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Health Physics Division

Applied Health Physics Radiation Survey Instrumentation

- by -

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Introduction

This manual is a revision of Instrument Manual ORNL 332. The manual has been extended to include Sources, Calibration Devices, and Maximum Permissible Contamination Levels. The Manual was revised by the Assays-Instruments Section of the Applied Health Physics Group of the Health Physics Division at ORNL.

The purpose of this manual is to give the surveyor in the Health Physics Division at ORNL a working knowledge of the radiation detection and measuring instruments currently in use at the Laboratory. The choice of the particular instruments is the result of several factors including availability at time of procurement, development and testing programs in progress, and economy. The rapid progress in the development and production of new types of instruments makes the cataloging of instruments a very difficult task. The inclusion of an instrument in this manual is not to be interpreted as an endorsement for that particular instrument nor is the omission of an instrument any reflection on its merits.

It is difficult for the authors to acknowledge properly the valuable assistance which they received in preparing this manual. Dr. E. E. Anderson gave valuable assistance in editing and correcting the manual. Mr. M. F. Fair offered many constructive comments and furnished some of the material in Section II. Miss A. E. Carter and Mr. F. A. Markli assisted with the circuit diagrams and some descriptions of operation of instruments. We acknowledge the assistance of Mrs. K. C. Scott in the preparation of this manuscript. Finally, we are grateful to J. C. Hart, Chief of Applied Health Physics Sections, for the many personal and official encouragements, valuable suggestions and active interest that have made this manual a reality.

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SECTION I

Section I -

Radiation Detection and Measuring Instruments Used by Applied Health Physics Section, ORNL.

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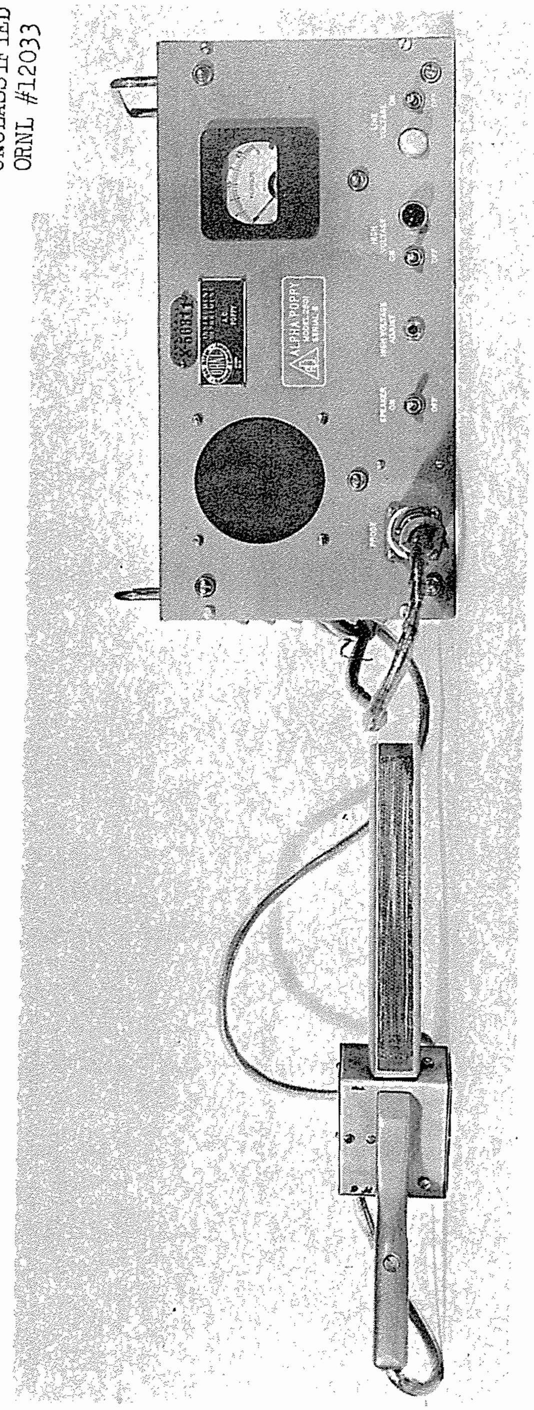


AC Alpha Poppy

The AC Alpha Poppy is used for the detection of alpha particle surface contamination. It consists of a proportional counter probe connected with a discriminating and amplifying circuit, and a count rate meter and loud speaker for indication of alpha radiation.

AC Alpha Poppy

A. Characteristics

1. Operates on 105-125 volt, 60 cycles.

2. Preamplifier incorporated in proportional counter probe to minimize microphonics and increase the plateau length.

3. Type indication: Speaker and count rate meter.

4. Geometry: Counts 15% of the alpha disintegrations from a source of smaller area than probe and having negligible surface density when a source is in contact with the probe window protective screen.

5. Full scale sensitivity ranges: 200 c/m
2,000 c/m
20,000 c/m

6. Meter can be used for measuring high voltage or counting rates; switch on instrument panel for changing voltmeter to count rate meter.

7. Background: No more than 2 counts per minute.

8. Probe cable: 25 ft.

9. Adjustable gain control.

10. Time constant in the order of 1 second.

11. Speaker "muting" switch.

12. Dimensions: 19" wide, 8-3/4" high, 14-7/8" deep. Weight: 63 lbs.

B. Application

1. Will detect alpha disintegrations on the order of 100 d/m or greater.

2. Proportional type counter is insensitive to moderate levels of beta and gamma radiation.

3. Proper adjustment of high voltage in the proportional region is critical.

4. Jarring or rough handling of probe will affect response.

5. Probe should be placed in position for several seconds to determine if radiation is present.

6. Instrument should be checked with an alpha source before use.

7. High humidity or extraneous electric fields will affect results.

C. <u>Calibration</u>

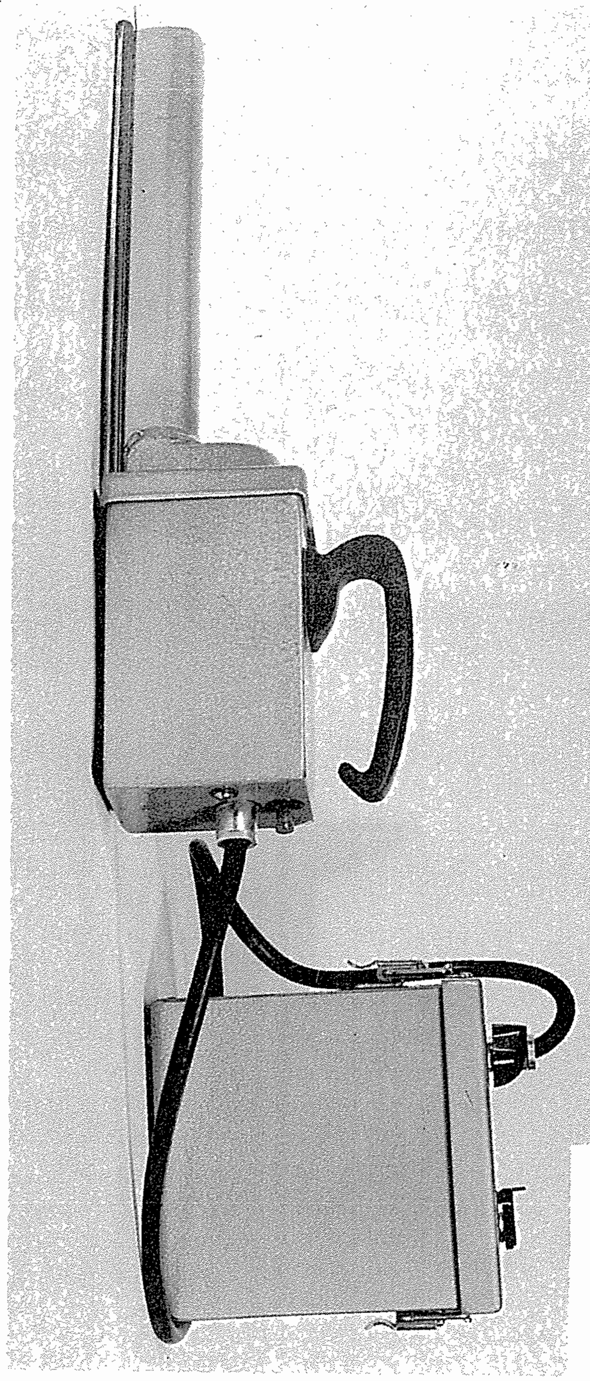
1. Source - alpha plaque.

2. Instrument should be turned on for several hours before operating.

3. Adjust high voltage such that an optimum condition results among low background counting rates, maximum sample counting rates, and insensitivity to gamma radiation.

4. Instrument should be checked for background counting rate and sensitivity to alpha source before each use.

D. Routine maintenance of this instrument is beyond the scope of this manual.



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Portable Alpha Poppy

The portable alpha poppy is used for the detection and semi-quantitative measurement of low level alpha radiation. The instrument is of light weight and includes a proportional counter, head phones for aural counting, and batteries to supply the required voltage.

Portable Alpha Poppy

A. Characteristics

1. Detects alpha radiation only.

2. Employs proportional counter operated at 1800 volts from parallel-charge, series-discharge condenser circuit.

3. Detection by means of head phones through three-stage wide-band amplifier with thyratron output.

4. Background count approximately 1 c/m. Counting efficiency approximately 15%.

5. Physically separated into two units: a probe, containing counter, HV switch and amplifier; battery box which hooks onto operator's belt.

