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ORNL-332 (Fifth Revision)

Health Physics Instrument Manual

E. D. Gupton

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INDUSTRIAL SAFETY AND APPLIED HEALTH PHYSICS DIVISION

Health Physics Instrument Manual

E. D. Gupton

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Part 2. Sources, Procedures, and Calibration Devices

Health Physics Instrument Manual

E. D. Gupton

INTRODUCTION

The purpose of this manual is to provide apprentice health physics surveyors and other operating groups not directly concerned with radiation-detection instruments a working knowledge of the radiation-detection and -measuring instruments in use at the Laboratory. The choice of an instrument is a result of several factors, which include availability at the time of request, development and testing programs in progress, and economy.

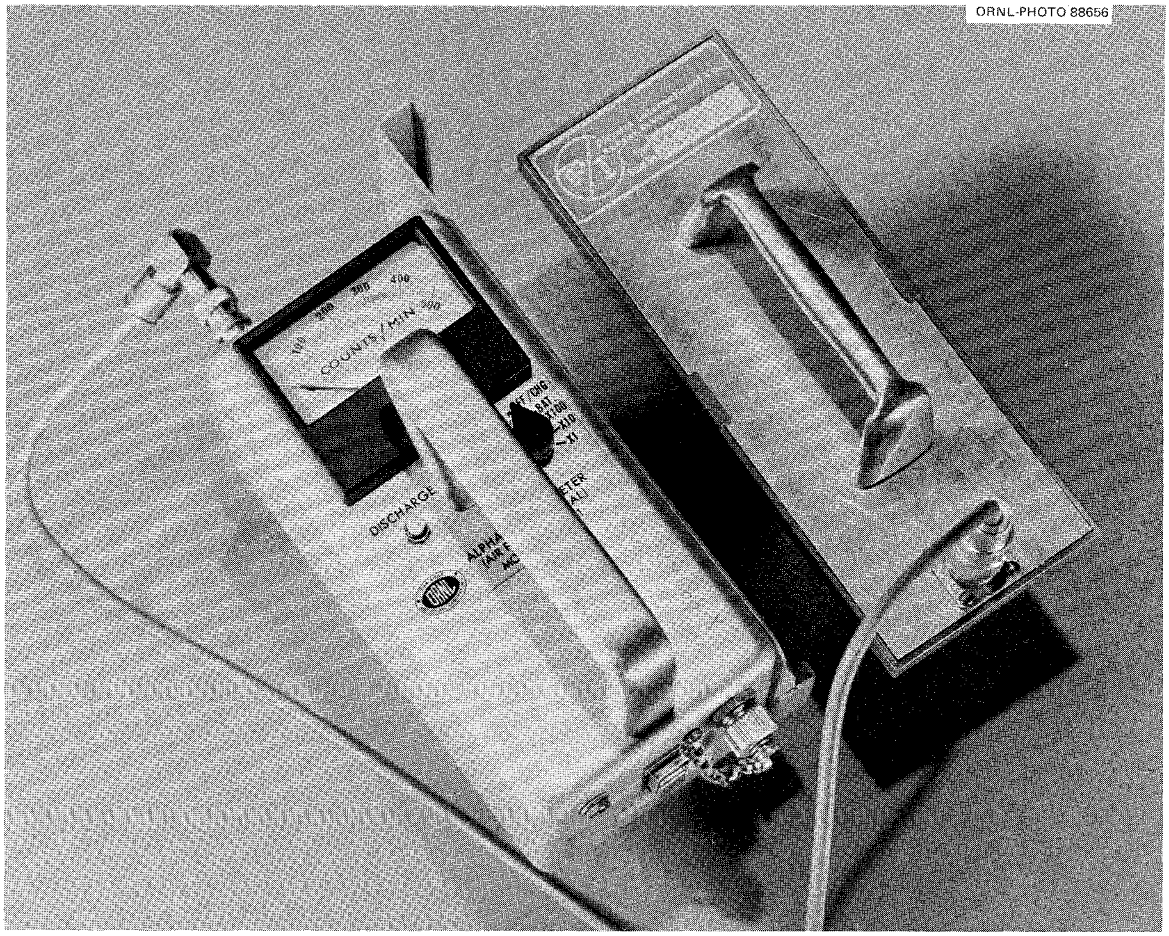
The inclusion of the description of an instrument in this manual is not to be interpreted as an endorsement for that instrument, nor is the omission of an instrument any derogatory reflection on its merits.

Part 1 of this manual is a ready reference to the radiation monitoring instruments (for personnel and for other kinds of monitoring) and is written as nontechnically as possible in order that even casual users of the instruments can quickly obtain the prominent characteristics and uses of the instruments. Part 2 is for those who need a working knowledge of sources and calibration procedures and devices.

Part 1

Some Models of Radiation Detection and Measuring Instruments Used for Health Physics Monitoring at Oak Ridge National Laboratory

1.1 Portable Instruments



Alpha Survey Meter, Air Proportional

The portable alpha air proportional counter has transistorized circuitry and a lightweight probe. It may be used in regions where the relative humidity is moderate to low. Pulses from the counter are indicated by a rate meter and an earphone. The power is supplied by nickel-cadmium cells, which are charged by a plug-in trickle charger operated from 110 V, 60 Hz.

ALPHA SURVEY METER, AIR PROPORTIONAL

Characteristics

1. Radiation detected: alpha
2. Ranges: ×1, ×10, ×100
3. Sensitivity: 500 counts/min, full scale, ×1
4. Geometry: 8 to 14% of 4π for ^{239}Pu
5. Sensitive area of detector: 90% of 100 cm^2
6. Gamma discrimination: 1 count/min per R/hr, ^{60}Co
7. Indicating devices: rate meter and earphones
8. Warm-up time: 10 sec
9. Power: Ni-Cd batteries
10. Dimensions: $8 \times 4\frac{1}{2} \times 4\frac{1}{2}$ in. high
11. Weight: $4\frac{1}{4}$ lb

Application

1. Will detect alpha in presence of nominal levels of beta and gamma radiation when high voltage and discriminator are properly adjusted.
2. May not operate properly in regions of high relative humidity.
3. Response will vary with temperature and atmospheric pressure.
4. Should be checked with a source before each use.

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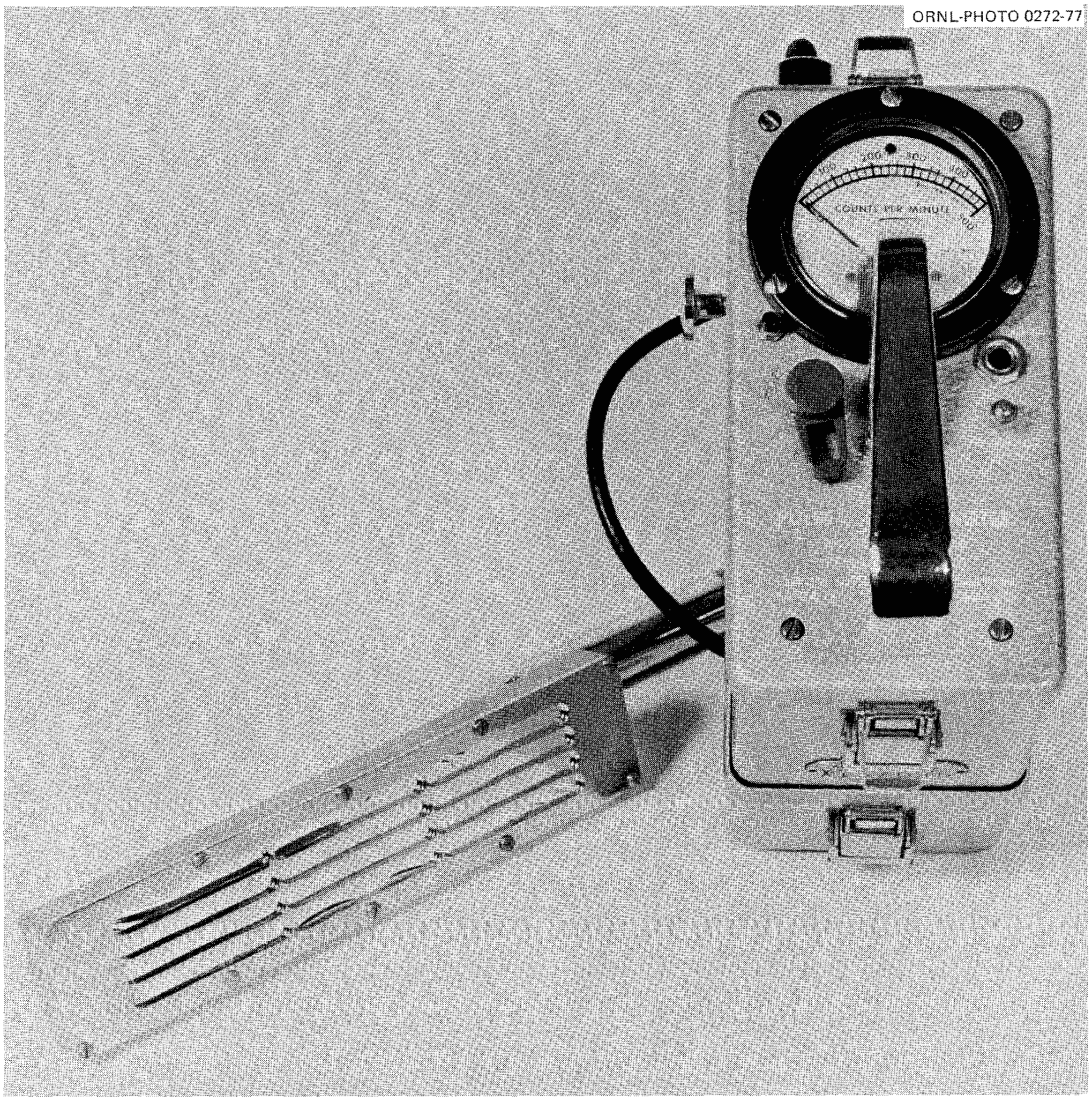

Alpha Survey Meter, Gas Proportional

The portable gas proportional alpha counter has a propane gas-flow chamber. The circuitry is transistorized and operated by dry-cell batteries. Pulses from the counter are indicated by a rate meter and earphones. The gas-flow counter is superior to an air proportional counter in regions of high relative humidity.

ALPHA SURVEY METER, GAS PROPORTIONAL

Characteristics

1. Radiation detected: alpha
2. Ranges: ×1, ×10, ×100, ×1000
3. Sensitivity: 500 counts/min, full scale, ×1
4. Geometry: 12 to 16% of 4π for ^{239}Pu
5. Sensitive area of detector: 61 cm^2
6. Gamma discrimination: 0.1 count/min per R/hr, ^{60}Co
7. Indicating devices: rate meter and earphones
8. Warm-up time: 3 min to flush counter
9. Power: dry-cell batteries
10. Dimensions: $8^1/_4 \times 4 \times 9^3/_4$ in. high
11. Weight: 9 lb

Application

1. Will detect alpha in the presence of nominal levels of beta and gamma radiation when high voltage and discriminator are properly adjusted.
2. May respond to fast neutrons by the (n,p) reaction in propane.
3. May be used in regions of high relative humidity.
4. Requires propane gas cylinder which will last about 12 hr.
5. Flush, operate, and off positions of gas valve should be properly used.
6. Should be checked with a source before each use.

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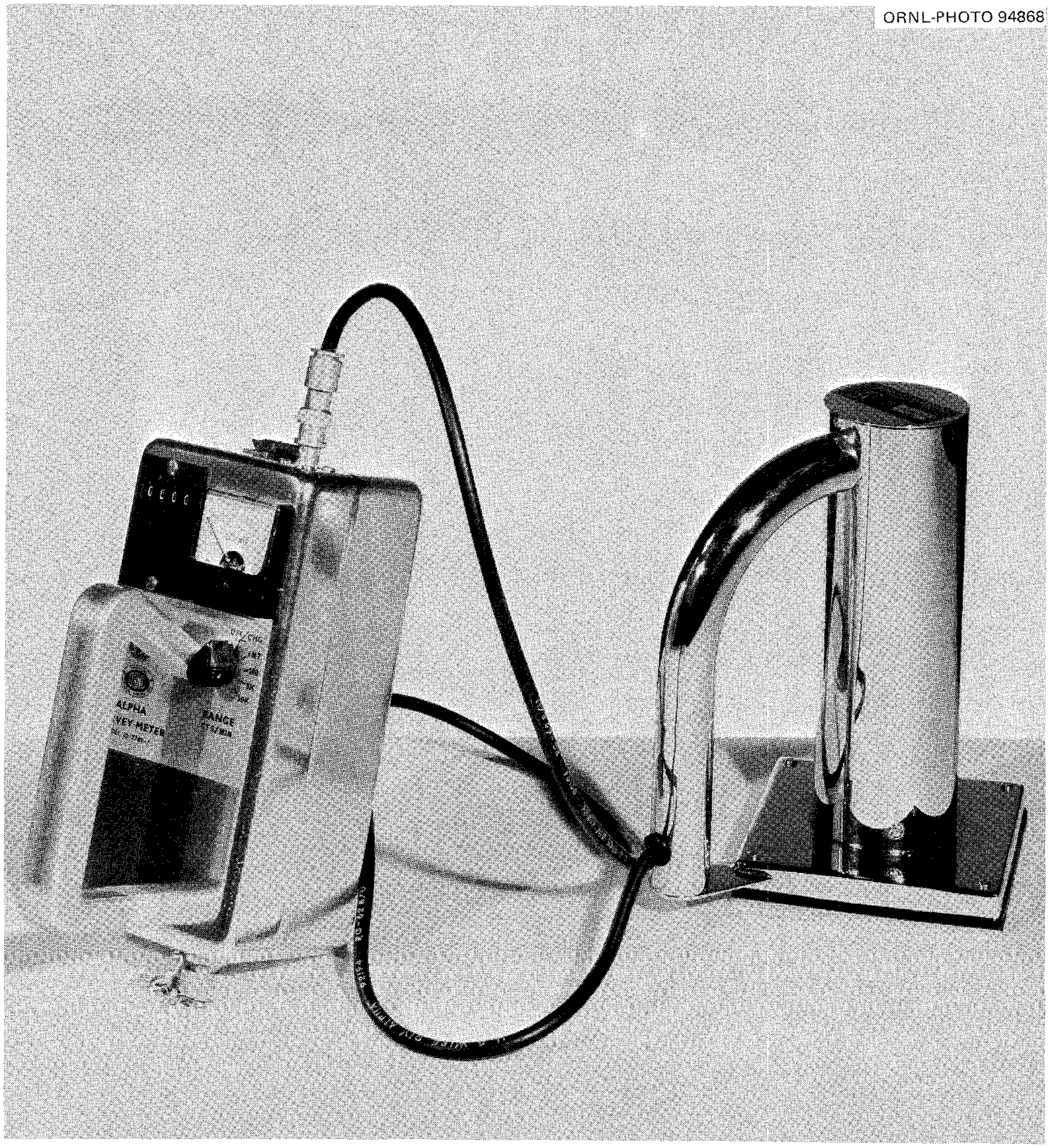


Alpha Survey Meter, Scintillation

The portable scintillation alpha survey meter is a battery-powered, transistorized amplifier with a high-voltage supply especially designed for use with an alpha scintillation probe. A register range is provided, thus obviating the difficulty of reading low counting rates on the meter. An output for earphone operation is also provided. The power is supplied by nickel-cadmium cells. The probe employs a 2-in. photomultiplier, a zinc sulfide phosphor, and a lighttight window.

ALPHA SURVEY METER, SCINTILLATION

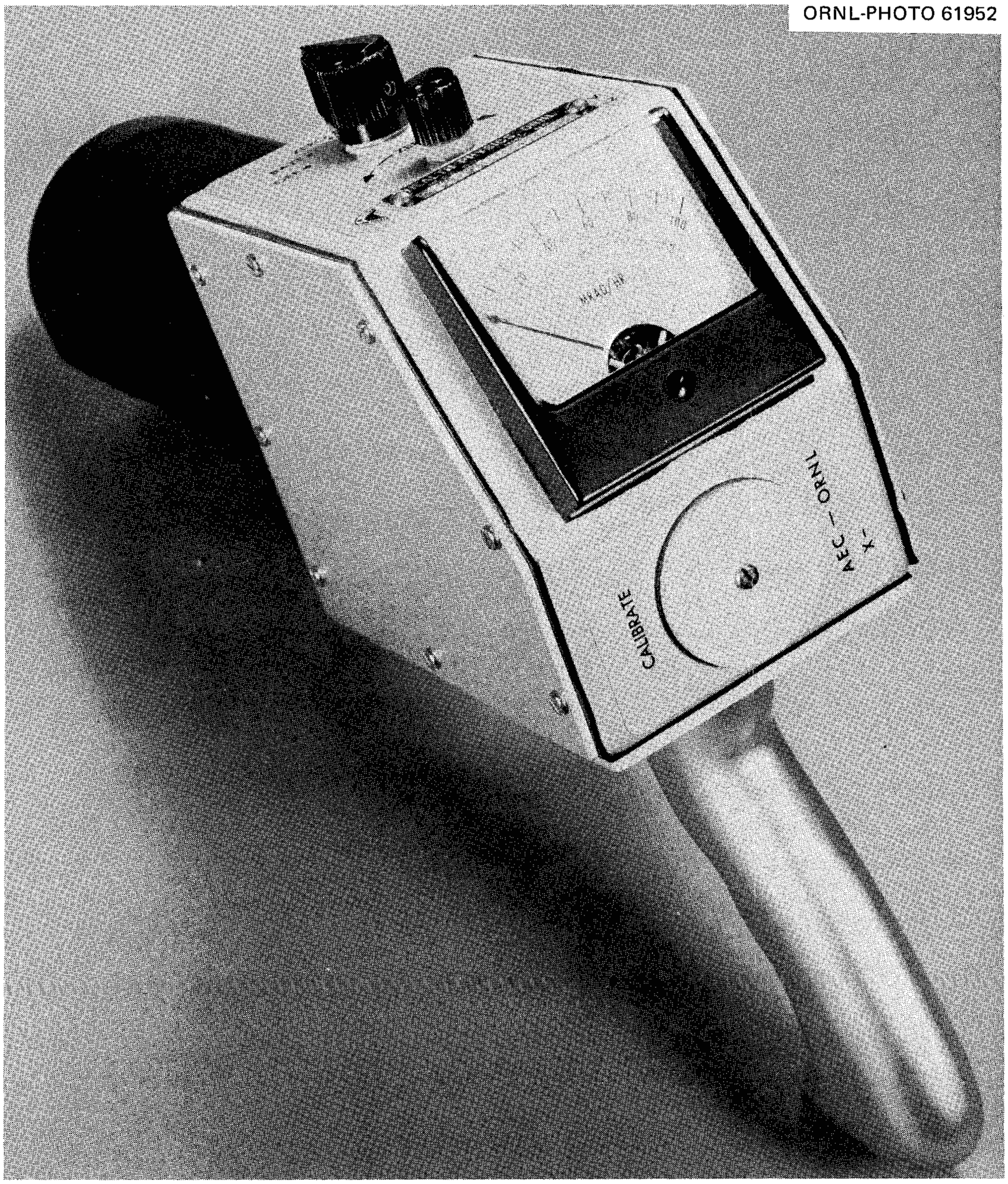
Characteristics

1. Radiation detected: alpha
2. Ranges: registered and 500, 5K, and 50K counts/min
3. Sensitivity: register, 1 count/register
4. Geometry: 10 to 15% of 4π for ^{239}Pu
5. Sensitive area of detector: 70% of 100 cm^2
6. Gamma discrimination: 20 counts/min per R/hr, ^{60}Co
7. Indicating devices: rate meter, register, and earphones
8. Warm-up time: 10 sec
9. Power: Ni-Cd batteries
10. Dimensions: $9\frac{1}{2} \times 3\frac{1}{2} \times 6$ in. high; probe, $5 \times 5 \times 8$ in. high

Application

1. Will respond to high levels of beta and gamma radiation and to fast neutrons.
2. The lighttight window should be protected from damage.
3. A high background rate may be due to light leakage rather than contamination.
4. The register may jam at rates in excess of 20 counts/sec.
5. Should be checked with a source before each use.

ORNL-PHOTO 61952



Cutie Pie (Standard Model)

This is a relatively small, lightweight, portable survey instrument used for the measurement of gamma air absorbed dose rates. It is also used for the indication of beta radiation.

CUTIE PIE (STANDARD MODEL)

Characteristics

1. Radiation detected: beta, gamma, X ray
2. Ranges: 100, 1000, and 10,000 mrad/hr, full scale
3. Accuracy: maximum error is ±10% of full scale
4. Chamber wall: air equivalent with 50% of lateral area 7 mg/cm^2 and 50% 150 mg/cm^2
5. Energy dependence: ±10% for gamma and X rays, 10 to 2000 keV
6. Response time: less than 3 sec to reach full scale
7. Warm-up time: 10 sec
8. Power: dry-cell batteries
9. Dimensions: overall, 10 × 3 × 8 in.; chamber, 6 × 3 in. diam
10. Weight: 2¾ lb

Application

1. The instrument is calibrated with gamma radiation, incident normally to the lateral surface of the chamber.
2. Beta radiation dose rates in tissue rads may be estimated within a factor of 2 by using the millirad per hour readings.
3. The instrument should not be used if the end or wall covering of the chamber is punctured.
4. The zero setting should be checked frequently during the first few minutes of use and subsequently at intervals of not more than 5 min.
5. The radiation response function of the instrument should be checked prior to each use.

