization

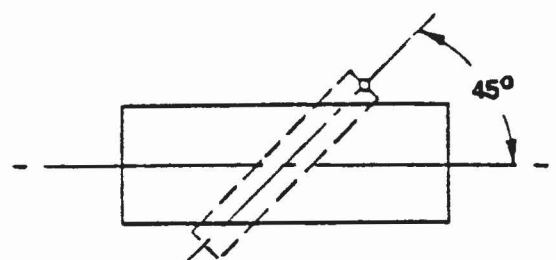
- (1) The equipment will be set up by the instructor as shown in Figure 29. The signal generator will be set at 10 GHz with a power output of .8 watts.
- (2) Check the battery and balance the detector with the x-band antenna connected.
- (3) Position the detector 9" away from the source antenna.
- (4) Rotate the detector antenna so that it is oriented in the different positions with respect to the source antenna as shown in Figure 33. Record the data in the spaces provided.

b. Shielding

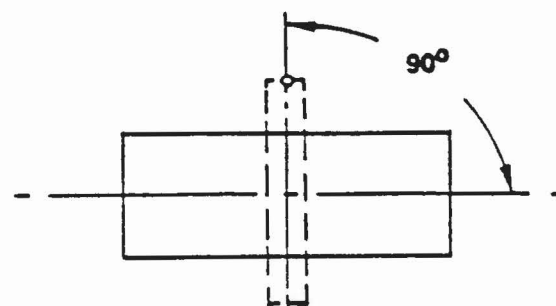
- (1) The equipment will be set up by the instructor as shown in Figure 29. (The signal generator will be set at 10 GHz with a power output of .8 watts.)
- (2) Check the Densimeter battery and balance the instrument with the x-band antenna in place.
- (3) Position the x-band detector antenna at 9" from the source antenna and align it for a maximum reading. Record the reading on Figure 34.
- (4) Interpose a sheet of $\frac{1}{4}$ inch thick AN-72 eccosorb between the source and detector. Record the reading on Figure 34.
- (5) Repeat step 4 using $\frac{3}{4}$ inch thick AN-74 eccosorb.
- (6) Repeat step 4 using copper screen having 169 squares/sq. inch.
- (7) Repeat step 4 using copper screen having 10 squares/sq. inch.
- (8) Repeat step 4 using copper screen having 169 squares/sq. inch with several damaged areas.

SOURCE
ANTENNADETECTOR
ANTENNA

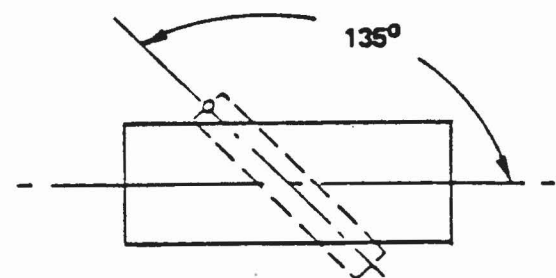
dB



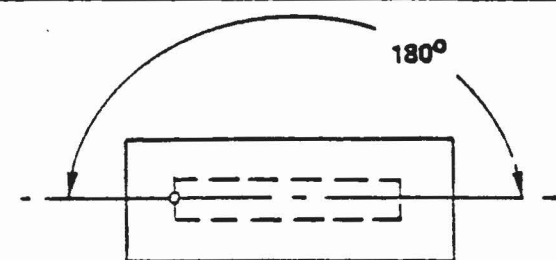
dB



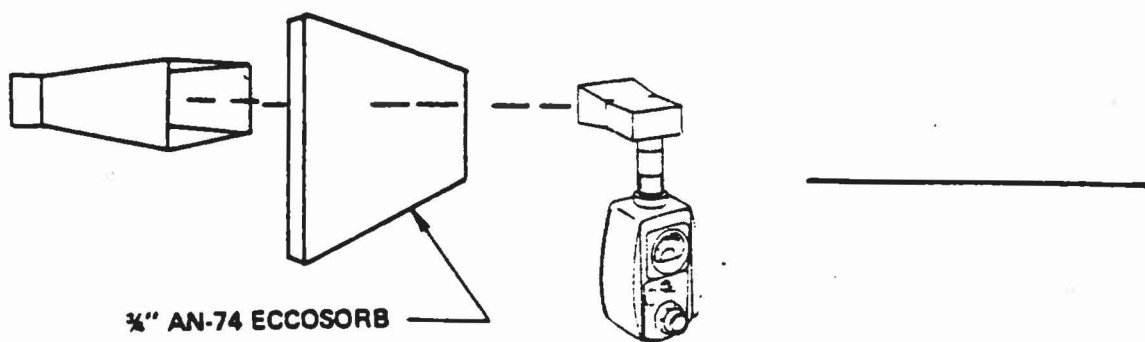
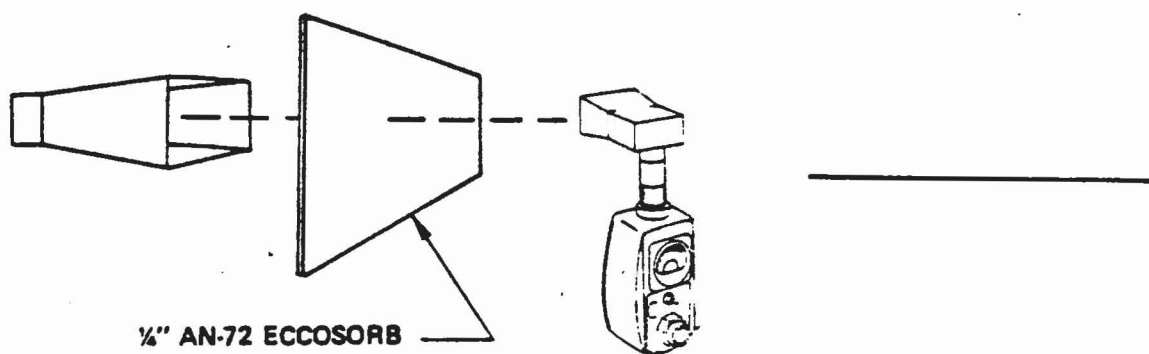
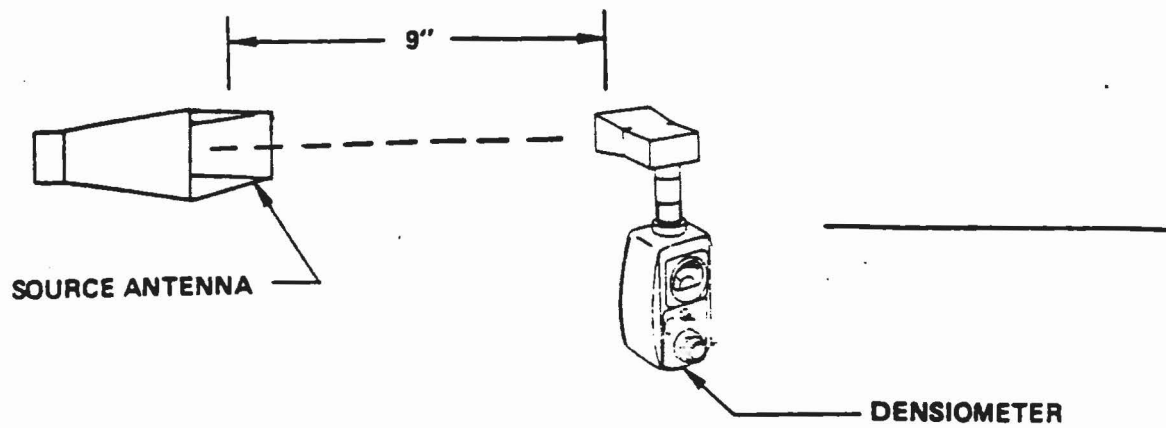
dB

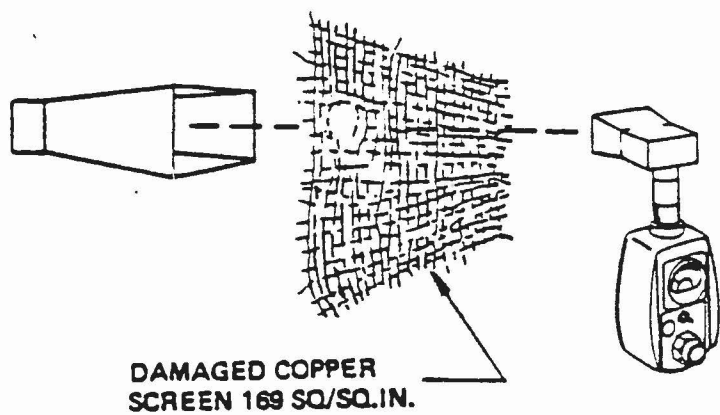
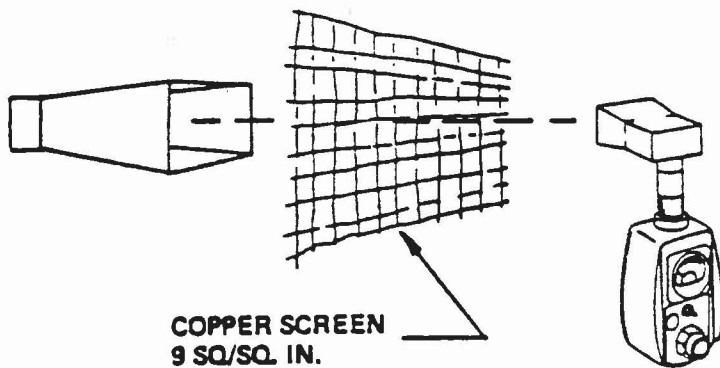
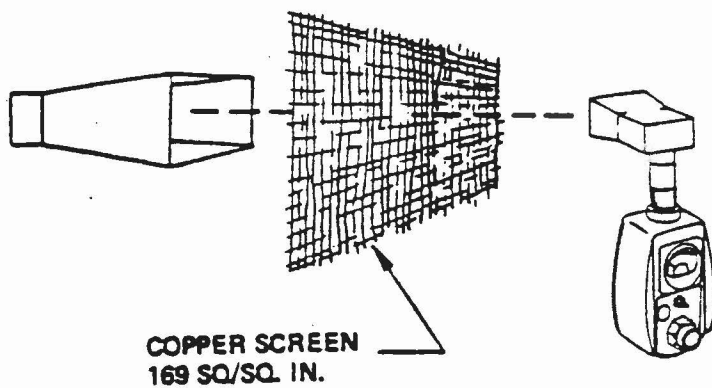


dB



dB





LABORATORY NO. 7
ULTRAVIOLET RADIATION

COURSE OUTLINE

VII. ULTRAVIOLET MONITORING

A. INTRODUCTION

1. Objectives
2. Overview
3. Equipment
4. Precautions

B. INSTRUCTOR'S DEMONSTRATION - LECTURE

1. Introduction
 - a. The Ultraviolet Region of the Electromagnetic Spectrum
 - b. Sources of Ultraviolet
2. Detection of Ultraviolet Radiation
3. Laboratory Equipment
 - a. The International Light IL600 Photometer
 - b. Using the International Light IL600 Photometer to Measure Actinic UV
4. Survey Technique
 - a. Introduction
 - b. General Information
 - c. Hazard Determination
 - d. Environment
 - e. Personnel
 - f. Personnel Protection
 - g. Certification
 - h. Comment

C. STUDENTS' LABORATORY EXERCISE

1. Introduction
2. Phase I. Survey of a Sunlamp
 - a. Measuring the Actinic UV
 - b. The Survey Record
3. Phase II. Properties of Ultraviolet Light
 - a. Transmission
 - b. Reflection

L7	ULTRAVIOLET MONITORING LAB	1
OBJECTIVES 1. REVIEW THE ULTRAVIOLET REGION, ITS SOURCES AND DETECTION 2. TO BE ABLE TO CONDUCT AN ULTRAVIOLET SURVEY 3. TO OBSERVE ULTRAVIOLET REFLECTION AND TRANSMISSION.		

VII. ULTRAVIOLET MONITORING

A. INTRODUCTION

1. Objectives

In this laboratory session students will:

- a. Review the ultraviolet region, its sources and detection.
- b. Make an ultraviolet survey using a photometer.
- c. Observe reflection and transmission properties of ultraviolet radiation.

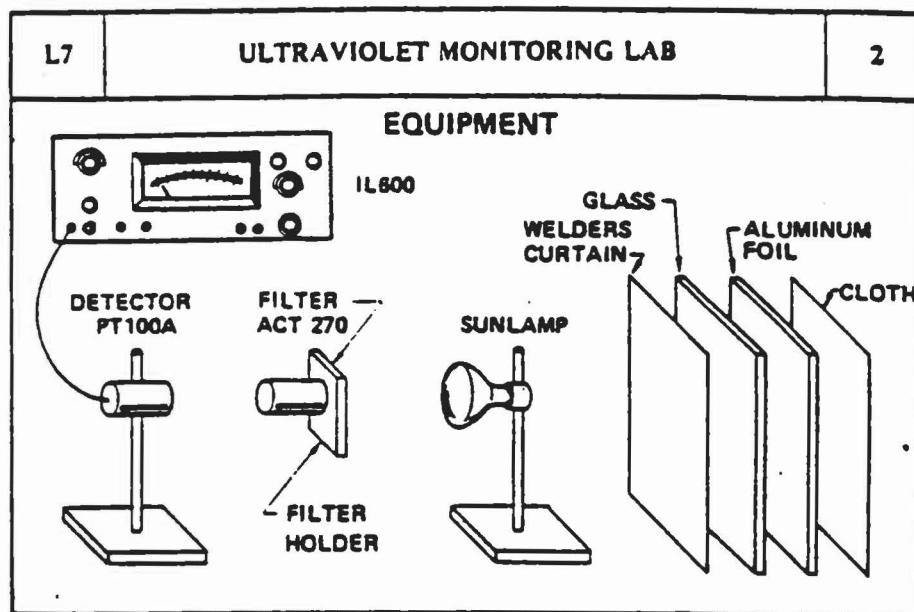
2. Overview

The lab starts with a brief review lecture concerning the ultraviolet region and its subdivisions. Sources and detection of ultraviolet radiation are outlined.

The instructor will then demonstrate the controls, connectors and use of an International Light IL600 Photometer.

The students, during their laboratory exercise, will use the photometer to measure the UV content of an ultraviolet source. They will then complete a survey form for this source. They will also observe properties of ultraviolet reflection and transmission of various materials.

Finally, the laboratory report will be submitted to the instructor when completed.



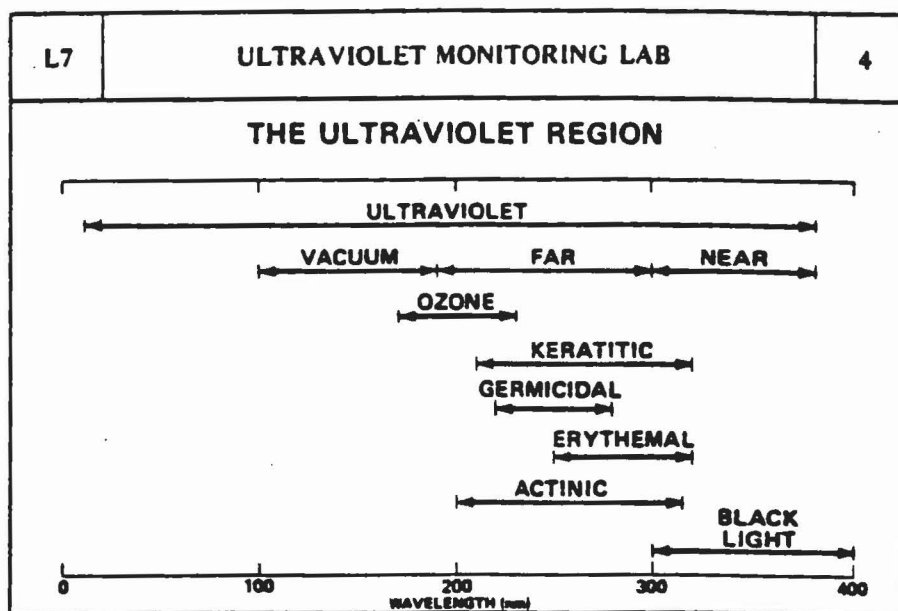
A. INTRODUCTION

3. Equipment List

- a. International Light IL600 Photometer with actinic PT100D probe.
- b. ACT270 band pass filter with sharp lower cut-off at 315 nm.
- c. Translucent welders curtain.
- d. Aluminum foil taped to cardboard.
- e. Glass 1/4" x 12" x 12".
- f. Sunlamp.
- g. White clothing material taped to cardboard.
- h. Protractor.
- i. Protective eyewear.
- j. UV hazard signs.
- k. Lab stands.

L7	ULTRAVIOLET MONITORING LAB	3
PRECAUTIONS 1. DO NOT LOOK DIRECTLY INTO THE SUNLAMP 2. DO NOT SPEND UNNECESSARY TIME NEAR THE SUNLAMP 3. LEAVE LAMP ON UNTIL EXPERIMENT IS COMPLETE 4. WEAR PROTECTIVE EYEWEAR WHEN CHANGING DETECTOR POSITIONS		

The above precautions will be observed during the instructor's demonstration - lecture and students' laboratory exercise.



B. INSTRUCTOR'S DEMONSTRATION-LECTURE

1. Introduction

a. The Ultraviolet Region of the Electromagnetic Spectrum

As shown in Figure 4, the ultraviolet region runs from 10 nanometers ($\text{nm} = 10^{-9} \text{ m}$) to 400 nanometers. This region has further been divided by physicists into the vacuum region (100 nm - 200 nm), far UV region (200 nm - 280 nm), and near UV region (315 nm - 400 nm). Other names have been associated with certain regions of the ultraviolet region according to photochemical and biological effects of the radiation. For example, the ozone production region (170 - 230 nm) is so named due to the production of ozone when this radiation passes through molecular oxygen. The keratitic (210 nm - 320 nm) region is the region where inflammation of the cornea is greatest. The Germicidal (220 nm - 280 nm) is associated with the greatest effect on bacteria. The erythema (250 nm - 320 nm) region is so designated due to the pronounced skin reddening and blistering which can occur in this region. In general, the wavelength most affecting man in an adverse way are covered by the actinic region (200 nm - 315 nm). The blacklight region (300 nm - 400 nm) is associated with the fluorescence caused in some materials by these wavelengths.

L7	ULTRAVIOLET MONITORING LAB	5
UV SOURCES 1. SUN 2. LOW INTENSITY - LOW PRESSURE MERCURY VAPOR - SUNLAMPS - BLACK-LIGHT LAMPS 3. HIGH INTENSITY - HIGH PRESSURE MERCURY VAPOR - HIGH PRESSURE XENON ARCS - XENON-MERCURY ARCS - CARBON ARCS - PLASMA TORCHES - WELDING ARCS - LASERS		

1. Introduction (contd.)

b. Sources of Ultraviolet

Sources of ultraviolet light can be divided into two groups, those occurring naturally and those that are man made. The naturally occurring source of UV is the sun. Most of the UV below 300 nm is effectively filtered out by the atmosphere. Man made sources can be divided into two groups, low intensity and high intensity. Low intensity sources are: low-pressure mercury vapor lamps, sunlamps and black-light lamps. High intensity sources are: high-pressure mercury vapor lamps, high-pressure xenon arcs, xenon-mercury arcs, carbon arcs, plasma torches, welding arcs and lasers.