6. Batteries:

300 V	Eveready 493
45 V	Eveready 455-P
3 V	Burgess B2BP
$1\frac{1}{2}$ V	Burgess 2FBP

7. Weight: 6 lbs.

B. Application

1. Insensitive to gamma radiation below 1 r/hr.

2. Sensitive to alpha radiation greater than 100 d/m at opening to chamber.

3. Insensitive to moderate levels of beta radiation.

4. Must be used with earphones to detect radiation.

5. Should be checked for spurious discharges before use.

6. Should not be jarred or handled roughly.

7. Gives immediate response to alpha radiation.

8. No warm up time or zero adjustments necessary.

C. Calibration

1. Source - Alpha plaques (See Section 3).

2. Plug in earphones, turn switch on and charge chamber.

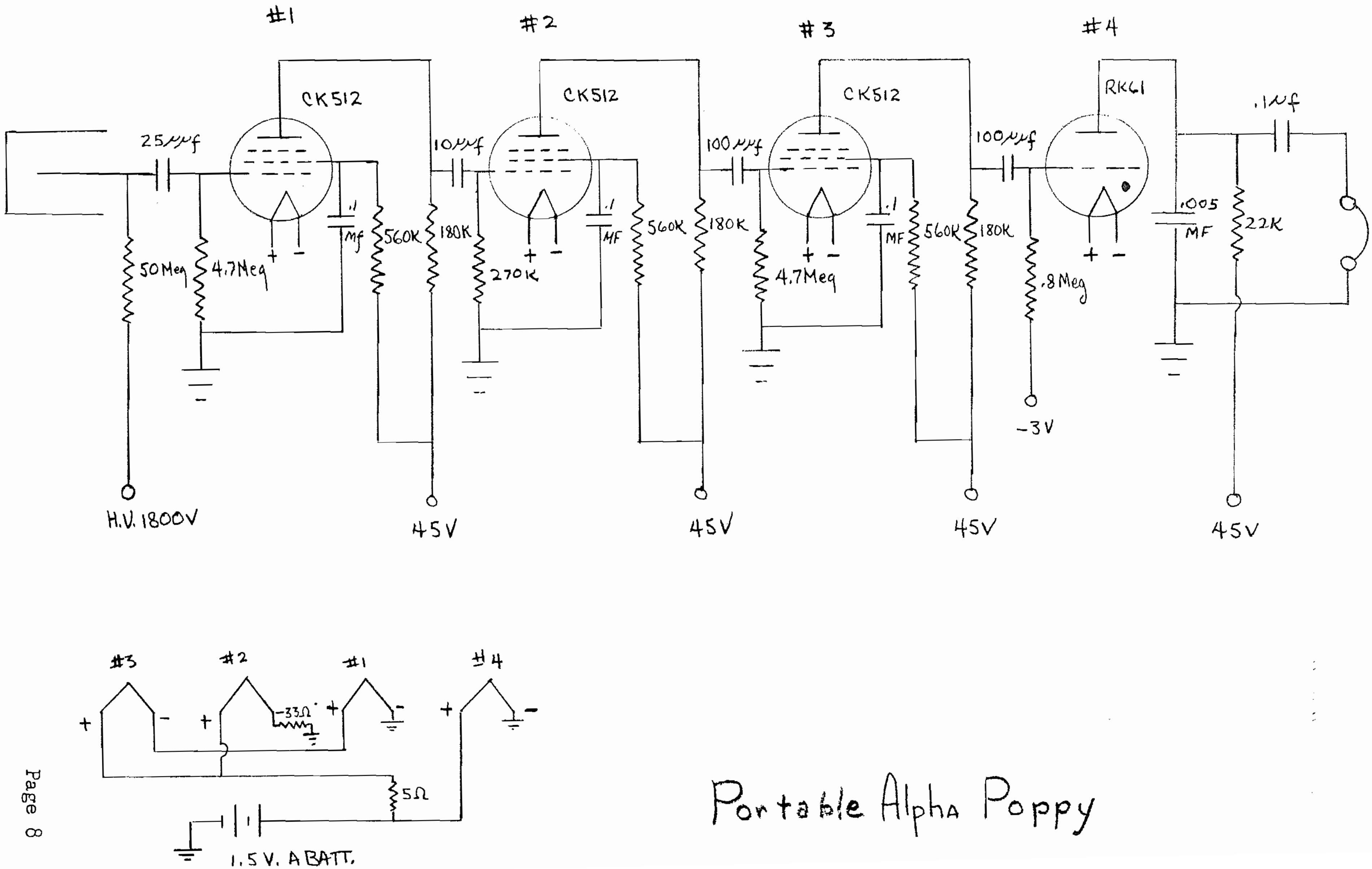
3. With the chamber removed from sources, determine background rate for one minute after charging. Background rate should not exceed 10 c/m.

4. Charge chamber and place directly over a 100 d/m source. The counting rate for the first three minutes after charging should be equal to or greater than twice the background counting rate.

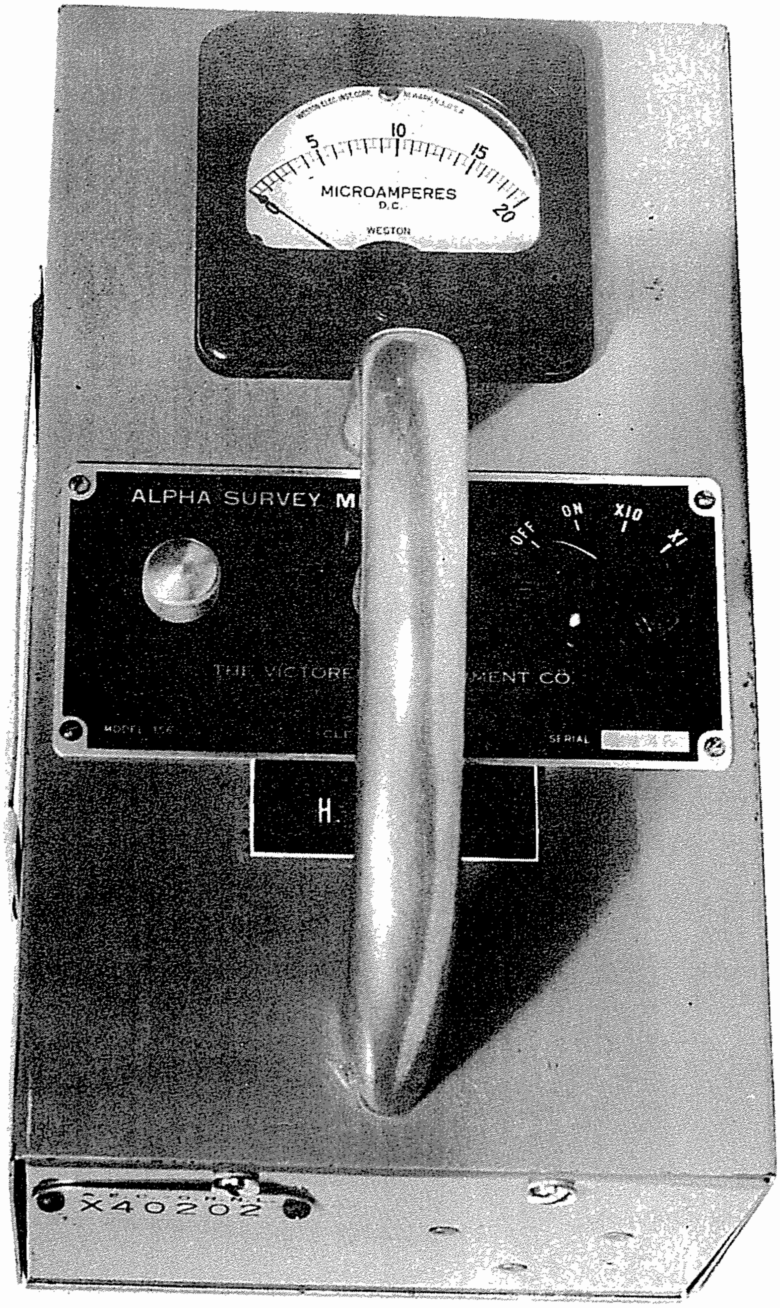
5. The instrument should be charged immediately before each reading is taken.

6. The instrument should be checked with an alpha source for stable operation before each use.

D. Routine maintenance of this instrument is beyond the scope of this manual.



Portable Alpha Poppy



Alpha Survey Meter (Zeuto)

The alpha survey meter is a lightweight portable instrument used for detecting and measuring intensity of alpha radiation. It is particularly designed to detect alpha contamination on benches, desks, tables, floors, and similar surfaces.

Alpha Survey Meter (Zeuto)

A. <u>Characteristics</u>

1. Radiation detected: Alpha Gamma Beta

2. Full scale reading:

		Alpha	Gamma
	X1	4000 d/m	4 mr/hr
	X10	40000 d/m	40 mr/hr

3. No screens to discriminate between types of radiation.

4. 0.2 Mil nylon screen on chamber, "Aquadag" coated.

5. Minimum energy of radiation detected: 25 Kev. Beta
   2 Mev. Alpha

6. Power Supply: Batteries:

Mfr.:	Eveready	Eveready	Burgess	Burgess	Ray-O-Vac
No.:	412	412	W5BP	W5BP	ZLP
Voltage:	22.5V	22.5V	7.5V	7.5V	1.5V
Use:	Plate	Chamber	Coupling	Bias	Filament
Life:	500 Hrs.	Shelf	Shelf	1000 Hrs.	200 Hrs.

7. Dimensions: 9.5" x 5" x 4".

B. <u>Application</u>

1. Indicates alpha, beta, and gamma radiation.

2. Calibrated only for alpha radiation.

3. External shield should be used to determine if radiation other than alpha is present.

4. Measures alpha radiation within the range of 300 d/m to 80,000 d/m.

5. Should be allowed to warm up for five minutes before use.

6. Accurate zero setting necessary.

7. Must be as close as possible to surface being measured.

8. Several seconds necessary in each position to determine if alpha activity is present.

C. <u>Calibration</u>

1. Sources - Alpha plaques (See Section 3).

2. Turn instrument on five minutes prior to calibration.

3. Check dial and meter function.

4. With instrument removed from source, zero on "on" position.

5. Choose sources permitting at least three readings on the times 1 and the times 10 positions.

6. Window of instrument should be placed directly over and as close to the source as possible.

7. Plot a curve of disintegrations per minute versus meter reading for each sensitivity position. Attach this curve to the side of the instrument.