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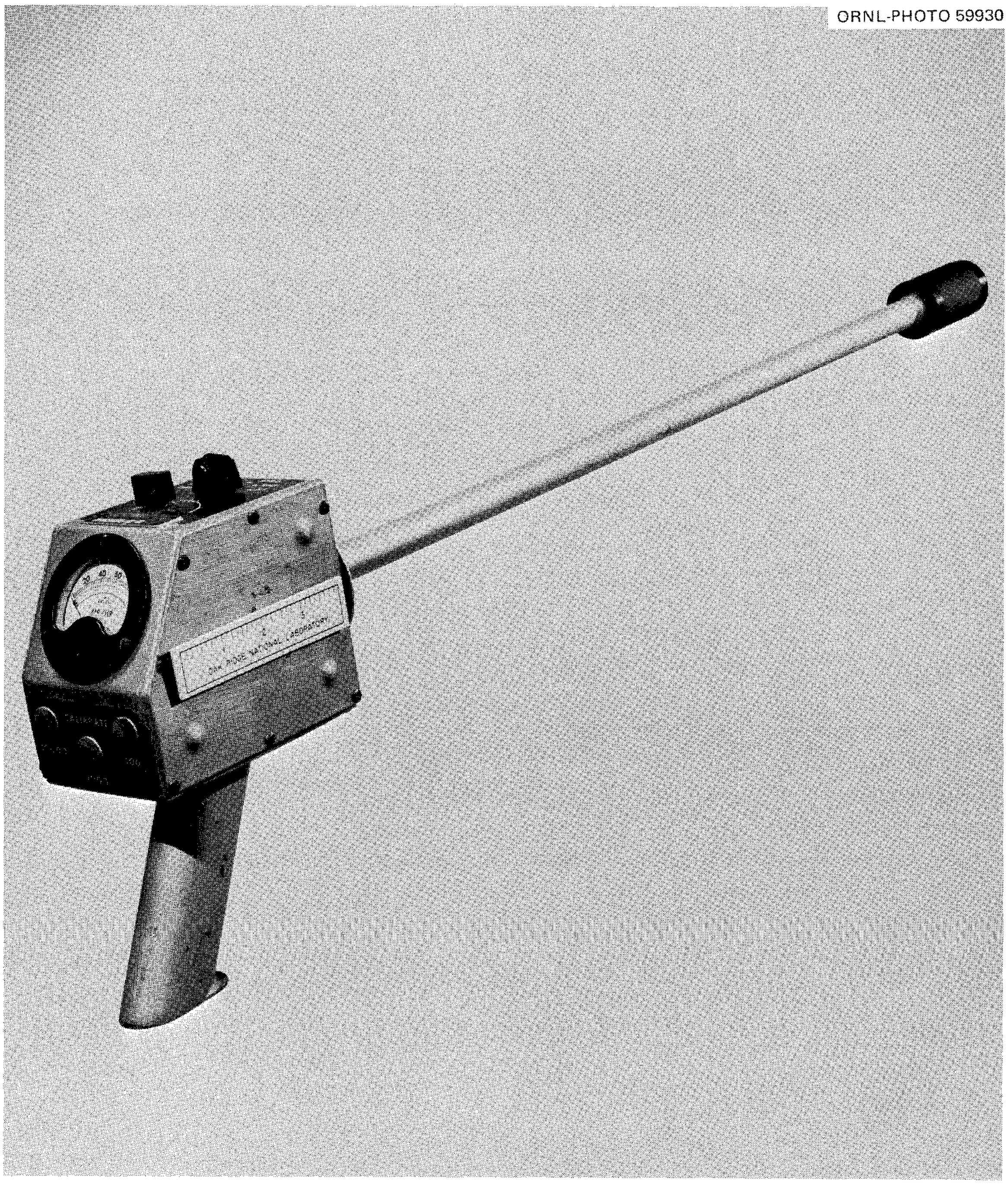
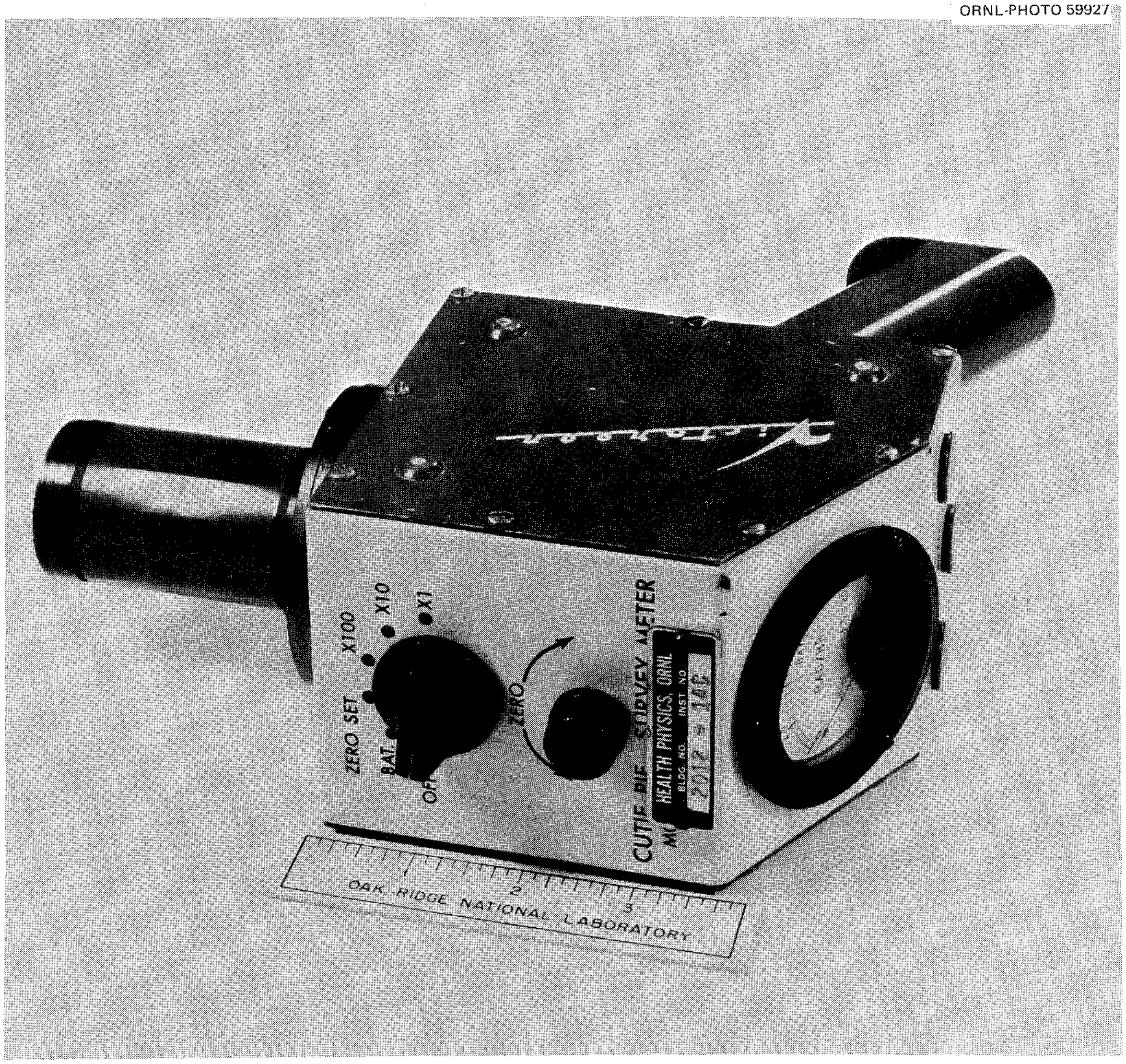


Extended Probe Cutie Pie

The extended probe cutie pie is similar to the standard cutie pie except that the chamber is smaller in volume and remotely affixed by means of a 2-ft length of rigid tubing. The full-scale ranges are 1, 10, and 100 rads/hr.

ORNL-PHOTO 59927



Hi-Range Cutie Pie

The hi-range cutie pie is similar to the standard cutie pie except that the chamber volume and the electrometer input resistors are adjusted to provide full-scale ranges of 10, 100, and 1000 rads/hr.

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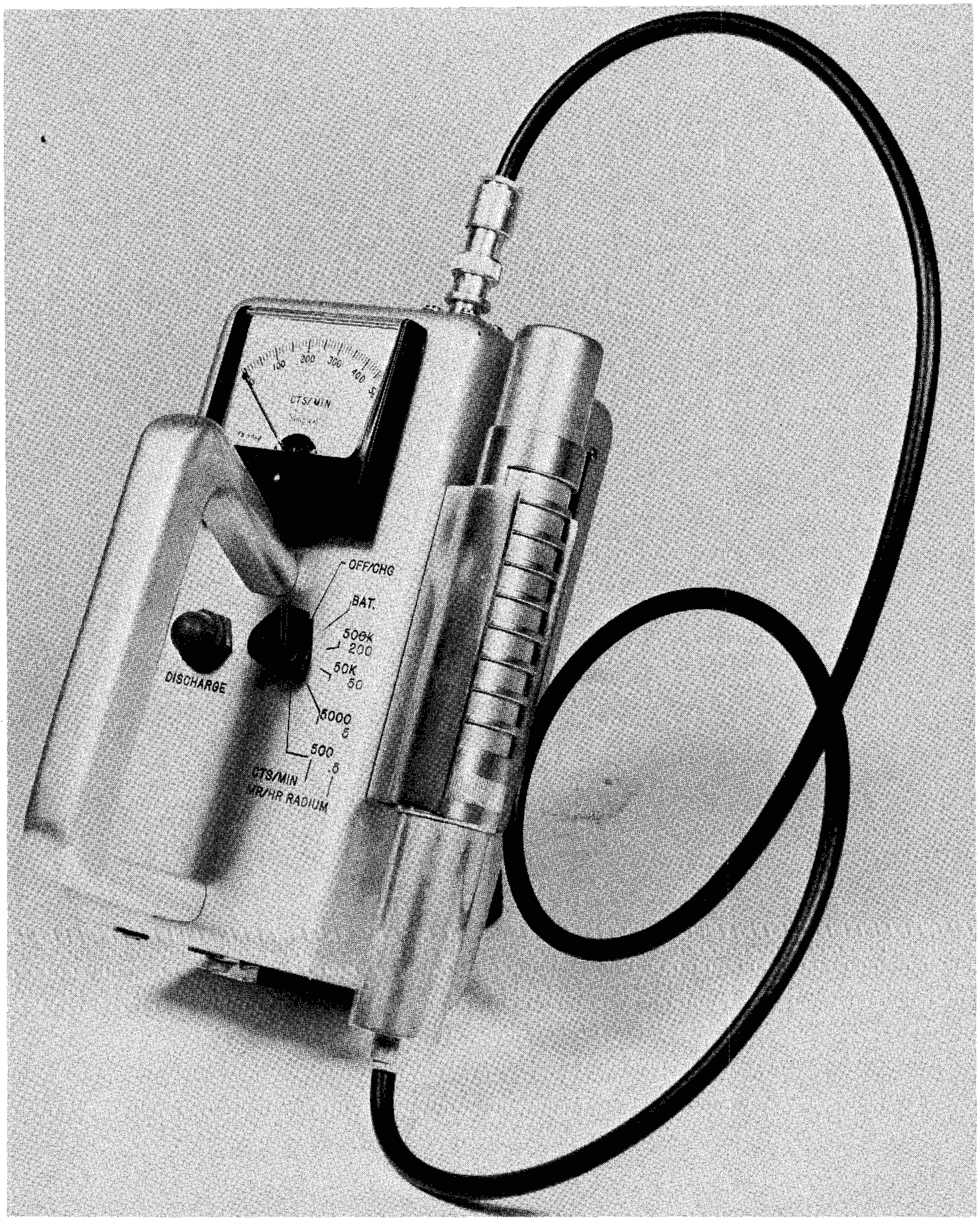


G-M Survey Meter

This device is a medium-weight, portable, beta-gamma indicating survey instrument. Audible or visible indication of radiation is afforded by means of earphones and a count rate meter. The Q-2092A survey meter was designed to operate in gamma ray intensities up to and exceeding 500 R/hr.

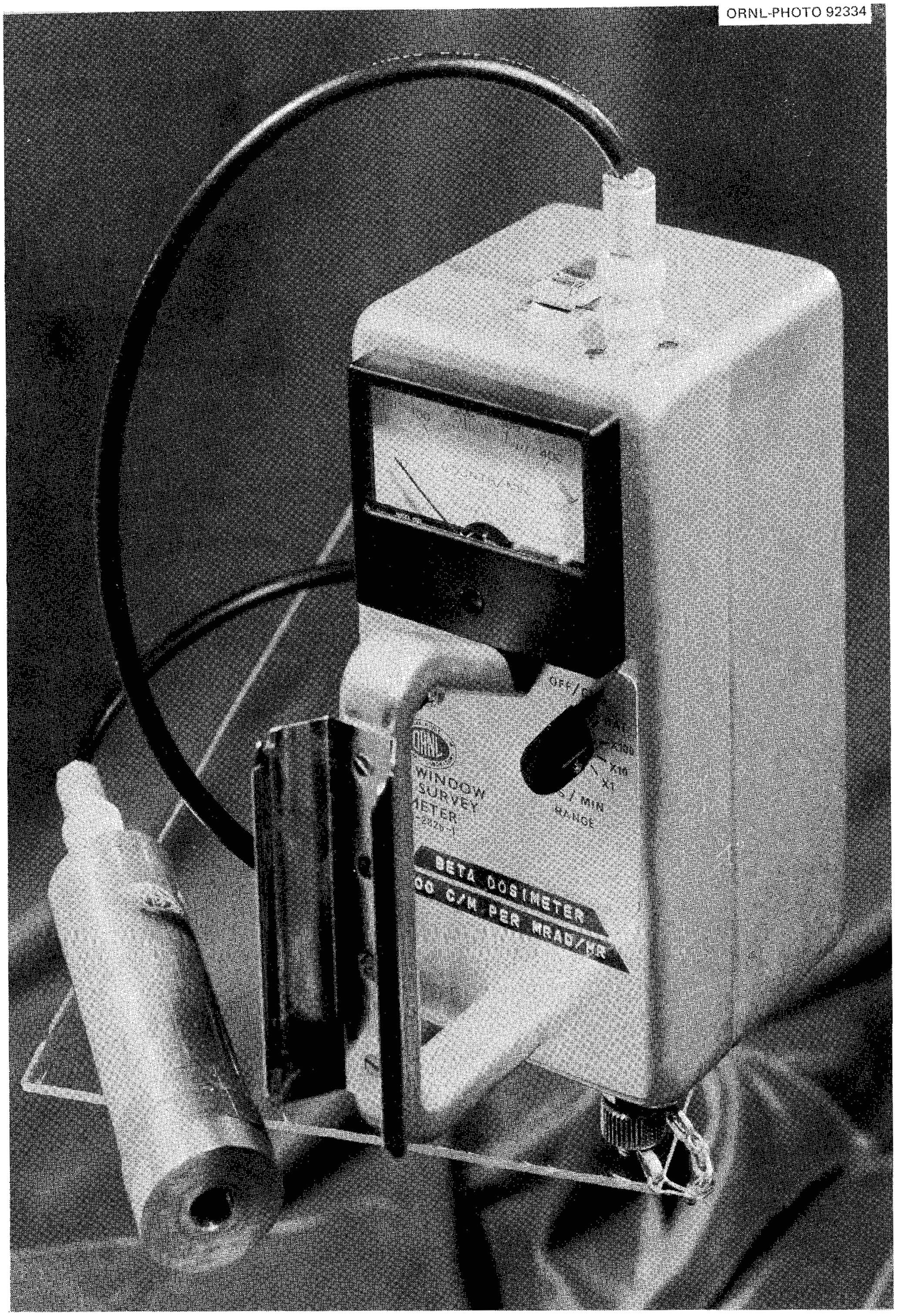
G-M SURVEY METER

Characteristics

1. Radiation detected: beta of energy greater than 0.2 MeV and gamma
2. Ranges: 500, 5000, 50,000, and 500,000 counts/min; corresponds roughly to 0.2 2, 20, and 200 mR/hr, radium-gamma
3. Probe: sliding shield for beta-gamma differentiation; 30 mg/cm^2, stainless steel cathode G-M tube
4. Indicating devices: rate meter and earphones
5. Warm-up time: 10 sec
6. Power: Ni-Cd battery
7. Dimensions: 8 × 5 × 6 in. high
8. Weight: 5$^1/_4$ lb

Application

1. Should not be used in measuring dosage rates, but rather as a detection instrument.
2. With shield open the meter indicates beta radiation above approximately 0.2 MeV.
3. Indicates approximately the magnitude of radium-gamma radiation between intensities of 0.05 and 200 mR/hr.
4. Should be used in conjunction with earphones, since they respond more quickly than the count rate meter to pulses.



End-Window G-M Survey Meter

This is a lightweight survey meter for low-energy beta radiation monitoring. The circuitry is transistorized and powered by a rechargeable cell.

END-WINDOW G-M SURVEY METER

Characteristics

1. Radiation detected: alpha, beta gamma
2. Ranges: ×1, ×10, ×100
3. Sensitivity: 500 counts/min, full scale, ×1
4. Probe: 1 in. diam, 2 mg/cm^2 mica window
5. Indicating devices: rate meter and earphones
6. Warm-up time: 10 sec
7. Power: Ni-Cd battery
8. Dimensions: 8 × 3$^5/_8$ × 7$^1/_2$ in. high
9. Weight: 3$^1/_2$ lb

Application

1. Should not be used for dose-rate measurements, except if calibrated and labeled for that purpose.
2. Care should be taken to prevent damage to the thin window of the detector.
3. Alpha and gamma radiation may interfere with beta measurements.

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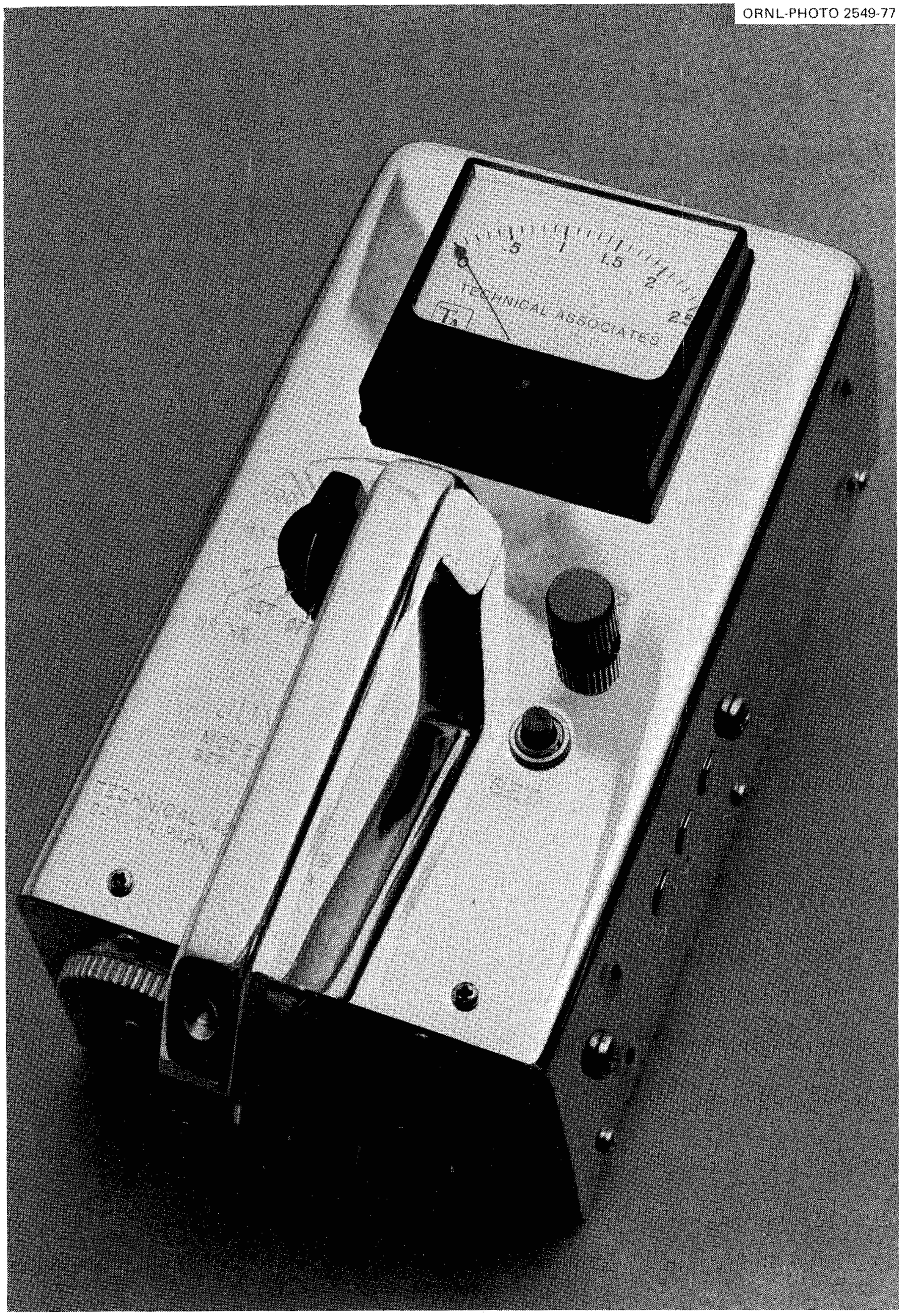


Juno Survey Meter

This instrument utilizes an ionization chamber with a rate meter to measure the intensity of gamma radiation and to indicate the relative intensity of beta-particle emission rates. Two manually positioned shields are incorporated to aid in determining types of radiation measured.

JUNO SURVEY METER

Characteristics

1. Radiation detected: alpha, beta, gamma
2. Absorbers: alpha, 1 mg/cm^2; beta, 50 mg/cm^2; gamma, $^3/_{32}$-in.-thick aluminum
3. Ranges: ×1, ×10, ×100, mR/hr and R/hr
4. Sensitivity: 2.5 mR/hr, full scale, ×1, mR/hr
5. Warm-up time: 15 sec
6. Power: dry-cell batteries
7. Dimensions: $11^1/_2$ in. long, $5^3/_4$ in. wide, $6^1/_2$ in. high
8. Weight: $6^1/_2$ lb

Application

1. With shields closed, the Juno will measure (within 10%) gamma radiation between the intensities of 0.5 mR/hr and 250 R/hr.
2. By using the movable filters, differentiation between alpha, beta, and gamma radiation may be facilitated.
3. For accurate gamma measurement, the instrument should be oriented with respect to the source as in the calibration procedure.

ORNL-PHOTO 62734

Fast-Neutron Survey Meter

This survey meter is a transistorized count rate meter calibrated in terms of millirems per hour. The detector is a tissue-equivalent proportional counter. A register is provided for very low dose-rate measurement. Unique circuitry provides excellent discrimination against gamma radiation.