L7	ULTRAVIOLET MONITORING LAB	6
UV DETECTION 1. PHOTON PHOTOELECTRIC PHOTOTUBE PHOTOMULTIPLIER PHOTOVOLTAIC SELENIUM PHOTO CELLS SILICON SOLAR CELLS 2. THERMAL THERMOPILE		

2. Detection of Ultraviolet Radiation

There are two major classes of instruments that have been used to measure ultraviolet radiation. These classes, photon and thermal, refer to the way in which the radiation interacts with the detector.

The photon devices in general use for ultraviolet measurements can be divided into two categories; photoelectric and photovoltaic.

The photoelectric devices used are the phototube and photomultiplier. Both of these instruments depend on the ejection of an electron when a light photon is absorbed in a metal. The photomultiplier is used where an extremely low level of UV energy is present.

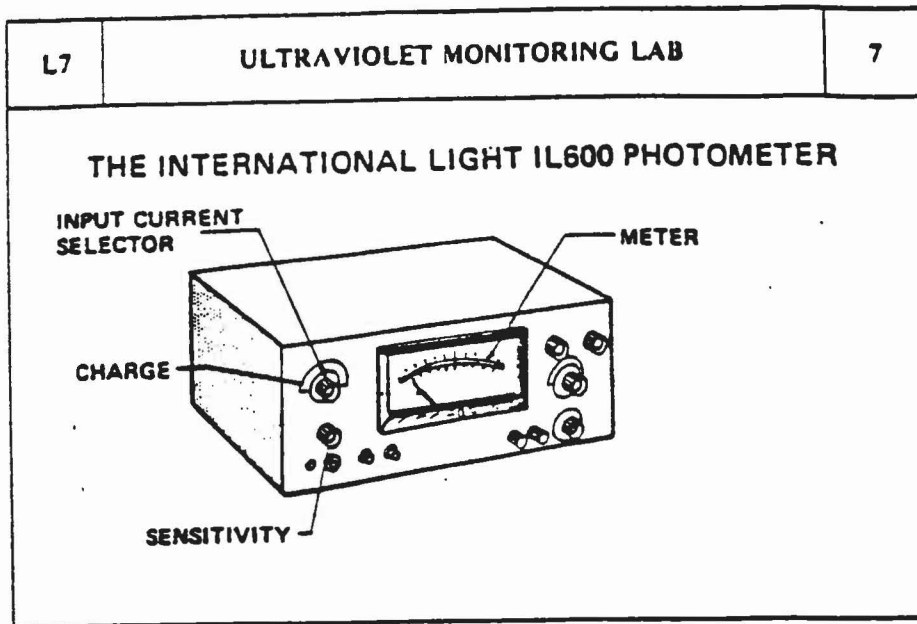
The photovoltaic devices used are selenium photocells and silicon solar cells. Both of these detectors depend on the liberation of an electron from an atom at the P-N boundary of the semiconductor.

A thermal device used for the detection of ultraviolet radiation is the thermopile. A thermopile is made by connecting several thermocouples in series. The total thermally produced voltage across the output terminals is the sum of the individual thermocouple voltages. As the thermocouple receiving element absorbs incident radiation, the temperature of each junction is increased and the thermopile voltage increases accordingly.

By the use of filters, the detector can be used to monitor different specific wavelengths. Filters with peak spectral response corresponding to that of the emitted radiation should be used.

The use of filters can be eliminated if the sensing element is coupled with a monochromator allowing the sensing element to look at single wavelength. Monochromators are made using diffraction gratings and prisms. If the response of the sensing element is known for the particular wavelengths being monitored, then the irradiance of the source may be calculated by summing the irradiance of the individual wavelengths components.

(The effective irradiance is calculated by multiplying the individual irradiance of single wavelengths by the relative spectral effectiveness and then summing over the wavelength band of interest.)



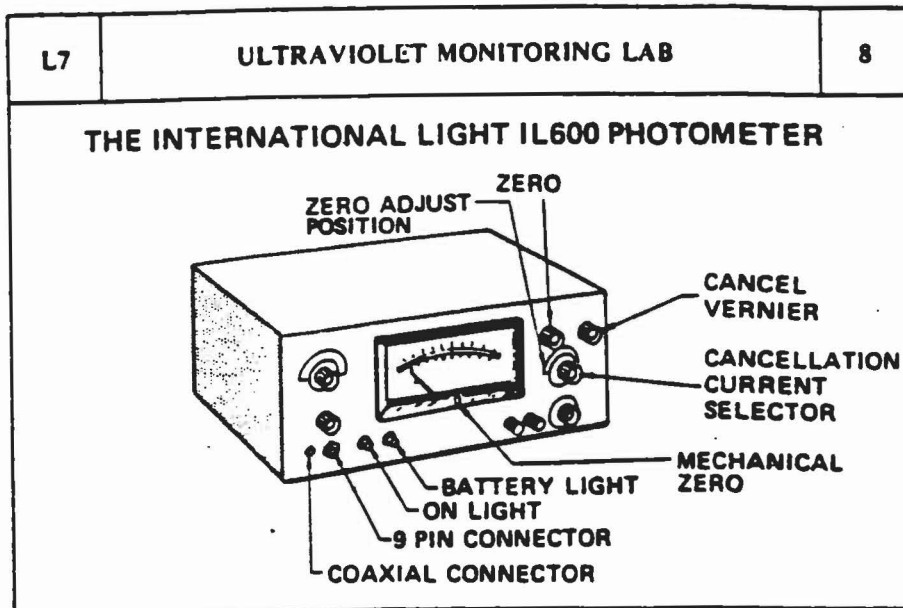
3. Laboratory Equipment

a. The International Light IL600 Photometer

The IL600 Photometer shown in Figure 7 is a sensitive indicating and control unit designed to provide power and commands to many different accessories, and to measure and record minute return signals. A variety of accessories are available providing a range in sensitivity, spectral response and speed of response. A monochromator as well as band pass filters can be used with the instrument to permit measurement of different portions of the spectrum. The IL600 Photometer provides control functions to establish the proper sensitivity, compensation, and power for measurement of current from the detector heads or accessories.

The unit is turned on by rotating the input current selector to any of the ranges. If the unit is plugged into the line, one may choose to recharge the battery by placing the selector on "Charge". Different sensitivities can be selected by snapping the sensitivity knob out of the calibrated position to any scale expansion from 1 to 3 times the selected range.

The meter reads in microamperes which are directly proportional to the light intensity. The selected range designates the current for a full scale deflection. Two scales 0-100 with 100 divisions and 0-30 with 60 divisions have a mirror backing to minimize the human error (parallax) of reading the dial.



3. Laboratory Equipment (contd.)

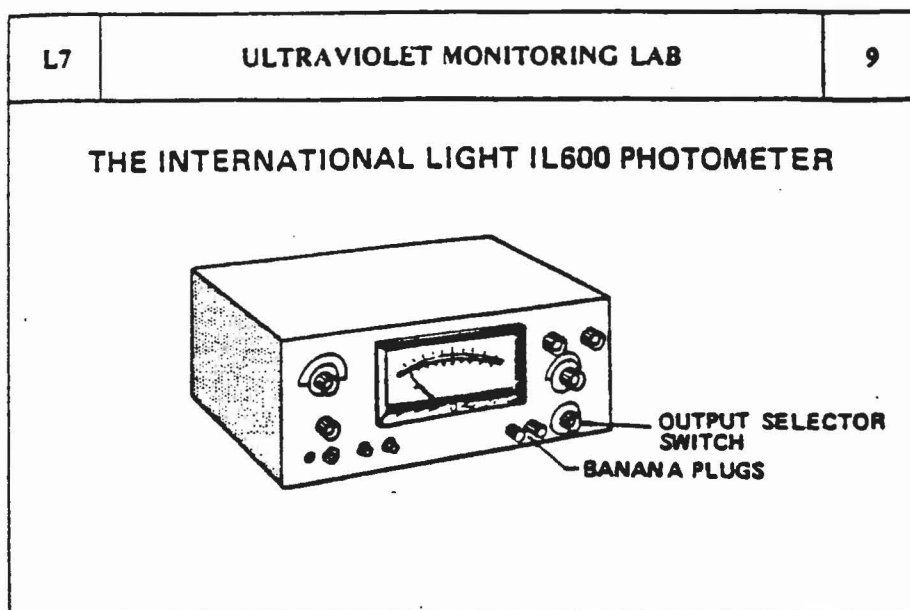
a. The International Light IL600 Photometer (contd.)

The cancellation current and cancel vernier provide compensation to allow operation in a lighted room without creating an error due to this unwanted source of light. A subtraction of the unwanted light can be made by selecting the necessary cancel current which establishes a zero reading on the meter. Then the additional light being measured will be directly indicated on the meter without the need for mathematical subtraction. The cancellation current selector provides a coarse current control which is finely adjusted using the cancel vernier.

A mechanical zero adjust can be made by covering the detector head and adjusting the screw (at the face of the meter) for a zero reading on the meter. A special feature is provided to allow a zero adjust even though light is falling on the detector. By selecting the zero adjust position on the Cancel Current rotary switch, the input is disconnected, and an accurate electrical zero can be performed using the zero control.

Two connectors, located on the front panel provide all connections for the input accessories. One is a 9 pin connector, the other a coaxial type connector. The coaxial type connector to the left of the 9 pin connector permits external control of the instrument's input operational amplifier. The sensing probe is connected using the 9 pin connector.

The "ON" light indicates that the circuits are operating. The red light on the front panel marked "Battery" indicates four states of operation. (1) If the light is on steady and bright, the unit is operating from the a.c. power, the battery is being charged and all regulated voltages are correct. (2) if the red light is steady and dim, the battery is supplying operating power to the unit and all regulated voltages are correct. (3) If the indication is dim and blinking, the unit is operating from battery power, but the battery charge is too low for satisfactory operation and must be charged or else a.c. power must be applied to continue the measurements. (4) If the indication is bright and blinking, the unit is operating from a.c. power, but the supply voltages are not correct.



3. Laboratory Equipment

a. The International Light IL600 Photometer (contd.)

The red and black banana plugs (spaced 3/4 inch apart for a standard plug) provide an output for accessories such as an oscillograph (chart recorder), oscilloscope, or remote readout. The five position output selector switch provides three magnitudes of full scale output voltage (10 mv, 100 mv, and 1 volt) and a "short" for establishing an accurate electrical zero in the accessory. Also there is an "open" position so that the IL600 can be disconnected without unplugging the cable. The "open" permits sharing of an accessory such as a recorder with many IL600 outputs or other instruments.

The power is provided by the self-contained nickle cadmium battery or from 115-v.a.c. 60 cycle. The selection is made automatically, depending upon whether the line cord is plugged in or not. On battery power the unit is capable of running about eight hours before it is necessary to recharge.

Maintenance other than external cleaning is not advised since there are ten precise adjustments which must be performed with the aid of calibrated current and voltage measuring equipment. If a malfunction occurs that can be traced to one of the two plug-in printed circuit boards, the power supply board (rear location), or the amplifier board (front location), then it is possible to return just the board for repair. In all other cases it is advisable to send the entire instrument so that calibration can be recertified for the entire unit.

If external cleaning becomes necessary, care should be exercised to prevent water, cleaning fluids, and foreign substances from leaking through the cabinet assembly to integral components. All filters, diffuser discs, lenses, and other input optics should be cleaned with lens cleaner and/or lens paper. First, surface mirrors should be cleaned with a fine camel's hair brush only. They should never be wiped.

L7	ULTRAVIOLET MONITORING LAB	10
USING THE INTERNATIONAL LIGHT IL600 PHOTOMETER TO MEASURE ACTINIC UV 1. CONNECT IL600 TO PT100D DETECTOR 2. CHECK MECHANICAL ZERO 3. CONNECT POWER – TURN INPUT CURRENT SELECTOR TO 100 μA – ALLOW 10 SEC WARM-UP – TURN SENSITIVITY CONTROL COUNTERCLOCKWISE 4. PUT "CANCEL CURRENT SWITCH" TO ZERO ADJUST POSITION—ADJUST THE ZERO VERNIER TO ZERO THE METER NEEDLE		

3. Laboratory Equipment (contd.)

b. Using the International Light IL600 Photometer to Measure Actinic UV

The IL600 Photometer uses simplified and convenient techniques for measuring current from accessories which measure steady light sources, a.c. sources, and pulsed sources. The following explains the operating procedure and set-up instructions to best realize the measurement capability of the instrument.

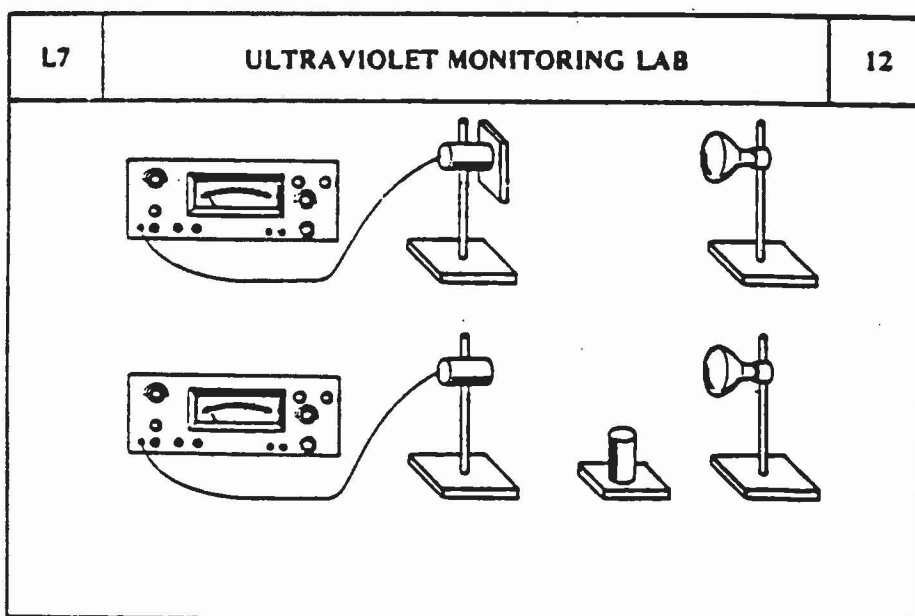
- (1) Connect the IL600 to the PT100D detector head by inserting the plug into the 9 pin connector. Always check to be sure that the detector filter combination has the correct spectral response for your application.
- (2) Check the mechanical zero of the microammeter. Adjust the meter to zero by turning the screw located over the pivot of the meter. Mechanical zero adjustment is usually unnecessary.
- (3) Connect the power cable to the three prong plug on the back panel, and connect the other end to external 115 v.a.c., 50-60 Hz power if battery operation is not desired. Turn the input current range selector clockwise to the 100 microampere scale. Allow a ten second warm-up to stabilize all circuits. Make sure the sensitivity control is in its full counter-clockwise position.
- (4) Turn the Cancel Current rotary switch counter-clockwise to the zero adjust position. This disconnects the input so that a true electrical zero may be made even though light is falling on the detector head. Adjust the zero vernier to zero the meter needle.

L7	ULTRAVIOLET MONITORING LAB	11
USING THE INTERNATIONAL LIGHT IL600 PHOTOMETER TO MEASURE ACTINIC UV 5. (a) TURN CANCEL CURRENT SWITCH TO OPEN - PLACE ACT 270 FILTER OVER PT100D. (b) TURN ON LIGHT TO BE MEASURED. (c) ROTATE INPUT CURRENT SELECTOR TO OBTAIN MIDSCALE READING. (d) USE CANCEL CURRENT SWITCH AND CANCEL VERNIER TO ZERO METER. (e) REMOVE ACT 270 FILTER FROM PT100D. (f) READ ACTINIC UV μA ON METER.		

3. Laboratory Equipment

b. Using the International Light IL600 Photometer to Measure Actinic UV (contd.)

- (5) Turn the Cancel Current switch to the "open" position. Place the ACT 270 filter over the detector. Turn on the light to be measured and rotate the input current selector until an adequate reading is obtained. This current reading is due to nonactinic light only, since the filter passes wavelengths greater than 315 nm. These wavelengths are not to be measured and are compensated for by selecting the proper range of Cancel Current and cancel vernier to zero the meter. Take the ACT 270 filter off and read the number of actinic micro-amperes directly on the meter. Be sure to read the appropriate scale for the range selected.



L7	ULTRAVIOLET MONITORING LAB	13
IRRADIANCE AND EXPOSURE TIME CALCULATION OF STEP b.6 6. $.5 \mu A \times 90.6 \text{ (C.F.)} = 45.3 \mu W/cm^2$ $\frac{3 \times 10^{-3} \text{ Joules/cm}^2}{45.3 \mu W/cm^2} = 66 \text{ sec.}$		

3. Laboratory Equipment

b. Using the International Light IL600 Photometer to Measure Actinic UV

- (6) To convert the microampere reading to an actinic irradiance value, multiply the current by the calibration factor obtained from the manufacturer. For example, if a current reading of $.5 \mu A$ is multiplied by the calibration factor 90.6* the resulting actinic irradiance is $45.3 \mu W/cm^2$.

To obtain the time a worker could be exposed to this radiation, divide $3 \times 10^{-3} \text{ Joules/cm}^2$ by the irradiance obtained above

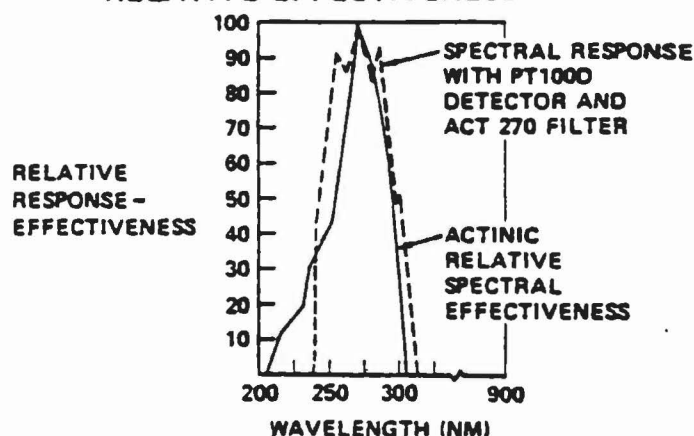
$$\frac{3 \times 10^{-3} \text{ Joules/cm}^2}{45.3 \mu W/cm^2} = 66 \text{ sec.}$$

This exposure time is in accord with the recommended NIOSH standard. This exposure time could also be obtained by referring to exposure time versus (actinic effective) irradiance plot of Figure 18.

Note: Watt = $\frac{\text{Joule}}{\text{Sec}}$

*C.F. units are $\frac{\mu W}{cm^2 \mu A}$

COMPARISON OF INSTRUMENT RESPONSE AND RELATIVE EFFECTIVENESS



3. Laboratory Equipment (contd.)

The NIOSH Standard, on which the exposure time was based, assumed that an irradiance was measured at several wavelength intervals in the actinic region. These irradiance levels were then multiplied by the relative actinic effectiveness and finally the irradiance levels were summed over all wavelength intervals. Obviously not all of these operations was performed in obtaining the exposure time just calculated. The instrument and detector filter arrangement approximated many of the mathematical operations. For example, as shown in Figure 14, the relative response of the detector-filter combination closely approximates the actinic relative effectiveness. In most cases 240 nm, the system "measures" slightly more actinic UV than is actually present. Below 240 nm the system is non-responsive. If a source was emitting strongly in this region, this detector-filter system would give an erroneously low reading. The system approximates the relative effectiveness weighting and summation operations. The filter in/filter out technique makes it appear that more actinic UV is present than is the case. When the filter is in place not all of the non-actinic light is passed due to surface reflection. Therefore, the Cancel Current established is too low. When the filter is removed, not all of the contribution due to non-actinic light is subtracted.