8. The instrument should be checked and recalibrated every four weeks.

D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, meter, and zero functions.

3. Check for response to alpha radiation.

4. The more common malfunctions may be due to one or more of the following:

    a. Leakage due to foreign material on insulators, high value resistors, electrometer tube, etc.

    b. Radioactive contamination

    c. Faulty switch

    d. Faulty tube

    e. Faulty meter

    f. Faulty potentiometer

    g. Improper bias adjustment

    h. Battery terminals reversed

    i. Intermittent, improperly shorted, or improperly opened connections.

    j. Alpha window too thick

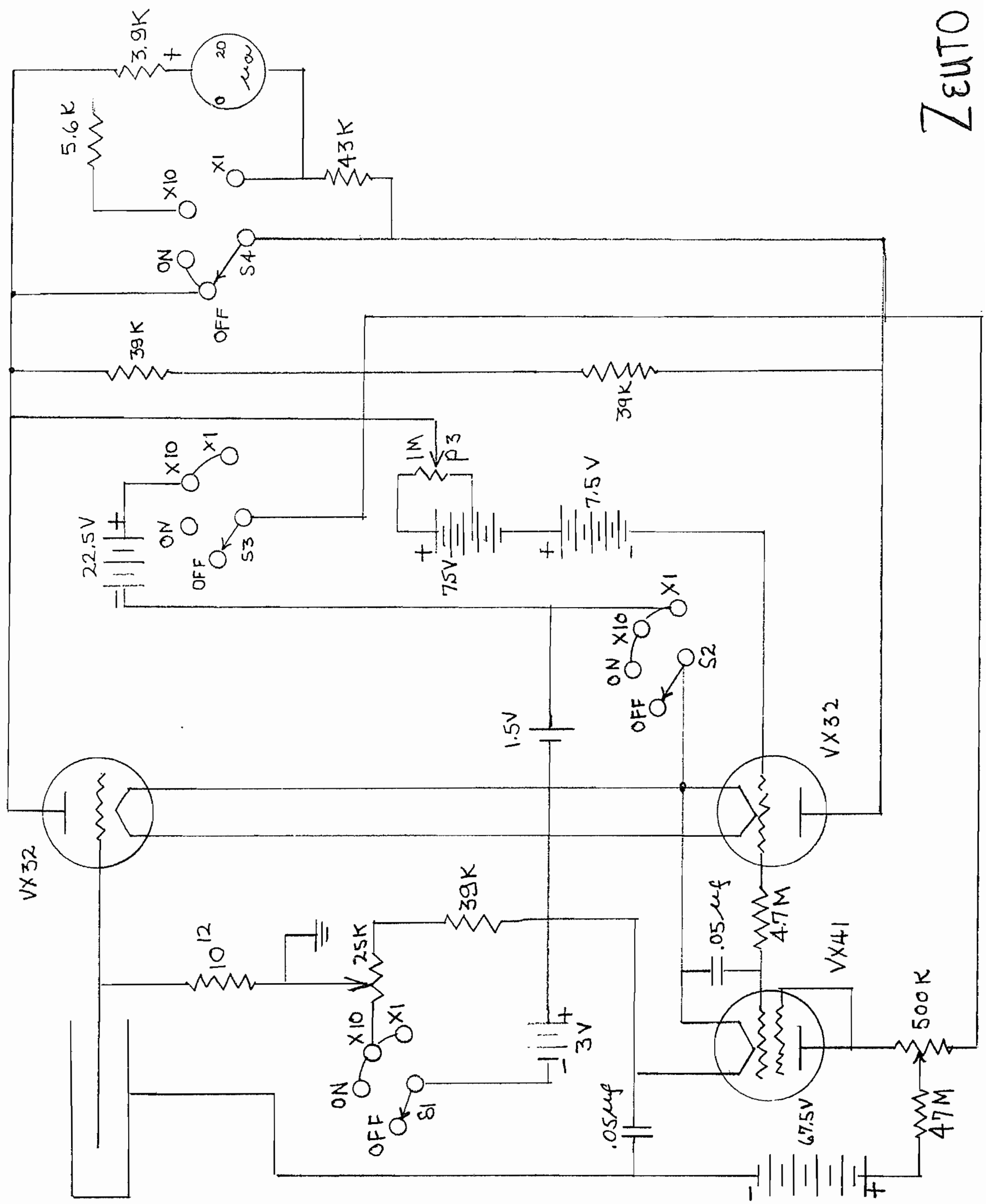
    k. Excessive humidity

5. Inability to zero may be due to c, d, e, f, g, h, or i.

6. Lack of or weak response to radiation may be due to c, d, e, g, j, or i.

7. Too great response to radiation may be due to a, b, d, g, i, or k.

8. Erratic readings may be due to a, c, d, e, f, g, h, or i.


ZEUTO
3.9K
5.6K
20
0
43K
X10
X1
ON
OFF
S4
39K
39K
22.5V
X10
X1
ON
OFF
S3
1M
P3
7.5V
7.5V
X1
X10
ON
OFF
S2
1.5V
VX32
VX32
10^12
25K
39K
X10
X1
ON
OFF
S1
3V
.05 uf
4.7M
VX41
500K
.05uf
67.5V
47M

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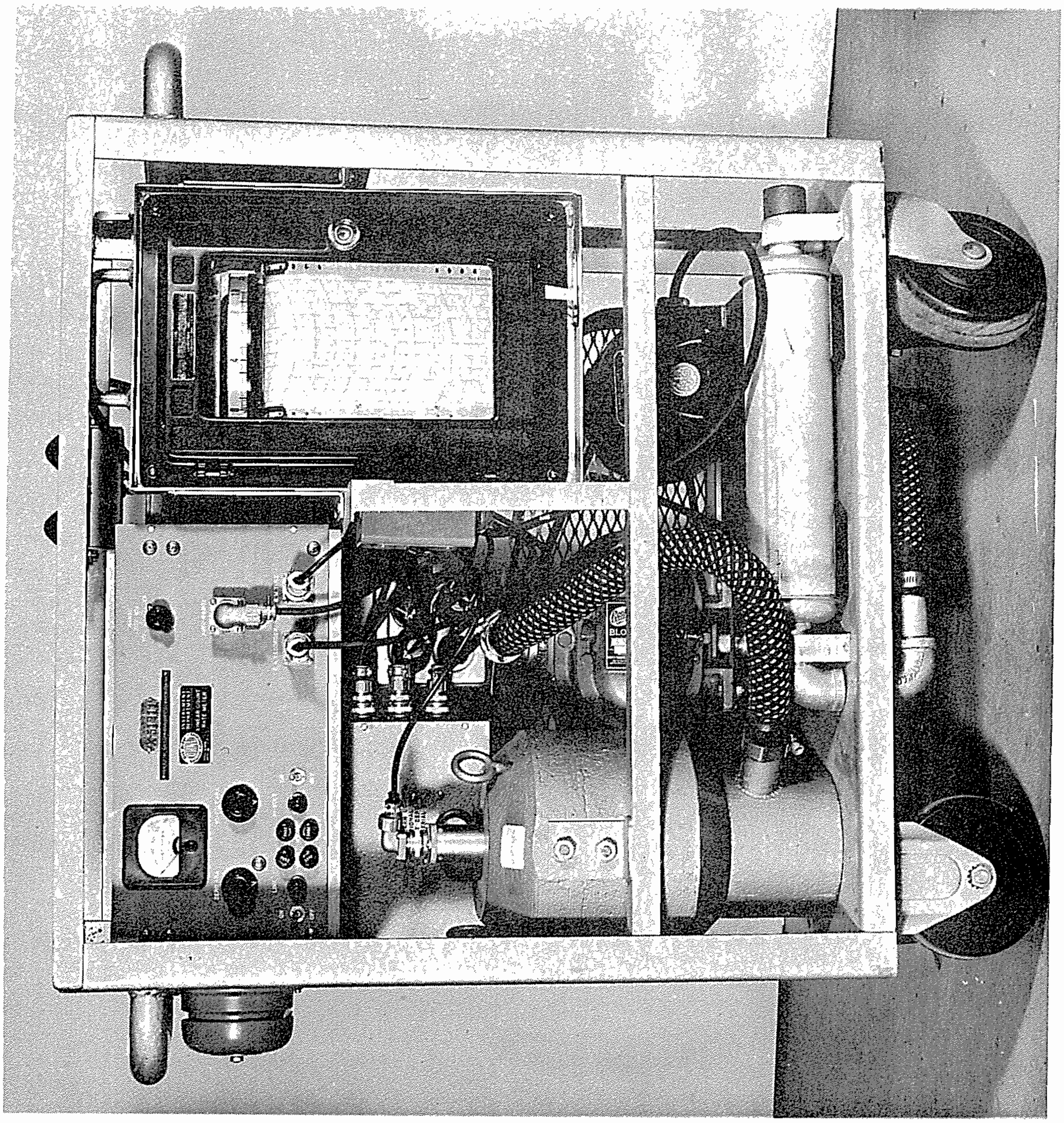


Constant Air Monitor

The constant air monitor is a device for monitoring the quantity of radiation present in the ambient air. A vacuum pump draws air through a filter around a GM tube mounted in a lead shield. The GM tube is connected with a count rate meter which, in turn, is connected with an Esterline Angus Recorder. The radiation level is indicated on the count rate meter and continuously recorded. An associated relay-alarm system allows the alarm to be sounded at predetermined levels.