FAST-NEUTRON SURVEY METER

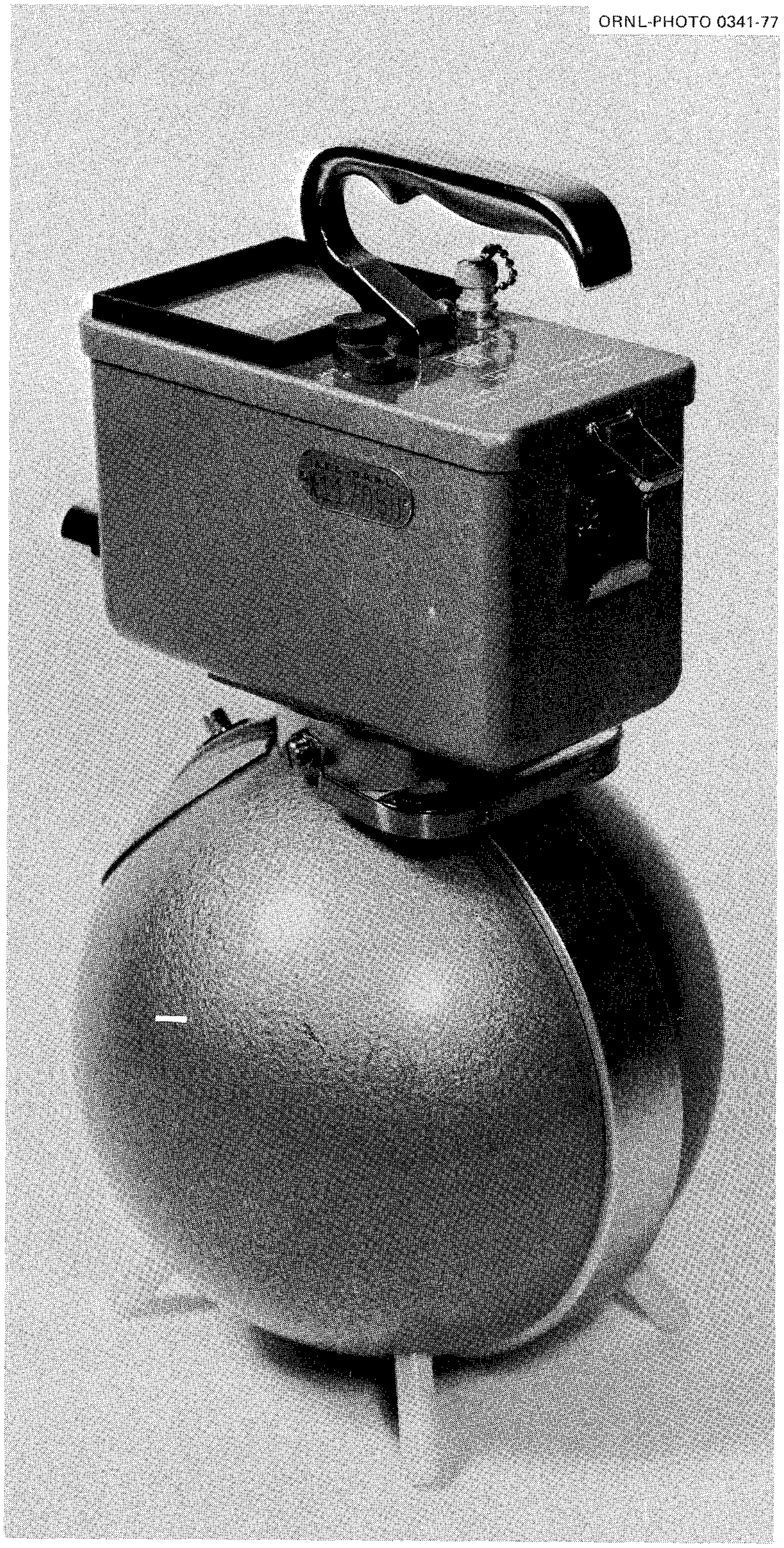
Characteristics

1. Radiation detected: fast neutrons
2. Ranges: 25, 250, and 2500 mrem/hr, plus count register
3. Energy response: ±20%, 0.2 to 10 MeV
4. Detector: proton recoil proportional counter
5. Gamma discrimination: <5 counts/min per R/hr, ^{60}Co
6. Indicating device: rate meter, register, and earphones
7. Warm-up time: 5 sec
8. Power: Ni-Cd batteries
9. Dimensions: 8½ in. long, 5 in. wide, 7½ in. high
10. Weight: 6¾ lb.

Application

1. When properly adjusted, it is sensitive only to fast neutrons.
2. Should be charged 3 hr for each hour of operation. Overcharging is not a problem.
3. Battery check should be made prior to use.
4. Register range may be used for integrating the dose.

ORNL-PHOTO 0341-77



Neutron Dosimeter

This dosimeter is equipped with a detector which has a response to neutrons in the energy range thermal to 15 MeV which approximates dose equivalent (rem) units.

NEUTRON DOSIMETER

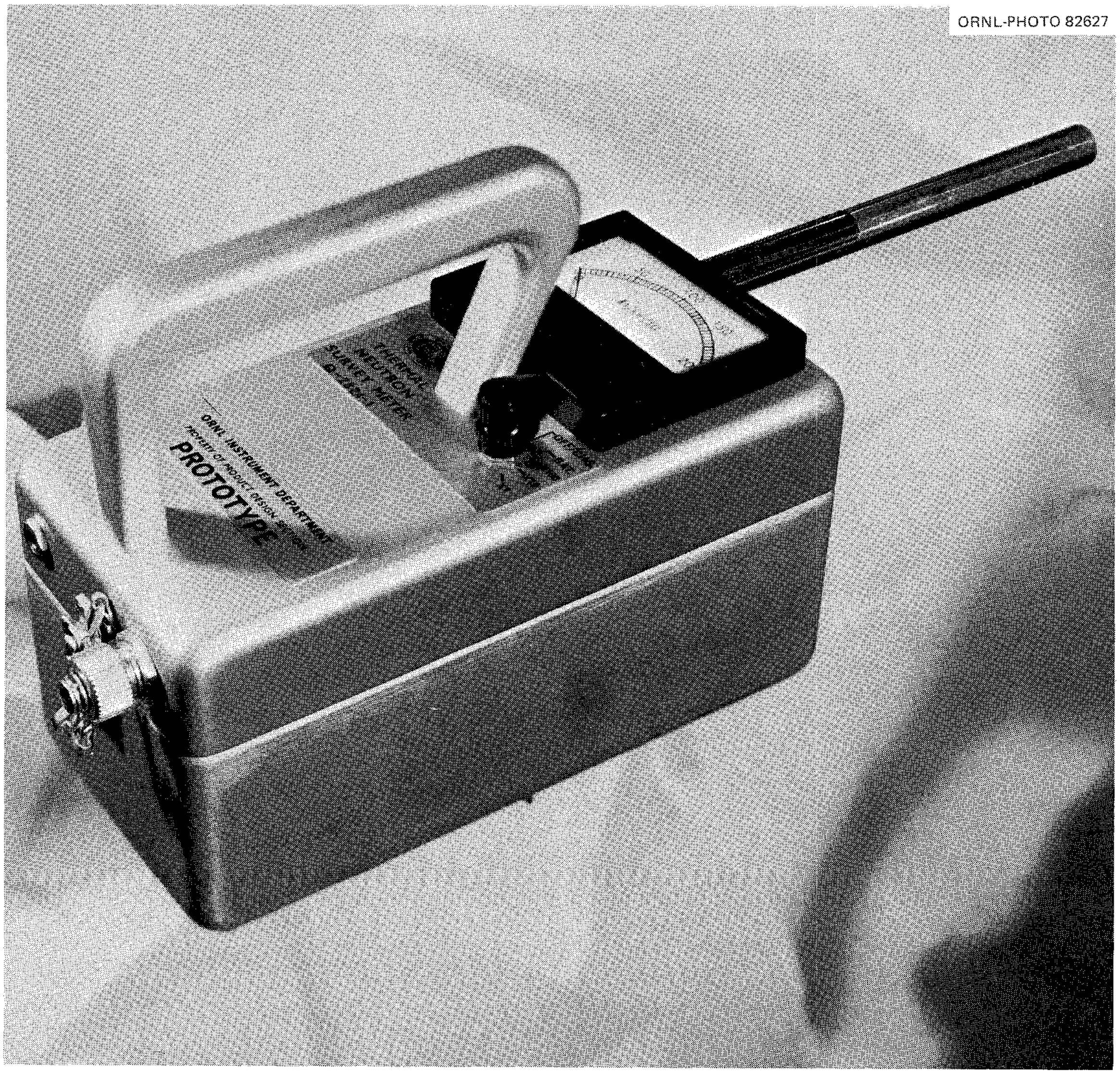
Characteristics

1. Radiation detected: neutron
2. Range: 1 to 5000 mrem/hr
3. Detector: BF_3 counter
4. Indicating devices: panel meter and headphones
5. Sensitivity: approximately 3000 counts/mrem
6. Dimensions: moderator, 9 in. diam; rate meter, 7¼ in. high, 4 in. wide, 9½ in. long
7. Weight: detector, 14 lb; rate meter, 6 lb

Application

1. High-voltage setting and neutron-source calibration should be periodically checked.
2. This instrument may be used to determine, within acceptable limits, the hazard from heterogeneous energy mixtures of neutrons. The determination is in dose equivalent units (rem).

ORNL-PHOTO 82627



Thermal-Neutron Counter (Portable)

The portable thermal-neutron counter is a lightweight instrument for measuring thermal-neutron fluence rates. All circuitry is transistorized, and power is provided by rechargeable nickel-cadmium cells. The detector is relatively insensitive to gamma radiation.

THERMAL-NEUTRON COUNTER (PORTABLE)

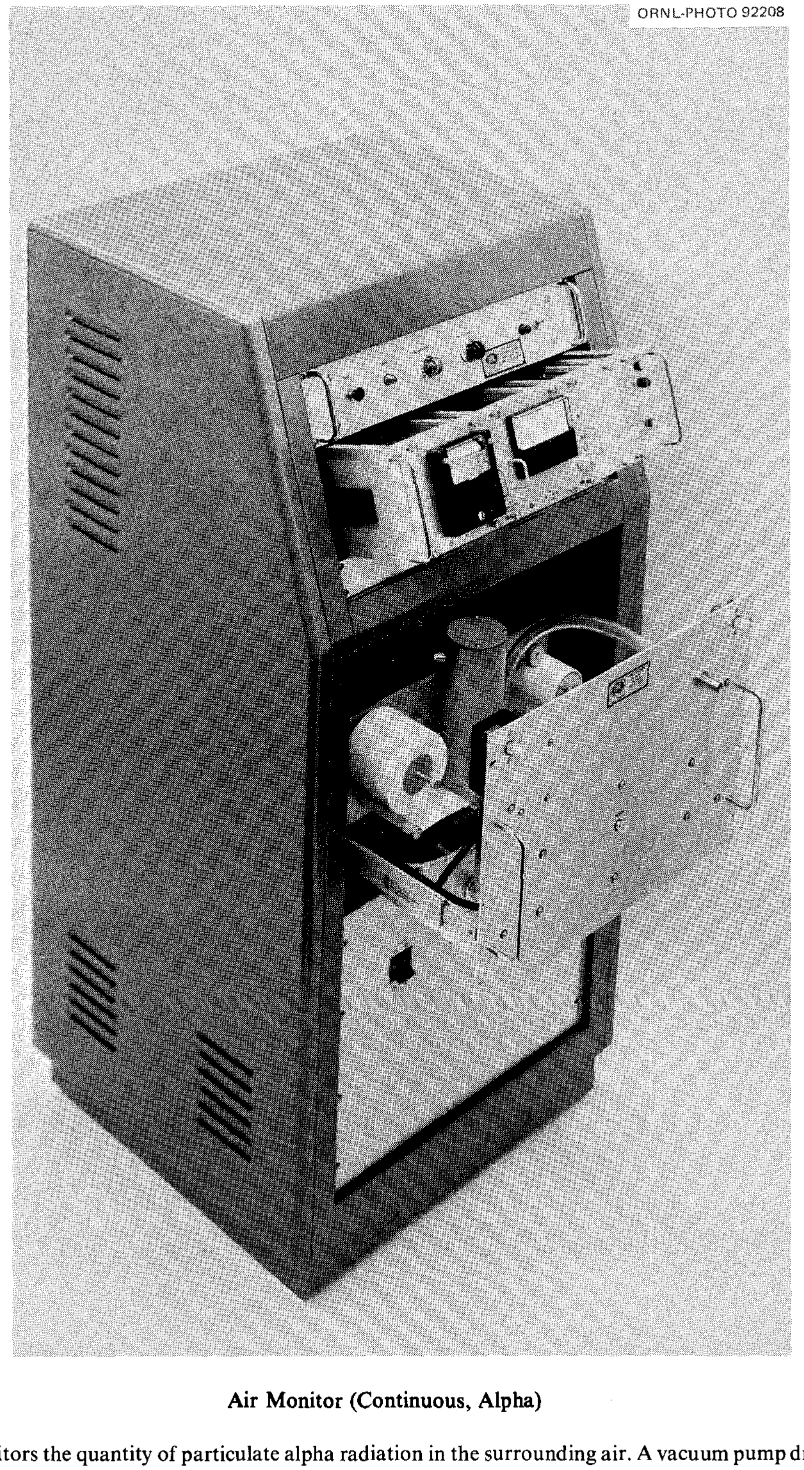
Characteristics

1. Radiation detected: thermal neutrons, relatively insensitive to gamma radiation
2. Ranges: ×1, ×10, ×100
3. Detector: BF_3 proportional counter
4. Sensitivity: 200 neutrons cm^{-2} sec^{-1}, full scale, ×1
5. Gamma discrimination: <1 count/min per R/hr, ^{60}Co
6. Indicating devices: rate meter and earphones
7. Warm-up time: 10 sec
8. Power: Ni-Cd batteries
9. Dimensions: main compartment, 8 × 3¾ × 6½ in. high; counter, 6 × ½ in. diam
10. Weight: 3¼ lb

Application

1. Instrument responds only to thermal neutrons.
2. Will detect fast and intermediate neutrons when equipped with moderator which is provided as an accessory.

1.2 Stationary Instruments



Air Monitor (Continuous, Alpha)

This device monitors the quantity of particulate alpha radiation in the surrounding air. A vacuum pump draws air through a filter under a scintillation detector. The detector is connected to a count rate meter which is connected to a strip-chart recorder, and the radiation level is continuously recorded. An associated relay-alarm system permits visible and audible alarms to be activated at predetermined levels.

AIR MONITOR (CONTINUOUS, ALPHA)

Characteristics

1. Radiation detected: alpha particles
2. Filter efficiency: 90% or greater for particle sizes >0.3 μ
3. Counting geometry: 40% of 4π
4. Detector: photomultiplier with ZnS phosphor
5. High voltage: 900 V
6. Rate meter range: 1000 counts/min
7. Recorder: 1 mA
8. Pump capacity: 8 to 10 ft^3/min
9. Airflow rate: nominally 3 ft^3/min
10. Alarm: amber light and 15-sec buzzer at 600 counts/min (caution level); red light and continuous bell at 800 counts/min (high level)
11. Other signals: tape-break buzzer and light
12. Automatic filter replacement by internal timer or if a preset counting rate is exceeded for 10 min, register indicates number of sample changes
13. Power: 110 V, 60 Hz
14. Dimensions: 24 in. wide, 24 in. deep, $51\frac{1}{4}$ in. high
15. Weight: 320 lb

Application

1. When properly adjusted, the instrument will maintain continuous monitoring of the air and keep a permanent record of the relative quantity of radioactivity collected on the filters.
2. The instrument does not differentiate between naturally occurring and man-made alpha emitters.
3. If the caution level is continuously exceeded for 10 min, a filter change is made automatically.
4. The high-level alarm will be sounded and "latched-in" whenever the high-level alarm point is exceeded.
5. The filter may be changed at any time by operation of a push-button switch.

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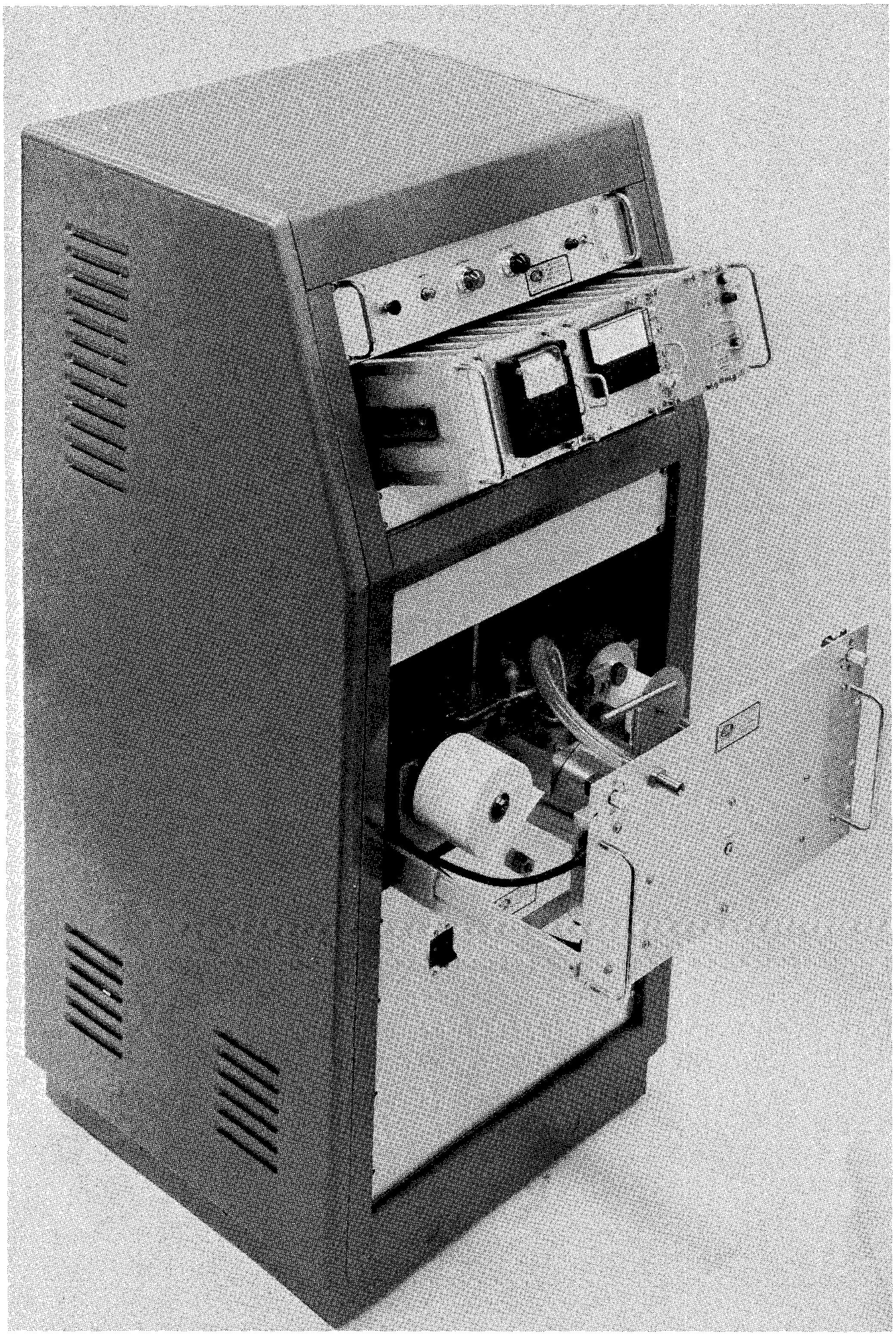

Air Monitor (Continuous, Beta-Gamma)

This device monitors the quantity of particulate beta-gamma radiation in the surrounding air. A vacuum pump draws air through a filter over a G-M tube mounted in a lead or stainless steel shield. The tube is connected to a count rate meter which is connected to a strip-chart recorder, and the radiation level is continuously recorded. An associated relay-alarm system permits visible and audible alarms to be activated at predetermined levels.

AIR MONITOR (CONTINUOUS, BETA-GAMMA)

Characteristics

1. Radiation detected: beta radiation of energy greater than 0.1 MeV and gamma rays
2. Filter efficiency: 90% or greater for particle sizes $>0.3\ \mu$
3. Counting geometry: 10% of 4π
4. Counter: halogen quenched, side-window G-M
5. High voltage: 900 V
6. Rate meter range: 5000 counts/min
7. Recorder: 1 mA
8. Pump capacity: 8 to 10 ft^3/min
9. Airflow rate: nominally 3 ft^3/min; adjustable
10. Alarm: amber light and buzzer at approximately 2000 counts/min; red light and continuous bell at approximately 4000 counts/min; alarm levels are adjustable
11. Other signals: tape-break buzzer and light
12. Filter may be automatically renewed by means of either a preset timer or a push-button switch
13. Shield: 2 in. of lead or stainless steel for G-M counter
14. Power: 110 V, 60 Hz
15. Dimensions: 24 in. wide, 24 in. deep, $51^1/_4$ in. high
16. Weight: 350 lb

Application

1. When properly adjusted, the instrument will maintain continuous monitoring of the air and keep a permanent record of the relative quantity of radioactivity collected on the filters.
2. The instrument does not differentiate between beta and gamma activity.
3. The instrument will respond to direct radiation which penetrates the shield and radioactivity collected on the filters.
4. Contamination of the tube or shield will give erroneous results.

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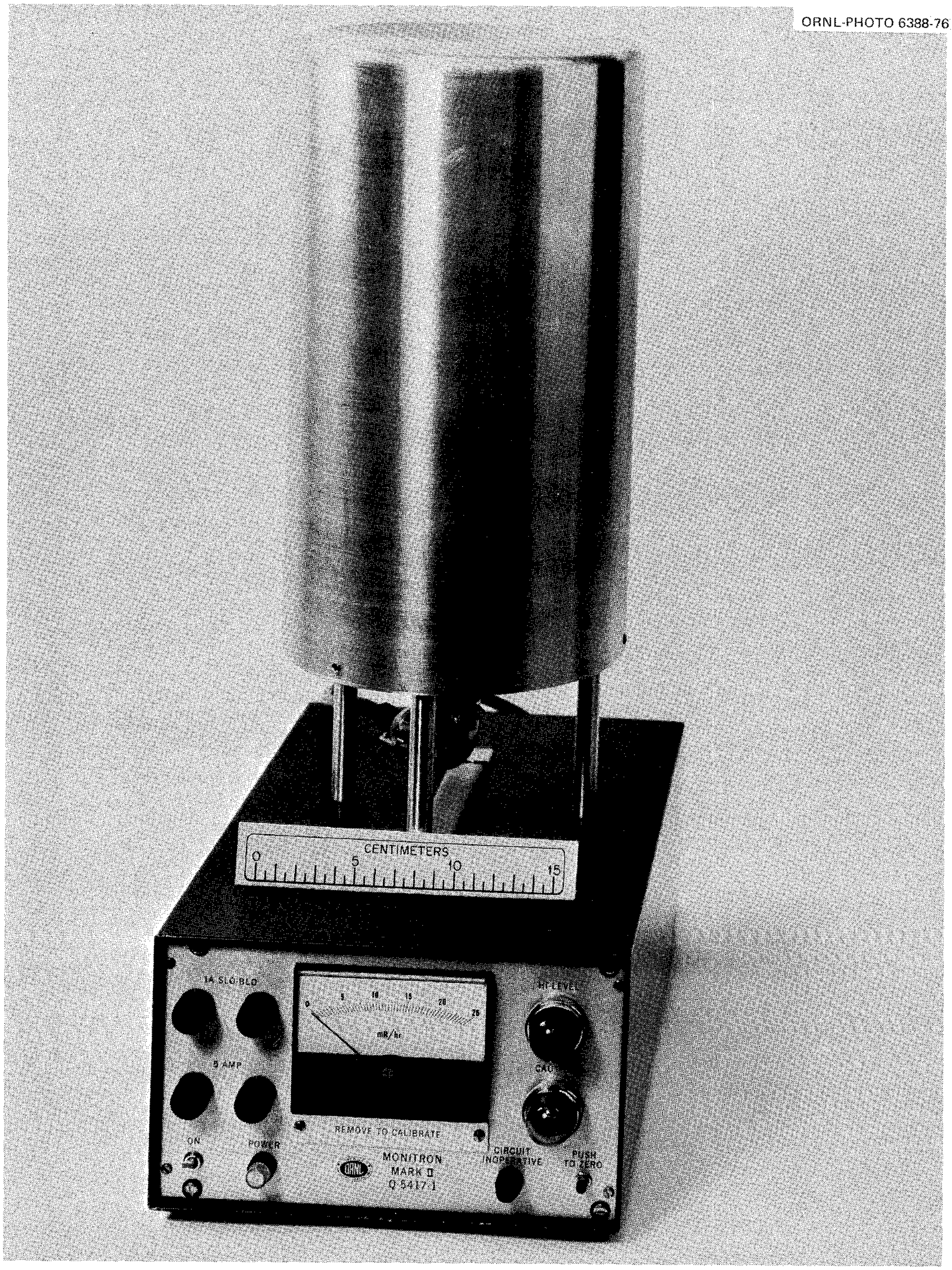

Monitron

The monitron employs a large ionization chamber and is used for the detection of gamma radiation. The ionization chamber is connected with an amplifier circuit and a count rate meter which reads directly in milliroentgens per hour. A relay circuit, actuating an alarm, may be set to go off at predetermined gamma radiation levels.