Other errors can be introduced due to the detector being too close to the source. The light being measured should be as nearly collimated as possible so that acceptance angle errors are not introduced. To approximate this condition, the detector should be at "minimum inverse-square distance" or greater which is a distance ten times that of the largest source dimension. Also reflections and absorption in air can cause erroneous readings.

In summary it should be noted that when making a measurement, consideration must be given to the instrument being used and the situation in which the measurement was observed. For the case just analyzed, the detector measures more actinic UV than is present for cases above 240 nm. For purposes of health protection, the detector-filter system will approximate the actinic UV plus a small safety factor.

L7	ULTRAVIOLET MONITORING LAB	15
SURVEY FORM GENERAL INFORMATION HAZARD ENVIRONMENT PERSONNEL PROTECTION CERTIFICATION		

4. Survey Technique

a. Introduction

In making an ultraviolet survey, several factors must be taken into consideration. The ultraviolet source must be classified regarding its potential for personnel injury, the operating environment must be evaluated, and the personnel and personnel protection measures considered.

The survey record form provides a means of systematically evaluating and recording the different aspects of an ultraviolet survey. The form has spaces provided for general information, ultraviolet hazard determination, environment, personnel, personnel protection and certification.

L7	ULTRAVIOLET MONITORING LAB										16
ULTRAVIOLET RADIATION SURVEY											
GENERAL INFORMATION	USING ORGANIZATION					ADDRESS					
	TYPE OF EQUIPMENT					INTENDED USAGE					
	MANUFACTURE			MODEL		SERIAL NUMBER			OTHER		
	WELDER ONLY	GAS	CURRENT	VOLTAGE	FILLER	MATERIAL	DUTY CYCLE				
	MONITORING INSTRUMENT			PROBE			FILTER				
	ATTACHMENT					WAVELENGTH OR WAVELENGTH RANGE					
	DISTANCE TO SOURCE (FEET)			D/R	KEY	INSTRUMENT READINGS (mW)	IRRADIANCE (mW/cm ²)		EXPOSURE/DAY (2 x 10 ⁻³ J/cm ²)		

4. Survey Technique (contd.)

b. General Information

Different types of general information are recorded on the survey record in the block entitled "General Information." The following information is required.

USING ORGANIZATION—In this space the company or division of a company should be recorded. **ADDRESS**—The address of the company or the building and room number. Enough information should be supplied so that someone unfamiliar with the location could find the source. **TYPE OF EQUIPMENT**—This refers to whether the source is a welder, solar simulator, germicidal lamp, xenon lamp, etc. **INTENDED USE**—This is the purpose for which the source is used. Examples of intended usage are research, construction, material testing, etc. **MANUFACTURE-MODEL-SERIAL NUMBER**—This information identifies the UV source manufacturer, the model number and the serial number. **OTHER** - This space is provided for recording general information not covered above and which may only apply to a particular case.

L7	ULTRAVIOLET MONITORING LAB										17	
ULTRAVIOLET RADIATION SURVEY												
GENERAL INFORMATION	USING ORGANIZATION						ADDRESS					
	TYPE OF EQUIPMENT						INTENDED USAGE					
	MANUFACTURE				MODEL		SERIAL NUMBER			OTHER		
	WELDER ONLY		GAS		CURRENT		VOLTAGE		FILLER		MATERIAL	
											DUTY CYCLE	
	MONITORING INSTRUMENT				PROBE				FILTER			
	ATTACHMENT						WAVELENGTH OR WAVELENGTH RANGE					
	DISTANCE TO SOURCE (FEET)				D/R		KEY		INSTRUMENT READING (uA)		IRRADIANCE (uA) = (CF) x (uA/cm ²)	
										EXPOSURE/DAY (3 x 10 ⁻³ J/cm ²)		
										IRRADIANCE		

4. Survey Techniques

c. Hazard Determination (contd.)

WELDER ONLY - This line of information pertains to the operating parameters of a welder. The survey and measurements made would apply to these particular welding operating conditions only. The GAS used or the CURRENT and VOLTAGE (if an electric welder is used) is recorded in the spaces provided. The welding rod material is written in the FILLER space. The MATERIAL on which the welding is being performed is also recorded. The DUTY CYCLE is the amount of time in an eight hour shift that the welder is being operated. Of course, the survey may not be of a welder and in this case the blanks are marked N.A. (not applicable).

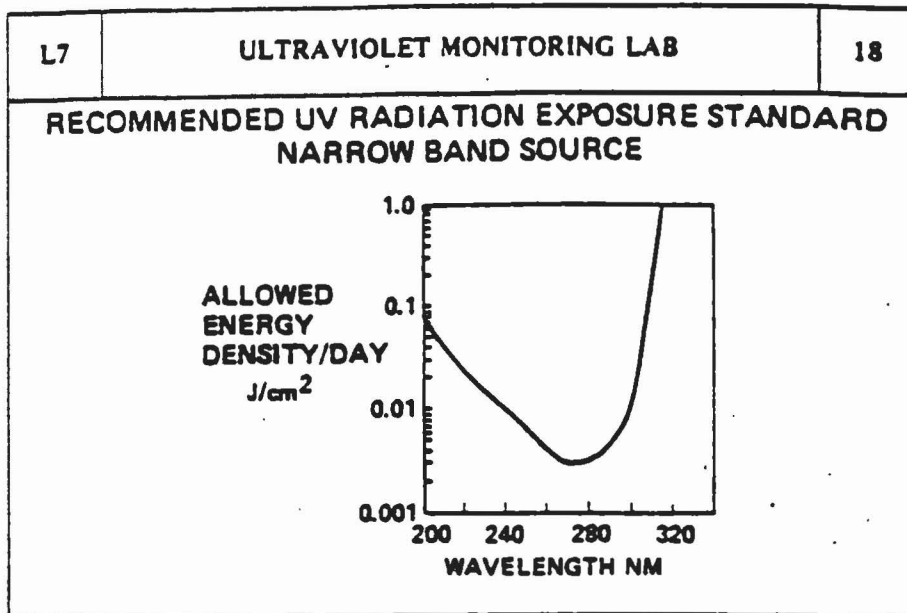
In any case, information pertaining to the instrument used in measuring the UV source is recorded. The MONITORING INSTRUMENT is the name of the device used to make the survey, for example International Light IL600 Photometer. The PROBE is the detector which is used in conjunction with the monitoring instrument (e.g. PT100D). The type or number of the filter used (if any) is recorded in the FILTER space (e.g. ACT270).

ATTACHMENTS can be attenuators, screens, beam splitters or any additional accessories used in the measuring set-up. The WAVELENGTH RANGE is the wavelength for which the composite system is sensitive. This assessment involves considering the detector response and band pass features of any filter or attachment used.

The next body of information pertains to the actual measurements and calculations which are made. The DISTANCE TO SOURCE is the distance to the UV source from the point of measurement. The column labeled D/R indicates whether the reading was made looking directly (D) at the source or looking at a reflection (R). The KEY relates measurements to a drawing of the UV source area. For example, an A in the key column means that this measurement was taken in the area marked by A on the drawing in the environment block.

(The remainder of this part of the hazard determination is in a form which applies to the IL600 with PT100D and ACT270 filter. For other detectors, a different scheme would need to be incorporated. The end result is the same for any scheme used, that is, it must result in irradiance values and maximum allowable exposure per day.)

The INSTRUMENT READING in μA from the IL600 is recorded after having compensated for ambient light. THE IRRADIANCE is calculated by multiplying the microamp reading by calibration factor (C.F.) supplied by the instrument manufacturer. The ALLOWED EXPOSURE/DAY is determined by dividing 3×10^{-3} Joules/cm² by the irradiance. The resulting answer is given in seconds.

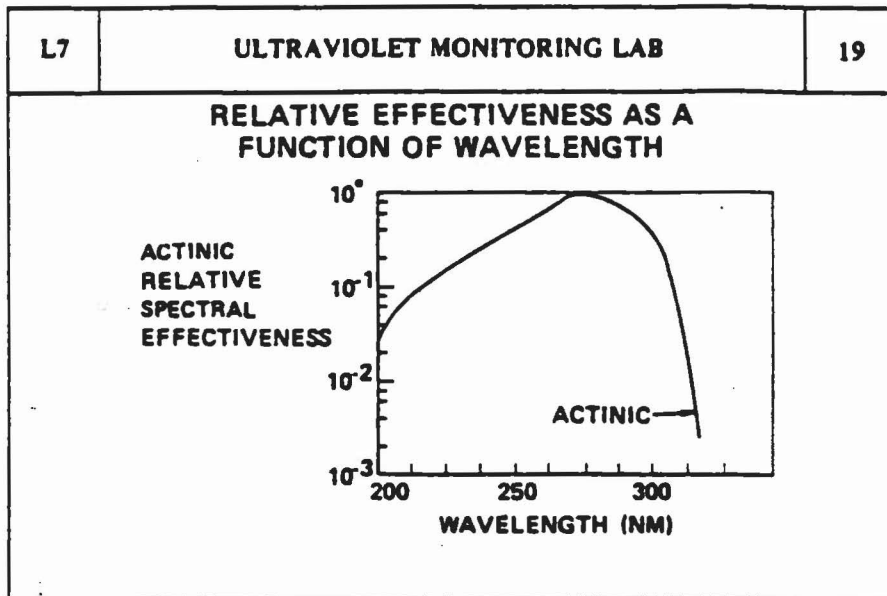


4. Survey Technique

c. Hazard Determination (contd.)

The allowed exposure/day (for actinic UV) is based on a National Institute for Occupational Safety and Health (NIOSH) Standard. NIOSH recommends that occupational exposure to ultraviolet energy in the workplace be controlled by compliance with the following standard.

- (1) If the ultraviolet energy is from a narrow-band or monochromatic source, permissible dose levels for a daily 8-hour period can be read directly from Figure 18.



4. Survey Technique

c. Hazard Determination (contd.)

- (2) If the ultraviolet energy is from a broad-band source, the effective irradiance (I_{eff}) relative to a 270 nm monochromatic source shall be by measuring the irradiance of various wavelengths and weighting them according to Figure 19. From I_{eff} the permissible exposure time in seconds for unprotected skin or eyes shall be computed by dividing $3 \times 10^{-3} \text{ J/cm}^2$, the permissible dose of 270 nm radiation, by I_{eff} in W/cm^2 .

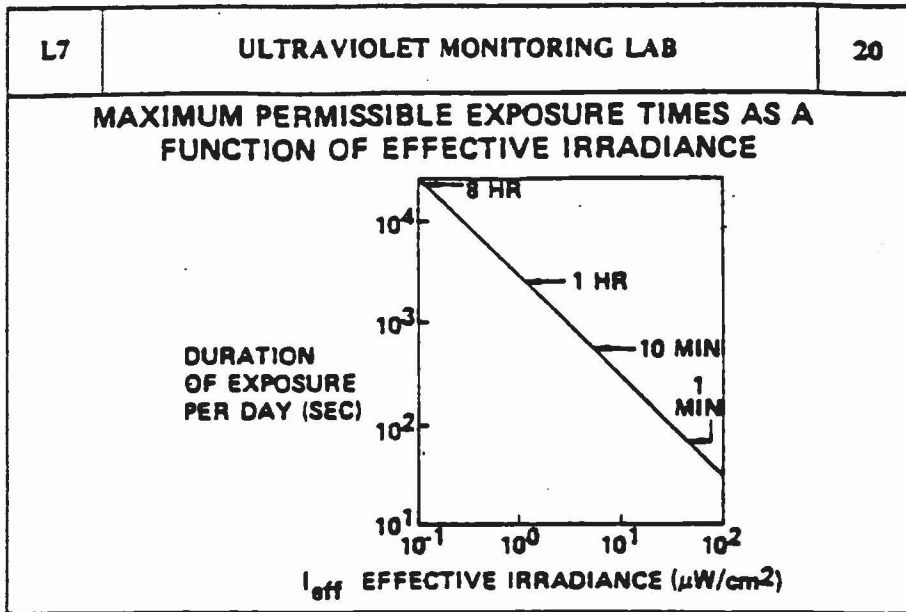
$$I_{eff} = \sum_{\lambda} I_{\lambda} S_{\lambda} \Delta\lambda$$

where I_{eff} = effective irradiance relative to a monochromatic source at 270 nm.

I_{λ} = spectral irradiance in $\text{W/cm}^2/\text{nm}$.

S_{λ} = relative actinic spectral effectiveness (unitless); see Figure 19 for values of S_{λ} at different wavelengths.

$\Delta\lambda$ = band width in nm.



4. Survey Technique

c. Hazard Determination (contd.)

Figure 20 shows permissible exposure times corresponding to selected values of I_{eff} in $\mu\text{W}/\text{cm}^2$.

This standard assumes that the individual spectral irradiances at given wavelengths can be determined. If instrumentation is not available to determine irradiance levels at given wavelengths, then approximations must be made, depending on the detector being used. Such approximations must be made for the detector used in today's lab. The approximations and their effect were elucidated during the lecture on the use of the IL600 photometer.

L7	ULTRAVIOLET MONITORING LAB	21
FACTORS INFLUENCING MEASUREMENTS 1. SENSITIVITY OF DETECTOR WITH RESPECT TO SPECTRAL OUTPUT OF SPECIFIC SOURCE. 2. CHANGE OF CALIBRATION DUE TO SOLARIZATION AND AGING OF LENSES & TUBE ENVELOPES. 3. WATER VAPOR IN ATMOSPHERE. 4. DIRECTIONALITY OF METERS 5. REFLECTIONS 6. CORRECT BY INVERSE SQUARE		

4. Survey Technique

c. Hazard Determination (contd.)

In order to avoid errors of major magnitude in assessing ultraviolet energy, the following must be given serious considerations:

- (1) The spectral output of the specific source being evaluated and the spectral response of the phosphor or phototube that is being utilized in measurement of ultraviolet energy. The meter or phototube selected should be one that is sensitive in the range most nearly covering that part of the spectrum under consideration.
- (2) Solarization and aging of lenses, tube envelopes, or cells. This can be determined only by calibration against a source of known wavelengths and intensity.
- (3) Water vapor in the atmosphere may cause absorption of ultraviolet energy as well as affecting the electronic circuitry.
- (4) The directionality of the meters. This is especially noticeable with the use of phototubes.
- (5) The reflection of ultraviolet from nearby surfaces or high intensity visible light can affect most of the phototubes and cells that are presently used for measurement of ultraviolet energy. These factors are of particular importance when measuring an intense wide-band source of ultraviolet energy.
- (6) If radiation intensity from a point source is known at some distance from the worker, then the radiation from that point to the worker can be calculated from the principle that radiation decreases with the square of the distance it must travel. For example, an object 3 feet away from a radiation source receives 1/9 the energy of an object 1 foot away. This assumption is conservative in some instances, since ultraviolet radiation, especially at very low wavelengths, may be absorbed by some components of the atmosphere. Where information on atmospheric absorption of ultraviolet radiation is known, further correction may be applied. The calculation of intensity of radiation at any given point by use of the inverse square formula explained above does not take into consideration reflected energy.

L7	ULTRAVIOLET MONITROING LAB				22
ULTRAVIOLET RADIATION SURVEY					
GENERAL INFORMATION	USING ORGANIZATION		ADDRESS		
	TYPE OF EQUIPMENT		INTENDED USAGE		
	MANUFACTURE	MODEL	SERIAL NUMBER	OTHER	
ENVIRONMENT					
	BACKGROUND				

4. Survey Technique (contd.)

d. Environment

A freehand drawing of the area in which the UV source is located is drawn in the block entitled environment. Top views and side views can be used to show pertinent features of the area. Letters (A, B, C, etc.) are located at given points in the sketch where measurements were made. These letters refer to the recorded information entered in the hazard determination block. Both direct and reflected measurements are shown. The number of people at a particular location with respect to the source are also entered on the sketch. Non-UV hazards are also noted on the figure. For example electrical shock, fumes, explosion, fire, ventilation, etc.

L7	ULTRAVIOLET MONITORING LAB		23
ULTRAVIOLET RADIATION SURVEY			
GENERAL INFORMATION	USING ORGANIZATION		ADDRESS
	TYPE OF EQUIPMENT		INTENDED USAGE
PERSONNEL PROTECTION	BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER		
	IN USE	SIGNS EYE PROTECTION RESTRICTED AREA GLOVES	SKIN CREAM CLOTHING CURTAINS ENCLOSURES
	RECOMMENDED	PARTITIONS OTHER	
IDENTIFICATION		RESPONSIBLE FOR	

4. Survey Technique (contd.)

e. Personnel

The **BACKGROUND** of the primary group or groups of people using the UV source is noted. They may be students, machinists, engineers, scientists, or a mix of these types of backgrounds. The amount of **SAFETY TRAINING** or safety awareness of the people using the source is also considered. The probability of an **UNAWARE ONLOOKER** being exposed to low or high exposure levels is noted. **OTHER** aspects of personnel which might have an effect on the hazard potential are also noted. For example, it might be noted that a particular individual was uncooperative in following or observing recommended safety practices.

f. Personnel Protection

The personnel protection block is divided into two groups; first those protective measures **IN USE**. And second, those protection measures **RECOMMENDED** after the hazard, environment, personnel and the current personnel protection measures have been evaluated. The personnel protection measures in use could be signs, eye protection, restricted area, gloves, skin creams, clothing, curtains, enclosures, partitions or some other form of safety measure. The safety measures recommended could be any one of the above, or some other recommendation such as repainting walls to cut down on reflections.

L7	ULTRAVIOLET MONITORING LAB		24
ULTRAVIOLET RADIATION SURVEY			
GENERAL INFORMATION	USING ORGANIZATION		ADDRESS
	TYPE OF EQUIPMENT		INTENDED USAGE
	MANUFACTURE	MODEL	SERIAL NUMBER
PERSONNEL PROTECTION RECOMMENDED	SKIN SEMI CREAM PROTECTIONS EYE PROTECTION CLOTHING OTHER RESTRICTED AREA CURTAINS GLOVES ENCLOSURES		
CERTIFICATION		PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE	

4. Survey Technique (contd.)

g. Certification

The certification entails obtaining the signature of the **PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION**. The safety monitor also signs the space marked **SURVEYED BY**, and finally the **DATE** of the survey is entered.

h. Comment

Additional information or drawings can be added to the back of the form if necessary. A check list might also be printed on the back of the form.

This general form presented is not intended to be a standard form. It merely points to various aspects which should be considered. Different forms can be developed as the need dictates.