Constant Air Monitor

A. Characteristics

1. Operates on 100 to 120 volts AC.

2. Maintains continuous monitoring of air for beta-gamma activity.

3. Filters air pumped by attached motor blower unit at rate of 5 cfm.

4. GM tube mounted within filter housing.

5. Count rate meter has three ranges: 2000 c/m
10000 c/m
20000 c/m

6. Associated recorder keeps permanent record of the counting rate vs. time.

7. Associated relay and alarm system automatically changes ranges and sounds corresponding alarm.

8. Counting geometry: 17.6%

9. Collection efficiency: 70% for particles greater than 0.5 microns.

10. Muffler to reduce motor noise.

11. Three inch wall thickness lead shield for GM tube and filter housing.

12. Dimensions: 30" x 16" x 36". Weight: 750 lbs.

B. Application

1. The instrument may be used wherever there is shelter from the weather and 110 V AC power available.

2. When properly adjusted, the instrument will maintain a constant monitoring of the air and keep a permanent record of the relative radioactivity collected on the filters.

3. The recorder sheet shows the rate of collection of activity as well as the total activity in any period.

4. The instrument will not differentiate between beta and gamma activity.

5. The instrument does not indicate the energy of the activity collected.

6. The instrument will respond to direct radiation which penetrates the lead shield as well as to radioactivity collected on the filters.

7. The meter, recorder, and relay function should be checked daily.

8. The instrument should be properly calibrated before use.

9. Contamination of the tube or shield will give erroneous results.

10. Filter paper should be changed daily.

11. Tube should be centered in holder.

12. Holder should be properly seated in lead shield.

13. Air flow rate should be accurately determined.

14. Measurements for air activity should not be made with tube removed from lead shield.

C. Calibration

1. Source - special CAM source (See Section 3).

2. Check all control, relay and chart functions.

3. Since the strength of the source used for calibration is sufficient to sound the alarm, persons in the vicinity should be warned of the calibration procedure, or the alarm may be inactivated at the discretion of the calibrator.

4. Place the uranium source in one of the slots where the filter paper normally fits, adjust "O" rings to hold source in place and return tube assembly into lead shield.

5. Adjust the sensitivity controls such that the EA recorder reading is approximately full scale when selector switch is on the 10K range, and half scale on the 20K range.

6. Record the reading of the EA recorder when on the 10K range on the card attached to the glass cover of the EA recorder. A typical recording on the instrument would be as follows: "Tolerance equals 10 divisions for an air flow rate of 5 cubic feet for a period of 30 minutes on the 10K scale."

7. The instrument should be checked daily and calibrated weekly.

Cutie Pie

The Cutie Pie is a relatively small, lightweight, portable survey instrument used for measurement of gamma ray dose rates. It is used also for the indication of beta radiation and thermal neutron radiation.*

*FF. See Appendix 2, Section 4,

Cutie Pie

A. Characteristics

1. Radiation detected: Alpha, Beta, Gamma and Thermal Neutrons.

2. Full scale readings: 0 - 100 mr/hr.
   0 - 1000 mr/hr.
   0 - 10000 mr/hr.

3. Input resistance: 10^{11} ohms 0 - 100 mr/hr.
   10^{10} ohms 0 - 1000 mr/hr.
   10^{9} ohms 0 - 10000 mr/hr.

4. Can be zero-set in presence of radiation.

5. Alpha and beta sensitivities depend on geometry, energy of particle, etc.

6. Chamber: 3" diameter x 6" long - modifications described in AI-115-53, (See Section 4).

7. Splash proof design.

8. Teflon insulation used in chamber.

9. Range switch made of teflon.

10. Calibration accuracy ± 10%.

11. Battery power supply:

Quantity	Description
4	No. 412 - 22½ volt (Eveready)
1	1.3 volt Mallory Cell

12. Battery Life: 200 hours

13. Dimensions: 10" x 3" x 8". Weight: 2-3/4 lbs.

B. Application

1. See Appendix 2.

C. Calibration

1. Source - 1 curie of Ra in well (See Section 3).

2. Turn instrument on five minutes before calibration.

3. Check meter and dial functions.

4. Orient instrument on side over source so that the zero position of the meter is downward.

5. Adjust zero on zero-set position.

6. Set on 10^{11} division (the most sensitive scale) and raise source until meter reads one-fourth of full scale. Determine mr/hr for this source position and record. Proceed as above for half scale reading, three-quarter scale reading, and full-scale reading.

7. Set on 10^{10} position and proceed as above.

8. Set on 10^{9} position and proceed as above.

9. For calibration of an ORNL Cutie Pie, see report AI-115-53.

10. Plot a curve of mr/hr versus meter reading for each scale position and attach to the side of the instrument.

D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, meter, and zero functions.

3. Check for response to gamma radiation.

4. The more common malfunctions may be due to one or more of the following:

   a. Leakage due to foreign material on insulators, high value resistors, electrometer tube, etc.

   b. Radioactive contamination.

   c. Faulty switch.

   d. Faulty tube.

   e. Faulty meter.

   f. Faulty potentiometer.

   g. Improper bias adjustment.

   h. Battery terminals reversed.

   i. Intermittent, improperly shorted, or improperly opened connection.

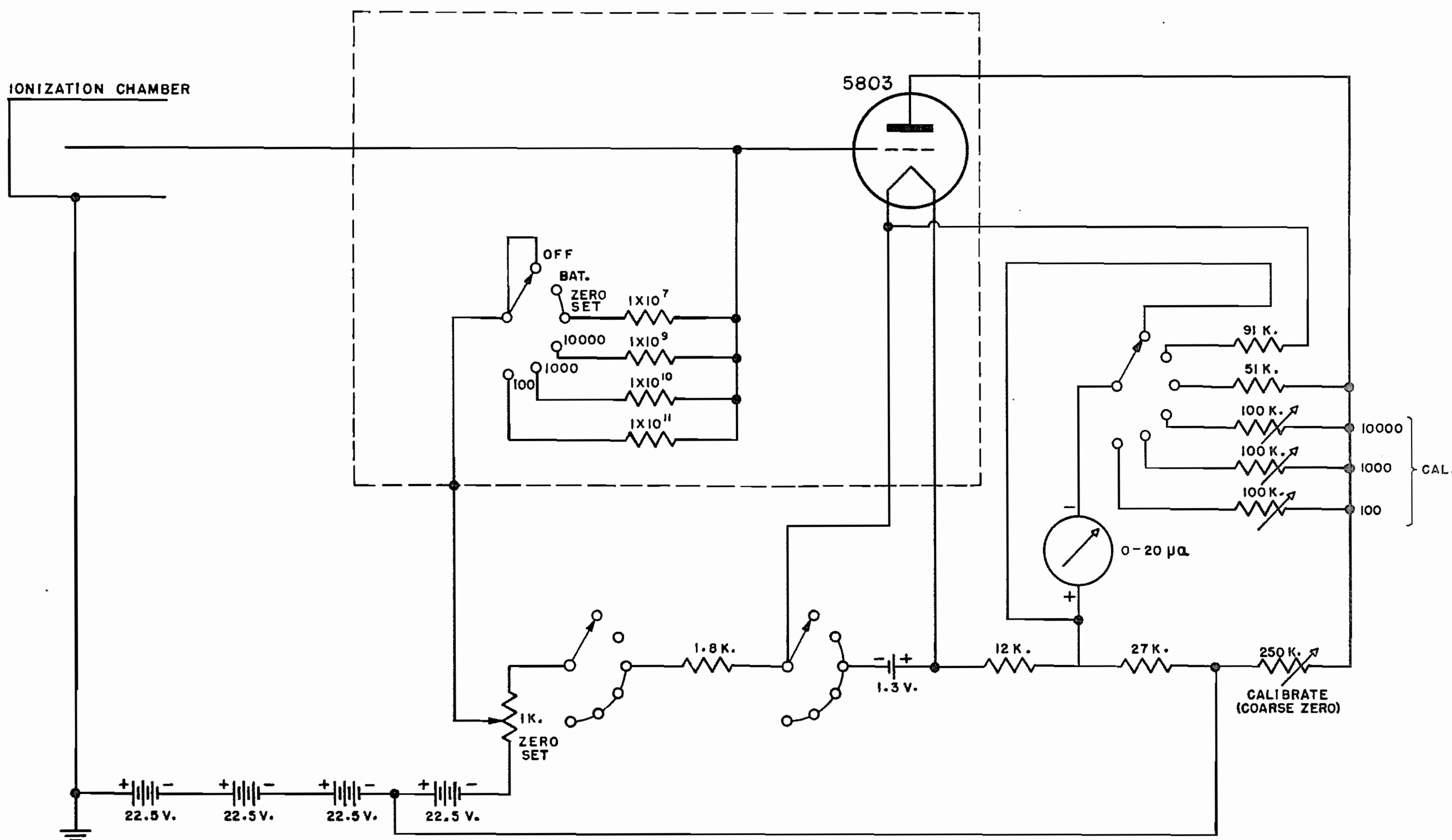
   j. Excessive humidity.