MONITRON

Characteristics

1. Radiation detected: gamma
2. Range: full-scale reading of 25 mR/hr
3. Components: consists of control chassis and a 4000-cm^3 ion chamber which can be located 150 ft or more from the control unit
4. Indicating devices: rate meter, alarm bell, and optional recorder
5. Power required: 110 V, 60 Hz
6. Recorder: external connection for strip-chart recorder
7. Dimensions: control chassis, 21 × 10½ × 14 in.; chamber, 20 in. high, 6½ in. diam
8. Weight: 70 lb

Application

1. Should be checked weekly for zero setting and alarm function.

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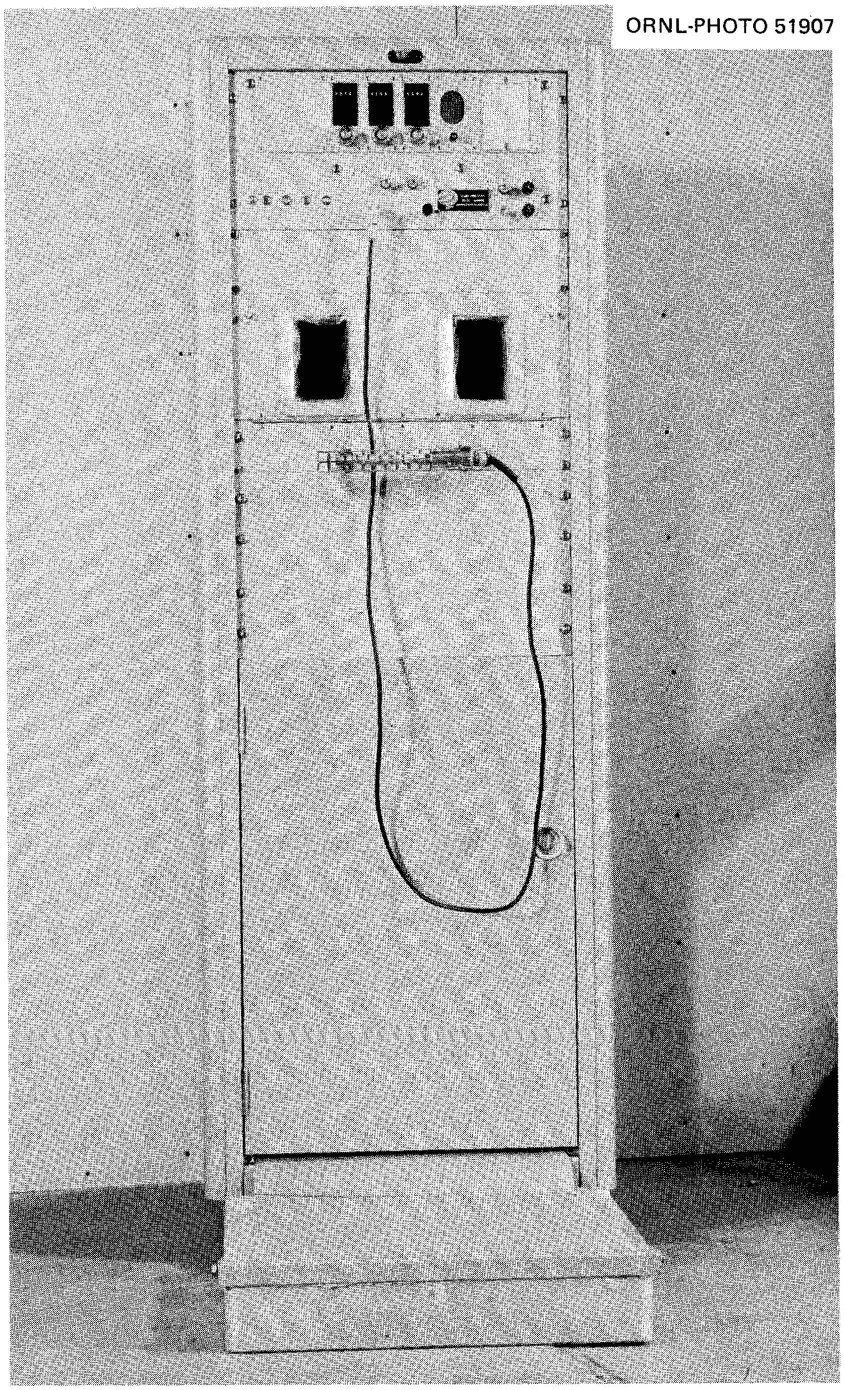


Hand and Foot Monitor

The hand and foot monitor is a semiautomatic device for detecting beta-gamma contamination of shoes and hands simultaneously. Counts obtained by G-M tubes during an automatically timed interval are indicated by registers. An auxiliary probe for monitoring other areas of the body or clothing is included.

HAND AND FOOT MONITOR

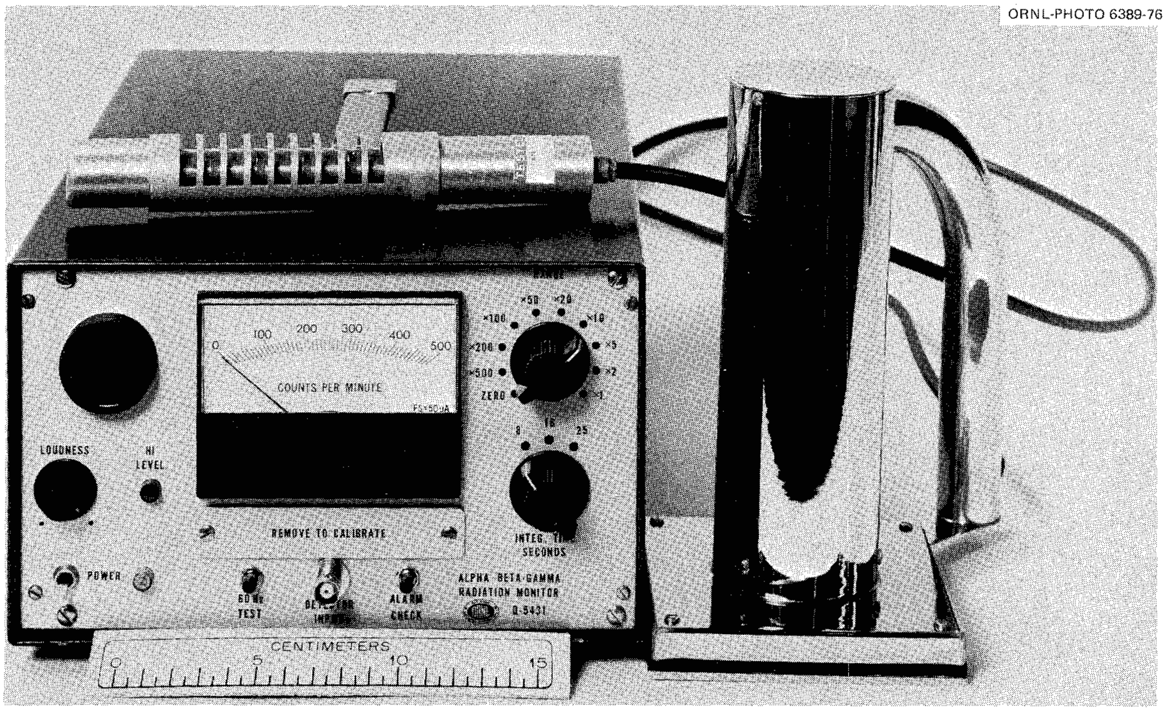
Characteristics

1. Radiation detected: beta, gamma
2. Counters: halogen-quenched G-M, 30 mg/cm^2
3. Beta sensitivity: minimum beta energy detected is 0.2 MeV
4. Counting interval: adjustable, usually 24 sec, hand-pressure start; push-button reset
5. High voltage: adjustable, 600 to 1000 V
6. Power: 110 V, 60 Hz
7. Dimensions: 76 in. high, 32 in. wide, 24 in. deep
8. Weight: 600 lb

Application

1. Background should be recorded daily.
2. Should be calibrated weekly.
3. To prevent contamination, hands should be washed before counting.
4. Hands, with fingers extended, should be inserted as far as possible into the opening before counting.
5. Will not detect low-energy beta contamination.

ORNL-PHOTO 6389-76



Lab Monitor, Alpha or Beta

This monitor consists of a versatile count rate meter, ac powered, and either a zinc sulfide scintillation probe for alpha detection or a G-M counter probe for beta-gamma detection.

LAB MONITOR, ALPHA OR BETA

Characteristics

A. Count Rate Meter

1. Ranges: ×1, ×2, ×5, ×10, ×20, ×50
2. Sensitivity: 500 counts/min, full scale, ×1
3. Indicating devices: rate meter and speaker
4. Alarm: relay-operated alarm circuit
5. Recorder: connector for 10 mV or 1 mA strip-chart recorder
6. Time constants: 1, 11, and 21 sec
7. Input sensitivity: 5×10^{-12} coulomb/μsec
8. High voltage: 900 V
9. Power: 110 V, 60 Hz
10. Dimensions: 10 in. wide, 10 in. deep, $8^3/_4$ in. high
11. Weight: 10 lb

B. Alpha Detector
Scintillation, ZnS(Ag), 10 × 10 cm, 1.2 mg/cm^2 aluminized Mylar, 10 to 14% geometry

C. Beta Detector
G-M tube probe with sliding shield, stainless steel cathode, 30 mg/cm^2, or mica end-window, 1 in. diam, 2 mg/cm^2

Application

A. Alpha Monitor—see Alpha Survey Meter, Scintillation, p. 6.

B. Beta Monitor—see G-M Survey Meter, p. 9, and End-Window G-M Survey Meter, p. 10.

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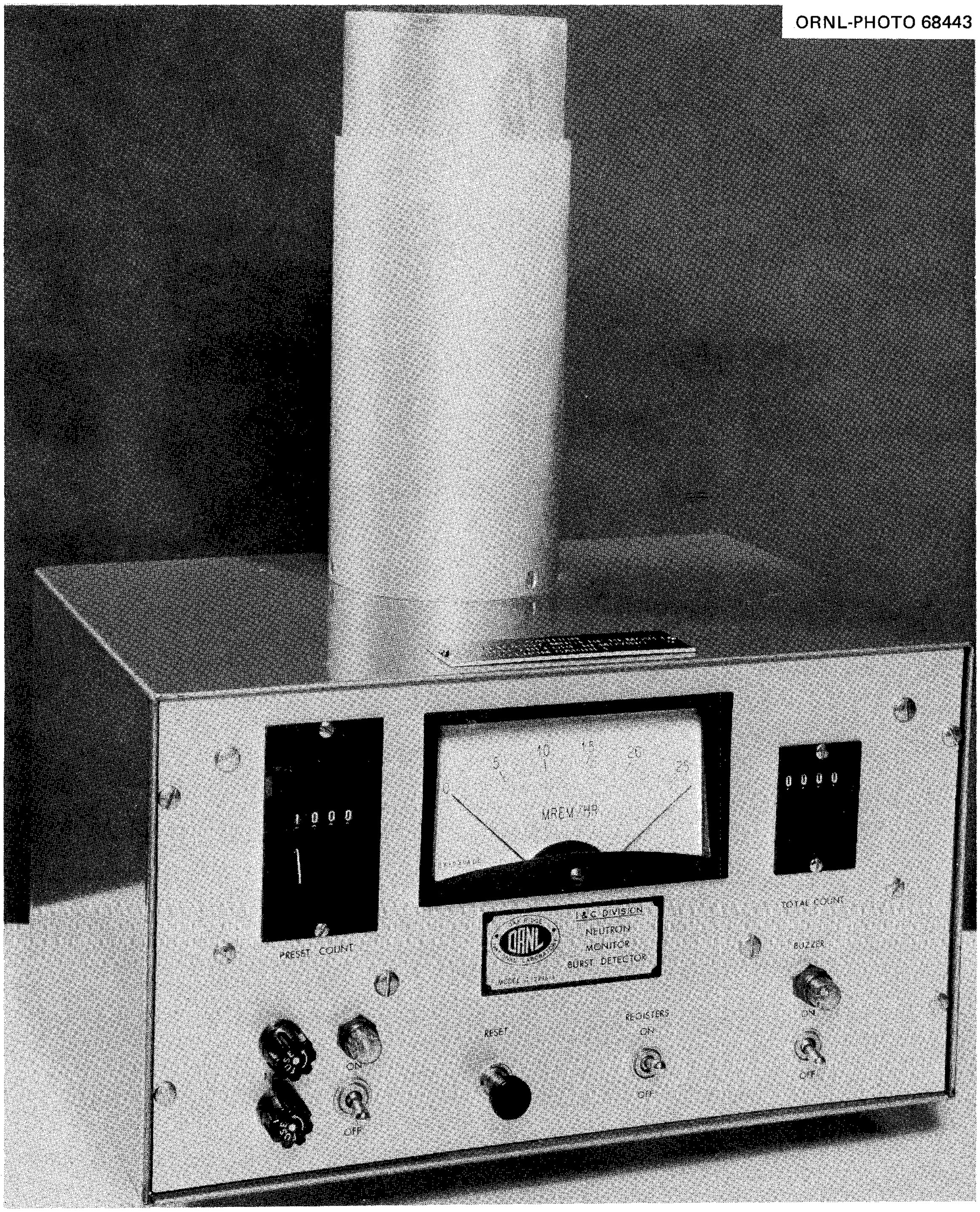


Neutron Monitor

This monitor (ORNL Q-2296) indicates the dose equivalent rate and integrated dose equivalent of neutrons and detects prompt critical bursts. The circuitry is transistorized; alarm relays and an output for a strip-chart recorder are provided.

NEUTRON MONITOR

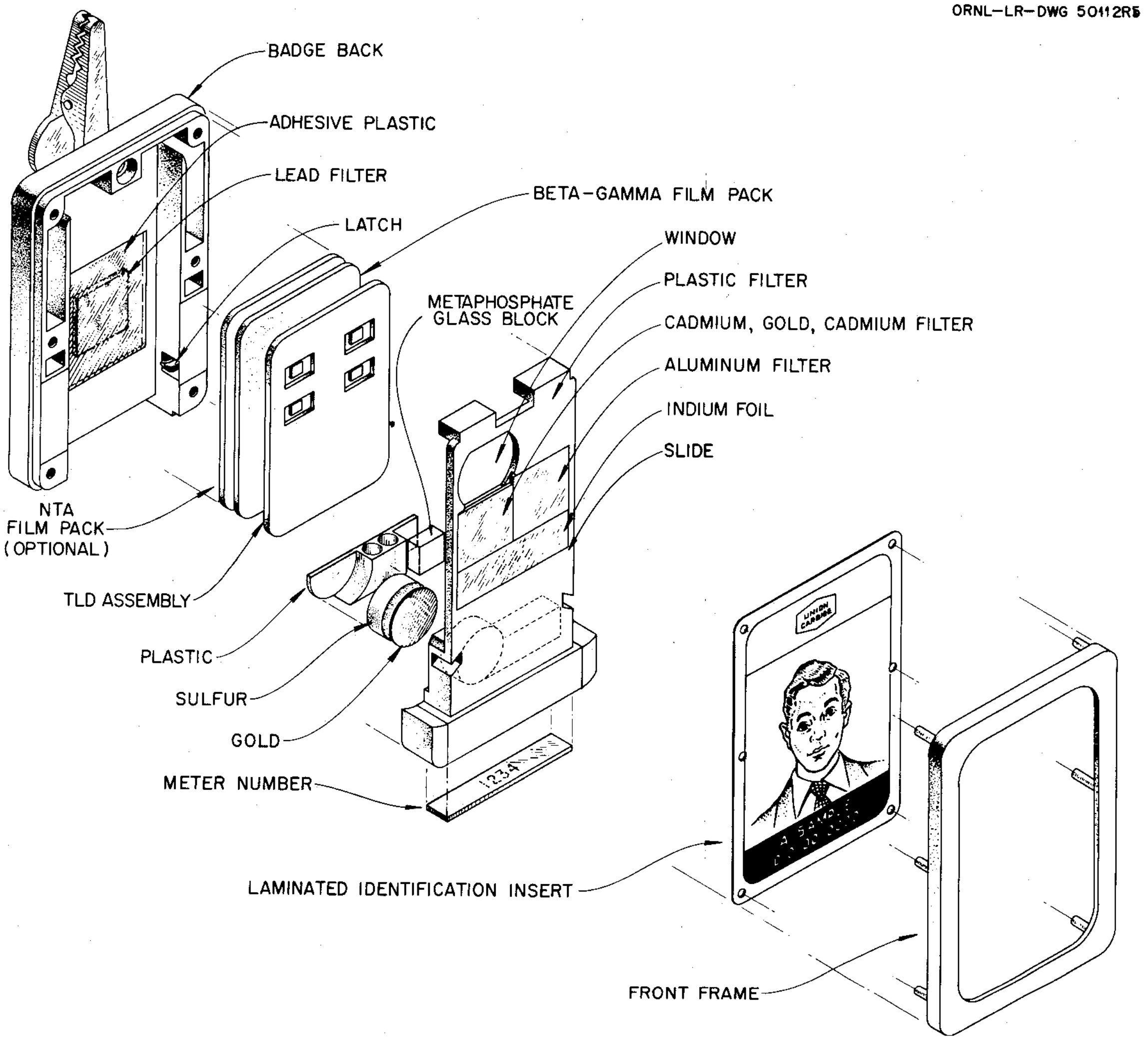
Characteristics

1. Radiation detected: neutrons (see 3, below), relatively insensitive to gamma radiation
2. Ranges: rate, 0 to 25 mrem/hr; integrate, 1,000,000 counts (10 counts per register); burst
3. Detector: BF_3 low-pressure-filled counter with cadmium-covered, high-density polyethylene moderator
4. Indicating devices: panel meter, count registers, buzzer alarm, latch-in relay for burst signal
5. Alarm levels: preset dose rate and preset integrated count with optional integrator
6. Power required: 110 V, 60 Hz, 12 W
7. Recorder: external connection for strip-chart recorder
8. Dimensions: main compartment, $13^1/_4$ in. wide, 9 in. deep, $7^1/_2$ in. high; detector assembly (integral with main compartment), 4 in. diam, $9^1/_2$ in. high
9. Weight: 21 lb

Application

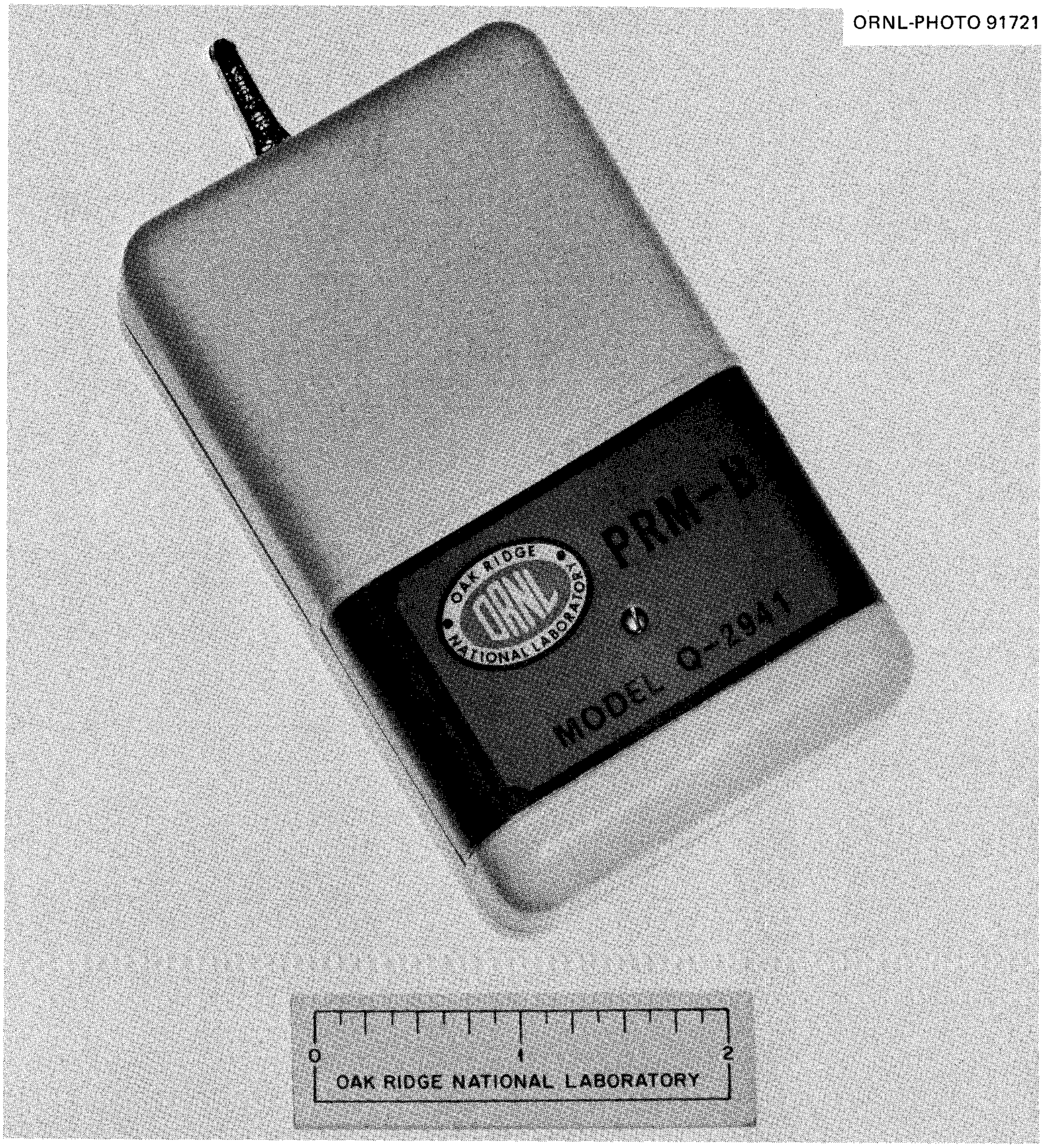
1. Relatively insensitive to gamma radiation.
2. Has no zero drift.
3. May be used for long-term integration from low-level neutron sources.
4. Is routinely calibrated with Pu-Be source.
5. One millirem is approximately equivalent to 500 register counts (5000 input counts).

1.3 Personnel Monitoring Instruments



ORNL Badge-Meter

The ORNL Badge-Meter is a combination identification, routine monitoring, and radiation accident monitoring device for personal use. It is described in *The ORNL Badge Dosimeter and Its Personnel Monitoring Applications,* ORNL-3126 and *Dosimetry with the ORNL Badge,* 1978, ORNL/TM-6357.