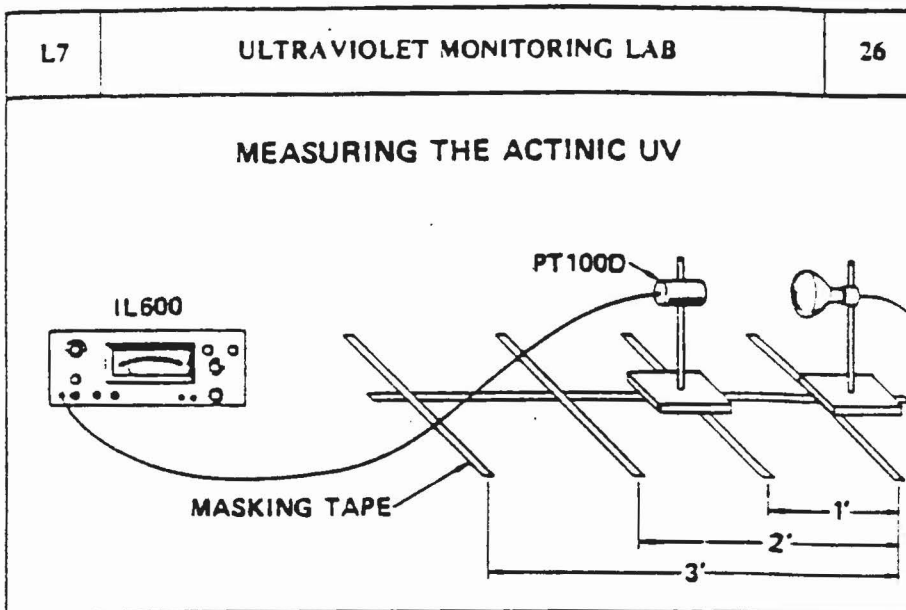
L7	ULTRAVIOLET MONITORING LAB	25
STUDENTS' LABORATORY EXERCISE PHASE I. SURVEY OF SUNLAMP MEASURING THE ACTINIC UV THE SURVEY RECORD PHASE II. PROPERTIES OF ULTRAVIOLET LIGHT TRANSMISSION REFLECTION		

C. STUDENTS' LABORATORY EXERCISE

I. Introduction

The students' laboratory exercise will be conducted in two phases. In Phase I the students will make a survey of a sunlamp using the IL600 with the PT100D detector and ACT270 filter. The actinic UV content will be determined at several points around the source. The students will then complete a Survey Record. To make the situation more realistic, the sunlamp will be imagined as a welder set-up. People will be assumed to be in various areas with respect to the sunlamp.

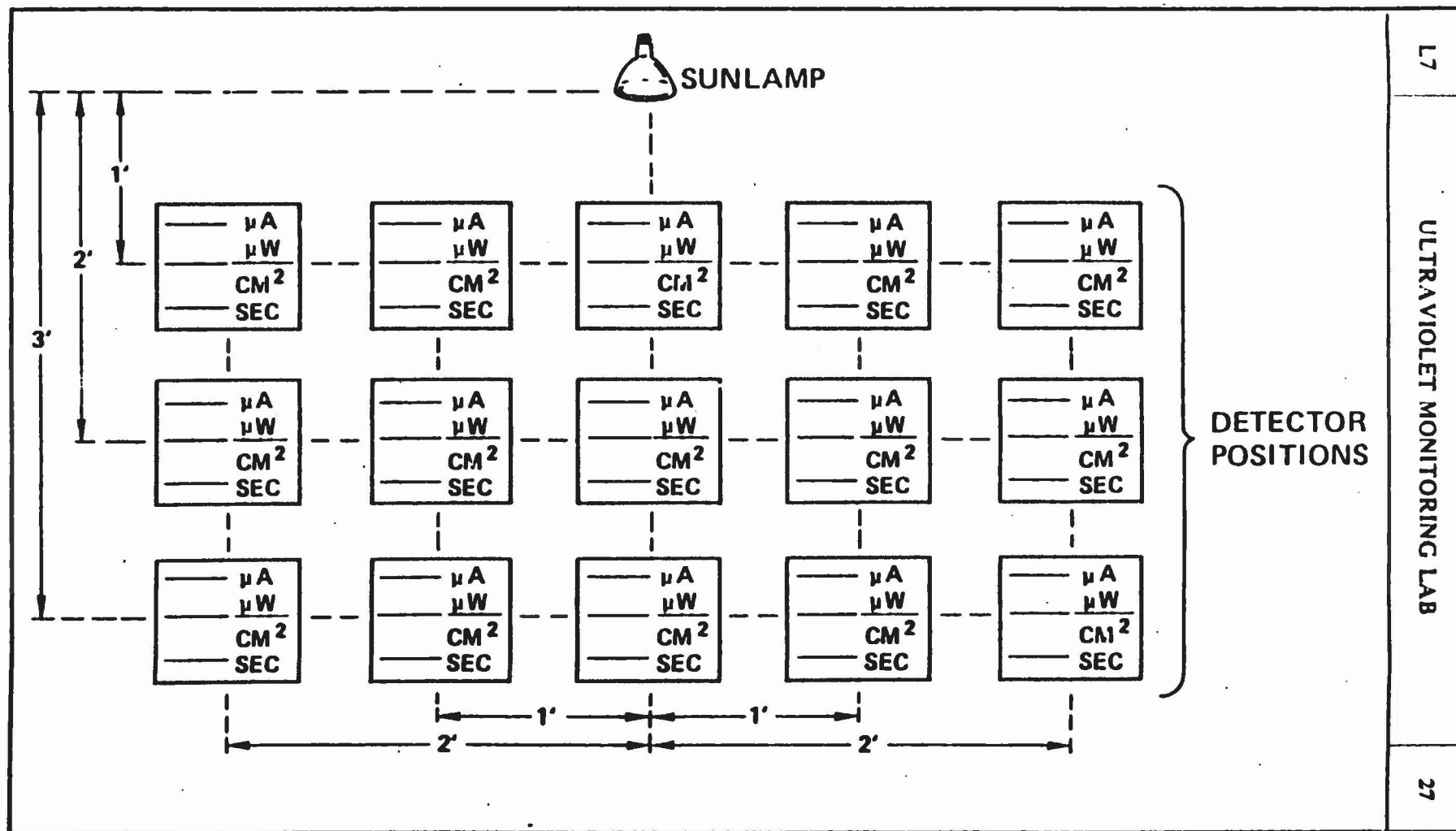
During Phase II the students will observe some properties of ultraviolet light. They will use the sunlamp-IL600 set-up to measure the transmission of UV through ordinary glass and welders curtain. They will then use this same set-up to measure the reflection of UV by cloth, glass, and aluminum.

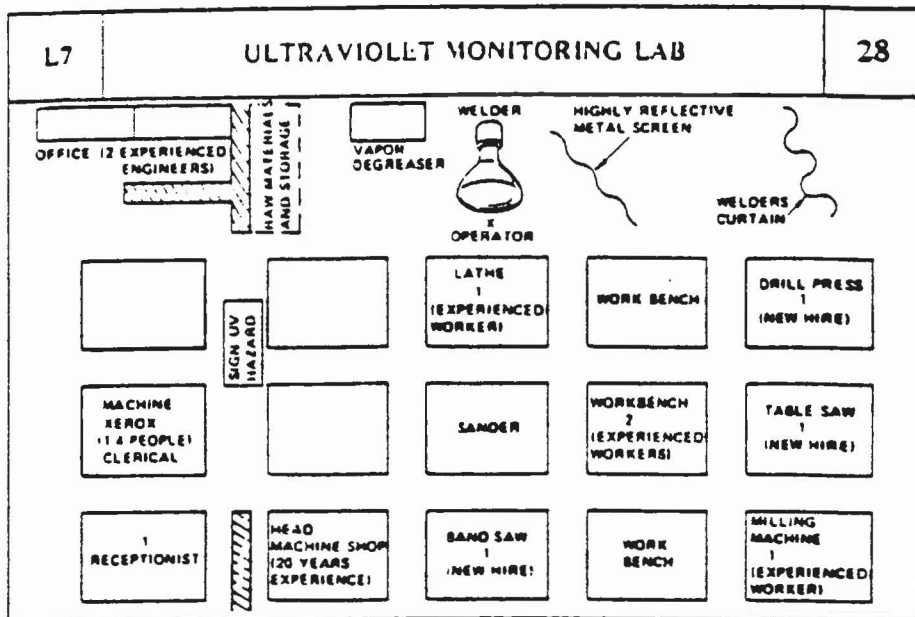


2. Phase I. Survey of a Sunlamp

a. Measuring the Actinic UV (contd.)

- (1) Set the equipment up as shown in Figure 26. Record data in the spaces provided in Figure 27.
- (2) Connect the IL600 to the PT100D detector head by inserting the detector plug into the 9 pin connector. Always check to be certain the detector filter combination has the correct spectral response for your application.
- (3) Check the mechanical zero of the microammeter. Adjust the meter to zero by turning the screw located over the pivot of the meter. Mechanical zero adjustment is usually unnecessary.
- (4) Connect the power cable to the three prong plug on the back of panel and connect the other end to external 115v.a.c., 50-60 Hz power if battery operation is not desired. Turn the input current range switch clockwise to the 100 microampere scale. Allow a ten second warm-up to stabilize all circuits.
- (5) Turn the Cancel Current rotary switch counter-clockwise to the zero adjust position. This disconnects the input so that a true electrical zero may be made even though light is falling on the detector head. Adjust the zero vernier to zero the meter needle.
- (6) Turn the Cancel Current switch to the "open:" position. Place the ACT270 filter over the detector with the detector 12" directly in front of the source. Turn on the light and rotate the input range selector until an adequate reading is obtained. This current reading is due to non-actinic light only, since the filter passes wavelengths greater than 315 nm. These wavelengths are not to be measured and are compensated for by selecting the proper range of cancel current and cancel vernier to zero the meter. Take the ACT270 filter off and read the number of actinic microamperes directly on the meter. Be sure to read the appropriate scale for the range selected.
- (7) To convert the microampere reading to an actinic irradiance value, multiply the current by the calibration factor obtained from the manufacturer. In our case, the calibration factor is $90.6 \text{ actinic } \mu\text{W}/\text{cm}^2/\mu\text{A}$. Divide $3 \times 10^{-3} \text{ Joules}/\text{cm}^2$ by the irradiance obtained to determine how long a worker could be exposed to this radiation according to the recommended NIOSH standard. The exposure time could also be obtained by referring to the exposure time versus (actinic effective) irradiance plot of Figure 19.
- (8) Place the detector in other positions as shown in Figure 27. Be sure the detector points toward the sunlamp for each reading made. Repeat steps 5, 6, and 7 for each position in Figure 27. Record the data in the spaces provided.





2. Phase I. Survey of a Sunlamp (contd.)

b. The Survey Record

Suppose the sunlamp is a welder. An example is a Weldfort Model 98B series 90B-485 welder which is being used by the Boeing Radiation Effects Laboratory which is located at 1420 Trenton, Seattle, Washington. The welder is used to construct laboratory test fixtures. The operator has the current set at 300 amps with a voltage of 220. The filler material used is 1/8" Al rod on aluminum. The welder is used about four hours per day.

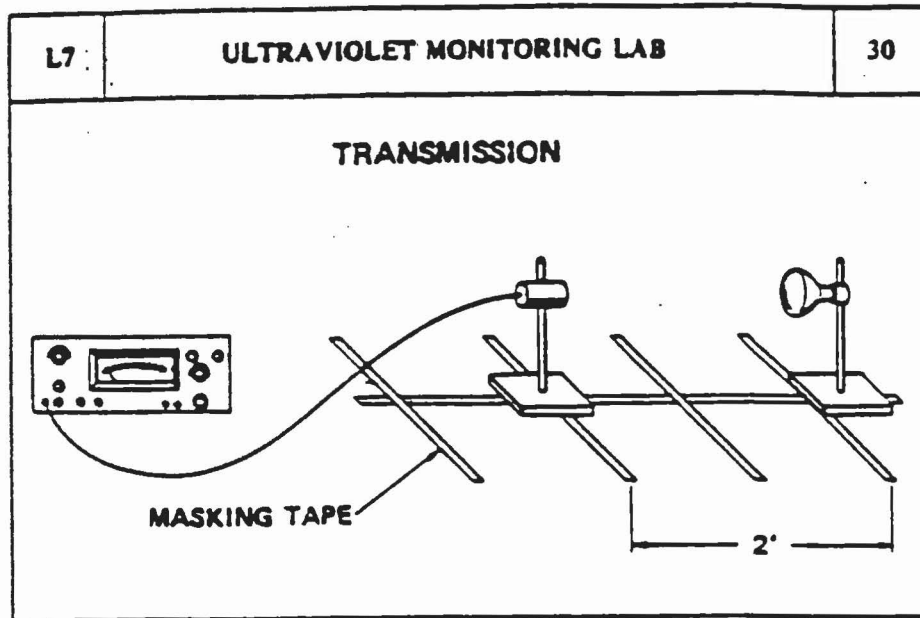
The environment in which the welder is operating is shown in Figure 28. The operator using the welder has 5 years experience as a welder and he has been briefed by the safety officer at the lab. During his first year on the job he received a bad neck burn and has since remembered to wear neck/face shields, gloves and heavy clothing.

There are several new workers in the area who have just been hired, as well as other experienced workers as shown in Figure 28. The new-hires have come on the job during the regular health officer's vacation. You are asked to make a survey of the area. Assume the measurements of Figure 27 were made at the corresponding positions in Figure 28, and complete the survey record given in Figure 29.

L7	ULTRAVIOLET MONITORING LAB	29
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ULTRAVIOLET RADIATION SURVEY

GENERAL INFORMATION	USING ORGANIZATION				ADDRESS			
	TYPE OF EQUIPMENT				INTENDED USAGE			
	MANUFACTURE		MODEL		SERIAL NUMBER		OTHER	
HAZARD DETERMINATION	WELDER ONLY	GAS	CURRENT	VOLTAGE	FILLER	MATERIAL	DUTY CYCLE	
	MONITORING INSTRUMENT			PROBE		FILTER		
	ATTACHMENT				WAVELENGTH OR WAVELENGTH RANGE			
	DISTANCE TO SOURCE (FEET)			D/R	KEY	INSTRUMENT READING (μA)	IRRADIANCE (μA) $\times$ (CF) = ($\mu W/cm^2$)	EXPOSURE/DAY ($3 \times 10^{-3} J/cm^2$) IRRADIANCE
ENVIRONMENT								
PERSONNEL	BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER							
PERSONNEL PROTECTION	IN USE	SIGNS EYE PROTECTION RESTRICTED AREA GLOVES		SKIN CREAM CLOTHING CURTAINS ENCLOSURES		PARTITIONS OTHER		
	RECOMMENDED							
CERTIFICATION		PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE						

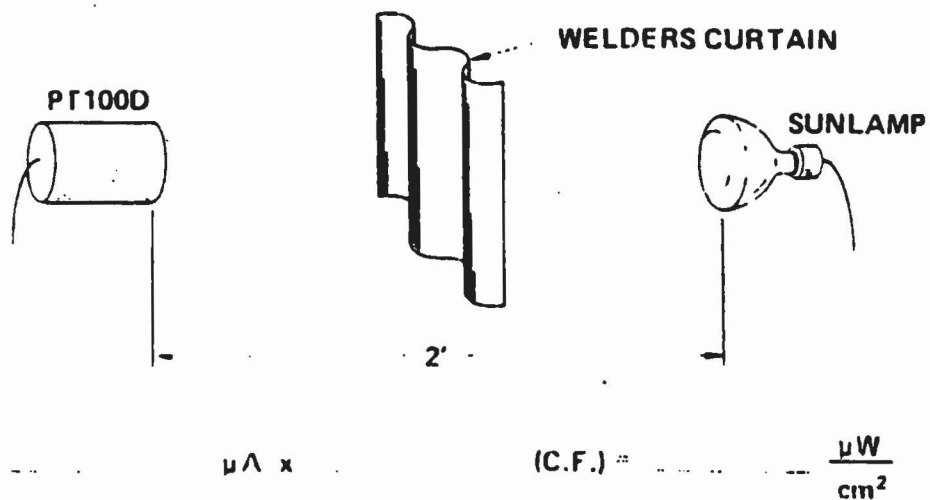
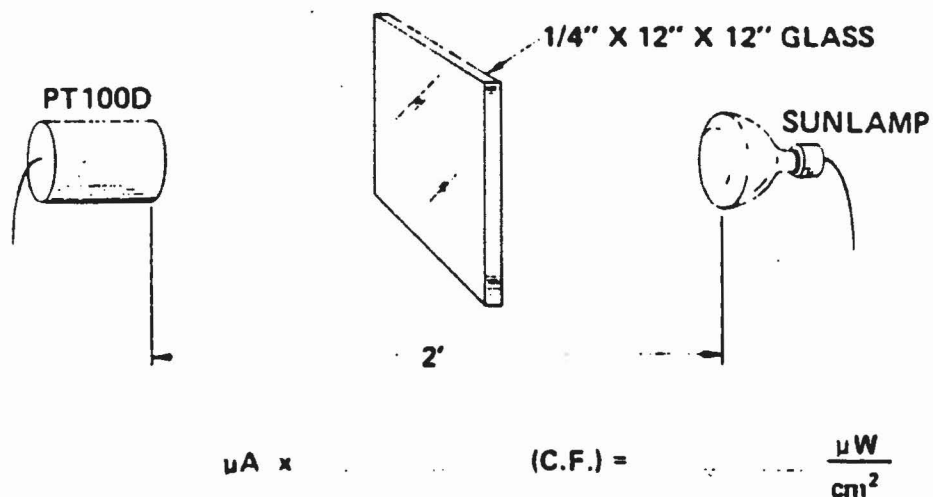
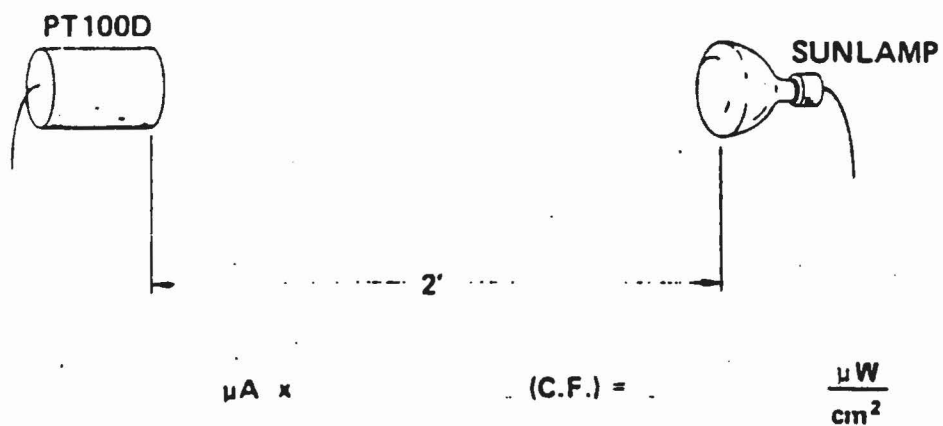


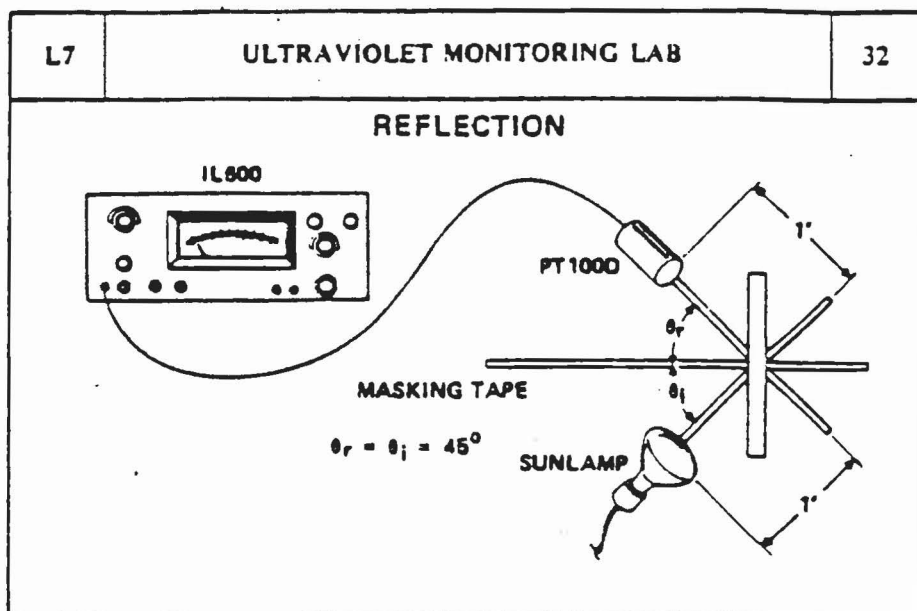
3. Phase II. Properties of Ultraviolet Light

a. Transmission

- (1) Setup the equipment as shown in Figure 30. The detector is placed 2 feet directly in front of the source.
- (2) Obtain the actinic UV reading with the source to detector distance being 2 feet and with no material between the source and detector. Use the filter-in/filter-out technique. Record data in the spaces provided in Figure 31.
- (3) Insert a piece of $1/4'' \times 12'' \times 12''$ glass between the source and detector. Determine the actinic UV passed using the filter-in/filter-out technique.
- (4) Repeat step 3 except use a piece of welders curtain.
- (5) What can you conclude regarding the passage of UV through welders curtain and glass? Record your answer on the back of Figure 31.