5. Inability to zero may be due to c, d, e, f, g, h, or i.

6. Lack of, or weak response to radiation may be due to c, d, e, g, or i.

7. Too great response to radiation may be due to a, b, d, g, i, or j.

8. Erratic readings may be due to a, c, d, e, f, g, h, or i.



ORNL CUTIE PIE CIRCUIT

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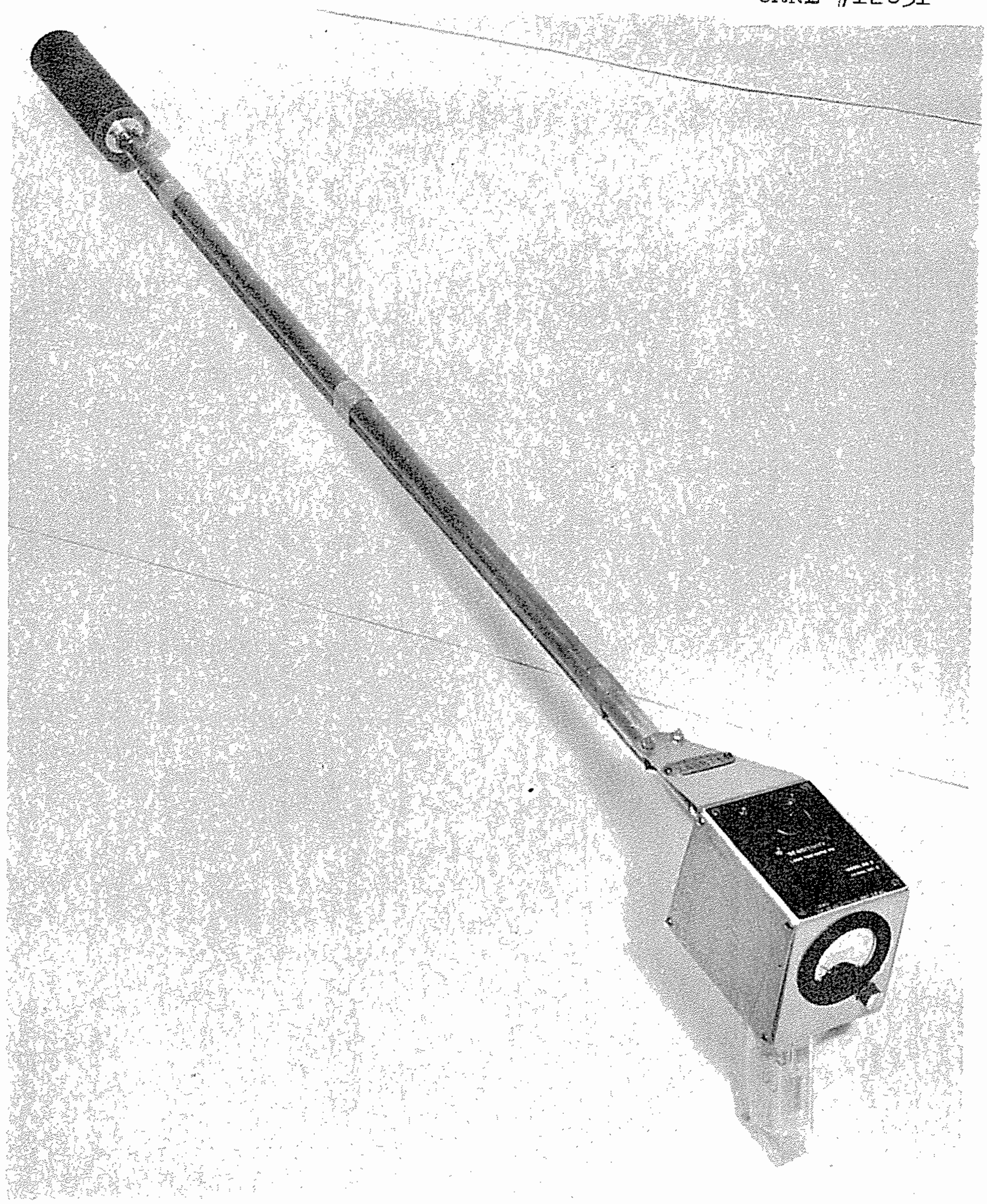

Long Tom Cutie Pie

The Long Tom Cutie Pie is a physical modification of the Cutie Pie. The distance from the ion chamber to the meter and handle is 40 inches. The gamma sensitivity, due to the reduced ion chamber volume, is approximately one-half that of the Cutie Pie.

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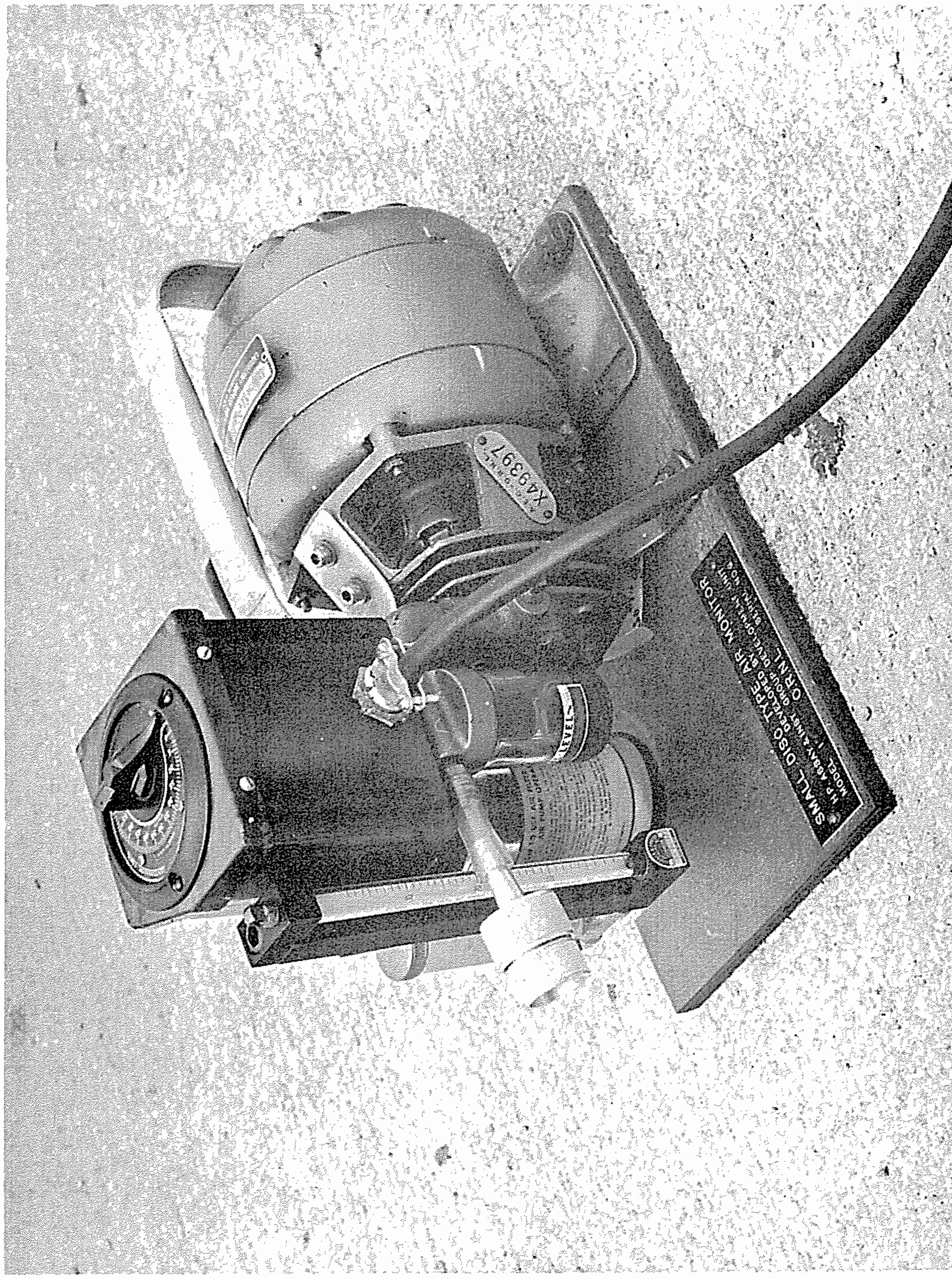

Disc Air Sampler

The disc air sampler is a motor-blower unit with attached filter holder. Air is drawn through the filter at the rate of one cubic foot per minute.

Disc Air Sampler

A. Characteristics

1. Operates on 100 to 120 volts AC.
2. Compact motor blower unit.
3. Air flow rate: 1 cu.ft./min.
4. Filter efficiency: > 90%.
5. Equipped with handle for portability.
6. Dimensions: 15" x 7" x 9". Weight: 25 lbs.

B. Application

1. May be used wherever 110 V AC power is available.
2. For accurate assay of radioactivity collected the collection time should be noted and the airflow rate gauged.
3. The filter disc should be smooth and free of holes.
4. The filter holder should be turned so that there is no obstruction in front of the filter.
5. Check the oil level in the glass jar at the intake.
6. Shut off power to motor before removing the filter.

C. Calibration

1. This device is calibrated only for air flow rate with flow meter supplied.

D. Routine maintenance of this device is beyond the scope of this manual.

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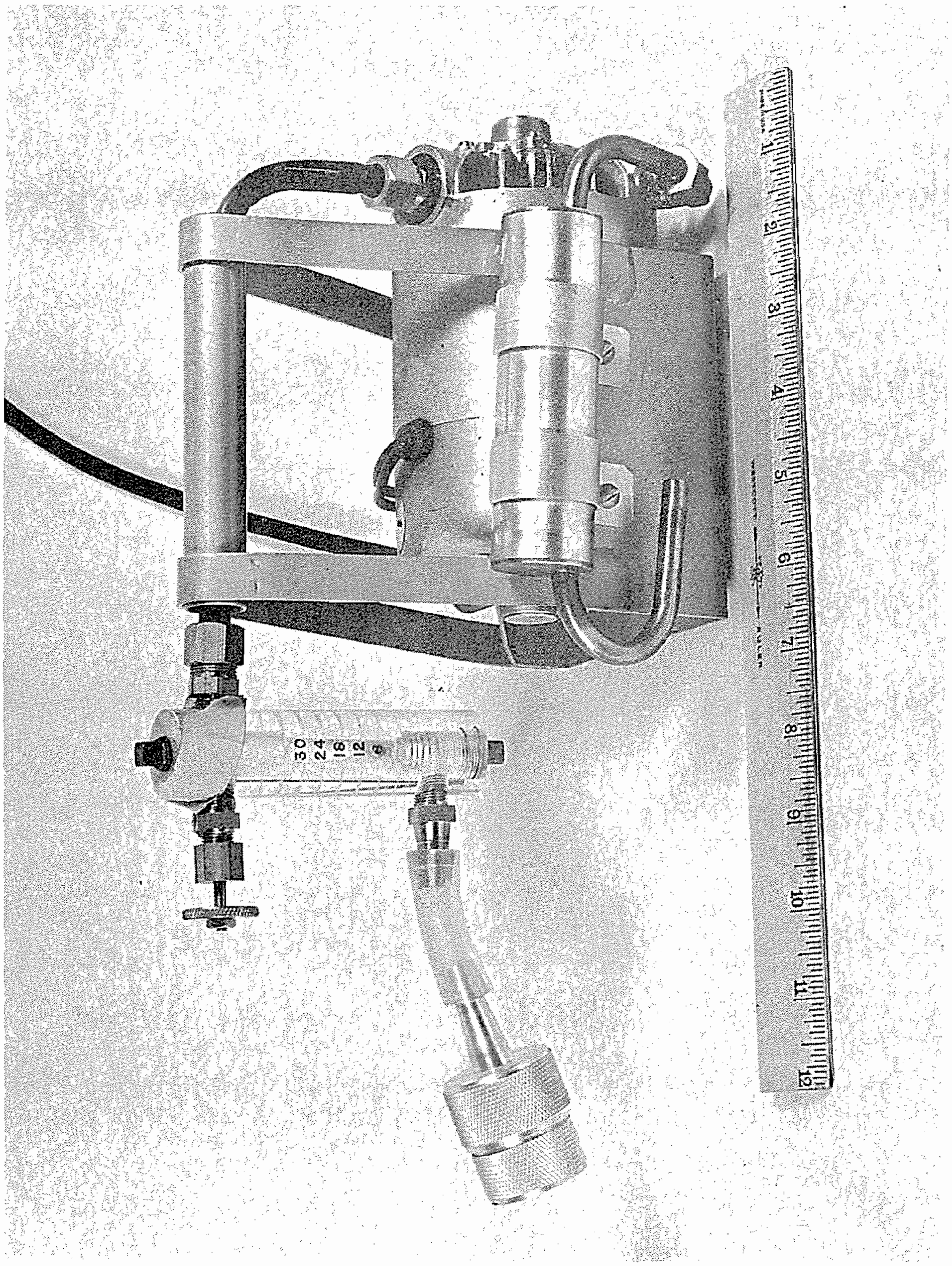