Personal Radiation Monitor

The personal radiation monitor is a cigarette-pack-shaped instrument for warning the user of the relative intensity of a field of radiation by means of an audible signal. It is especially useful in operations where high levels of exposure may occur without warning.

PERSONAL RADIATION MONITOR

Characteristics

1. Radiation detected: gamma and X ray
2. Range: normally, one fixed range from less than 1 mR/hr to signal frequency saturation above about 1 R/hr (see 4, below); other ranges available by circuit modification
3. Detector: G-M counter tube
4. Indicating signals: audible "chirp" type signal; signal repetition rates are proportional to the radiation exposure rate; the repetition rate and pitch of the audible signal increase with increasing exposure rate until a continuous, high-pitched signal is emitted for exposure rates greater than that which causes the maximum available repetition rate of the signal
5. Power: mercury battery, 4.2 V, TR-163; no on-off switch provided so that for safety the instrument may not be switched off
6. Battery life: about six months of continuous operation in low levels of radiation
7. Dimensions: $3^5/_8$ in. × $2^1/_4$ in. × 1 in. thick
8. Weight: 3.5 oz

Application

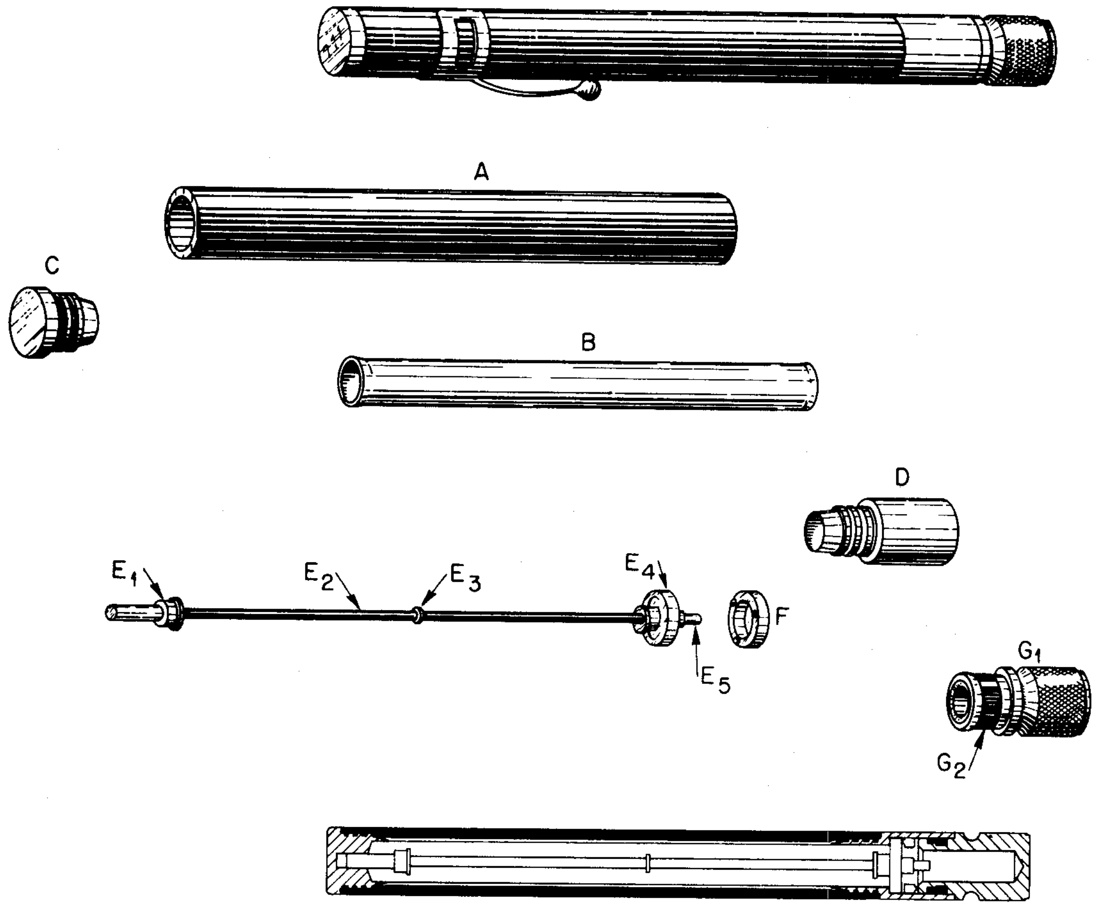
1. For use as a warning device and to indicate relative intensities of photon radiation. This instrument is useful primarily because of its sensitivity and its audiovisual characteristics. However, because its response is dependent on the energy as well as the exposure rate of radiation, this device should not be used to make quantitative radiation measurements unless the energy and type of radiation is similar to that for which the instrument has been calibrated.
2. Should be routinely checked for proper operability with a radiation source. The occasional chirp emitted and the "buzz" of the oscillator are indicative of operable condition.

ORNL-PHOTO 12040

Pocket Ionization Chamber

The pocket ionization chamber is an indirect-reading gamma dosimeter for the measurement of low-level personnel exposures in the 5- to 200-mrem range. The principal components are a cylindrical outer wall, a central-rod electrode, insulators, and a protective cap. The chamber is used in conjunction with a charger-reader (Minometer) for dose measurement.

ORNL–LR–DWG 50004



VICTOREEN POCKET METER, MODEL 352

A. LOW ATOMIC NUMBER WALL
B. GRAPHITE-COATED PAPER SHELL
C. ALUMINUM TERMINAL HEAD
D. ALUMINUM TERMINAL SLEEVE
E_1 POLYSTYRENE SUPPORT BUSHING
E_2 CENTRAL ELECTRODE, GRAPHITE COATED
E_3 POLYETHYLENE INSULATING WASHER
E_4 POLYSTYRENE FIXED BUSHING
E_5 ELECTRODE CONTACT
F. RETAINING RING
G_1 ALUMINUM BASE CAP
G_2 POLYETHYLENE FRICTION BUSHING

POCKET IONIZATION CHAMBER

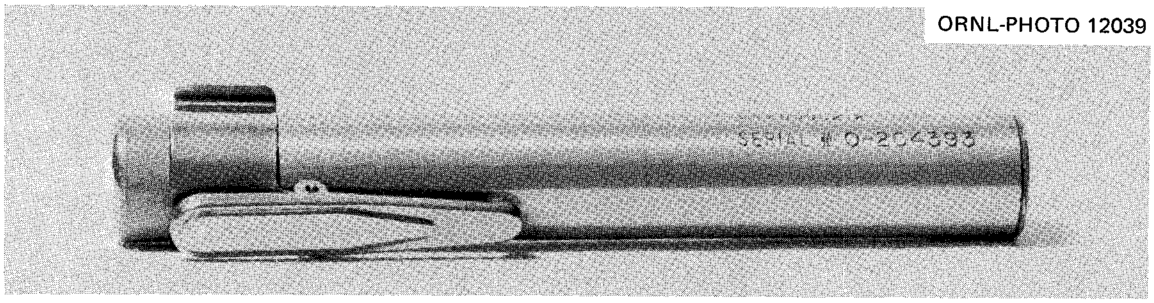
Characteristics

1. Radiation detected: X ray and gamma
2. Ranges: 0 to 200 mR
3. Accuracy: within ±10% of full scale
4. Energy response: between 0.1 and 3 MeV. The readings will be correct to within ±5% of Minometer meter reading [see Charger-Reader for Pocket Ionization Chambers (Minometer II, p. 51)]
5. Indicating device: associated charger-reader
6. Power: same as that for the associated charger-reader
7. Dimensions: $^1/_2$ in. diam, $5^1/_2$ in. long
8. Weight: $^1/_2$ oz.

Application

1. Will measure X- or gamma-radiation exposures between 0 and 200 mR (see 2, above).
2. Is insensitive to beta radiation below 1 MeV, max.
3. Will not differentiate between beta radiation above 1 MeV and gamma or X radiation.
4. For accurate comparison with badge-meter readings, the pocket meters should be worn near the badge meter.
5. Orientation of the meter with respect to the source may greatly affect the results.
6. The knowledge of Minometer techniques is necessary to properly interpret pocket-meter results.
7. These meters are calibrated with a radium source, and those which deviate more than ±10% are rejected.

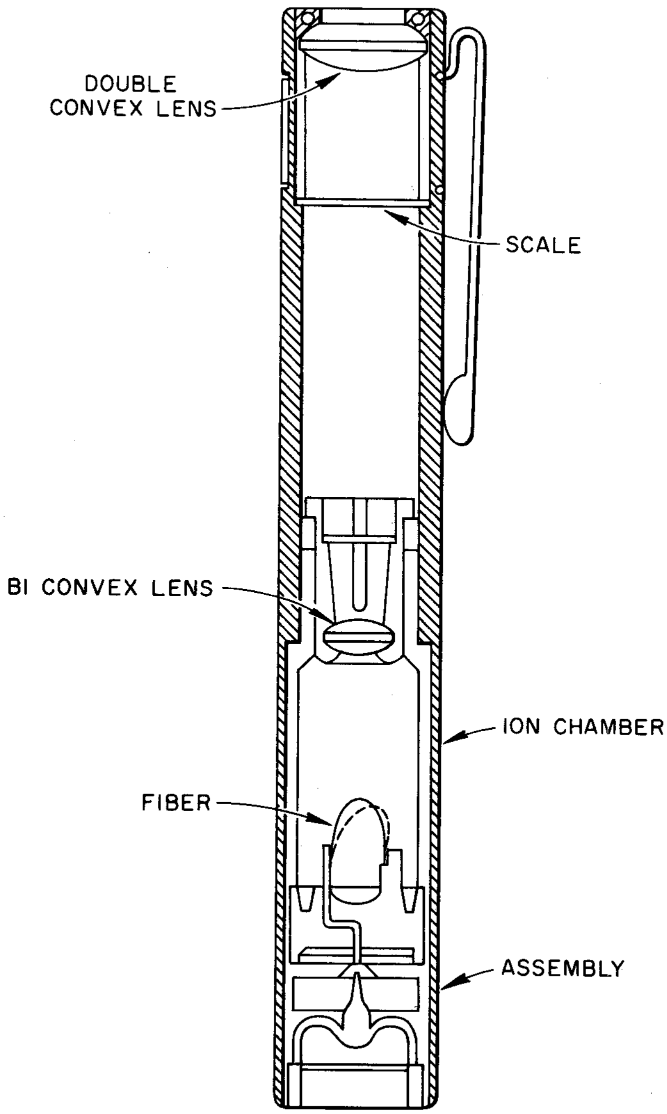
ORNL-PHOTO 12039



Dosimeter (Fiber Type)

The pocket dosimeter is a small pencil-type ionization chamber containing a quartz-fiber electrometer unit. The fiber unit, mounted into one end of the instrument, is viewed through a lens from the opposite end. A rectifier circuit or battery supply is used to charge the dosimeter. After the dosimeter has been charged, the displacement of the fiber indicates the exposure to the meter.

ORNL-LR-DWG 49998



DOSIMETER (FIBER TYPE)

Characteristics

1. Radiation detected: gamma
2. Range: 200 mR for routine use
3. Accuracy: ±10% of full scale
4. Indicating device: magnified quartz-fiber image on etched scale, viewed through end of instrument
5. Energy response: 0.1 to 3 MeV, ±5%
6. Power: charged by accessory variable voltage, 150 to 200 V; dc supply
7. Dimensions: 1/2 in. diam, 4 in. long
8. Weight: 1 oz

Application

1. The instrument will measure within ±10% gamma-radiation exposures from 5 to 200 mR.
2. It will not measure beta or low-energy photons.
3. A separate charging unit is necessary for charging the instrument.
4. Attention should be given to the position in which the meter is worn and read.
5. It is calibrated with radium-gamma radiation and the calibration factor is attached to the instrument.

1.4 Sample Counters

Alpha Sample Counter (Scintillation)

These counters, used for the assay of alpha emitters in various types of samples, consist of a lighttight sample holder, a zinc sulfide phosphor, and a photomultiplier. They may be housed in a separate unit or be included as an integral part of the associated scaler and power supply.

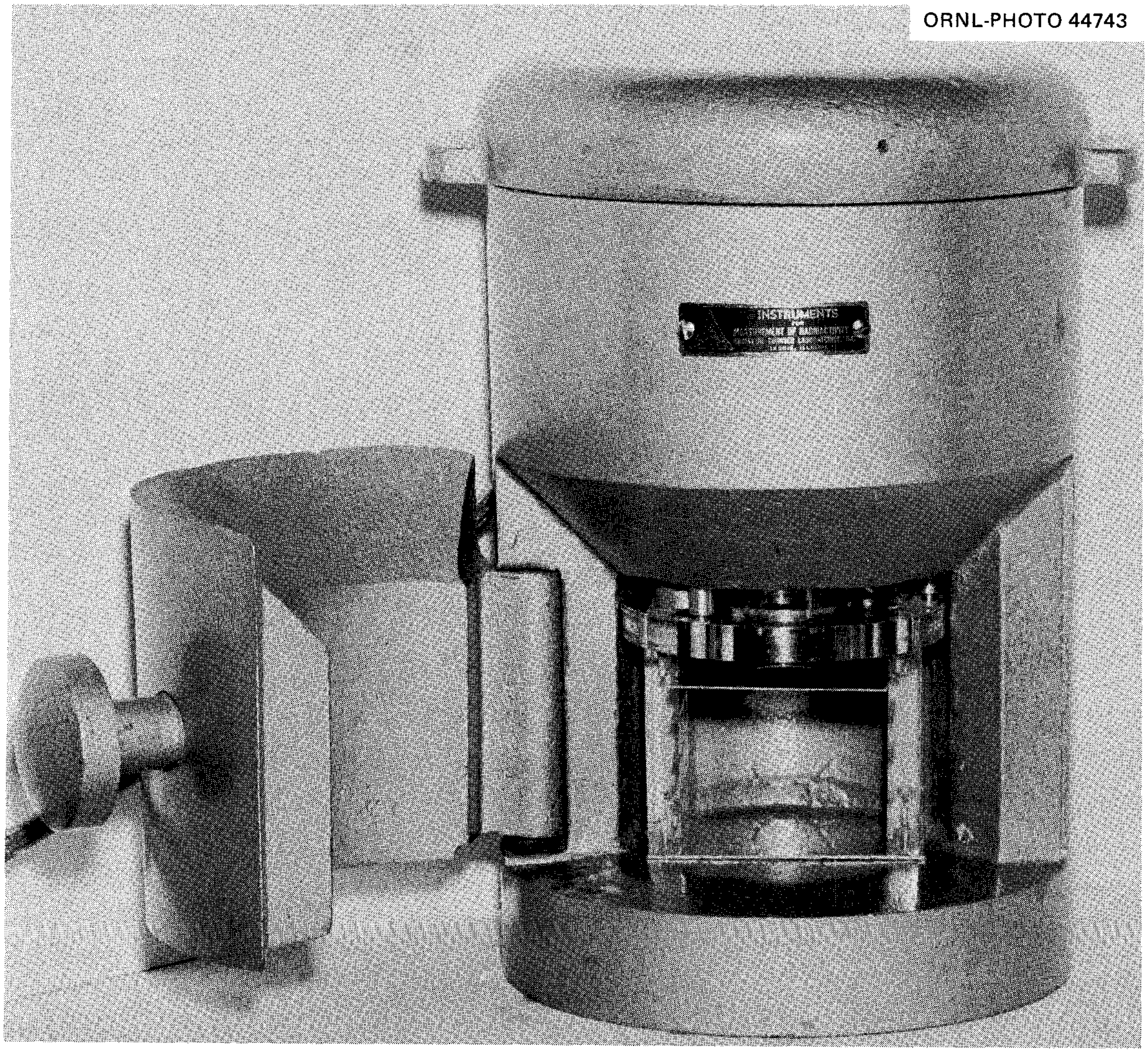
ALPHA SAMPLE COUNTER (SCINTILLATION)

Characteristics

1. Radiation detected: alpha
2. Geometry: 30 to 40% of 4π
3. Background: 5 to 15 counts/hr

Application

1. Should be calibrated with a standard source.
2. Care should be taken to prevent radioactive contamination.



G-M Counter (End-Window Type)

This G-M counter has a thin mica window. A cylindrical lead or iron shield houses the counter, which is usually mounted in the upper part of the cylinder, and the mica window is aimed downward. Located under the counter window is a slotted sample carrier, accessible through a hinged door. An absorber can be interposed in the slot between the sample and the counter window.

G-M COUNTER (END-WINDOW TYPE)

Characteristics

1. Radiation detected: high-energy alpha, medium- and high-energy beta, and gamma
2. Detector: halogen G-M counter, 2 mg/cm^2, mica, 1 in. diam
3. Efficiency: 100% for beta and alpha radiation entering the counter, approximately 1% for gamma
4. Geometry: varies with shelf position and window thickness
5. Shielding: approximately 2 in. of lead and/or iron
6. Dimensions: 15 in. high, 9$^1/_2$ in. diam
7. Weight: 180 to 250 lb
8. Mica window: 1 to 1$^1/_2$ in. diam, 1.5 to 4.0 mg/cm^2 thick

Application

1. For detecting and counting beta radiation of energies above 0.03 MeV.
2. It is a convenient counter to use for making beta-absorption studies.

ORNL-PHOTO 45072

Sample Counter (Gas Flow, Proportional)

The gas-flow proportional counter is a very efficient alpha and beta analyzer. It has a low alpha background and a 2π geometry. It discriminates between alpha and beta-gamma radiation in combination. It requires, as accessories, a timer and a scaler that are capable of supplying the necessary power.

SAMPLE COUNTER (GAS FLOW, PROPORTIONAL)

Characteristics

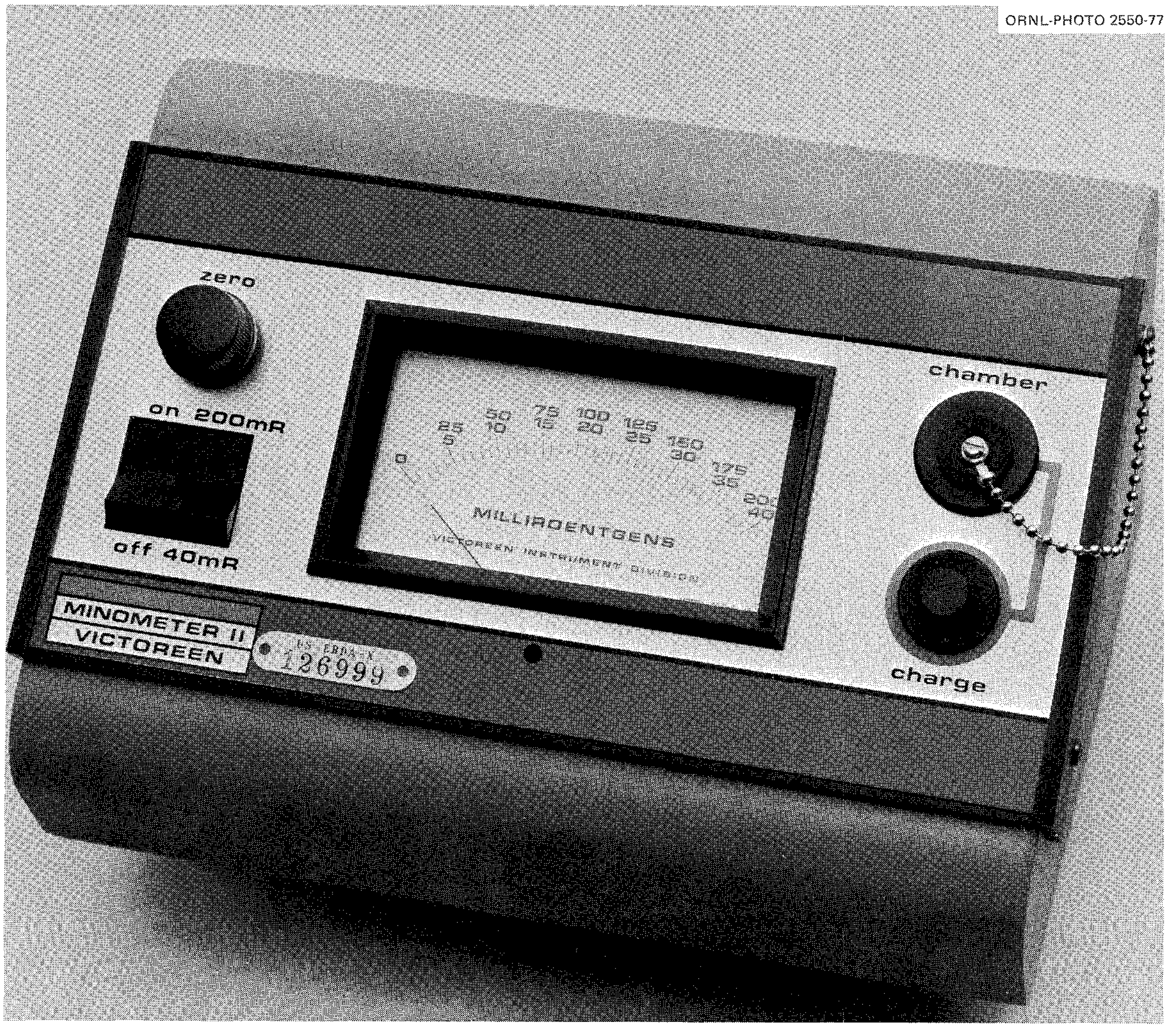
1. Radiation detected: alpha, beta, gamma
2. Discrimination: by proper adjustment of high-voltage levels
3. Efficiency: alpha, 51%; beta, 55 to 57%; gamma, 2%
4. Background: alpha, 6 to 10 counts/hr; beta-gamma, 45 to 50 counts/min
5. Operating voltages: alpha, 900 to 1200 V; beta, 1700 to 1900 V
6. Gas required: 90% argon, 10% methane
7. Dimensions: $6\frac{1}{2}$ in. wide, $8\frac{1}{2}$ in. high, $12\frac{1}{2}$ in. long
8. Weight: 13 lb

Application

1. This counter has a long voltage plateau for consistent counting.
2. The dead time is relatively short.
3. The stream of counter gas tends to blow contamination from the sample to the wall of the counter and the loop electrode, necessitating decontamination of these components.
4. Must be adjusted and calibrated with standard sources.

1.5 Miscellaneous Instruments

ORNL-PHOTO 2550-77



Charger-Reader for Pocket Ionization Chambers (Minometer II)

The Minometer II is an electronic charger-reader for indirect reading dosimeters (ionization chambers). The unit has a transistorized printed circuit and a meter which is calibrated in milliroentgens.