TRANSMISSION



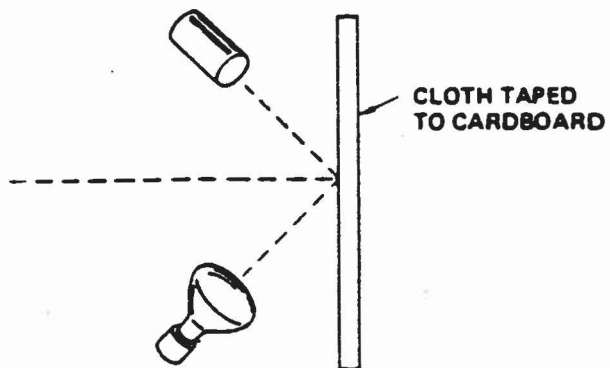


3. Phase II. Properties of Ultraviolet Light (contd.)

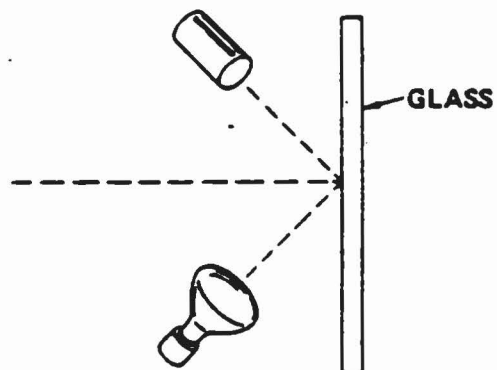
b. Reflection

- (1) Setup the equipment as shown in Figure 32. The source to reflecting surface distance is 1 foot and the detector to reflecting surface distance is 1 foot. Make sure the sunlamp-reflecting surface-detector are aligned so that the angle of incidence equals the angle of reflection.
- (2) Insert a piece of white clothing material taped to cardboard as shown in Figure 33. Determine actinic UV reflected by using the filter-in/filter-out technique. Record the data in the spaces provided in Figure 33.
- (3) Repeat Step 2 using a $\frac{1}{2}$ " x 12" x 12" piece of glass.
- (4) Repeat step 2 using a $\frac{1}{4}$ " x 12" x 12" aluminum foil taped to cardboard.
- (5) Write your conclusion regarding the reflection of UV from various materials on the back of Figure 33.

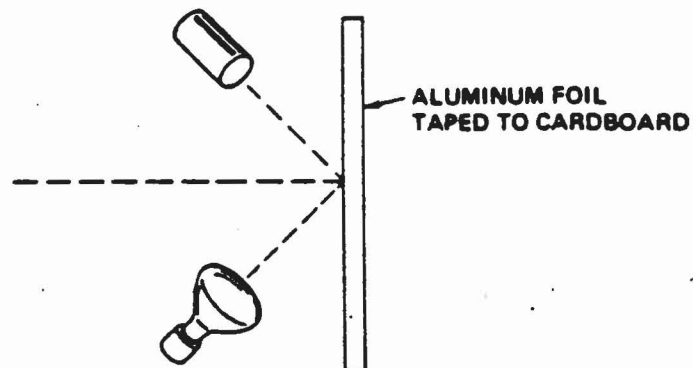
REFLECTION



_____ μA x _____ C.F. = _____ $\frac{\mu W}{cm^2}$



_____ μA x _____ C.F. = _____ $\frac{\mu W}{cm^2}$



_____ μA x _____ C.F. = _____ $\frac{\mu W}{cm^2}$

LABORATORY NO. 8
LASERS

COURSE OUTLINE

VIII. LASER LAB

A. INTRODUCTION

1. Objectives
2. Overview
3. Equipment List
4. Precautions

B. INSTRUCTOR'S DEMONSTRATION - LECTURE

1. Introduction
2. Types of Lasers
3. Detection of Laser Light
4. Laboratory Equipment
 - a. The International Light IL600 Photometer
 - b. Using the International Light IL600 Photometer to Measure HeNe Laser Light
5. Survey Technique
 - a. Introduction
 - b. General Information
 - c. Hazard Determination
 - d. Environment
 - e. Personnel
 - f. Personnel Protection
 - g. Certification
 - h. Comment

C. STUDENTS' LABORATORY EXERCISE

1. Introduction
2. Phase I. Making a Laser Survey
 - a. Measuring the Irradiance
 - b. The Survey Record
3. Phase II. Properties of Laser Light
 - a. Transmission
 - b. Variation of Laser Irradiance With Distance
 - c. Diffraction of Laser Light

L8	LASER LABORATORY	1
<u>OBJECTIVES</u> 1. TO REVIEW THE BASIC PRINCIPLES OF LASER LIGHT, SOURCES AND DETECTION 2. TO BE ABLE TO CONDUCT A LASER SURVEY USING THE INTERNATIONAL LIGHT IL600 PHOTOMETER 3. TO OBSERVE TRANSMISSION, VARIATION WITH DISTANCE AND DIFFRACTION OF LASER LIGHT		

A. INTRODUCTION

1. Objectives

- a. To review the basic principles of laser light, sources and detection.**
- b. To be able to conduct a laser survey using the International Light IL600 Photometer.**
- c. To observe transmission, variation with distance, and diffraction of laser light.**

2. Overview

The instructor will review basic principles of laser operation and laser light. He will also review the types of detectors which can be used to monitor laser light.

The instructor will then demonstrate the use of the International Light IL600 Photometer in detecting light from a laser. The technique and important aspects of making a laser survey will also be presented.

The students will make a survey of a HeNe laser and complete a laser survey record. They will also observe transmission, the variation with distance, and diffraction of laser light.

The lab report will be submitted to the instructor at the end of the laboratory period.

BIBLIOGRAPHY - NIOSH 583

See also References listed in Text.

"Human Exposure to Nonionizing Radiant Energy - Potential Hazards and Safety Standards," S. M. Michaelson, Proceedings of IEEE, Vol. 60, April 1972, p. 389.

"Non-Ionizing Radiation," G. M. Wilkening, Chap. 28 in "The Industrial Environment - its Evaluation and Control," HEW, GPO.

"Nonionizing Radiation: Lasers, Microwaves, Light." Chapter 7 in "Fundamentals of Industrial Hygiene," Olishifski and McElroy, Ed., National Safety Council.

"Instrumentation for Environmental Monitoring," Volume 3 Radiation (UV, IR, RF), Lawrence Berkeley Laboratory (LBL), Univ. of Calif.

"Criteria for a Recommended Standard, Occupational Exposure to Ultraviolet Radiation," NIOSH, HEW.

"American National Standard for the Safe Use of Lasers," ANSI, Z136, 1-1973.

"Laser Health Hazards Control," AFM 161-8, USAF, 1969.

"Control of Hazards to Health from Laser Radiations," TB MED 279, US Army, 1975.

"Industrial, Scientific, and Medical Applications of Microwaves," Special Issue, Proceedings of IEEE, January 1974.

"Biological Effects fo EM Waves," C. C. Johnson and A. W. Guy, Proceedings of IEEE, Vol. 60, p. 693, June 1972.

L8	LASER LABORATORY	3
PRECAUTIONS 1. DO NOT LOOK DIRECTLY INTO THE LASER BEAM 2. DO NOT LOOK AT SPECULARLY REFLECTED LASER LIGHT 3. DO NOT AIM THE LASER WITH THE EYE: DIRECT REFLECTION COULD CAUSE EYE DAMAGE 4. TURN THE LASER OFF WHEN NOT IN USE		

4. Precautions

The precautions stated above shall be rigorously followed during the demonstration and during the students' laboratory exercise.

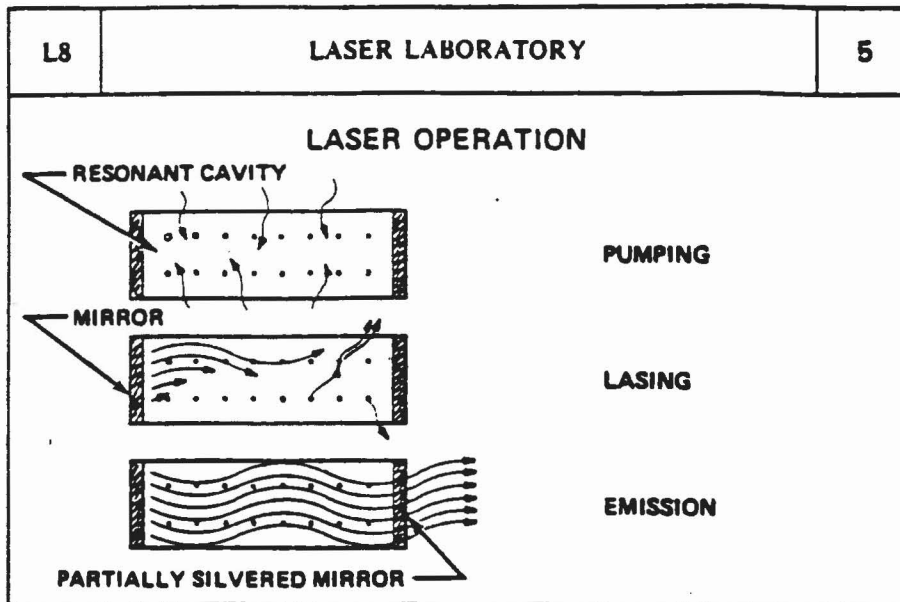
L8	LASER LABORATORY	4
INTRODUCTION 1. LASER LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION 2. ORDINARY LIGHT IS INCOHERENT 3. LASER LIGHT IS COHERENT ONE FREQUENCY ONE PHASE		

B. INSTRUCTOR'S DEMONSTRATION: LECTURE

1. Introduction

Laser is an acronym from Light Amplification by Stimulated Emission of Radiation. Since lasers are basically light sources, what makes them so unique? Ordinary light is incoherent, laser light on the other hand, is coherent. The many advantages of lasers derive from this coherence.

True coherence has two prerequisites: time coherence and spatial coherence. Time coherence implies one frequency --one color; it is monochromatic. Spatial coherence means the waves are in phase or in step.



1. Introduction (contd.)

The sequence of producing laser light can be summarized as: (a) Pumping—creates a population inversion by exciting the atoms in the medium. (b) Lasing—begins when a photon is spontaneously emitted along the axis of the resonant cavity. This photon stimulates another atom in its path. (c) Emission—lasing process continues as the photons are reflected back and forth between the mirrors of the resonant cavity, until the amplification is so great that the beam of light bursts through the partially silvered mirror. Thus a narrow, parallel, concentrated, coherent beam of light is created.

L8	LASER LABORATORY	6
TYPES OF LASERS BEAM 1. PULSED 2. CONTINUOUS WAVE – CW 3. Q-SWITCHED		

2. Types of Lasers

Classification by beam.

There are three general types of lasers: pulsed, continuous-wave, and Q-switched (or Q-spoiled).

- a. Pulsed lasers deliver the output energy in short pulses. An intense flash of light is used to “pump” a ruby rod, silvered at both ends. Light waves reflect off the mirrors until the intensity is great enough to flash through the partially silvered mirror. The light emerges from this laser in a short, powerful burst.
- b. Continuous-wave lasers generate an uninterrupted beam. If the pumping energy and stimulated emission occur simultaneously, electrons falling back to ground state can be “pumped” up again. This action will result in an uninterrupted beam.
- c. Q-switched lasers have output pulses of higher power and shorter duration than normal pulsed lasers. Q pertains to the “Quality” of the resonant cavity. A high Q encourages oscillations; a low Q would indicate a poor resonator. Somewhere in the cavity, i.e., between the mirrors, a device is inserted which will permit rapid changing of the Q of the cavity. When a resonating cavity is Q-spoiled, the light reflections between mirrors do not occur. In this condition, a much larger population inversion results. When the Q-switching device finally permits the reflections to occur, the resulting output is of tremendous power.

L8	LASER LABORATORY	7.
TYPES OF LASERS MEDIUM 1. SOLID STATE OR IONIC 2. GAS 3. SEMICONDUCTOR 4. CHEMICAL		

2. Types of Lasers (contd.)

Lasers are also classified according to the lasing medium. In general they are:

- a. Solid state or ionic lasers, such as a ruby and neodymium.
- b. Gas lasers, such as HeNe, argon, CO₂, and Krypton.
- c. Semiconductor lasers, such as gallium arsenide (GaAs).
- d. Chemical lasers, such as HCL and CF₃I.

L8	LASER LABORATORY	8
DETECTION OF LASER LIGHT PHOTON DEVICES 1. PHOTOELECTRIC VACUUM PHOTOTUBES PHOTOMULTIPLIERS 2. PHOTOCONDUCTIVE CADMIUM SULPHIDE CADMIUM SELENIDE 3. PHOTOVOLTAIC SELENIUM PHOTOCELLS SILICON SOLAR CELLS		

3. Detection of Laser Light

The wide variety of lasers now available with their different wavelengths, pulse durations, power densities, and energy densities makes detection with one particular instrument difficult. Thus, a variety of detectors have been utilized and can be classified under one of two general categories: Photon devices and thermal devices. These two classifications of light detectors are based on the two ways in which light interacts with matter. Several laser detection accessories can be used in conjunction with these detectors to provide versatile measurements.

Photon devices measure the rate at which light quanta are absorbed. The response at any particular wavelength is proportional to the rate at which photons of that wavelength are absorbed. These detectors have a strong wavelength dependence.

There are three ways to categorize photon devices: photoelectric, photoconductive, and photovoltaic. Electrons in a material may absorb energy from incident light quanta. When an electron is ejected or completely removed from a metal upon absorption of a light photon, the photoelectric effect has occurred. Examples of instruments operating on this principle are phototubes and photomultiplier tubes. If the electron is liberated from a particular atom but is not ejected from the metal, this is termed the photoconductive effect. Characteristic photoconductive cells are cadmium sulphide and cadmium selenide. When the photoconductive effect occurs at the P-N boundary of semiconductors or at the boundary between a metal and a semiconductor, a potential difference will develop. This is classified as the photovoltaic effect. Photovoltaic detectors may be selenium photocells or silicon solar cells.

L8	LASER LABORATORY	9
DETECTION OF LASER LIGHT PHOTON DEVICES THERMAL DEVICES 1. CALORIMETERS 2. BOLOMETERS THERMISTOR BARETTER 3. THERMOCOUPLES THERMOPILE		

3. Detection of Laser Light (contd.)

Thermal devices measure the effect of heat and temperature changes on materials when absorbing light energy. There are three general categories: calormeters, bolometers and thermocouples.

Calorimeters absorb the total light energy, and the corresponding temperature rise indicates the amount of energy absorbed.

Bolometers are detectors whose resistance changes when heated. Measuring this change in resistance provides a means of determining the incident power of the absorbed radiation. The most common bolometer is the thermistor whose resistance decreases as temperature increases. Another device similar to the thermistor is the baretter. In a baretter, an increase of temperature causes an increase in resistance. Another thermal device to measure temperature rise is the thermocouple. A thermocouple consists of a pair of junctions between two different metals, such as antimony and bismuth. Since the two metals have different thermal properties, a small voltage difference can be produced when the junctions are at different temperatures.

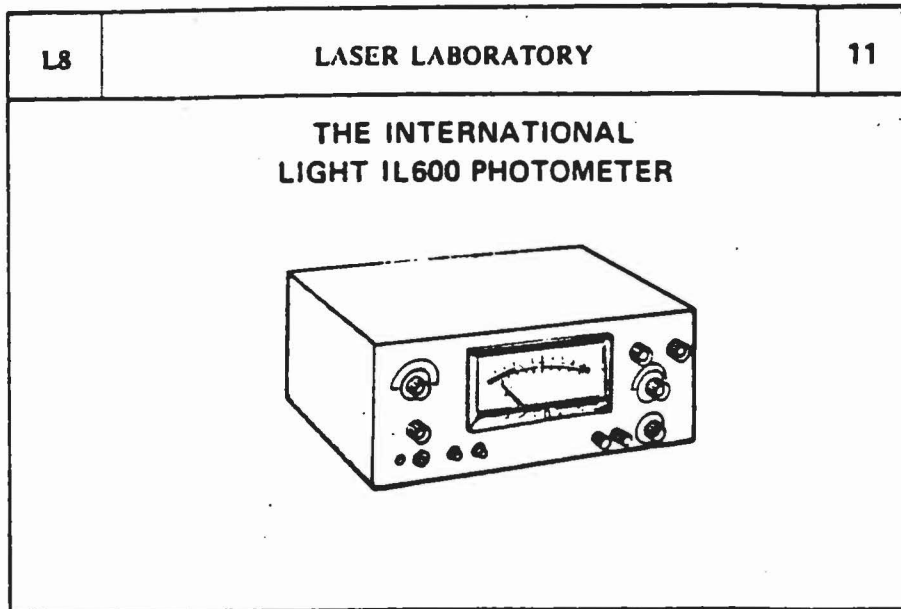
A thermopile is made by connecting several thermocouples in series. The total thermally produced voltage across the output terminals is the sum of the individual thermocouple voltages.