Midget Disc Air Sampler

The Midget Disc Air Sampler is similar to the Disc Air Sampler, except for weight (5 lbs) and size (8" x 5" x 6"). This instrument is for intermittent operation.

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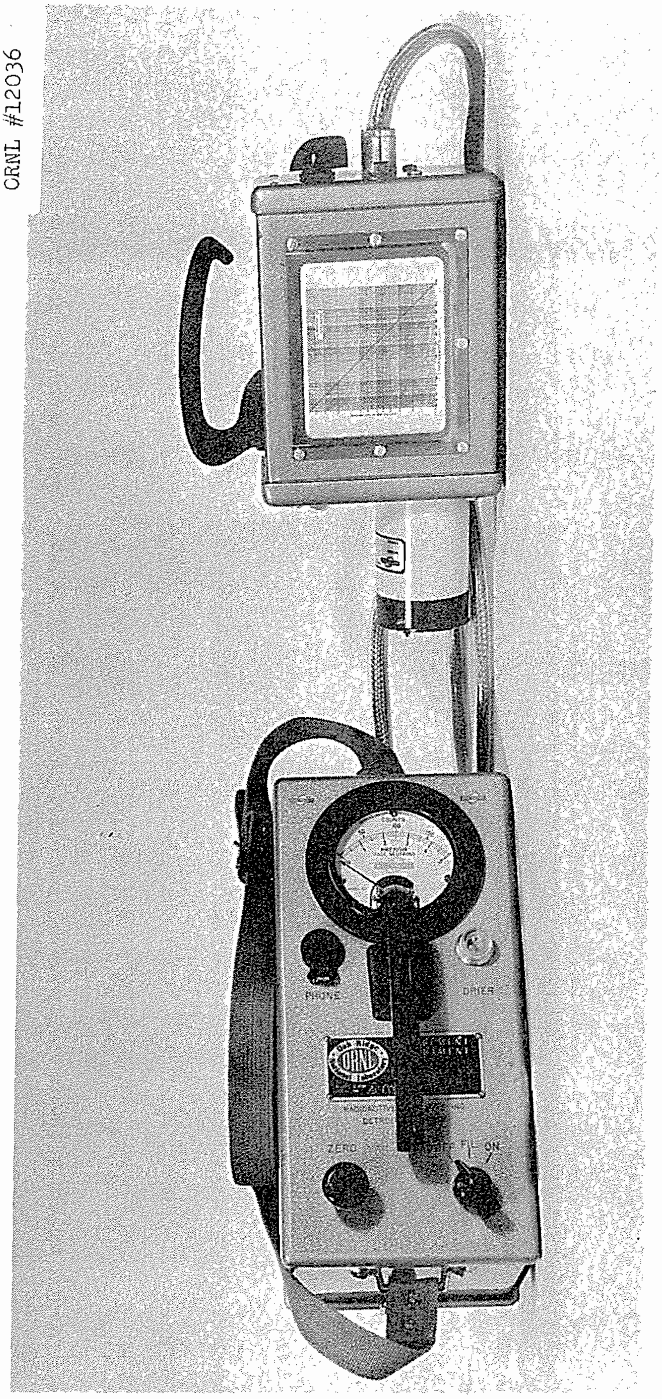


Fast Neutron Dosimeter

The fast neutron dosimeter is designed for measurement of fast neutron dose rate. It is a portable survey meter consisting essentially of a proton recoil proportional counter, wide-band pulse amplifier, univibrator, vacuum tube volt meter for a rate meter, vibrator high voltage source and associated battery power supplies.

Fast Neutron Dosimeter

A. Characteristics

1. Detects fast neutrons only.

2. Employs proton recoil proportional counter.

3. Four ranges: INT
   5 mrep/hr
   50 mrep/hr
   500 mrep/hr

4. Response proportional to human tissue sensitivity over the energy range of 0.2 - 10 Mev fast neutrons.

5. Directional response 2:1, front to side.

6. Counter operates at 1400 volts, producing 75 mv pulses for gammas, up to 750 mv pulses for neutrons, depending upon energy.

7. Circuit consists of two-stage negative feedback pulse amplifier, univibrator, integrator, ratemeter.

8. External Controls: on-off switch, range selector switch, zero adjust.

9. Batteries: one Eveready 7603, 22½V, one Burgess B2BP, 3V, one Burgess F2BP, 3V, one Burgess 4FH, 1½V, one Burgess XX30E, 45V.

10. Dimensions: Battery box 4-3/4" x 5-1/2" x 10".
    Hand unit 3" x 5" x 6-1/2".
    Weight: 10½ lbs total for both units.

B. Application

1. When properly adjusted is sensitive only to fast neutrons.

2. Should be allowed to warm up 3 minutes before use.

3. Zero should be carefully checked.

4. Should be checked for gamma sensitivity before measuring neutrons.

5. Accuracy of measurement depends upon orientation of instrument.

6. Familiarity with operating routine necessary in interpreting results.

C. Calibration

1. Source - 25 millicurie Ra and a Po-Be source and fast neutron setup (See Section 3).

2. Turn switch to filament for 10 seconds, then to "on", adjust the B^+ to mark indicated on meter.

3. Return range switch to normal and allow three minutes for the instrument to warm up.

4. Adjust bias. With a 25 millicurie Ra source placed 5 centimeters from the end of the counter, the range selector on 5 millirep per hour, adjust "set bias" so that the meter reads between 3.5 and 4.5.

5. Set a Po-Be neutron source at such a distance that a 25 mrep/hr dose is received at the center of the counter. With the range set on 50 adjust "calibrate rate meter" so that the meter reads 25 mrep/hr.

6. Check 500 mrep/hr scale at 250 mrep/hr.

7. Check 5 mrep/hr scale at 2.5 mrep/hr.

8. With neutron source set so that dose at center of counter is 2.5 mrep/hr adjust "calibrate integrater" such that the meter reads full scale in 80 seconds. Range selector is set on "INT" during timing.

9. This instrument should be checked and calibrated every three to four weeks.

C. <u>Routine Maintenance</u>

1. Check and replace weak batteries.

2. Check switch, control, meter, and zero functions.

3. Check for response to fast neutron radiation.

4. The more common malfunctions may be due to one or more of the following:

   a. Leakage due to foreign material on insulators.

   b. Radioactive contamination.

   c. Faulty switch.

   d. Faulty counter.

   e. Faulty meter.

   f. Faulty potentiometer.

   g. Improper bias adjustment.

   h. Battery terminals reversed.

i. Intermittent, improperly shorted, or improperly opened connection, particularly in connecting cable to power supply.