CHARGER-READER FOR POCKET IONIZATION CHAMBERS (MINOMETER II)

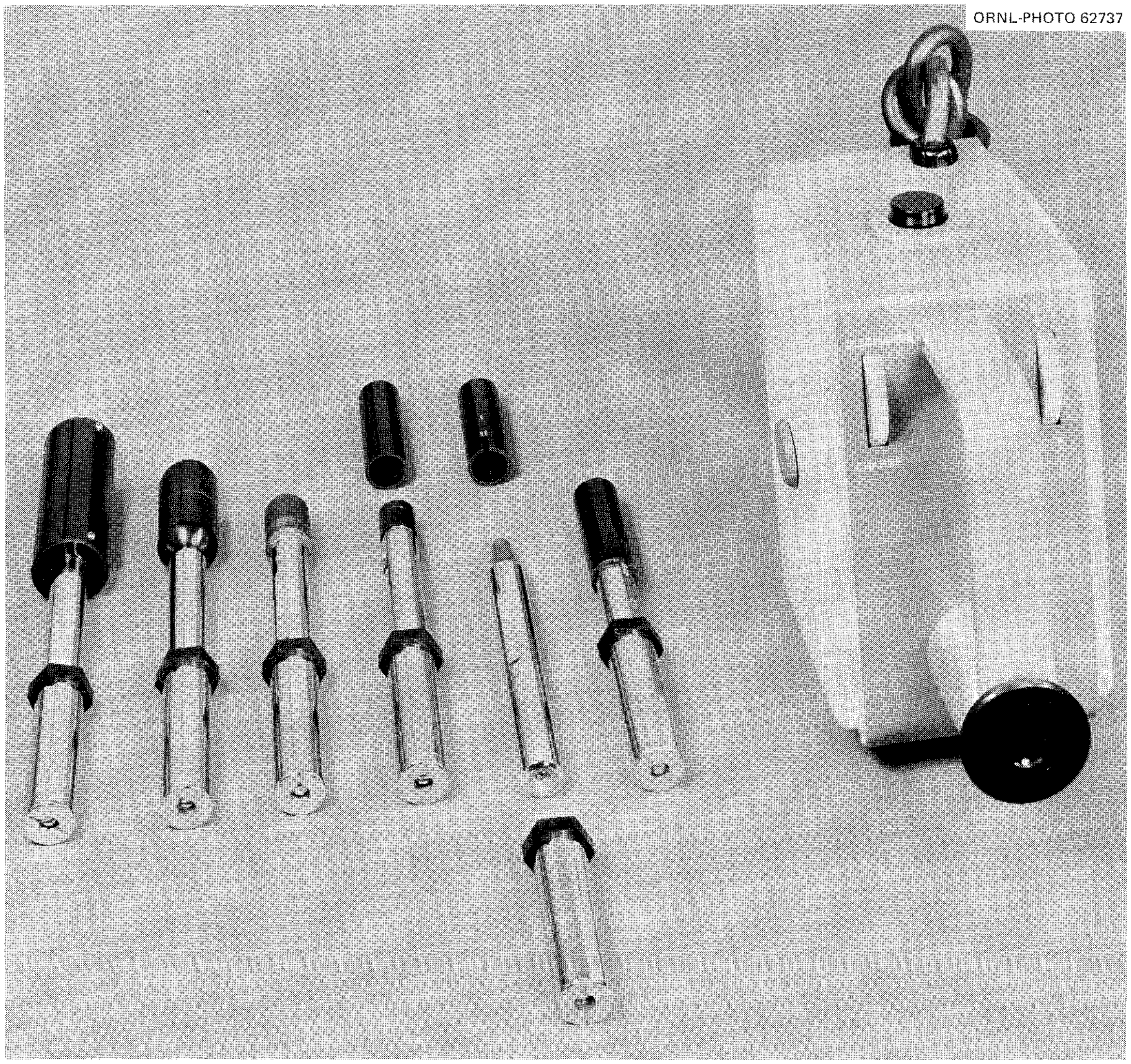
Characteristics

1. Ranges: 0 to 40 mR, 0 to 200 mR
2. Accuracy: within ±10% of full scale
3. Indicating device: large, mirrored panel meter
4. Power: 110 V, 60 Hz
5. Dimensions: $5^1/_4 \times 10^3/_4 \times 7^1/_2$ in. high
6. Weight: 9 lb

Application

1. Designed to charge and read the discharge in terms of milliroentgens on pocket ionization chambers.
2. The equilibrium voltage range is 130 to 80 V for 0 to 200 mR.
3. The scale in the minometer is calibrated in milliroentgens from 0 to 40 and from 0 to 200.
4. The instrument should be turned on for several minutes before using.
5. Note range selected.
6. Zero the minometer before inserting the dosimeter; insert dosimeter and note reading before depressing charge button.
7. Recharge dosimeter after reading is noted.
8. Dosimeters should be inserted and removed from the minometer gently.

ORNL-PHOTO 62737



R-Meter (Condenser)

This meter is used for measuring exposure of X and gamma radiation. Components include a charger-reader and an exchangeable condenser ion chamber. It is used for measurements as secondary to the standard air chamber.

R-METER (CONDENSER)

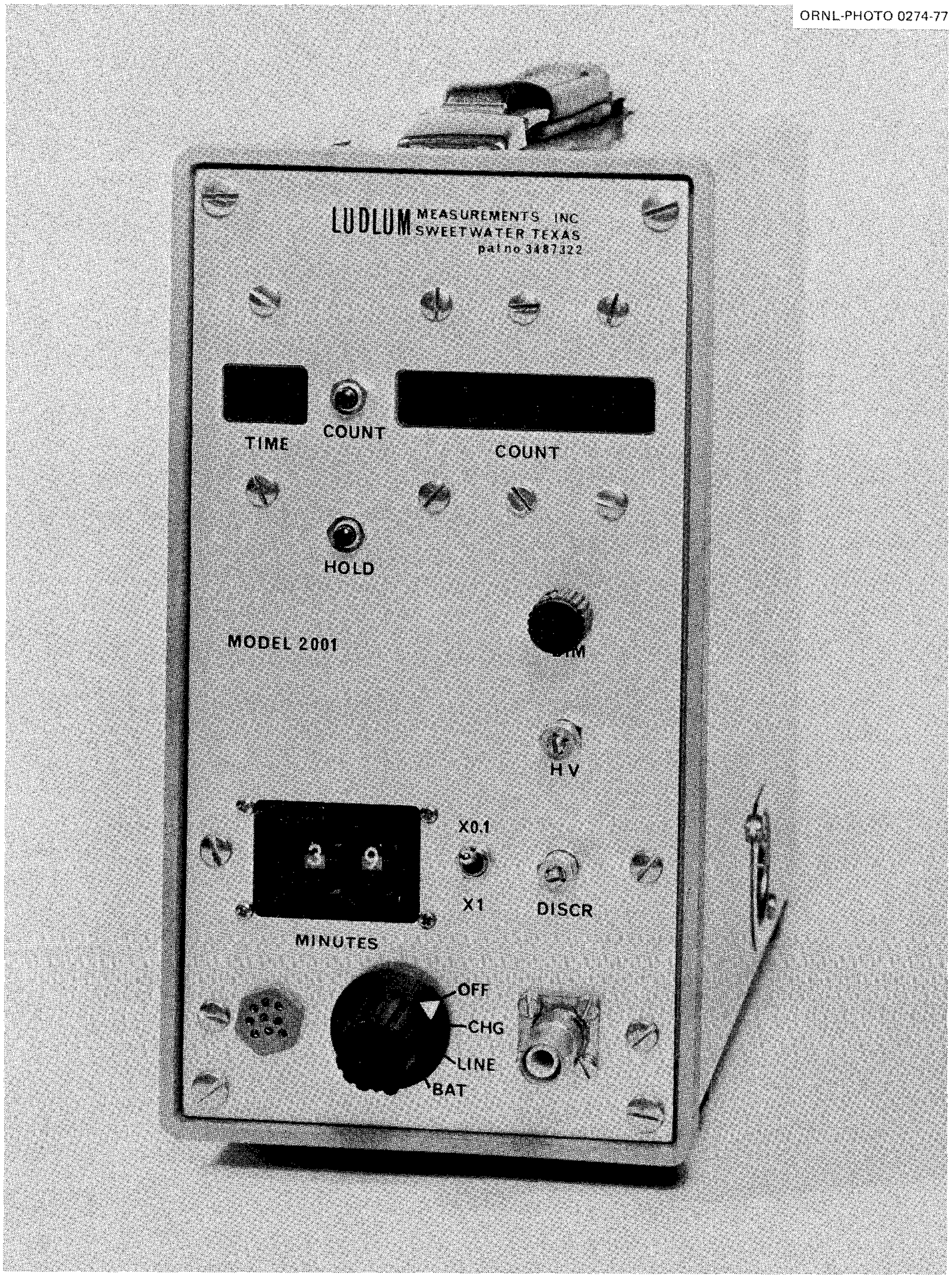
Characteristics

1. Radiation measured: X and gamma
2. Ranges: chambers available for full-scale readings of 0.25 to 2500 R
3. Energy dependence: function of chamber; chambers available for energy ranges 6 to 35 keV (low energy), 30 to 400 keV (medium energy), and 400 to 1300 keV (high energy)
4. Intensity limits: varies with chamber; examples for medium-energy chamber: 10-R probe has intensity limit of 5 R/sec; 100-R probe, 75 R/sec; and 250-R probe, 120 R/sec
5. Accuracy: maximum error is 2% and 10%, depending on the chamber
6. Power: 110 V, 60 Hz
7. Dimensions: 8 in. long, 3 in. wide, $8\frac{1}{2}$ in. high
8. Weight: 10 lb

Application

1. A practical instrument for rapid determination of X-ray exposure in roentgens.
2. The detachable chamber tube which this instrument features is valuable for direct measuring in small cavities or phantoms.
3. The ionization chamber tube is nonionizable and, therefore, is not affected by radiation.
4. The ionization chambers may be considered as "air-wall" chambers, inasmuch as their atomic number closely approximates that of air.
5. All readings taken on the instrument should be started from the zero division of the scale.
6. For accuracy, corrections must be made for temperature and barometric pressure.

ORNL-PHOTO 0274-77



Scaler

This is a versatile unit for use with sample counters in health physics applications. Timer, discriminator, and high voltage are incorporated.

SCALER

Characteristics

1. Input sensitivity: 2 to 100 MV
2. Input impedance: 0.1 MΩ
3. Resolution: 4 μsec
4. High voltage: 700 to 2400 V
5. Timer: Elapsed or preset time, 0.1 to 99 min
6. Power: Four D cells or 115 V, 60 Hz
7. Dimensions: $4^1/_2 \times 8^1/_2 \times 10^1/_2$ in. deep
8. Weight: 12 lb

Application

1. May be used with either beta (halogen G-M) or alpha (ZnS plus photomultiplier) counters for health physics sample counting.
2. Batteries should be removed if only ac operation is anticipated.

Part 2

Sources, Procedures, and Calibration Devices

2.1 GAMMA SOURCES

2.1.1 Radium

1. Radium, in equilibrium with its decay products, is used as a standard in the gamma calibration of survey and monitoring instruments.

2. The half-life of radium is approximately 1600 yr, so that a source may be used for several years after standardization without the necessity for correction of the dosage rate due to radioactive decay.

3. The unit most commonly used in expressing the strengths of radium sources is the curie. The curie was originally defined as that quantity of radon in radioactive equilibrium with 1 g of radium. This definition has been extended such that a curie of any radioactive material is that quantity which has a disintegration rate of 3.700×10^{10} dis/sec, since this is the presently accepted value of the disintegration rate of 1 g of radium.

4. The gamma radiation from a radium source is almost entirely from its equilibrium products, Ra *B* and Ra *C*. The approximate gamma-ray spectrum of radium and its equilibrium decay products is shown in Table 2.1. The effective average energy of the radiation is approximately 0.7 MeV.

Table 2.1. Approximate gamma-ray spectrum of radium and its equilibrium decay products

Transition		Quanta per radium disintegration	Energy per photon (MeV)
Ra	Rn	0.012	0.184
Ra *B*	Ra *C*	0.115	0.241
		0.258	0.294
		0.450	0.350
Ra *C*	Ra *C′*	0.658	0.607
		0.065	0.766
		0.067	0.933
		0.206	1.120
		0.063	1.238
		0.064	1.379
		0.258	1.761
		0.074	2.198
	Total	2.3	

5. The principal decay scheme of radium is as follows:

$$^{226}\text{Ra}(1590\text{ yr}) \xrightarrow{\alpha} {}^{222}\text{Rn}(3.825\text{ days}) \xrightarrow{\alpha} \underset{(\text{Ra } A)}{^{218}\text{Po}(3.05\text{ min})} \xrightarrow{\alpha}$$

$$\underset{(\text{Ra } B)}{^{214}\text{Pb}(26.8\text{ min})} \xrightarrow{\beta} \underset{(\text{Ra } C)}{^{214}\text{Bi}(19.7\text{ min})} \xrightarrow{\beta} \underset{(\text{Ra } C')}{^{214}\text{Po}(1.5 \times 10^{-4}\text{ sec})} \xrightarrow{\alpha}$$

$$\underset{(\text{Ra } D)}{^{210}\text{Pb}(22\text{ yr})} \xrightarrow{\beta} \underset{(\text{Ra } E)}{^{210}\text{Bi}(5\text{ days})} \xrightarrow{\beta} \underset{(\text{Ra } F)}{^{210}\text{Po}(140\text{ days})} \xrightarrow{\alpha} \underset{(\text{Ra } G)}{^{206}\text{Pb(stable)}} .$$

It may be noted from the transitions giving gamma radiation that the daughters, Ra *C* and Ra *C′*, reach equilibrium as the radon reaches equilibrium, since their half-lives are appreciably less than that of radon. The transitions beyond Ra *D* are of negligible importance in the production of gamma rays.

6. Due to the heterogeneity of the gamma-ray energies obtained from radium, in attenuation and/or shielding calculations involving radium, each gamma ray must be treated separately or the attenuation must be experimentally determined. For example, if a given thickness of some material reduces the dosage rate from a radium source to one-half the original value, addition of a second layer of the same material of the same thickness will not again reduce the dosage rate by one-half. With each addition of absorber the effective energy of the transmitted radiation is increased, thereby increasing the thickness required for an additional "half-value layer."

7. Radium sources are, most commonly, radium salt solutions in glass ampules or, solid radium salts (usually RaBr) sealed in small, hollow needles or cylinders of platinum, Monel, brass, or glass.

8. These sources may be calibrated by the National Bureau of Standards in the United States or by the Canadian National Research Laboratories. A sample certification of a calibration is shown as Fig. 2.1.

9. Amounts of radium are determined by comparing the gamma radiation of the unknown sample with that of a carefully weighed standard; conditions of filtration, the instrumentation, and the geometry must not vary from sample to sample.

10. The equivalent value in milligrams of radium, given in Fig. 2.1, is that amount of radium which, if contained in a tube of Thuringian (soft) glass 0.27 mm thick, would give a gamma radiation equivalent to that of the source being measured.

11. In applying the formulas for determining dose rates obtained at various distances from the source, this equivalent value must be increased by the amount designated in the note at the bottom of the figure. This increased value is the absolute radium content (within the errors specified in the report) of the source.

12. The absolute value in milligrams of the radium in the source is to be used for M in the following:

$$\text{mR/hr} = \frac{KM}{d^2},$$

where d = distance from source in centimeters and K = factor as noted below.

Material of source container	Thickness (mm)	K
Platinum	0.2	8700
Platinum	0.5	8200
Platinum	1.0	7600
Monel	1.0	8600
Monel	1.5	8300

13. If the radium source is encased additionally to the capsule in which it was standardized, the additional reduction in exposure rate must be considered.

14. For ready reference, a typical exposure rate vs distance plot is shown in Fig. 2.2.

Form 801–M

UNITED STATES DEPARTMENT OF COMMERCE
WASHINGTON

National Bureau of Standards

Certificate

FOR

ONE SPECIMEN OF RADIUM SALT
NBS No. 26947

SUBMITTED BY

Eldorado Mining and Refining (1944) Ltd.,

Port Hope, Ontario, Canada.

DESCRIPTION.—The material is contained in a metal cell 11.2 mm long and 1.20 mm in external diameter. The specimen and container weigh 193.2 mg . The Bureau is informed that the material is a compound of *radium*. After the measurements had been completed the specimen with a card bearing the number of this certificate was enclosed in a package suitably inscribed and secured by a seal of this Bureau.

THIS CERTIFIES that the specimen described in the preceding paragraph has been compared with the Radium Standard of this Bureau and has been found to have a gamma radiation equivalent to that from

9.78 *milligrams of radium*

in radioactive equilibrium and contained in a tube of Thüringian glass 0.27 mm thick. The uncertainty in this value does not exceed 0.5 percent. Observations extending over 49 days indicate that the radium contained in the specimen is in radioactive equilibrium.

For the Director,
by

Test No. 118618 -7
November 18, 1948.

L. F. Curtiss, Chief,
Radioactivity Section,
Division of Atomic and Molecular Physics.

NOTE.—The Bureau is informed that the cell is of 10% iridium platinum - - - - - - - - - - - - and has walls 0.2 mm thick. On this basis if the radioactive material were contained in a glass tube of the kind specified above, the gamma radiation from the specimen when in equilibrium would be approximately 1.5 percent greater than the value named in the body of this certificate.

The observations upon which this certificate is based do not serve to distinguish between radium preparations and those containing mesothorium or radiothorium.

GPO 16—48807-1

Fig. 2.1. Sample certification of calibration by the National Bureau of Standards.

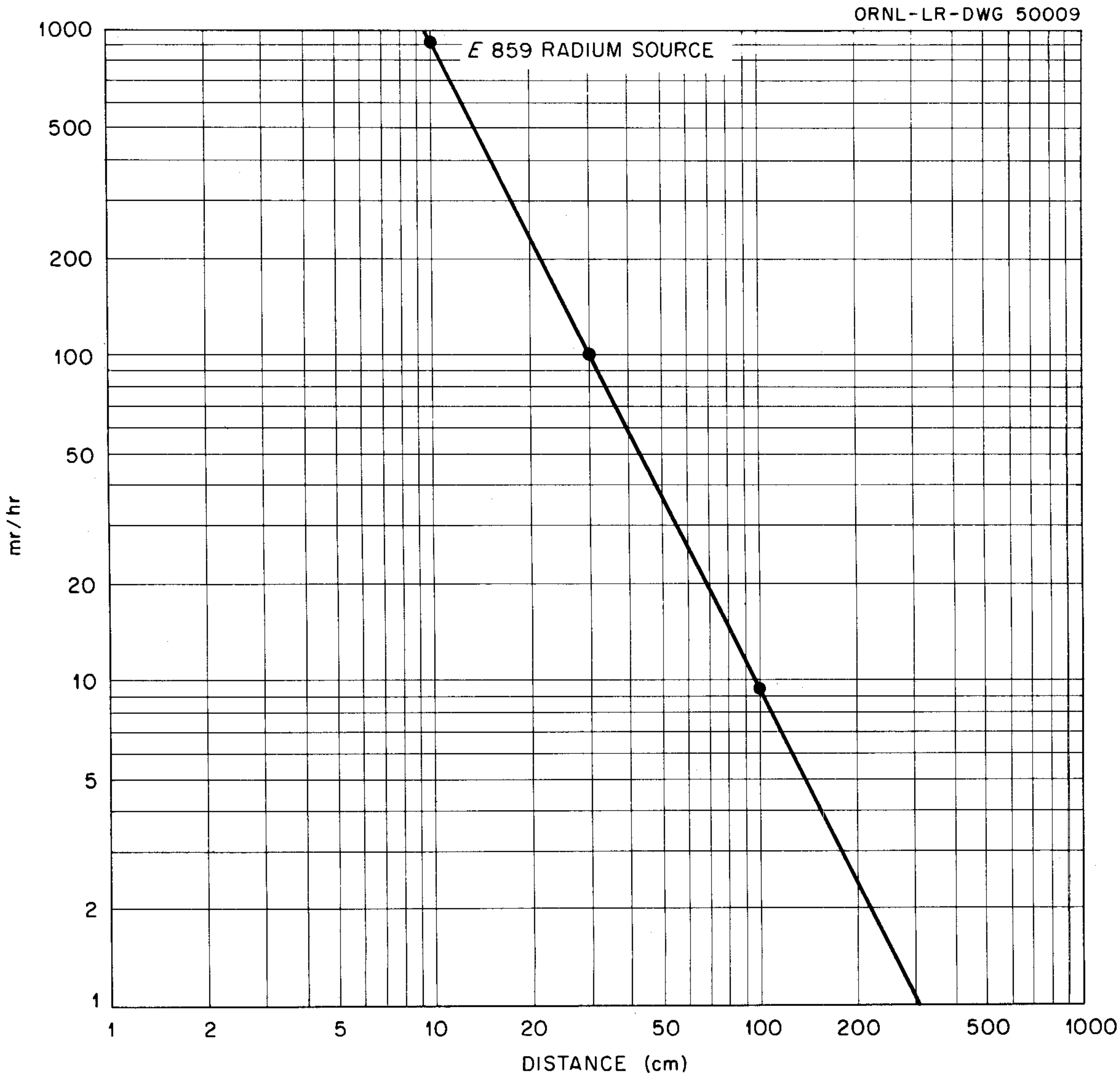


Fig. 2.2. A typical exposure rate vs distance curve for a gamma-ray point source.

2.1.2 Artificially Produced Radioisotopes

Source Material

Any gamma-ray emitter may be used for gamma calibration, particularly if it has the following properties:

1. A relatively long half-life, so that too-frequent decay corrections are not necessary.
2. Photon energies within the range 0.1 to 2 MeV, so that simplified calculations may be used.
3. A simple, accurately known decay scheme.
4. High specific activity. This permits the use of small sources
5. Relatively short activation time in available fluxes.

Source Production

Artificially produced radioisotopes most commonly used as gamma sources are produced either by exposure to the neutron flux in a nuclear reactor or as products of nuclear fission.

For those materials produced by neutron activation, the curie content is a function of:

1. The amount of the stable isotope (target material) present before irradiation.
2. The neutron flux.
3. The time during which the material was exposed to the neutron flux.
4. The activation cross section of the target material.
5. The amount of contaminant in the target material, either as part of chemical compound or as an impurity. These may greatly decrease the effective activation cross section by "soaking up" neutrons which might otherwise activate the target material.
6. The time elapsed since exposure.

The specific activity of a radioisotope is usually expressed in terms of disintegrations per second per gram of target material or separated element. For a target irradiated in a neutron flux, there may be very few of the total atoms which are radioactive.

The specific activity of an element irradiated in a nuclear reactor is given, approximately, by the equation

$$S = \frac{1.64 \sigma F}{10^{11} A} [1 - \exp(-0.693t/T)] ,$$

where

S = the specific activity in curies per gram of the target element on removal from the reactor,
F = the neutron flux in neutrons cm^{-2} sec^{-1},
A = atomic weight of the element,
σ = activation cross section in barns (1 b = 10^{-24} cm^2),
t = irradiation time,
T = half-life of isotope formed (same units as t).

After irradiation for approximately seven half-lives of the isotope formed, the decay rate approaches equilibrium with the production rate, and further irradiation is of little value in increasing the yield.

For an isotope whose half-life is long compared with the irradiation time (t less than $0.15T$), the following simplified equation may be used:

$$S = \frac{1.136 \sigma F t}{10^{11} A T} ,$$

where the units are the same as those above.