L8	LASER LABORATORY	10.
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LASER DETECTOR ACCESSORIES	
DEVICE	FUNCTION
1.	FILTERS – WAVELENGTH SELECTION, ATTENUATION
2.	GRATINGS – WAVELENGTH SELECTION
3.	DIFFUSERS – BEAM SPREADING
4.	SPLITTERS – POWER REDUCTION
5.	MULTIPLE APERTURE – POWER REDUCTION
6.	COMPENSATOR – AMBIENT LIGHT COMPENSATION

3. Detection of Laser Light (contd.)

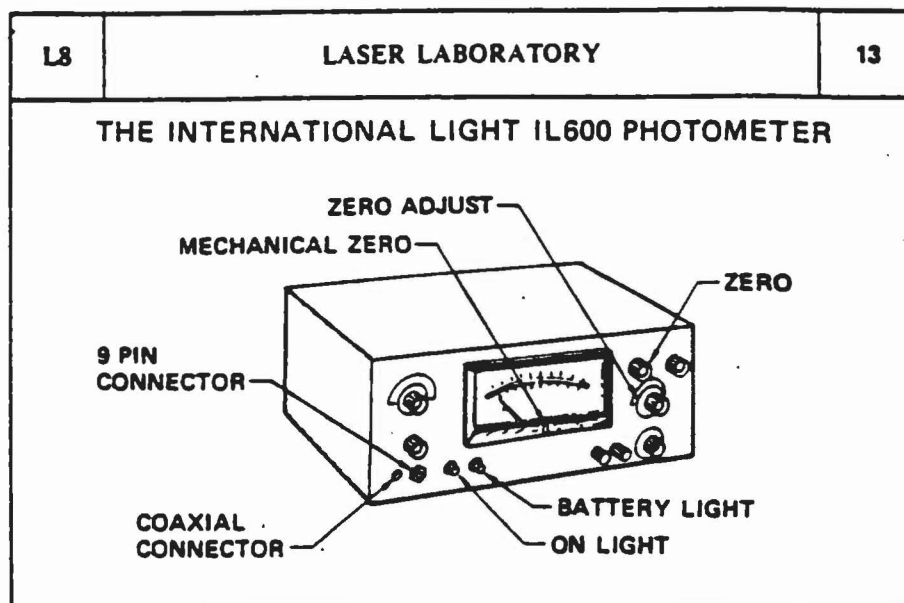
Several laser detection accessories are very useful for versatile measurements. (1) Filters can be used to select specific wavelengths of the operating laser; they also attenuate the beam so the full energy of the laser does not damage the detector. (2) Gratings also are wavelength selectors which prove to be more exact than filters. (3) When the beam is small compared to the active detector area, diffusers spread the beam over the entire detector surface. (4) Measuring high-power lasers calls for a beam splitter to split the beam and select only a fraction to be incident on the detector. This fraction can then be extrapolated to the total power. (5) A multiple-aperture dish is utilized to vary the power level falling on the detector. It is simply a dish with numerous holes. (6) Another handy accessory is the ambient light to be electronically dialed out.



4. Laboratory Equipment

a. The International Light IL600 Photometer

The IL600 Photometer shown in Figure 11 is a sensitive indicating and control unit designed to provide power and commands to many different accessories, and to measure and record minute return signals. A variety of accessories are available providing a range in sensitivity, spectral response and speed of response. A monochromator as well as band pass filters can be used with the instrument to permit measurement of different portions of the spectrum. The IL600 Photometer provides control functions to establish the proper sensitivity, compensation, and power for measurement of current from the detector heads or accessories.



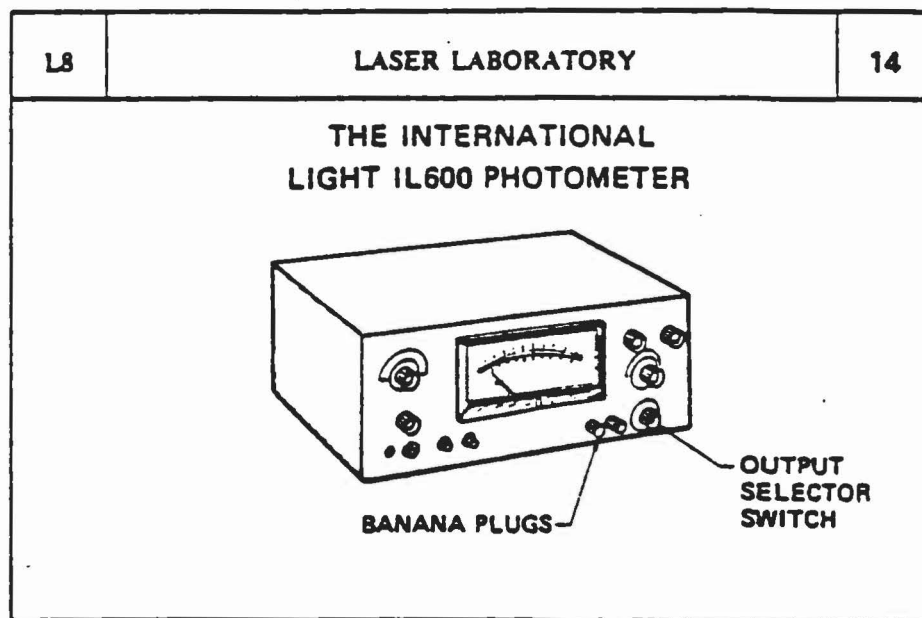
4. Laboratory Equipment

a. The International Light IL600 Photometer (contd.)

A mechanical zero adjust can be made by covering the detector head and adjusting the screw (at the face of the meter) for a zero reading on the meter. A special feature is provided to allow an electrical zero adjust even though light is falling on the detector. By selecting the zero adjust position on the cancel current rotary switch, the input is disconnected, and an accurate electrical zero can be obtained using the zero control.

Two connectors, located on the front panel provide all connections for the input accessories. One is a 9 pin connector, the other a coaxial type connector. The coaxial type connector to the left of the 9 pin connector permits external control of the instrument's input operational amplifier. The sensing probe is connected using the 9 pin connector.

The ON light indicates that the circuits are operating. The red light on the front panel marked Battery indicates four states of operation. (1) If the light is on, steady and bright, the unit is operating from the a.c. power, the battery is being charged and all regulated voltages are correct. (2) If the red light is steady and dim, the battery is supplying operating power to the unit and all regulated voltage are correct. (3) If the indication is dim and blinking, the unit is operating from battery power, but the battery charge is too low for satisfactory operation and must be charged or else a.c. power must be applied to continue the measurements. (4) If the indication is bright and blinking, the unit is operating from a.c. power, but the supply voltages are not correct.



4. Laboratory Equipment

a. The International Light IL600 Photometer (contd.)

The red and black banana plugs (spaced $\frac{3}{4}$ inch apart for a standard plug) provide an output for accessories such as an oscilloscope (chart recorder), oscilloscope, or remote readout. The five position output selector switch provides three magnitudes of full scale output voltage (10 mv, 100 mv, and 1 volt) and a "short", for establishing an accurate electrical zero in the accessory. Also there is an "open" position so that the IL600 can be disconnected without unplugging the cable. The "open" permits sharing of an accessory such as a recorder with many IL600 outputs or other instruments.

The power is provided by the self-contained nickel cadmium battery or from 115v a.c. cycle. The selection is made automatically, depending upon whether the line cord is plugged in or not. On battery power the unit is capable of running about eight hours before it is necessary to recharge.

Maintenance other than external cleaning is not advised since there are ten precise adjustments which must be performed with the aid of calibrated current and voltage measuring equipment. If a malfunction occurs that can be traced to one of the two plug-in printed circuit boards, the power supply board (rear location), or the amplifier board (front location), then it is possible to return just the board for repair. In all other cases it is advisable to send the entire instrument so that calibration can be recertified for the entire unit.

For cleaning and care consult the instrument manual.

L8	LASER LABORATORY	15
USING THE INTERNATIONAL LIGHT IL600 PHOTOMETER TO MEASURE HeNe LASER LIGHT 1. CONNECT THE IL600 TO THE PT 200A/203A DETECTOR 2. CHECK MECHANICAL ZERO 3. CONNECT POWER – TURN INPUT CURRENT SELECTOR TO 100 μA – ALLOW 10 SEC. WARM-UP – TURN SENSITIVITY CONTROL COUNTER CLOCKWISE 4. PUT "CANCEL CURRENT SWITCH" TO ZERO ADJUST POSITION – ADJUST THE ZERO VERNIER TO ZERO THE METER NEEDLE		

4. Laboratory Equipment (contd.)

b. Using the International Light IL600 Photometer to Measure HeNe Laser Light

The IL600 Photometer uses simplified and convenient techniques for measuring current from accessories which measure steady light sources, a.c. sources, and pulsed sources. The following explains the operating procedure and set-up instructions to best realize the measurement capability of the instrument for CW HeNe laser light.

- (1) Connect the IL600 to the PT 200A/203A detector head by inserting the detector plug into the 9 pin connector. Always check to be sure that the detector filter combination has the correct spectral response for your application.
- (2) Check the mechanical zero of the microammeter. If necessary adjust the meter to zero by turning the screw located over the pivot of the meter. Mechanical zero adjustment is usually unnecessary.
- (3) Connect the power cable to the three prong plug on the back panel, and connect the other end to external 115v a.c., 50 - 60 cycle power if battery operation is not desired. Turn the input current range switch clockwise to the 100 microampere scale. Allow a ten second warm-up to stabilize all circuits. Make sure the sensitivity control is in its full counter-clockwise position.
- (4) Turn the cancel current rotary switch counter-clockwise to the zero adjust position. This disconnects the input so that a true electrical zero may be made even though light is falling on the detector head. Adjust the zero vernier to zero the meter needle.

L8	LASER LABORATORY	16
USING THE INTERNATIONAL LIGHT IL600 PHOTOMETER TO MEASURE HeNe LASER LIGHT 5. (a) TURN CANCEL CURRENT SWITCH TO OPEN POSITION (b) ROTATE INPUT CURRENT SELECTOR SWITCH TO OBTAIN MIDSCALE AMBIENT LIGHT READING (c) USE CANCEL CURRENT SWITCH AND CANCEL VERNIER TO ZERO THE METER (d) TURN THE HeNe LASER ON AND READ METER		

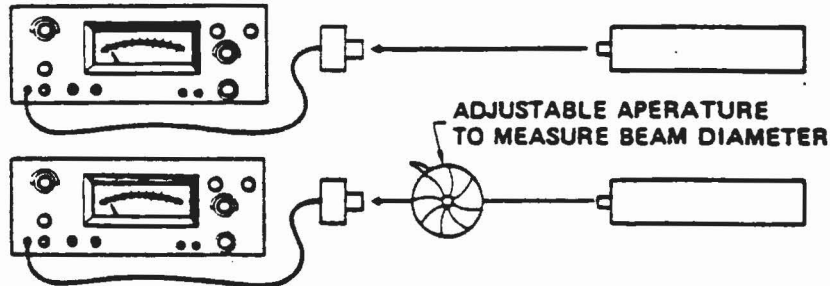
4. Laboratory Equipment

b. Using the International Light IL600 Photometer to Measure HeNe Laser Light (contd.)

- (5) Turn the cancel current switch to the "open" position. Rotate the input current selector until an adequate ambient room light reading is obtained. This current reading is due to non-laser light only and is not to be measured. Therefore, compensate for it by selecting the proper range of cancel current and cancel vernier to zero the meter. Turn the HeNe laser ON and read the number of microamperes directly on the meter. Be sure to read the appropriate scale for the range selected.**

NOTE: Ambient light conditions can vary, and proper compensation should be verified for precise measurements.

USING THE INTERNATIONAL LIGHT IL600 PHOTOMETER TO MEASURE HeNe LASER LIGHT



$$6. \quad .01 \mu\text{A} \times .425 \frac{\text{WATT}}{\mu\text{A}} = 4.25\text{m WATTS}$$

$$\frac{4.25\text{m WATTS}}{\pi \left(\frac{.5}{2}\right)^2 \text{cm}^2} = 21.6\text{m WATTS/cm}^2$$

4. Laboratory Equipment

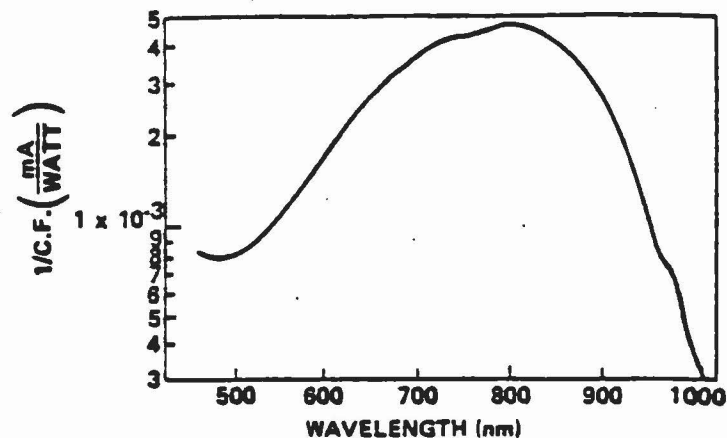
b. Using the International Light IL500 Photometer to Measure HeNe Laser Light (contd.)

- (6) To convert the microampere reading to a laser power value, multiply the current by the HeNe calibration factor obtained from the manufacturer. Convert the power to an irradiance value by dividing the power by the beam area.

The beam diameter is determined by using a limiting aperture and then measuring this hole diameter using a vernier caliper.

Suppose the calibration factor is .425 watt/ μA then the radiant power would be $(.01 \mu\text{A}) \times (.425 \frac{\text{W}}{\mu\text{A}})$ or 4.25 mW. Given a beam diameter of .5 cm then the irradiance would be $4.25 \text{ mW} / \pi \left(\frac{.5}{2}\right)^2 \text{cm}^2 = 21.6 \text{ mW/cm}^2$.

RECIPROCAL CALIBRATION FACTOR VS WAVELENGTH



4. Laboratory Equipment

b. Using the International Light IL600 Photometer to Measure HeNe Laser Light (contd.)

Since the ambient light is subtracted and the laser emits at one wavelength only, the reciprocal calibration factor at the wavelength of interest can be applied to convert microamps to watts. The reciprocal calibration factor versus wavelength, for the PT 200A/203A detector is shown in Figure 18. For sources emitting at one known wavelength in the range from 500nm to 1000nm the IL600 200A/203A set-up gives an accurate measurement of the power being emitted.

This detector should not be used to monitor sources emitting single wavelengths in the tail-end regions of Figure 18. In these regions errors can occur due to the steep fall-off of the detectors response.

Filters are necessary if this detector is to be used to monitor a source emitting multiple wavelengths over the detector's region of response. This is due to the fact that the calibration factor is not flat over the detector's wavelength response.

L8	LASER LABORATORY	19																																																																																																				
GENERAL INFORMATION ▷ HAZARD DETERMINATION ▷ ENVIRONMENT ▷ PERSONNEL ▷ PERSONNEL PROTECTION ▷ CERTIFICATION ▷	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 5%; text-align: center; vertical-align: middle;">1</td> <td style="width: 15%; text-align: center; vertical-align: middle;">2</td> <td style="width: 15%; text-align: center; vertical-align: middle;">3</td> <td style="width: 15%; text-align: center; vertical-align: middle;">4</td> <td style="width: 15%; text-align: center; vertical-align: middle;">5</td> <td style="width: 15%; text-align: center; vertical-align: middle;">6</td> <td style="width: 15%; text-align: center; vertical-align: middle;">7</td> <td style="width: 15%; text-align: center; vertical-align: middle;">8</td> <td style="width: 15%; text-align: center; vertical-align: middle;">9</td> <td style="width: 15%; text-align: center; vertical-align: middle;">10</td> <td style="width: 15%; text-align: center; vertical-align: middle;">11</td> <td style="width: 15%; 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5. Survey Technique

a. Introduction

In making a laser survey, several factors must be taken into consideration. The laser source must be classified regarding its potential for personnel injury, the operating environment must be evaluated, and the personnel and personnel protection measures considered.

The survey record form provides a means of systematically evaluating and recording the different aspects of a laser/maser survey. The form has spaces provided for general information, laser hazard determination, environment, personnel, personnel protection and certification.

L 8	LASER LABORATORY				20																					
<table border="1" style="width: 100%; border-collapse: collapse; margin: 0 auto;"> <tr> <th colspan="2" style="text-align: center;">LASER/MASER</th> <th colspan="2" style="text-align: center;">SURVEY RECORD</th> </tr> <tr> <td rowspan="4" style="width: 5%; text-align: center; vertical-align: middle;">GENERAL INFORMATION</td> <td colspan="2" style="text-align: center;">USING ORGANIZATION</td> <td colspan="2" style="text-align: center;">ADDRESS</td> </tr> <tr> <td colspan="2" style="text-align: center;">TYPE OF EQUIPMENT</td> <td colspan="2" style="text-align: center;">INTENDED USAGE</td> </tr> <tr> <td style="text-align: center;">MANUFACTURE</td> <td style="text-align: center;">MODEL</td> <td style="text-align: center;">SERIAL NUMBER</td> <td style="text-align: center;">OTHER</td> </tr> <tr> <td colspan="2" style="text-align: center;">WAVELENGTH</td> <td style="text-align: center;">BEAM DIAMETER AT X</td> <td style="text-align: center;">ANGLE CONV/DIV</td> </tr> </table>						LASER/MASER		SURVEY RECORD		GENERAL INFORMATION	USING ORGANIZATION		ADDRESS		TYPE OF EQUIPMENT		INTENDED USAGE		MANUFACTURE	MODEL	SERIAL NUMBER	OTHER	WAVELENGTH		BEAM DIAMETER AT X	ANGLE CONV/DIV
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	MANUFACTURE	MODEL	SERIAL NUMBER	OTHER																						
	WAVELENGTH		BEAM DIAMETER AT X	ANGLE CONV/DIV																						

5. Survey Technique (contd.)

b. General Information

Different types of general information are recorded on the survey record in the block entitled general information. The following information is required.

USING ORGANIZATION. In this space the company or division of a company should be recorded. **ADDRESS.** The address of the company or the building and room number. Enough information should be supplied so that someone unfamiliar with the location could find the source. **TYPE OF EQUIPMENT.** This refers to whether the source is a HeNe laser, CO₂ laser, Maser, etc. **INTENDED USAGE.** This is the purpose for which the source is used. Examples of intended usage are research, construction, surveying, etc. **MANUFACTURE - MODEL - SERIAL NUMBER.** This information identifies the laser or maser manufacturer, the model number and the serial number. **OTHER.** This space provides a means of recording general information not covered by the above and which may only apply to a particular case.