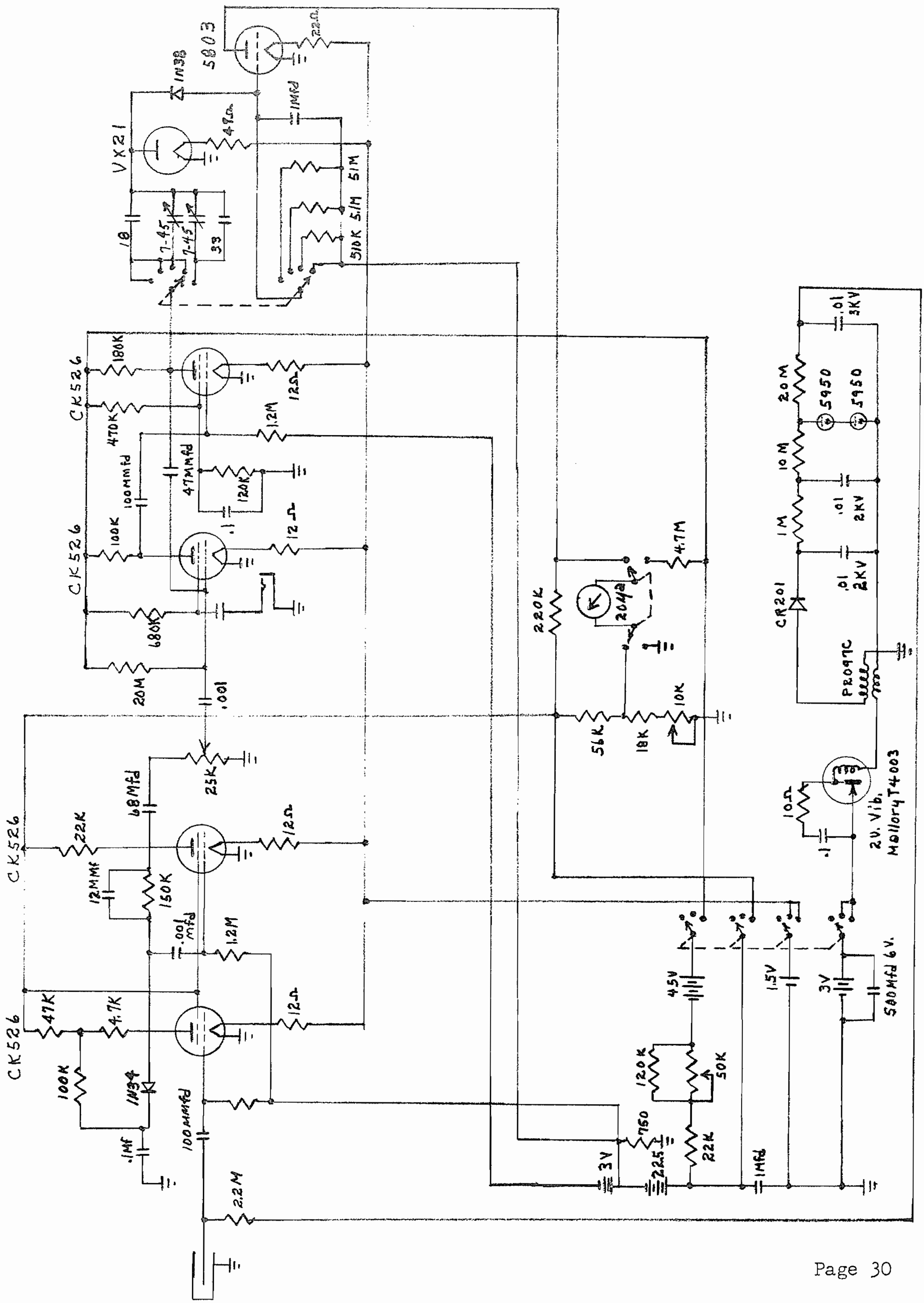
j. Faulty electrometer tube.

k. Faulty amplifier tube.

l. Faulty vibrator.

m. Faulty rectifiers or voltage regulators.

5. Special equipment is required to service this instrument. Refer to operating and maintenance instructions.



Fast Neutron Dosimeter

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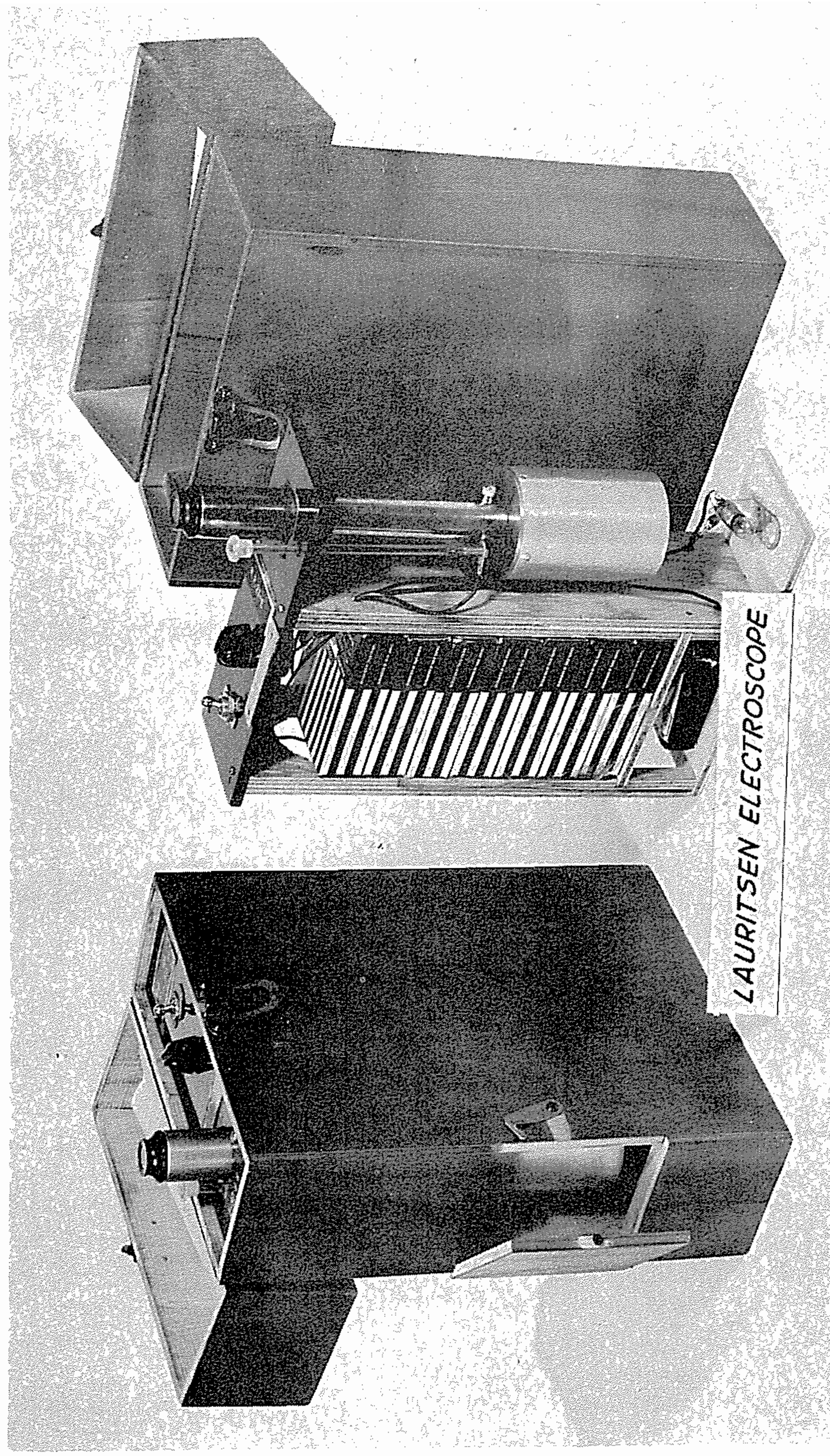


Lauritsen Electroscope

The Lauritsen Electroscope is a medium size, gamma measuring, beta indicating, portable survey instrument. The instrument consists of an ion chamber and a quartz fiber suspension system which is charged by means of an included power supply. The fiber, which is viewed through an attached microscope, is displaced, after charging, at a rate proportional to the radiation dose rate. The inner surface of the ionization chamber may be coated with enriched boron and used for the measurement of thermal neutron fluxes.

Lauritsen Electroscope

A. Characteristics

1. Measures gamma radiation, thermal neutrons*, and ionization due to beta radiation.

2. Useful range: 1 mr/hr to 1000 mr/hr.

3. Consists of Fred C. Henson, Model 1, Electroscope mounted in portable plywood box. Battery supply and lamp included.

4. Chamber is aluminum - 2-1/4" D x 2-3/4" L. May be boron coated for thermal neutron detection.

5. Chambers available with windows for detecting alpha and beta.

6. Batteries: five Burgess XX30E, 45V, and two size D flashlight cells.

7. Dimensions: 8" x 3" x 14". Weight: 8 lbs.

B. Application

1. Measures within 1% hard gamma radiation within the ranges of 1 mr/hr to 1000 mr/hr.

2. With plywood window open is sensitive to hard beta radiation.

3. Calibrated for gamma radiation only, unless supplied with boron coated chamber.

4. The boron coated chamber is sensitive to thermal neutrons.

5. Instrument supplied with boron coated chamber is calibrated in terms of thermal neutron tolerance.

6. The instrument should be used only over the portion of the scale for which it is calibrated.

7. Where applicable, instrument should be charged for several minutes before use.

8. Accurate timer necessary for proper use.

9. Distance from source to instrument important in interpreting results.

C. Calibration

1. Source - electroscope set-up (See Section 3).

*With boron coated chamber.

2. Check light functions and charging mechanism. Charge instrument to zero and allow to stand for several minutes before calibration.

3. Determine background by comparison with "standard electroscope."

4. Note and record the time in seconds required for the fiber to be displaced 10 divisions (from 1 to 2) at dose rates of 2, 10, 50, and 100 mr/hr.

5. Repeat the above for time of travel for 50 divisions (1 to 6) at dose rates of 50, 100, 500, and 1000 mr/hr.

6. Plot a curve of dose rate versus time for 10 divisions (1 to 2) and for 50 divisions (1 to 6). Place this curve in the inside of the instrument case.

7. For thermal neutron calibration, use Po-Be source and paraffin holder (See Section 3).

8. From source data, determine distances to obtain dose rates corresponding to 1/2, 1, and 2 times the thermal neutron tolerance.

9. Take readings at these distances with the uncoated member of the matched pair of electroscopes.

10. Take readings at these distances with the boron-coated electroscope.

11. The differences between these two readings gives the gamma equivalent for thermal neutron tolerances. Plot a curve of mr/hr versus thermal neutron tolerance and attach to the instrument.