Exposure-Rate Determinations

1. Geometry considerations which apply to radium sources apply also to other gamma-ray sources.
2. By neglecting scattering, shielding, and self-absorption, the approximate exposure rate produced by gamma rays from a point source may be estimated.

3. For gamma-ray energies between 0.1 and 2 MeV, the air-absorption coefficient is approximately 3.5×10^{-5} per centimeter. Therefore, within this range of energies, the exposure rate is given approximately by the equation

$$R_f = 6CE\,,$$

where R_f = roentgens per hour at 1 ft, C = curies of activity, and E = total energy of photons.

This equation is derived as follows: Let d = distance in centimeters, F= gamma flux in photons per square centimeter per second, and K = fraction of incident energy absorbed per centimeter in air (the absorption coefficient).

The gamma fluence rate in photons per square centimeter per second is

$$F = \frac{3.7 \times 10^{10}\, C}{4\pi d^2}\,.$$

The energy absorbed per cubic centimeter is

$$KFE = \frac{K \times 3.7 \times 10^{10}}{4\pi d^2}\, CE\,,$$

where K is a function of E. In the range 0.1 to 1.5 MeV, the value is relatively constant and averages about 3.5×10^{-5} cm^{-1}.

The energy required to produce an ion pair in air is about 32.5 eV, and the number of ion pairs in 1 esu is 2.08×10^9.

By substituting these values, the exposure rate, in roentgens per hour, is

$$R_f = \frac{3.5 \times 10^{-5}\ \text{cm}^{-1} \times 3.7 \times 10^{10}\ \text{dis sec}^{-1}\ \text{curie}^{-1} \times 10^6\ \text{eV/MeV} \times 3600\ \text{sec/hr} \times CE}{32.5\ \text{eV/ion pair} \times 2.08 \times 10^9\ \text{ion pair per cm}^3\text{/roentgen} \times 4\pi \times 929\ \text{cm}^2\text{/ft}^2}\,,$$

$$R_f = 6CE\,,$$

where R_f= roentgens per hour at a distance of 1 ft, C= curie content of the source, and E= total gamma-ray energy per disintegration, in million electron volts.

Or, if it is desired to use distances in meters,

$$R_m = 0.56CE\,,$$

where R_m = roentgens per hour at 1 m, and C and E are the same as above.

4. Applications of these formulas are given as follows:

(1) To determine the gamma dose rate at a distance of 1 m from a 1-curie source of ^{60}Co:

(a) Refer to Fig. 2.3 and note from the decay scheme of ^{60}Co that for each disintegration of ^{60}Co there are emitted two gamma rays of 1.1 and 1.3 MeV, respectively.

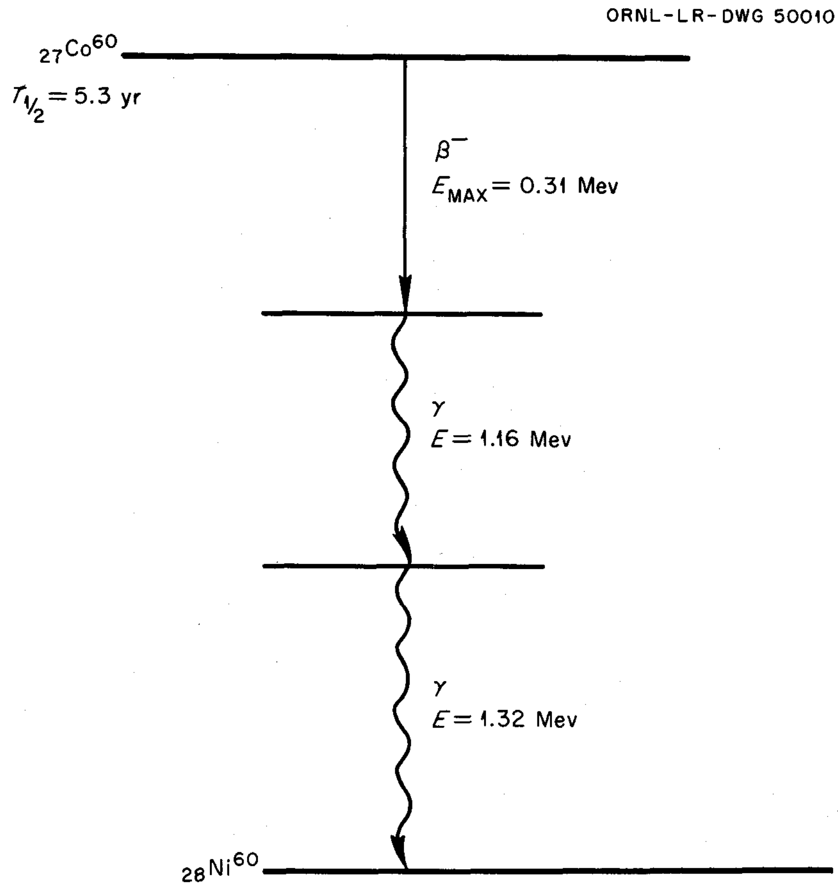


Fig. 2.3. ^{60}Co decay scheme.

(b) Apply the formula:

$$R_m = 0.56CE ,$$

where $C = 1$ curie, $E = (1.1 + 1.3)$, and $R_m = (0.56)(1)(2.4) = 1.3$ R/hr at 1 m.

(2) To determine the gamma exposure rate at a distance of 1 ft from a 2.6-curie ^{189}Au source:
   (a) Refer to Fig. 2.4, the decay scheme of ^{198}Au. The gamma spectrum, per disintegration, consists of 100% 0.41 MeV, 15% 0.16 MeV, and 15% 0.21 MeV photons.
   (b) Apply the formula:

$$R_f = 6CE ,$$

where $C = 2.6$ curies, $E = (100/100)(0.41) + (15/100)(0.16) + (15/100)(0.21)$, and $R_f = 6(2.6)(0.41 + 0.024 + 0.0315)$, $R_f = 6(2.6)(0.466)$, $R_f = 7.3$ R/hr at 1 ft.

5. If the curie content of the source is not known, and/or if the attenuation of the source container or other shielding agent is not known, the exposure rate may be determined by comparison with a standard source under "free-air" conditions.

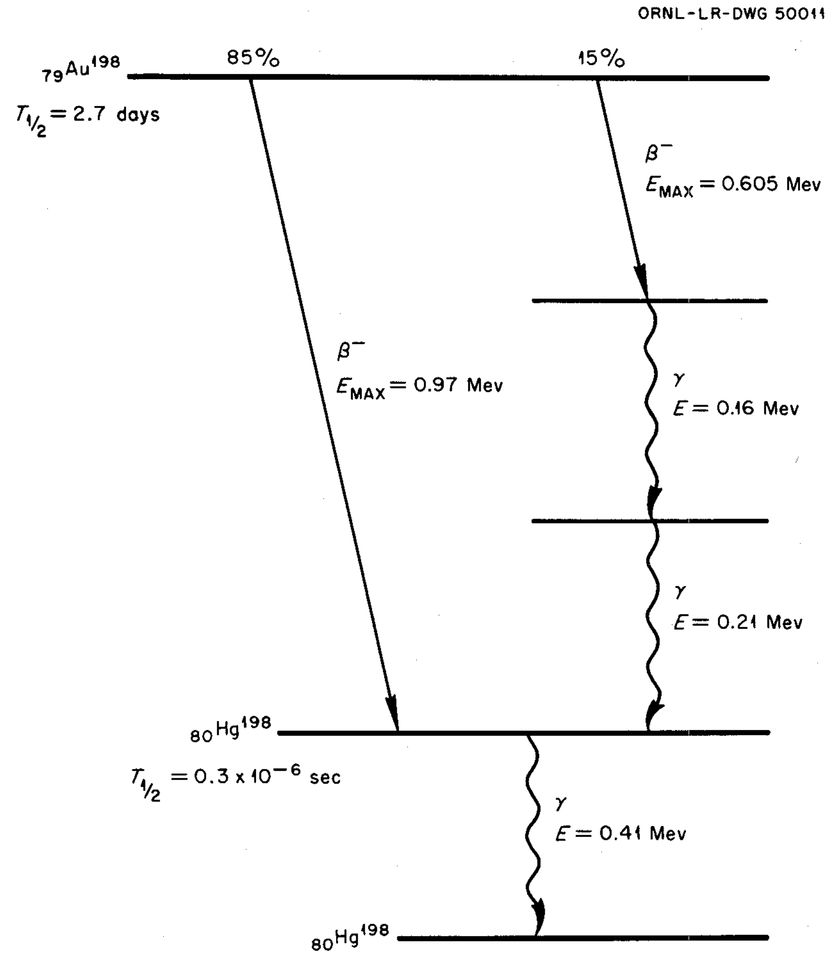


Fig. 2.4. ^{198}Au decay scheme.

Computation of Exposure Rate When One Distance Is Known

Exposure rates at any distance may be calculated if the exposure rate at one distance is known and if the proper geometric conditions exist.

1. The law used to calculate the exposure rates is referred to as the "inverse-square law" and is written

$$\frac{R_1}{R_2} = \frac{d^2{}_2}{d^2{}_1} ,$$

where R_1 and R_2 are the exposure rates as a function of distances d_1 and d_2, respectively, from a point source.

2. The inverse-square law applies if R is in roentgens; only where the absorber between R_1, R_2, and the source is a uniform layer of air; where the photon energies from the source have approximately the same absorption coefficients in air; and where the distance from the source is such that the proper geometry is obtained (approximation to a point source).

3. A straight line is obtained if exposure rate vs distance from the source is plotted on logarithmic paper. To plot such a calibration curve, do the following: (1) calculate or measure the exposure rate at one distance from the source, (2) calculate the exposure rate at a second convenient distance, and (3) plot a curve as shown in Fig. 2.2.

Decay of the Source

Radioactive decay of the source must be taken into account when it is used at some time after the initial curie-content determination.

The decline of the exposure rate at a fixed distance varies with time as follows:

$$R = R_0 e^{-\lambda t} = R_0 \exp(-0.693t/T) \ ,$$

where

R = exposure rate at time t,
R_0 = initial exposure rate at $t = 0$,
t = time since initial exposure rate determination,
λ = decay constant,
T = half-life, in same units at t.

A 2% reduction in exposure rate is obtained when $t = T/35$. Thus, there is a 2% reduction in the exposure rate from radium in $1600/35 \approx 46$ yr, ^{60}Co in $60/35 \approx 2$ months, and ^{198}Au in $2.7 \times 24/35 \approx 2$ hr.

A curve of relative exposure rate vs time may be plotted as a straight line on semilogarithmic paper by letting the slope equal (50%/T). Figure 2.5 is the curve for ^{60}Co.

Contributions by Scattering and Buildup Factors

Scattering and buildup factors may contribute significantly to the radiation dose from a point source under certain conditions. The formulas in Sects. 2.1.1 (12) and 2.1.2 (4,5) should be used only if the distance between the source and the detector is not less than six times the maximum dimension of either, if any scattering agent is not closer to the source or the detector than the distance between the source and the detector, and if the air buildup factor is insignificant.

2.2 BETA SOURCES

Beta-emitting isotopes may be used for calibration purposes if: (1) the dose rate from the beta emitter is known, (2) the source and the indicating device have the same geometry in all cases, (3) the beta emitter is used only as a secondary standard, and (4) the radioactive decay rate is taken into account.

2.3 ALPHA SOURCES

2.3.1 Preparation

Alpha sources are prepared by electroplating a metallic alpha emitter, usually uranium or plutonium, onto a disk of silver or platinum.

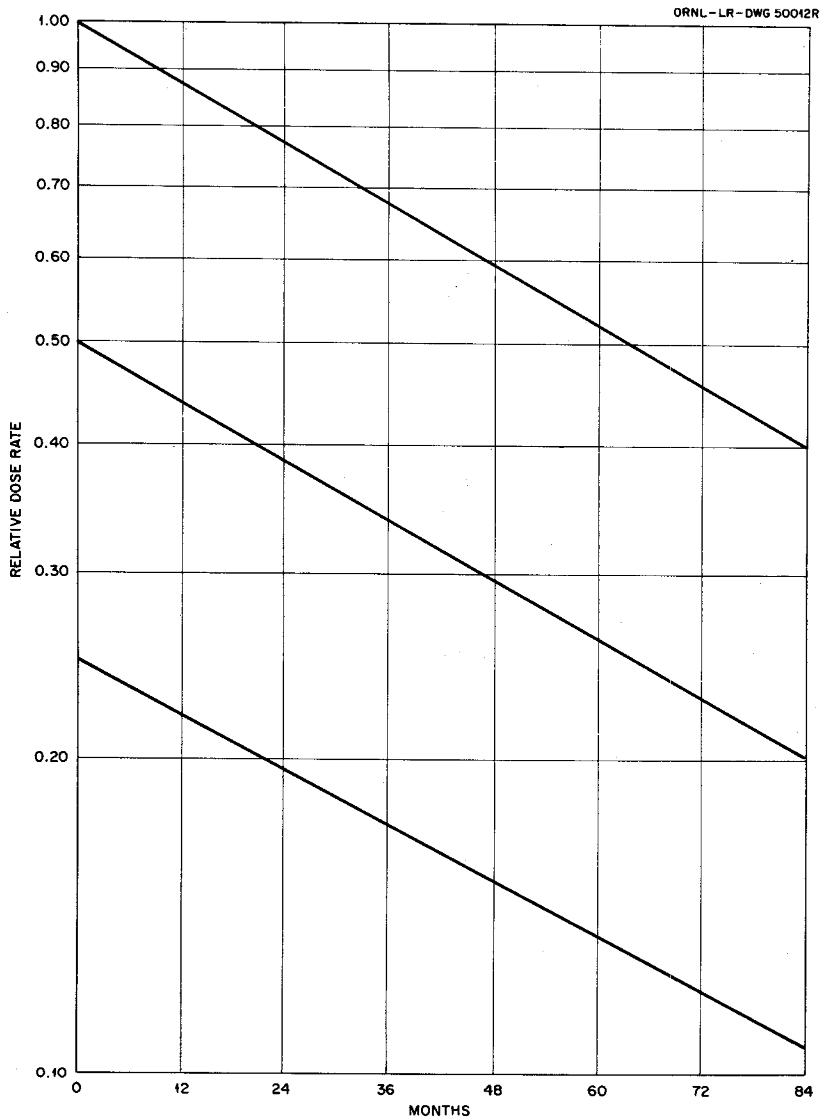


Fig. 2.5. Relative dose rate vs time for a ^{60}Co source.

2.3.2 Assay

The prepared source is assayed, in terms of disintegrations per minute, using a standard alpha counter.

2.4 NEUTRON SOURCES

2.4.1 Types of Sources

The sources used at ORNL are ^{238}Pu-Be (α, n) and ^{252}Cf (spontaneous fission), doubly encapsulated.

2.4.2 Source Calibration

The neutron emission rate, neutrons per second, should be determined by a standards laboratory. Secondary sources may be calibrated by comparison with a standardized source.

2.4.3 Energy Fluence Rate

At distances up to about 2 meters from a "point" source in air, the neutron energy spectrum may be assumed to be the same as at the point of origin and the fluence rate to vary inversely with the square of the distance from the source, i.e., at a distance *d*,

$$\mathrm{n} \times \mathrm{cm}^{-2}\ \mathrm{sec}^{-1} = \mathrm{n} \times \mathrm{sec}^{-}1\ (\mathrm{source})/4\pi d^2 \ .$$

2.4.4 Dose Equivalent Rate

Neutron dose equivalent rate is a nonlinear function of the energy fluence rate. An acceptable approximation to dose equivalent rate may be calculated using the energy fluence rate and the quality factors given in NCRP No. 38.

2.4.5 Thermal Neutrons

Thermal neutrons may be obtained conveniently by means of a paraffin moderator for the neutrons from a sealed source. About 10 cm of paraffin is optimum for maximizing the thermal to source emission neutron ratio. The gold foil technique is used to determine the thermal neutron fluence rates.

2.5 SPECIAL SOURCES

2.5.1 Hand and Foot Counter Calibration Sources

Hand-Counter Calibration Source

Figure 2.6 is a photograph of a hand-counter calibration source. The construction of the hand-counter source is based on a dose value of 50 mrad per week per square inch to an average hand (21 in.^{2}) and a dose rate of 240 mrad/hr at the surface of normal uranium.

If 1 in.^{2} of uranium gives a dose of 240 mrad in 1 hr to 1 in.^{2} of a surface with which it is in contact, then

$$\frac{50}{240 \times 168}\left(\frac{\dfrac{\mathrm{mrad}}{\mathrm{week} \times \mathrm{in.}^2}}{\dfrac{\mathrm{mrad}}{\mathrm{hr} \times \mathrm{in.}^2 \times \mathrm{in.}^2\ \mathrm{of\ U}} \times \dfrac{\mathrm{hr}}{\mathrm{week}}}\right) = 1.24 \times 10^{-3}\ \mathrm{in.}^2\ \mathrm{uranium}\ .$$

Therefore, a dose of 50 mrad/week will be received by 1 in.^{2} of area exposed to 1.24×10^{-3} in.^{2} of uranium.

An area of 21 in.^{2} will receive an average dose of 50 mrad per week per square inch if exposed to 2.625×10^{-2} in.^{2} of uranium. The hand-counter sources have exposed an area of 0.02625 in.^{2} of normal uranium 0.020 in. thick.

ORNL-PHOTO 12042

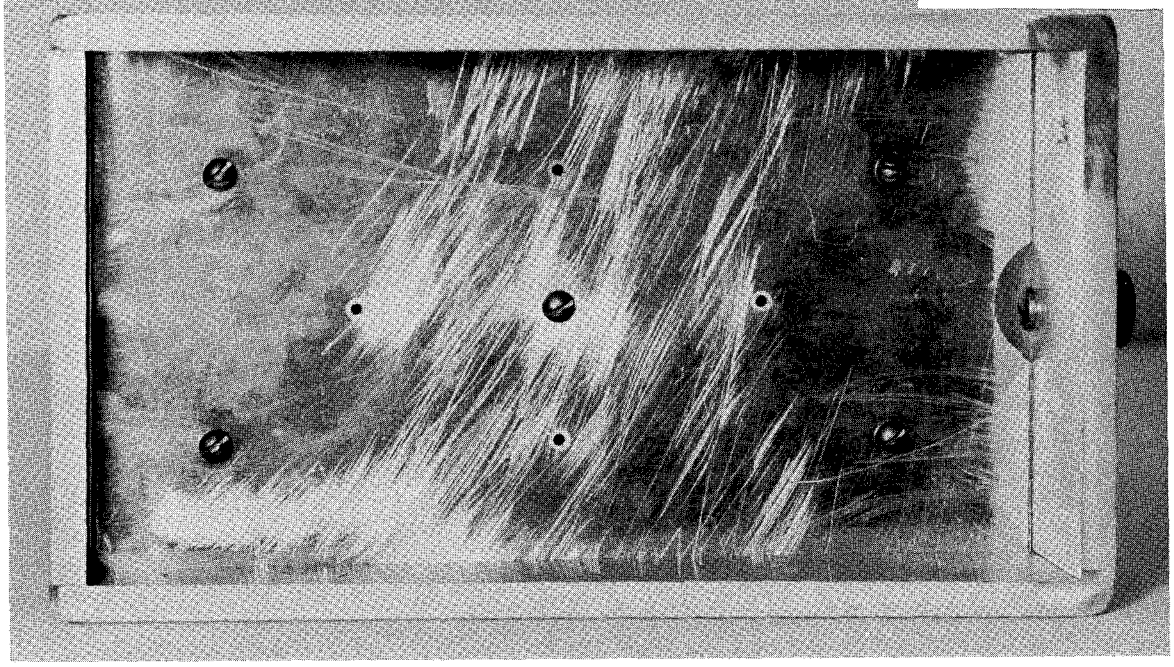


Fig. 2.6. Source for hand monitor.

Foot-Counter Calibration Source

Figure 2.7 is a photograph of a foot-counter calibration source. The source for the foot counter is constructed similarly to the hand-counter source as follows:

1. Dose value = 100 mrad/week.
2. The area of shoe bottom is assumed to be 40 in.^{2}.
3. The area of uranium exposed in each foot source is:

$$A = \frac{100 \text{ mrad/week} \times 40 \text{ in.}^2}{240 \text{ mrad/hr} \times 168 \text{ hr/week}} = 9.9 \times 10^{-2} \text{ in.}^2 .$$

2.5.2 CAM Calibration Source

Figure 2.8 is a photograph of a CAM calibration source. The preparation of the source is based on the following factors: (1) collection of air containing 3×10^{-9} μCi/cm^3 of particulate beta-gamma activity, (2) a collection period of 30 min, (3) an airflow rate of 5 ft^3/min, and (4) a collection efficiency of 70%. These factors may be used to obtain the following: 70% $\times$ 28,320 cm^3/ft^3 $\times$ 5 ft^3/min $\times$ 30 min/sample $\times$ 3×10^{-9} μCi/cm^3 $\times$ 3.7×10^4 dis/sec/μCi = 332 dis/sec per sample.

The preparation of the source consists in adjusting the area of a portion of sheet uranium such that the counting rate when mounted within the plastic holder is equivalent to 332 dis/sec.

The plastic holder is machined to fit within a slot of the CAM filter-paper holder.

2.5.3 Laundry Monitor Calibration Source

Figure 2.9 is a photograph of the source used for checking the laundry monitors. The source assembly is similar to that for the hand and foot counter and is based on the following factors: (1) area of

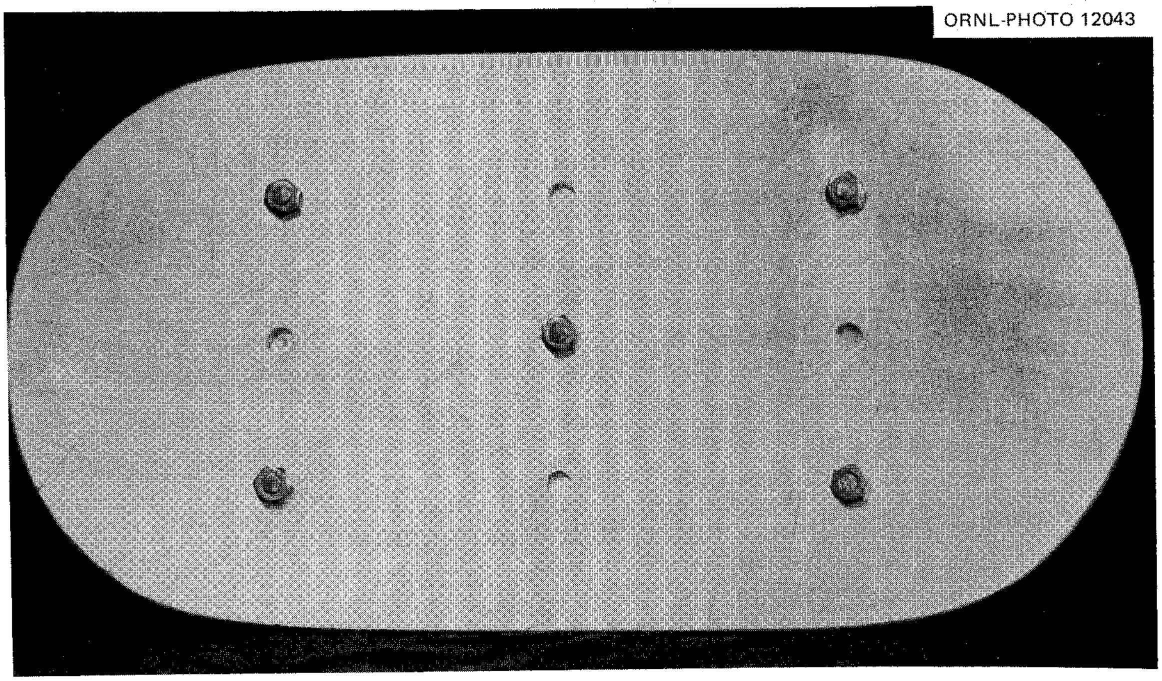


Fig. 2.7. Source for foot monitor.