L8		LASER LABORATORY										21																																																																							
<table border="1"> <tr> <td rowspan="6">HAZARD DETERMINATION</td> <td colspan="2">WAVELENGTH</td> <td colspan="4">BEAM DIAMETER AT X</td> <td colspan="5">ANGLE CONV/DIV</td> </tr> <tr> <td colspan="2">PEAK POWER</td> <td colspan="4">AVERAGE POWER</td> <td colspan="2">PULSED</td> <td colspan="3">ENERGY/PULSE</td> </tr> <tr> <td colspan="2">PULSE TIME</td> <td colspan="2">PRF</td> <td colspan="2">CLASS</td> <td colspan="2">COLLIMATED</td> <td colspan="2">EXTENDED</td> <td colspan="1">OTHER</td> </tr> <tr> <td colspan="2">DISTANCE TO SOURCE (FEET)</td> <td colspan="1">D/R</td> <td colspan="1">KEY</td> <td colspan="1">INST. READING (uA)</td> <td colspan="1">POWER I = C.F. = (mW)</td> <td colspan="1">IRRAD WA = (mW/cm²)</td> <td colspan="6">TLV</td> </tr> <tr> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1">EXP. TIME (SEC)</td> <td colspan="2">OCULAR (IRRADI)</td> <td colspan="1">OCULAR (I.O.D.)</td> <td colspan="1">SENS. (IRRADI)</td> <td colspan="1">EXT. SWP. (IRRADI)</td> </tr> <tr> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> <td colspan="1"></td> </tr> </table>														HAZARD DETERMINATION	WAVELENGTH		BEAM DIAMETER AT X				ANGLE CONV/DIV					PEAK POWER		AVERAGE POWER				PULSED		ENERGY/PULSE			PULSE TIME		PRF		CLASS		COLLIMATED		EXTENDED		OTHER	DISTANCE TO SOURCE (FEET)		D/R	KEY	INST. READING (uA)	POWER I = C.F. = (mW)	IRRAD WA = (mW/cm ²)	TLV												EXP. TIME (SEC)	OCULAR (IRRADI)		OCULAR (I.O.D.)	SENS. (IRRADI)	EXT. SWP. (IRRADI)											
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5. Survey Technique (contd.)

c. Hazard Determination

WAVELENGTH. This is the wavelength at which the laser or maser is operating. The HeNe laser has wavelength of 632.8 nm. The **BEAM DIAMETER** is the diameter of the laser beam. The location at which the diameter was determined is also noted. For example the beam diameter could be .5 cm measured at 12 inches from the laser. **ANGLE CONV/DIV.** This is the angle of convergence or divergence. Two beam diameter measurements at different distances from the laser are made and then the angle of convergence or divergence is calculated. Such a calculation will be made during the laboratory exercise. If the laser has a continuous wave output the CW box is checked. The **PEAK POWER** and **AVERAGE POWER** output can be obtained from the manufacturer. If the laser is **PULSED** a check is placed in the pulse box. A Q is placed in this space if the laser is Q-switched. The **ENERGY / PULSE**, **PULSE TIME** and **PRF** can be obtained from the manufacturer. PRF is the pulse repetition frequency.

L8	LASER LABORATORY	22
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SURVEY TECHNIQUE	
LASER CLASSIFICATION	
CLASS I	INCAPABLE OF CREATING BIOLOGICAL DAMAGE
CLASS II	LOW POWERED
CLASS III	MEDIUM POWERED
CLASS IV	HIGH POWERED
CLASS V	CLASS II, III, IV THAT ARE ENCLOSED

5. Survey Technique

c. Hazard Determination (contd.)

The CLASS of the laser depends upon its capability for personnel injury. Class I lasers are incapable of creating biological damage. Class II lasers are low-powered and the beam may be viewed directly under carefully controlled conditions. Class III lasers are medium in power and their beams may not be viewed directly. Class IV lasers are high-powered and their direct and diffuseley reflected beams cannot be viewed or contact the skin. Class V are Class II, III, IV lasers which are completely enclosed so that no radiation can leak out. For detailed information regarding laser classification refer to the ACGIH standard.

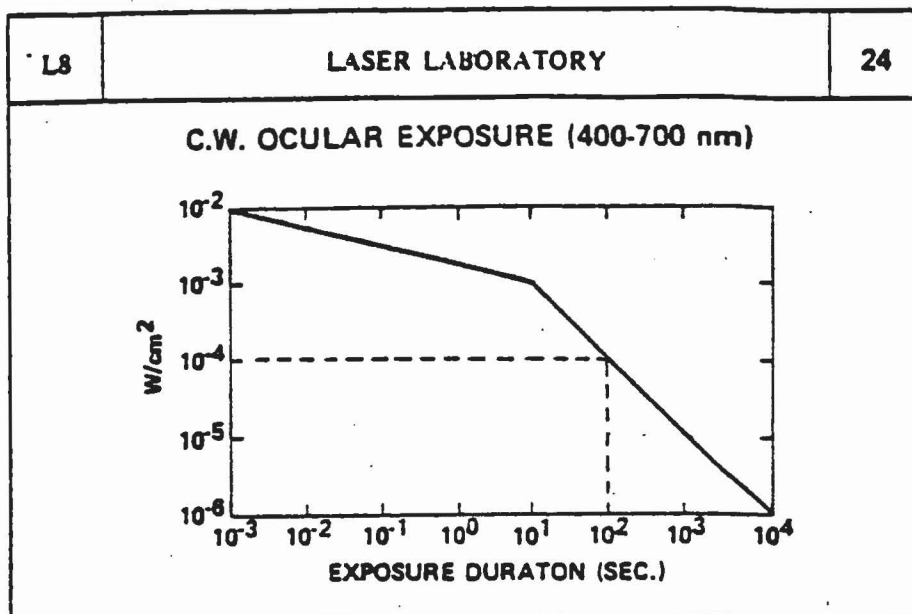
L8		LASER LABORATORY										23	
GENERAL INFORMATION	MANUFACTURE		MODEL		SERIAL NUMBER				OTHER				
	WAVELENGTH		BEAM DIAMETER AT Z		ANGLE CONV/DIV								
HAZARD DETERMINATION	PEAK POWER		AVERAGE POWER		PULSED		ENERGY/PULSE						
	PULSE TIME		PRP		CLASS		COLLIMATED		EXTENDED		OTHER		
	DISTANCE TO SOURCE (FEET)		D/R	KEY	INST. READING (uA)	POWER I = C.F. * (W)	IRRAD P/A = (W/cm ²)	EXP. TIME (SEC)	OCULAR (IRRAD)	O.D.J.	EXT DIFF	IRRAD	

5. Survey Technique

c. Hazard Determination (contd.)

The source will be either **COLLIMATED** or **EXTENDED**. Most lasers fall in the collimated category. Figure 26 is used to determine whether the laser source is extended or collimated. **OTHER** refers to information which is not covered by the above.

The next body of information pertains to the measurements made using the laser light detector. The **DISTANCE TO SOURCE** is the distance to the source from the point of measurement. It can also be the distance in front of the source with a given distance to the left or right of this centerline. The column labeled **D/R** refers to whether the reading was made looking directly (**D**) at the source or looking at a reflection (**R**). The **KEY** refers measurements to a drawing of the laser area. For example, an **A** in the key column means that this measurement was taken in the area marked **A** on the drawing. (The next three columns refer to measurements made using an **IL600** photometer. Other instruments or using the **IL600** with a flash integrator would require a modification of these columns.) **INST. READING**. This is the microamp reading from the **IL600** after ambient light has been subtracted using the cancel current switch. The **POWER** is calculated by multiplying the calibration factor of the wavelength of interest times the instrument reading. The resulting answer is in watts. The irradiance **IRRAD**. is the power divided by the area of the beam at the detector. This area is determined using an adjustable aperture.



5. Survey Technique

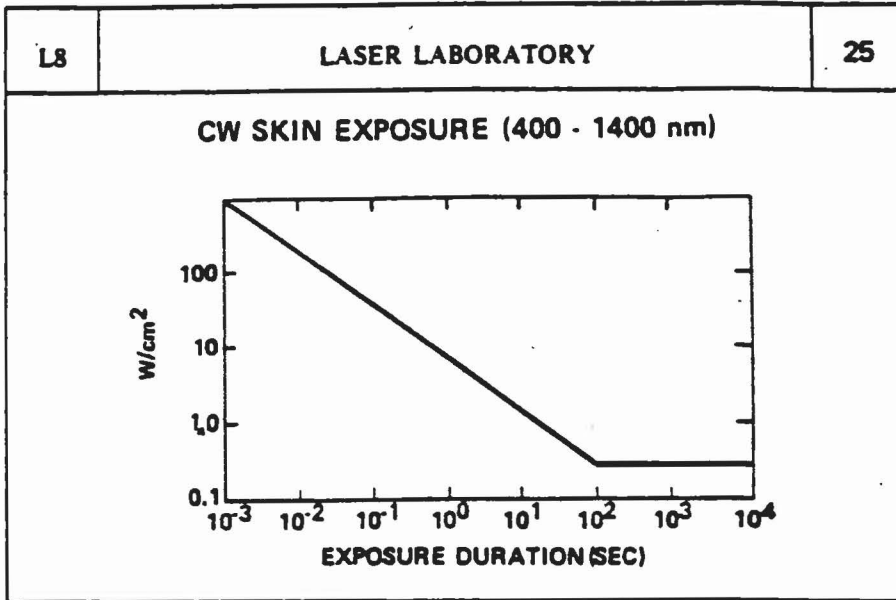
c. Hazard Determination (contd.)

After the irradiance has been measured (or radiant exposure for pulsed sources) the length of time during which personnel might be exposed to this laser light is entered in the column headed EXPOSURE TIME. The THRESHOLD LIMITING VALUE for OCULAR, SKIN, or EXTENDED/DIFFUSE is obtained by using the exposure time and consulting the tables and graphs of the ACGIH standard. If the measured irradiance is greater than the ocular TLV for the exposure time considered then the optical density required to reduce the measured irradiance to the TLV is entered in the O.D. column.

$$\text{O.D.} = \log \frac{I_M}{I_T} \quad \text{Where } I_M = \text{Irradiance measured, } I_T = \text{TLV}$$

Irradiance and O.D. = optical density.

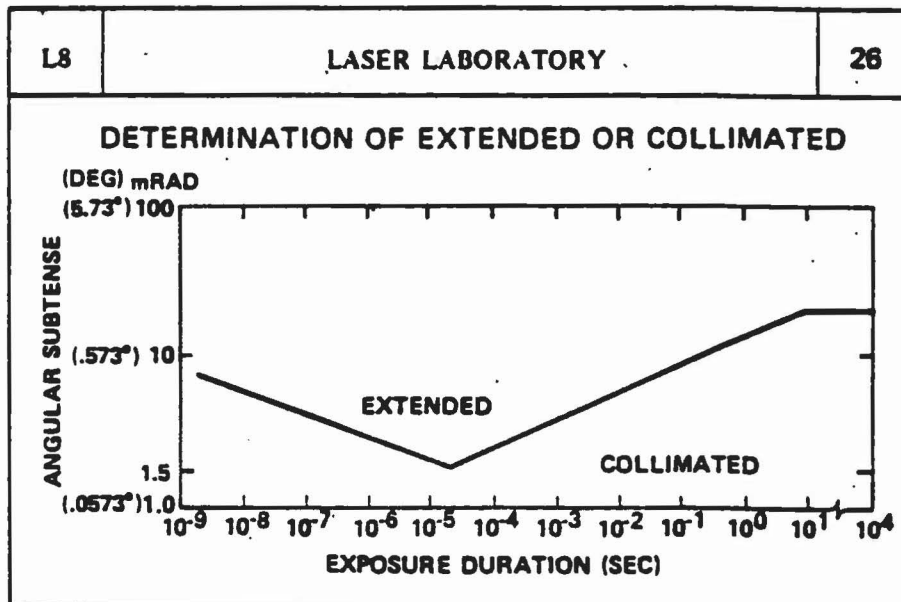
Suppose the measured irradiance from a HeNe laser was $5 \times 10^{-3} \text{ W/cm}^2$ and the desired exposure time for ocular viewing was 1.67 minutes, (100 sec.). Then from the ACGIH curve shown in Figure 24 the ocular TLV would be $1 \times 10^{-4} \text{ W/cm}^2$. The optical density required to reduce $5 \times 10^{-3} \text{ W/cm}^2$ to $1 \times 10^{-4} \text{ W/cm}^2$ is 1.7.



5. Survey Technique

c. Hazard Determination (contd.)

The TLV for skin exposure for an exposure time of 100 seconds is $.3\text{W/cm}^2$, as given by Figure 25. Thus the measured irradiance of $5 \times 10^{-3} \text{ W/cm}^2$ is less than the skin TLV so no protective clothing is required.



If the angular subtense is less than 1.5m rad, the source is considered as collimated (See Figure 26) and an extended source TLV need not be determined.

L8	LASER LABORATORY	27
FACTORS INFLUENCING MEASUREMENTS 1. SENSITIVITY OF DETECTOR WITH RESPECT TO SPECTRAL OUTPUT OF A SPECIFIC SOURCE 2. CHANGE OF CALIBRATION 3. DUST IN ATMOSPHERE 4. DIRECTIONALITY OF METERS		

5. Survey Technique

c. Hazard Determination (contd.)

In order to avoid errors of major magnitude in assessing the irradiance or radiant exposure, the following must be given serious consideration:

- (1) The spectral output of the specific source being evaluated and the spectral response of the detector that is being utilized in measurement of the laser output. The selection of meter or phototube should be one that is sensitive in the range covering that wavelength under consideration.
- (2) Solarization and aging of lenses, tube envelopes, or cells. This can be determined only by calibration against a source of known wavelengths and intensity.
- (3) Dust in the atmosphere may cause scattering of laser light.
- (4) The directionality of the meters. This is critical with the use of phototubes.

L8	LASER LABORATORY		28

5. Survey Technique (contd.)

d. Environment

A freehand drawing of the area in which the laser/maser source is located is drawn in the block entitled **ENVIRONMENT**. Top view and side view can be used to show pertinent features of the area. Letters (A,B,C, etc.) are located at given points in the sketch where measurements were made. These letters refer to the recorded information entered in the hazard determination block. Both direct and reflected measurements are shown. The number of people at a particular location with respect to the source are also entered on the sketch. The azimuth/elevation angle and the horizontal/vertical range are also noted for laser operation outdoors.

Non-UV hazards are also noted on the figures. Examples are electrical shock, fumes, explosion, fire, ventilation etc.

For an example of the sketch see Figure 38. The sketch may be made on the back of the Survey Form if the amount of detail requires additional space.

L8		LASER LABORATORY		29	
PERSONNEL		BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER			
PERSONNEL PROTECTION	IN USE	EYEWEAR CLOTHING APERTURE OTHER	INTERLOCKS LIGHT SIGNS	SHIELDING FILM BADGE CONTROLLED AREA	
	RECOMMENDED				
		PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION			
		SURVEY			

5. Survey Technique (contd.)

e. Personnel

The **BACKGROUND** of the primary group or groups of people using the laser source is noted. They may be students, machinists, engineers, scientists, or a mix of these types of backgrounds. The amount of **SAFETY TRAINING** or safety awareness of the people using the source is also considered. The probability of an **UNAWARE ONLOOKER** being exposed to low or high exposure levels is noted. **OTHER** aspects of personnel which might have an effect on the hazard potential are also noted. For example, it might be noted that a particular individual was uncooperative in following or observing recommended safety practices.

f. Personnel Protection

The personnel protection block is divided into two parts. first, those protective measures **IN USE**. And, second, those protection measures **RECOMMENDED** after the hazard, environment, personnel and the current personnel protection measures have been evaluated.

aperture, sign, controlled area access or other forms of safety measures. The safety measures recommended could be any one of the above or some other recommendation.

L8	LASER LABORATORY		30								
<table border="1"> <tr> <td>PERSONNEL RECOMMENDATION</td> <td colspan="3">  </td> </tr> <tr> <td>CERT.</td> <td colspan="3"> PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE </td> </tr> </table>				PERSONNEL RECOMMENDATION				CERT.	PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE		
PERSONNEL RECOMMENDATION											
CERT.	PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE										

5. Survey Technique (contd.)

g. Certification

The certification entails obtaining the signature of the **PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION**. The safety monitor also signs the space marked **SURVEYED BY**, and finally the **DATE** of the survey is entered.

h. Comment

It should be pointed out that if a space requires information which does not apply, the space should be marked **N.A.** (not applicable).

Additional information or drawings can be added to the back of the form if necessary. A check list might also be printed on the back of the form.

The general form presented is not intended to be a standard form. It merely points to various aspects which should be considered. Different forms can be developed as the need dictates.

L8	LASER LABORATORY	31
STUDENTS' LABORATORY EXERCISE 1. PHASE I. MAKING A LASER SURVEY MEASURING THE IRRADIANCE THE SURVEY RECORD 2. PHASE II. PROPERTIES OF LASER LIGHT TRANSMISSION VARIATION OF IRRADIANCE WITH DISTANCE DIFFRACTION		

C. STUDENTS' LABORATORY EXERCISE

1. Introduction

The students' laboratory exercise will be conducted in two phases. During Phase I the students will make a survey of a HeNe laser. A survey record will be completed and a situation will be assumed to make the exercise more realistic.

In Phase II the students will study some properties of laser light. They will observe the transmission of laser light through various materials. They will also determine the variation of irradiance with distance and diffraction of laser light.

2. Phase I. Making a Laser Survey

a. Measuring the Irradiance

- (1) The laser and detector will be set-up as shown in Figure 32. Leave the laser off until instructed to turn it on.
- (2) Connect the IL600 to the PT200A/203A detector head by inserting the detector plug into the 9 pin connector. Always check to be sure that the detector filter combination has the correct spectral response for your application.
- (3) Check the mechanical zero of the microammeter. If necessary, adjust the meter to zero by turning the screw located over the pivot of the meter. Mechanical zero adjustment is usually unnecessary.
- (4) Connect the power cable to the three prong plug on the back panel, and connect the other end to external 115 v.a.c. 50-60 cycle power. Turn the input current range switch clockwise to the 100 microampere scale. Allow a ten second warm-up to stabilize all circuits. Make sure the sensitivity control is in its full counterclockwise position.
- (5) Turn the cancel current rotary switch counter-clockwise to the zero adjust position. This disconnects the input so that a true electrical zero may be made even though light is falling on the detector head. Adjust the zero vernier to zero the meter needle.
- (6) Turn the cancel current switch to the "open" position. Rotate the input range selector until an adequate ambient room light reading is obtained. This current reading is due to non-laser light only. This light is not to be measured. Therefore, compensate for it by adjusting the cancel current and cancel vernier to zero the meter. Turn the HeNe laser on and read the appropriate scale for the range selected.
- (7) To convert the microampere reading to power, multiply the current by the HeNe wavelength calibration factor obtained from the manufacturer. In our case, the calibration factor is .425 watts/ μ A for light having a wavelength of 632.8nm. Record data in Figure 32.

2. Phase I. Making a Laser Survey

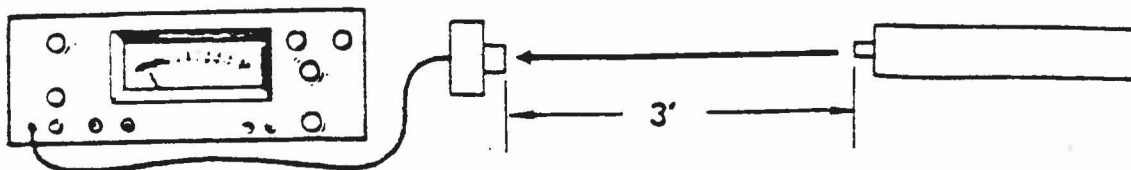
a. Measuring the Irradiance (contd.)

L8

LASER LABORATORY

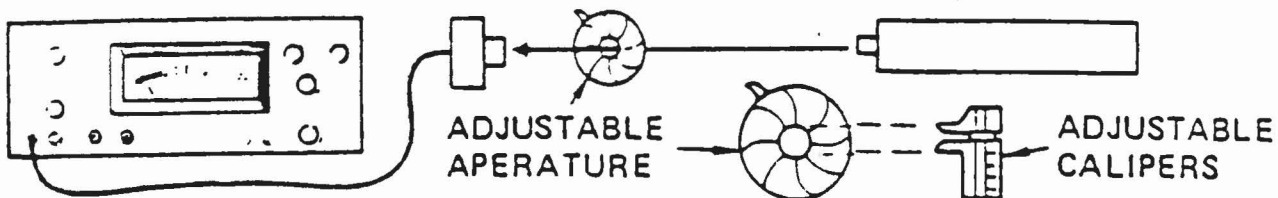
32

MEASURING THE POWER



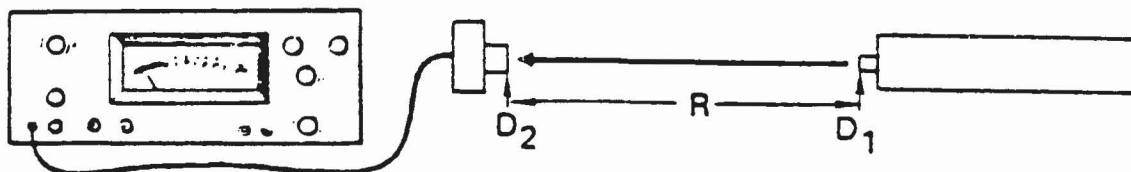
$$\text{_____ } \mu\text{A} \times \text{_____ C.F.} = \text{_____ WATTS}$$

MEASURING THE BEAM SIZE AND DETERMINING THE IRRADIANCE



$$\text{IRRADIANCE (E)} = \frac{\text{WATTS}}{(\frac{D}{2})^2 \pi} = \text{_____ } \frac{\text{WATT}}{\text{cm}^2}$$

MEASURING THE BEAM DIVERGENCE



$$\theta = \text{ARCSIN } \frac{D_2 - D_1}{R} =$$

2. Phase I. Making a Laser Survey

a. Measuring the Irradiance (contd.)

- (8) To convert the measured power to irradiance, the laser beam diameter must be measured. This is done by placing the adjustable aperture perpendicular to the beam and just in front of the PT200A detector. Adjust the aperture down until the laser beam just passes through the opening. Remove the aperture from the beam and measure the diameter of the opening using a vernier calipers or millimeter scale. The aperture should be held steady in the laser beam by a lab stand and clamp.
- (9) Calculate the irradiance using the following formula:

$$\text{Irradiance (E)} = \frac{\text{Power}}{\text{Area}} = \frac{\text{Watts Measured}}{(D/2)^2 \pi}$$

D = Beam Diameter

Enter data on Figure 32.

- (10) To calculate the beam divergence, the beam diameter at the laser exit port must be measured. Measure the beam diameter at the laser exit port using the same procedure as in Step 8.
- (11) Calculate the beam divergence using the following formula:

$$\theta = \arcsin \frac{D_2 - D_1}{R}$$

(for $\theta < .37$ rad)

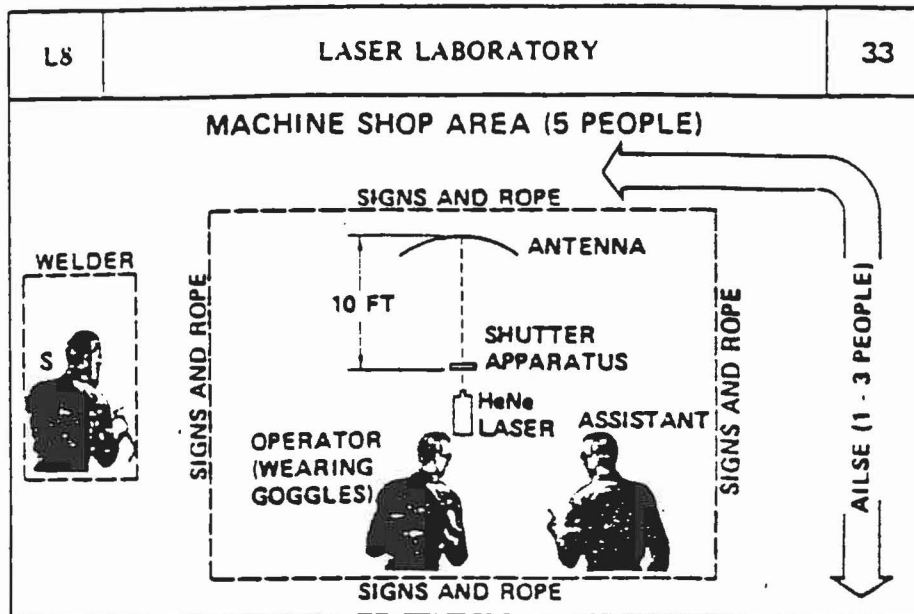
$$\theta \approx \frac{D_2 - D_1}{R}$$

Where: D_1 is the diameter of the laser beam at the exit port.

D_2 is the diameter of the laser beam at the detector point.

R is the distance between the laser exit port and the detector. θ is the beam divergence angle.

Record data on Figure 32.



2. Phase I. Making a Laser Survey (contd.)

b. The Survey Record

Suppose that the laser, of which you have just measured the irradiance, is being used to make antenna contour maps.

The Boeing Antenna Systems Company located at 1420 South Trenton Street, Seattle, Washington, is using the HeNe laser to map the contour of an antenna they have just constructed. The laser is (*) nm. and it has a power output of (*).

The environment in which the laser is operating is shown in Figure 33. The operator of the laser, Ann Tenner, has been an engineer in the antenna group for two years and is familiar with laser safety practices. She may be exposed to the direct or specularly reflected beam for five minutes or less, while using the laser.

Assume that you have been asked to make a laser survey of the operation just described. Use your measurements in Figure 32, the situation as shown in figure 33 and complete the Survey Record Form provided in Figure 34.

*Obtain information from laser used in lab.

2. Phase I. Making a Laser Survey (contd.)
 - b. The Survey Record

LASER/MASER										SURVEY RECORD				
GENERAL INFORMATION	USING ORGANIZATION					ADDRESS								
	TYPE OF EQUIPMENT					INTENDED USAGE								
	MANUFACTURE			MODEL		SERIAL NUMBER				OTHER				
HAZARD DETERMINATION	WAVELENGTH			BEAM DIAMETER AT X			ANGLE CONV/DIV							
	PEAK POWER			AVERAGE POWER			PULSED		ENERGY/PULSE					
	PULSE TIME		PRF		CLASS		COLLIMATED		EXTENDED		OTHER			
	DISTANCE TO SOURCE (FEET)	D/R	KEY	INST. READING (μA)	POWER I x C.F. = (W)	IRRAD P/A = (W/cm ²)	TLV							
							EXP. TIME (SEC.)	OCULAR (IRRAD) (O.D.)		SKIN (IRRAD)	EXT DIFF (IRRAD)			
ENVIRONMENT														
PERSONNEL	BACKGROUND SAFETY TRAINING UNAWARE ONLOOKER OTHER													
PERSONNEL PROTECTION	IN USE	EYEWEAR CLOTHING APERTURE OTHER					INTERLOCKS LIGHT SIGNS			SHIELDING FILM BADGE CONTROLLED AREA				
	RECOMMENDED													
CERT.	PERSONNEL RESPONSIBLE FOR EQUIPMENT OPERATION SURVEYED BY DATE													

3. Phase II. Properties of Laser Light

a. Transmission

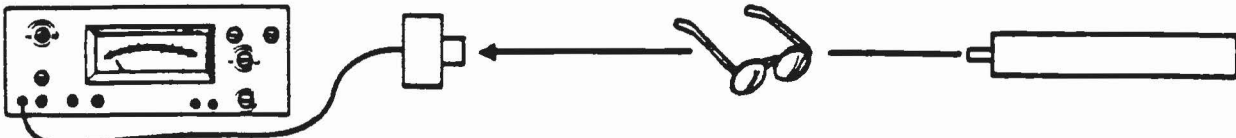
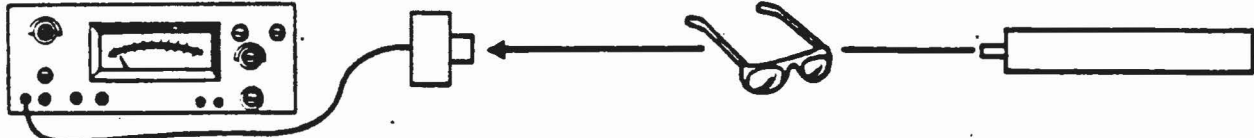
- (1) Set up the laser and detector as shown in Figure 35.
- (2) Cancel for ambient light using the cancel current and cancel vernier of the IL600.
- (3) Turn on the laser and insert one lens of a pair of eye-glasses into the HeNe laser beam. Measure the amount of HeNe laser light passed. Record the irradiance in Figure 35.
- (4) Repeat step (3) using goggles designed for a CO₂ laser.
- (5) Repeat step (3) using goggles designed for a HeNe laser.
- (6) Compare results of setp (3), (4), and (5). Which of the goggles mcasured would be sufficient for viewing this particular laser all day long? State conclusion on back of Figure 35.

b. Variation of Laser Irradiance with Distance

- (1) Set of the laser and detector as shown in Figure 36.
- (2) Determine the irradiance at one foot. Recall that the irradiance is the power ($\mu\text{A} \times \text{C.F.}$) divided by the beam area at the point of measurement. Record your measurment on Figure 36.
- (3) Repeat step (2) except at a source to detector distance of 2 and then 4 feet.
- (4) Does the irradiance vary as the inverse square of the distance?

2. Phase II. Properties of Laser Light (contd.)

a. Transmission

L8	LASER LABORATORY	35
PHOTOMETER DETECTOR EYEGLASSES LASER  _____ μA x _____ $\frac{\text{WATTS}}{\mu\text{A}}$ _____ WATTS _____ WATTS/ _____ cm^2 _____ WATTS/cm^2		
PHOTOMETER DETECTOR GOGGLES A LASER  _____ μA x _____ $\frac{\text{WATTS}}{\mu\text{A}}$ _____ WATTS _____ WATTS/ _____ cm^2 _____ WATTS/cm^2		
PHOTOMETER DETECTOR GOGGLES B LASER  _____ μA x _____ $\frac{\text{WATTS}}{\mu\text{A}}$ _____ WATTS _____ WATTS/ _____ cm^2 _____ WATTS/cm^2		

3. Properties of Laser Light (contd.)

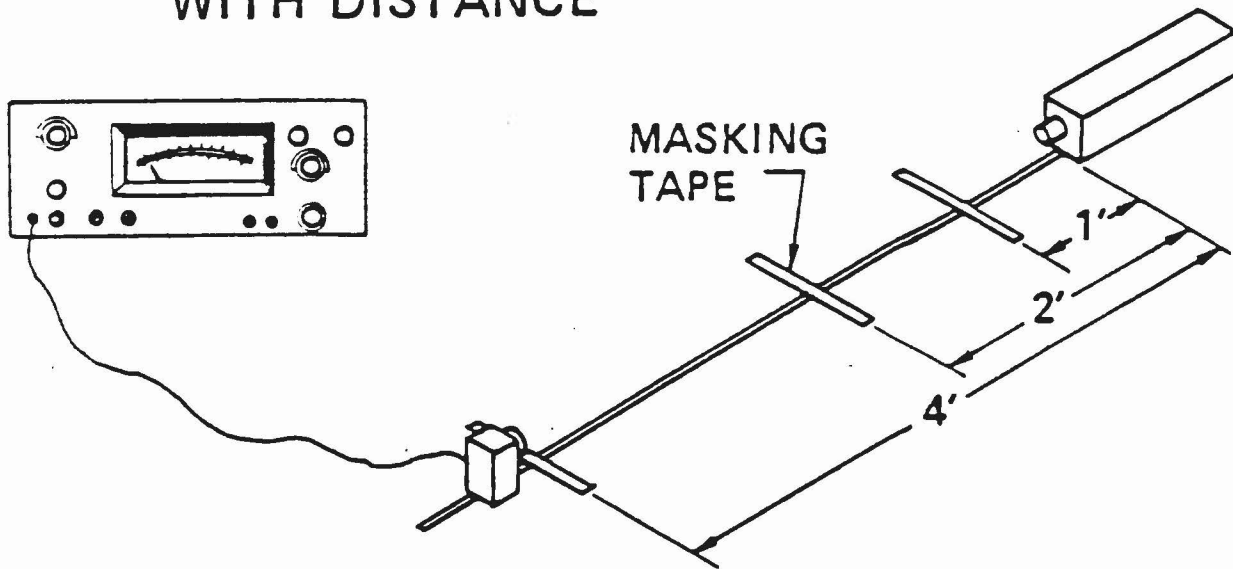
b. Variation of Laser Irradiance with Distance

L8

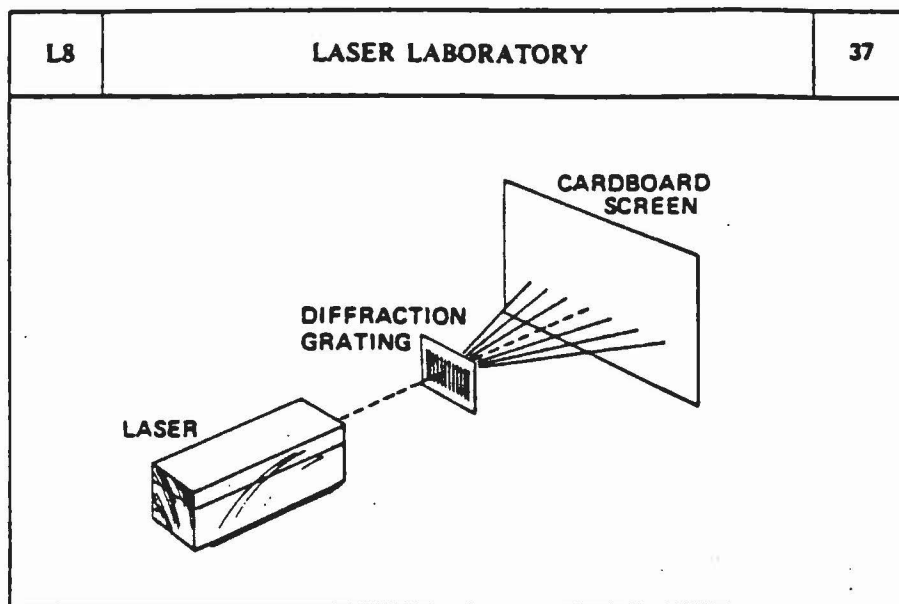
LASER LABORATORY

36

VARIATION OF IRRADIANCE
WITH DISTANCE



DISTANCE	READING			1/R ²
FEET	μA	$\mu A \times C.F.$	$\frac{\mu A \times C.F.}{AREA}$	$\frac{WATTS AT 1' =}{N}$
1				()/1 =
2				()/4 =
4				()/16 =

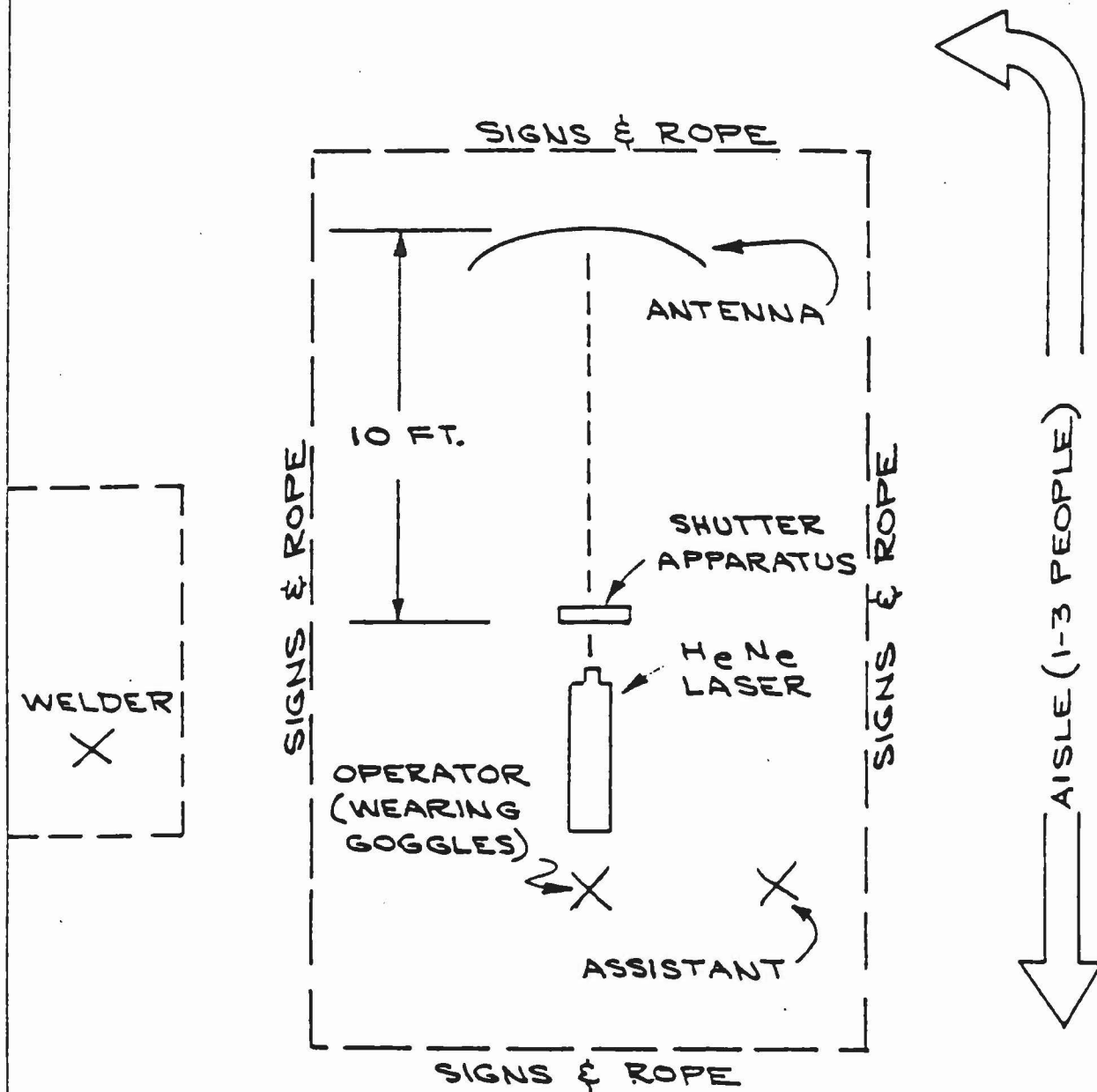


3. Phase II. Properties of Laser Light (contd.)

c. Diffraction of Laser Light

- (1) Set up the laser, diffraction grating and screen as shown in Figure 37. Turn out the room lights so that pattern may easily be viewed.
- (2) How many bright spots do you observe projected on the screen?
- (3) Can you explain this phenomenon?

MACHINE SHOP AREA
(5 PEOPLE)



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See also References listed in Text.

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