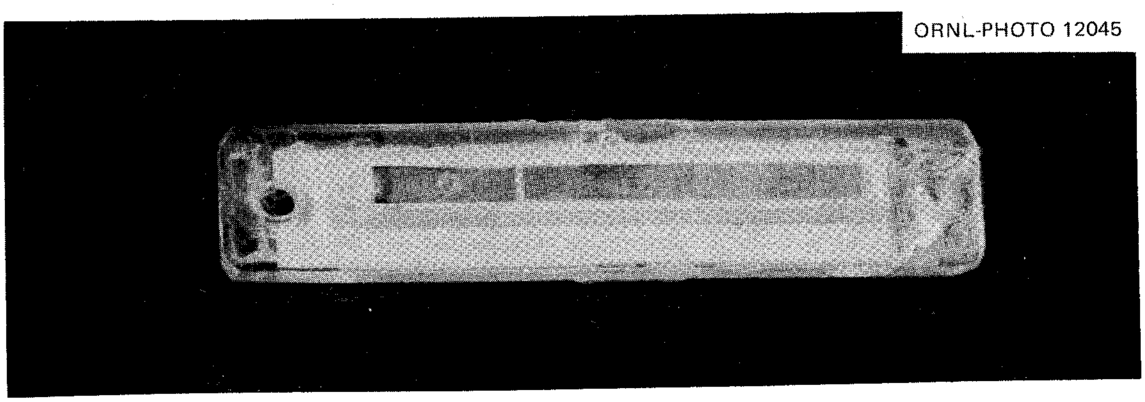


Fig. 2.8. Source for beta-gamma air monitor.

source face = 100 in.^{2} (10 × 10 in.), (2) a dose value of 0.75 mrad/hr/100 in.^{2}, and (3) beta dose rate at the surface of normal uranium = 240 mrad/hr/in.^{2}. The area of uranium exposed is

$$\frac{0.75 \text{ mrad/hr} \times 100 \text{ in.}^2}{240 \text{ mrad/hr}} = 0.313 \text{ in.}^2 .$$

The source exposes 16 uranium circles, each of 0.160 in. diameter.

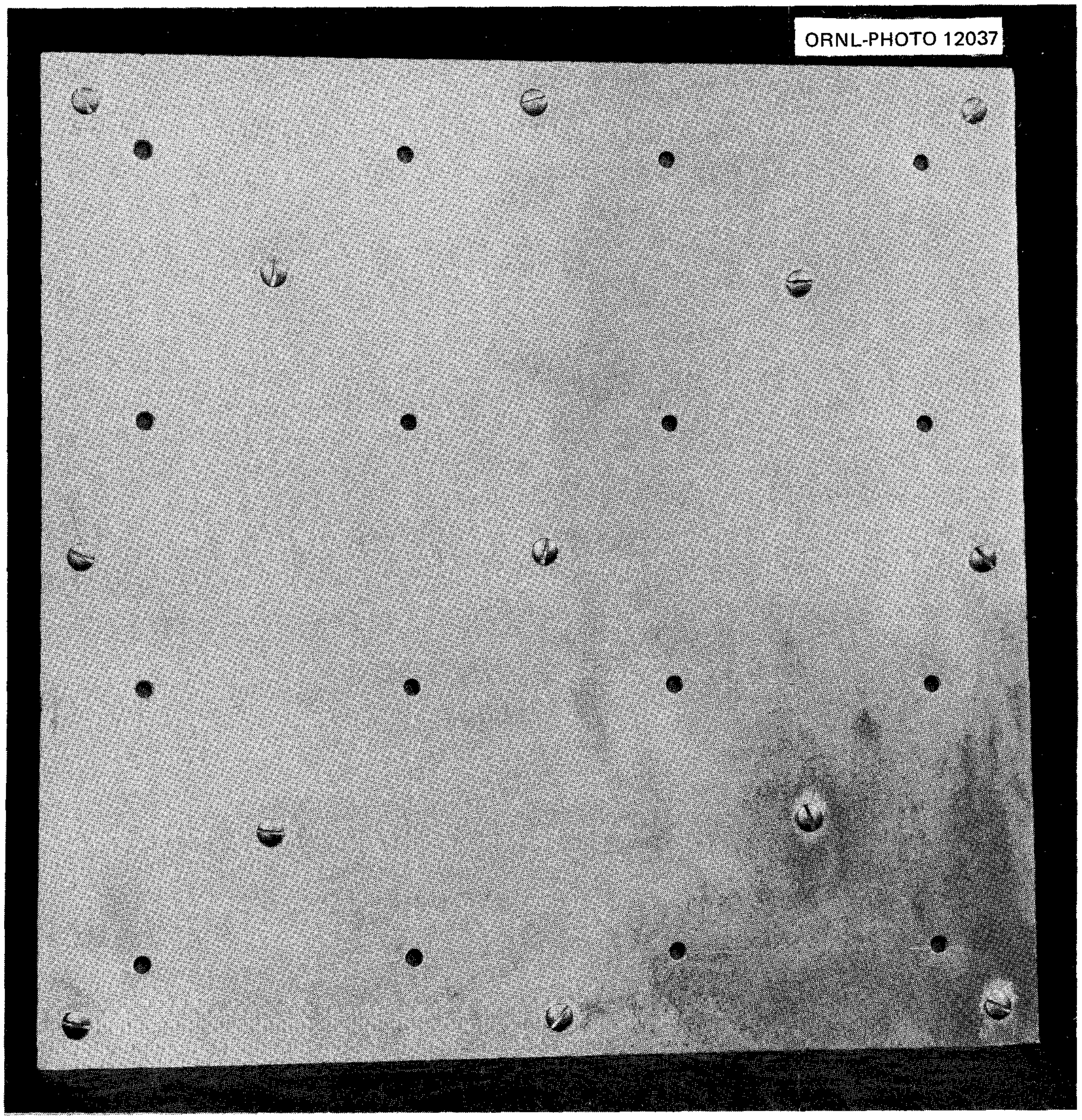


Fig. 2.9. Source for laundry monitor.

2.6 GAMMA CALIBRATION DEVICE FOR BADGE DOSIMETERS

Figure 2.10 is a photograph of the badge mounting ring, source tube, and source-storage shield. Figure 2.11 is a photograph of the operating console. Figure 2.12 is a block diagram of the functional parts.

When not in operation, the source is situated within the lead shield. The source is raised from the shield to the stop at the top of the plastic tube when the vacuum pump is switched on. The timers may be set for exposure periods ranging from 1 min to 24 hr. At the end of the exposure period, the vacuum pump is shut off automatically, and the source drops into the shield.

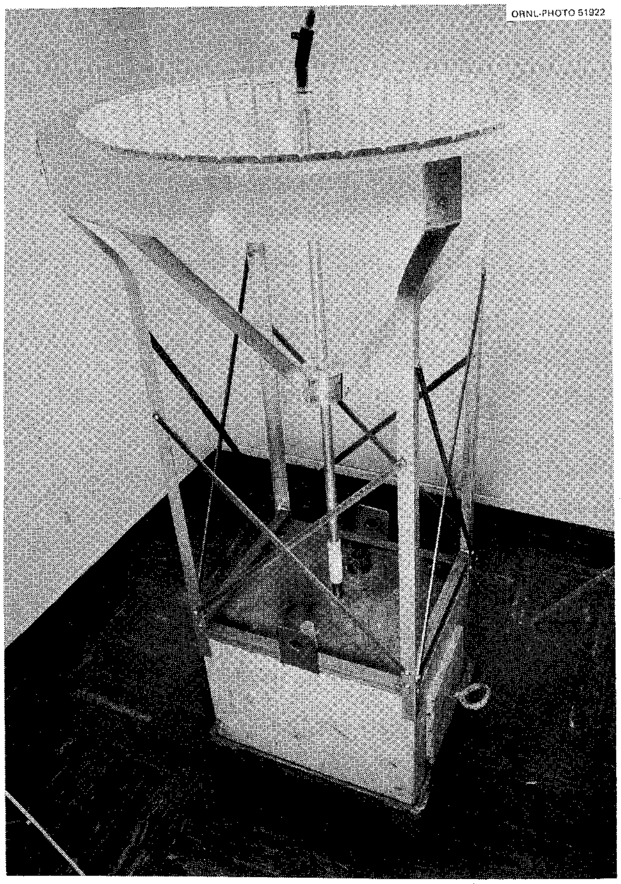


Fig. 2.10. Device for gamma calibration of badges and pocket chambers.

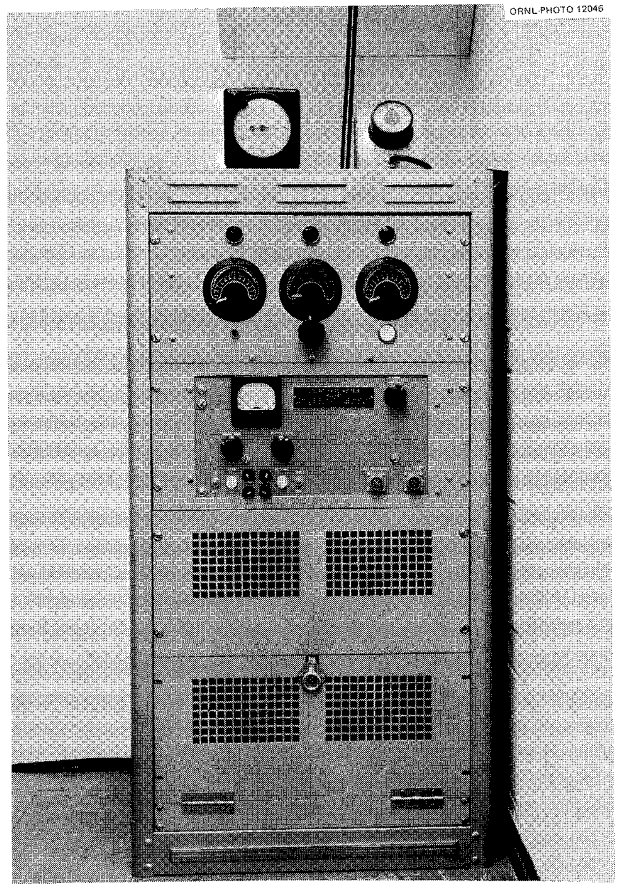


Fig. 2.11. Monitoring and operating console for gamma calibration device for films.

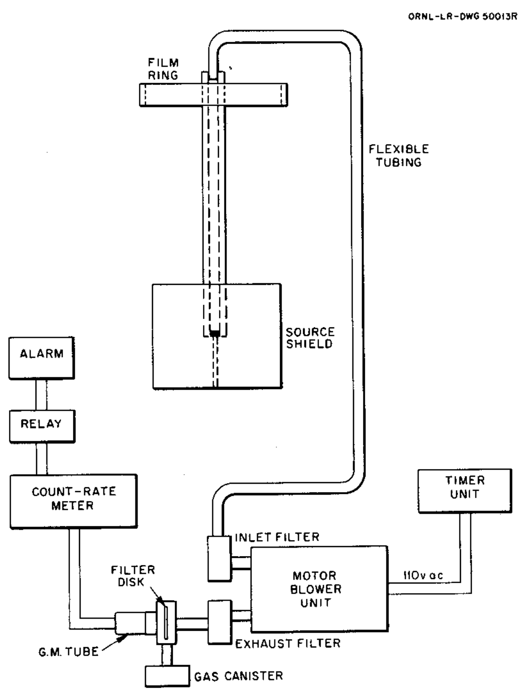


Fig. 2.12. Diagram of gamma calibration device for films.

The exhaust gas from the pump is filtered through two oil and wool-fiber filters and then passes through a paper filter which is located at the window of a G-M tube. This tube is connected with a counting rate meter. A relay connected with the counting rate meter will actuate an alarm if the counting rate exceeds a preset level.

The source shield will accommodate two sources, either of which may be selected by a switching device. The sources normally used are 100 and 500 mCi of radium.

2.7 CALIBRATION DEVICE FOR IONIZATION CHAMBERS ("WELL")

Figure 2.13 is a photograph of the device (termed the "well") used for gamma calibration of ionization chambers. The radiation dose rate at the position occupied by the ionization chamber is determined by a primary calibration. Due to the collimation and filtration applied, close agreement with the inverse-square law is obtained. The plastic platform serves three functions: (1) as a support for the ionization chamber, (2) as a means of transporting instruments between the operator and the proper position over the well, and (3) as the prescribed thickness of air-equivalent material necessary for assuring that the secondary radiation is in equilibrium with the medium (air) in which it is being measured.

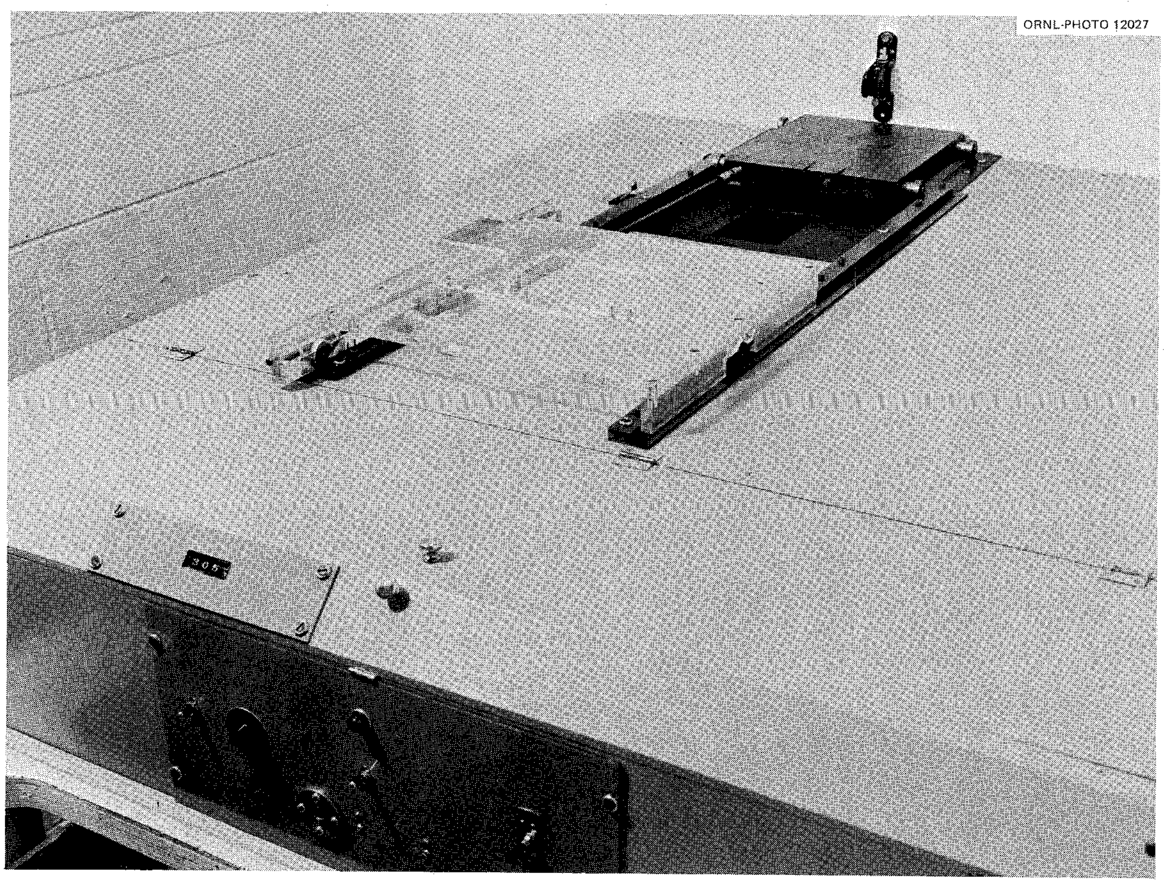


Fig. 2.13. Operator controls and exposure platform of "well" gamma calibration device.

The movable lead filter may be used to reduce the radiation by a factor of approximately 5.

By means of the controls on the operator's panel, the source may be adjusted to ±1 mm as read from the indicating register. Controls are supplied, also, for moving the plastic platform to and from the operator and for inserting or removing the lead absorber.

The well, which is 15 ft deep, serves to minimize the time required for calibration and to reduce the radiation exposure to personnel.

A 1-g radium capsule is normally used as a source in the well.

Signal lights indicate the relative level of the source in the well.

The source is contained in a holder mounted on a rider which travels up and down along a track mounted to the side of the well (Fig. 2.14).

An electric motor, gears, and chain drive are employed to raise and lower the source. Limit switches prevent overrunning at top and bottom.

An additional motor is used for positioning the plastic platform.

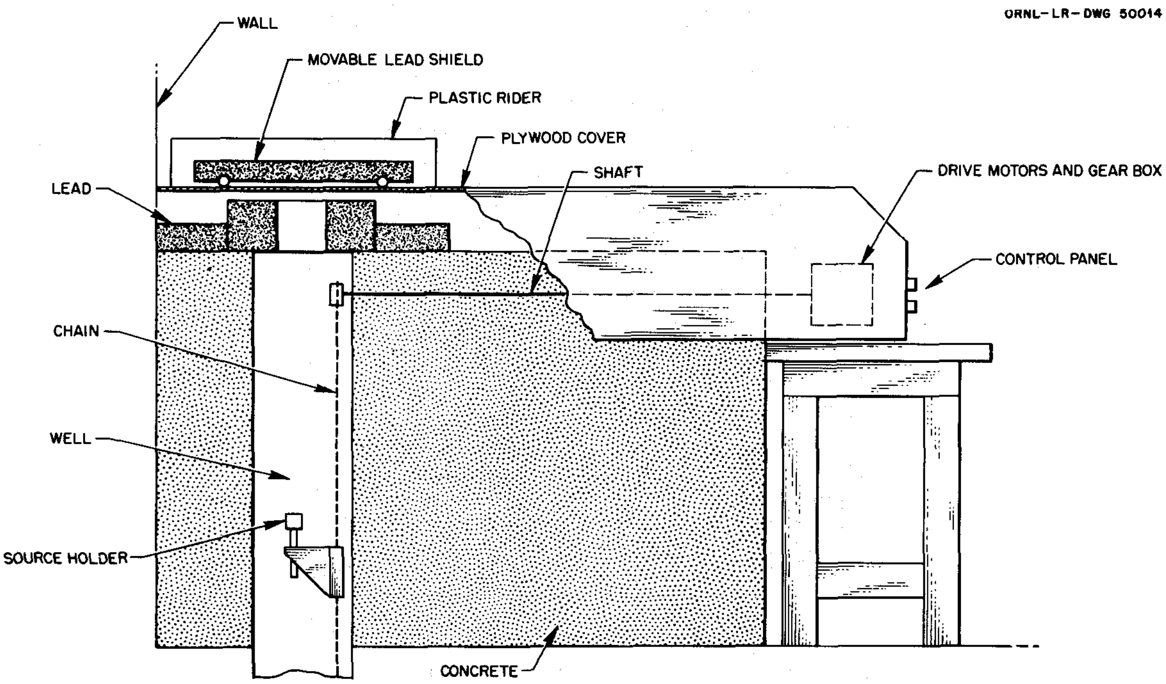


Fig. 2.14. Sectional view of "well" gamma calibration device.

2.8 ALPHA CALIBRATION SOURCE

Figure 2.15 shows one of the sources used for alpha-particle calibration. The source is prepared by electrodepositing plutonium on a stainless steel disk. The disk is mounted on a Bakelite plaque to facilitate handling. The sources cover the range 250 to 250,000 dis/min.

ORNL-PHOTO 12026

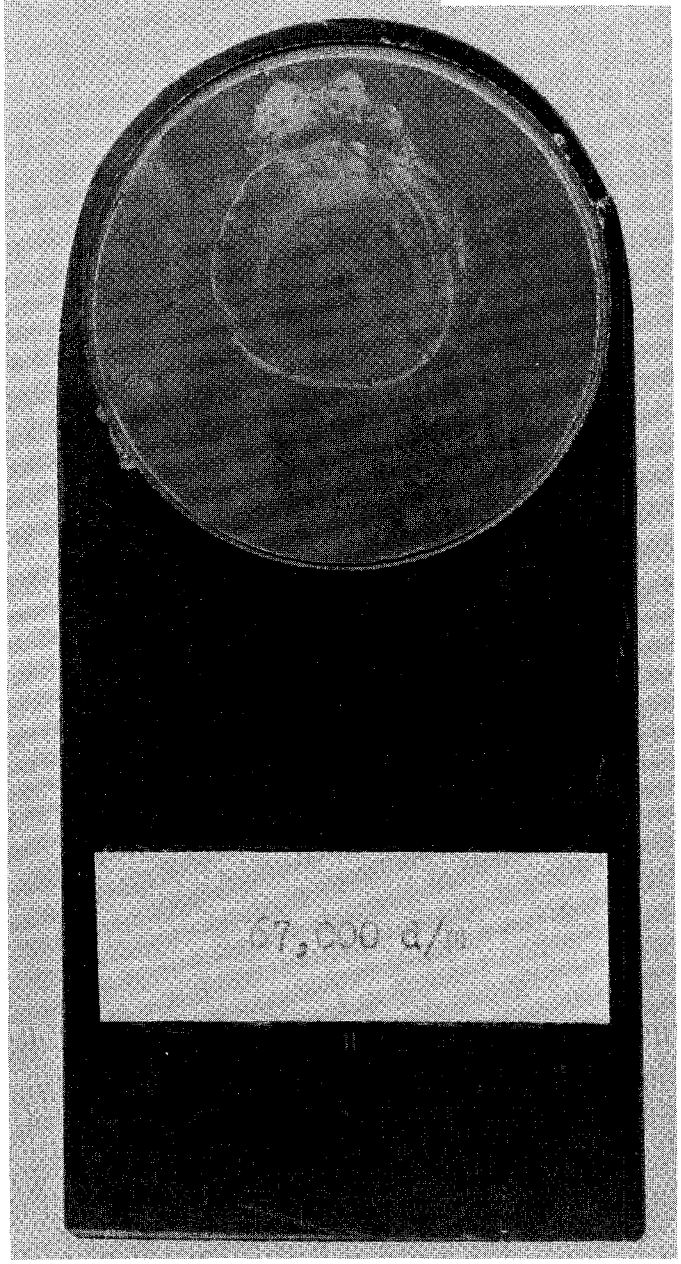


Fig. 2.15. Typical alpha calibration source.

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