D. <u>Routine Maintenance</u>

1. Check and replace weak batteries.

2. Check charging function and scale alignment.

3. Check for response to gamma radiation.

4. Inability to zero may be due to

   a. Damaged fiber

   b. Faulty potentiometer

5. Drifting fiber may be due to

   a. Dirty insulator

   b. Dirty fiber

   c. Faulty fiber

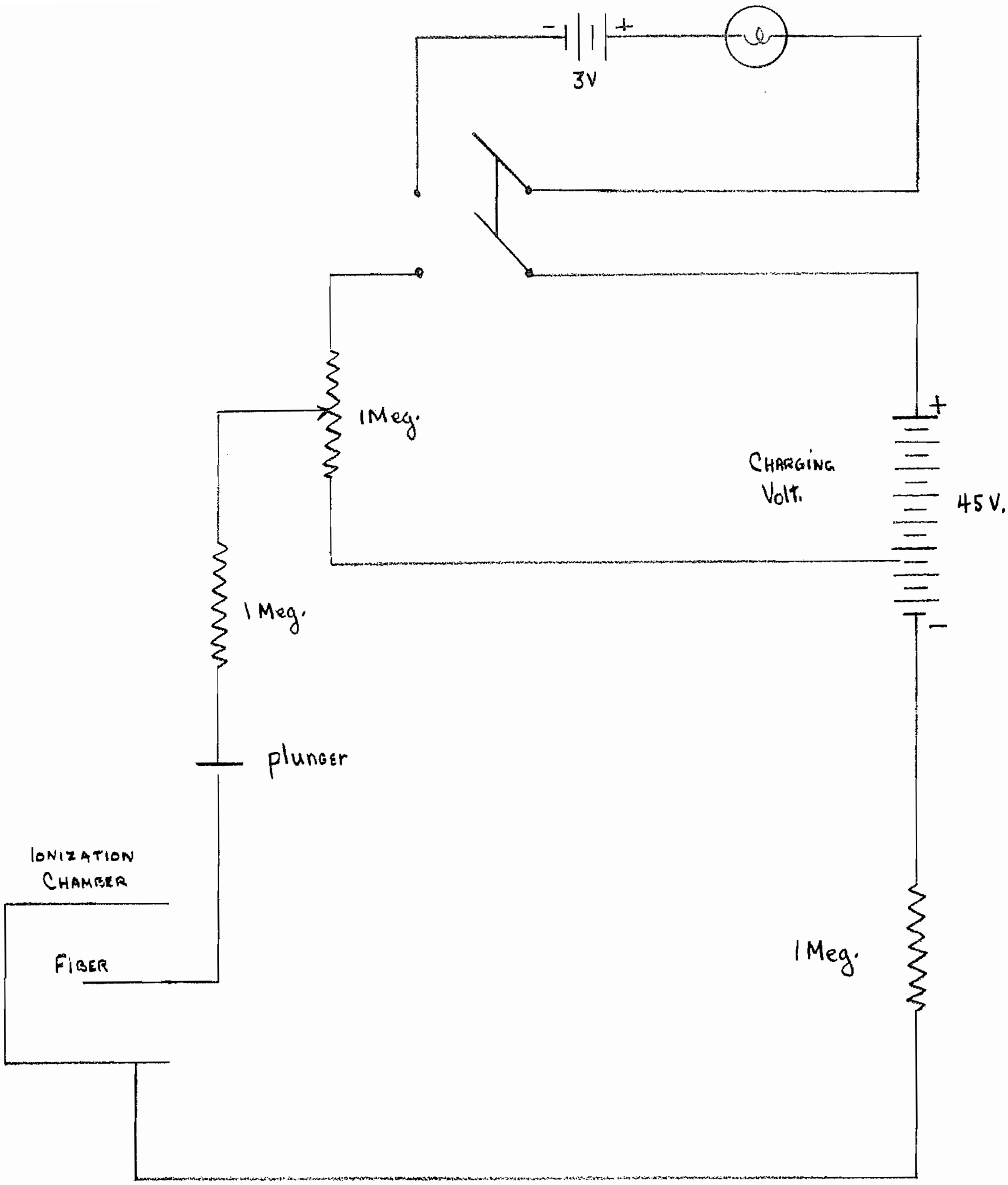
d. Radioactive contamination

6. Difficulty in viewing scale or fiber may be due to

   a. Lens not properly focused

   b. Dirty lenses

7. Caution: Never remove ion chamber in the field.



Lauritsen Electroscope

UNCLASSIFIED
ORNL #11049

Film Dosimeter

The film meter is used to determine the weekly exposure of an individual to beta, gamma, X ray, and neutron radiation. Two meters, one black and one red, are provided each employee. While one of the meters is being worn by the employee, the other is being processed by the Personnel Monitoring Section.

Film Dosimeter

A. Characteristics

1. Film Holder (Badge)

a. The film holder or badge is fabricated of plastic. It is fastened to the clothing by a metal alligator clip.

b. Three metal filters are used in the badge to aid in determining the energy, and subsequently dose, of the radiation exposure. The filters are lead, .020", cadmium, .030", and copper, .040".

c. The size of the badge is 1-1/2 x 2-3/16 x 1/4". The badge fully loaded weighs approximately 21 grams.

2. Film

a. Two film packs are used in the badge. One is the duPont type 553 and the other is the Eastman NTA.

b. The duPont 553 pack contains three films, the 502, 510, and 606.

c. The NTA film is changed on a weekly basis for persons normally exposed to neutrons, quarterly for others.

B. Application

1. Normal useful range of approximately 50 mr to 500 r when exposure is X or gamma radiation of energies from .3 to 2 Mev.

2. Range may be extended by approximately a factor of 10 by varying processing techniques.[1]

3. By utilizing filters, exposures to soft X or gamma rays and beta radiation may be reliably determined.[2]

4. NTA films will permit determination of neutron exposures from maximum permissible level to approximately 100 times this level.

5. Copper filter provides an additional means of determining neutron dose in case of accidental exposure to extremely high neutron flux.

C. Calibration

1. Gamma (See Gamma Calibration Device for Monitoring Film, Section 3)

a. Films are calibrated with 100 and 500 mgs of Ra.

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[1] Ra-Det, Vol. 5, Nos. 7-8.

[2] A Review of Film Dosimetry, Davis and Hart.

b. Normal calibration points are 100, 250, 500, 750, 1000, 2000, 5000, 10000, and 20000 mr.

2. Beta (See Beta Calibration Device for Monitoring Film (Section 3)

a. Films are calibrated with uranium, assuming 240 mrep/hr at surface of uranium.

b. Normal calibration points are 100, 200, 500, 750, 1000, 2000, 5000, and 10000 mrep.

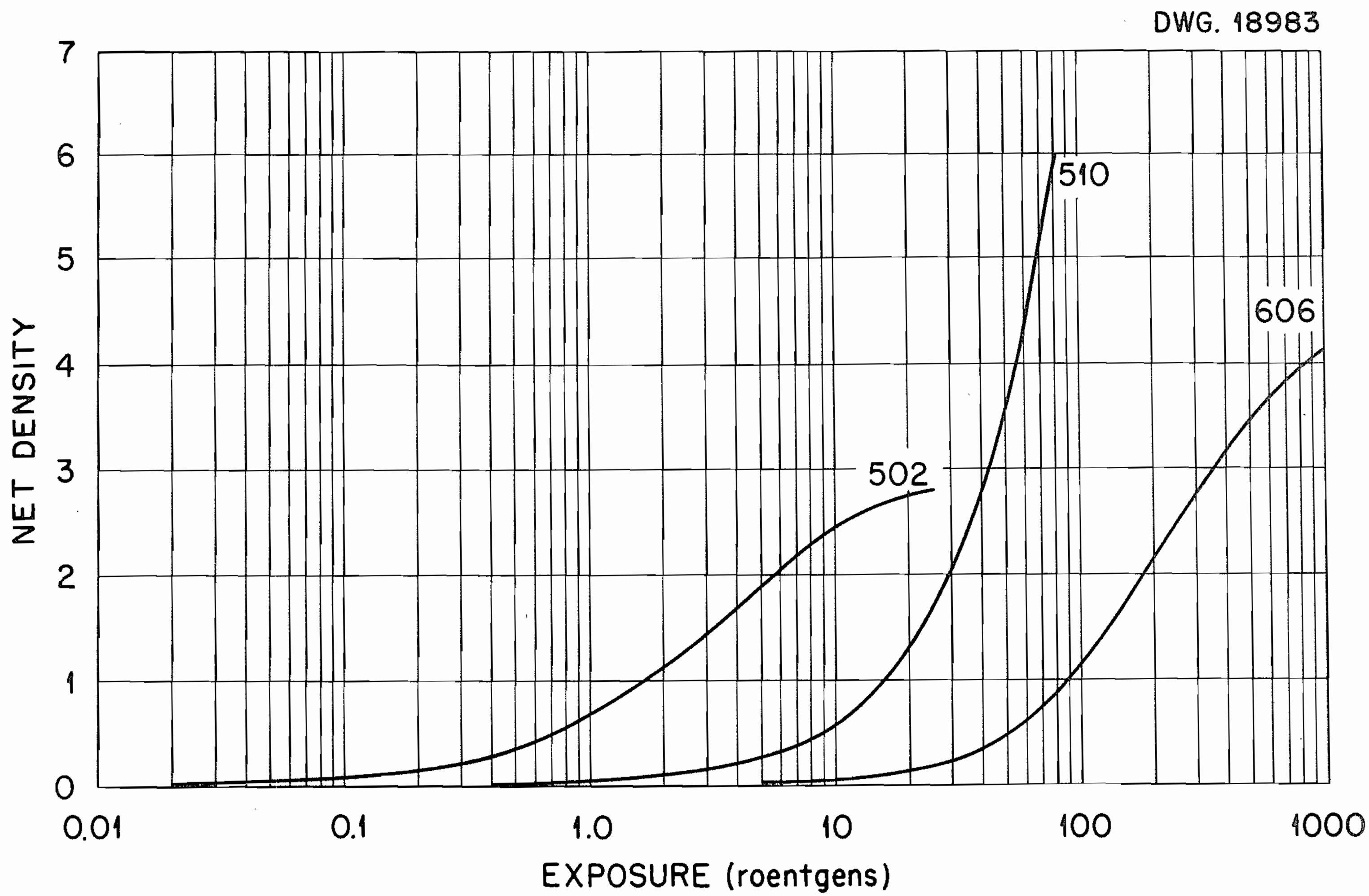
3. Neutron

a. Films are calibrated at Graphite Reactor, utilizing Indium Foil.

b. Normally the films are exposed to 40 weeks tolerance.

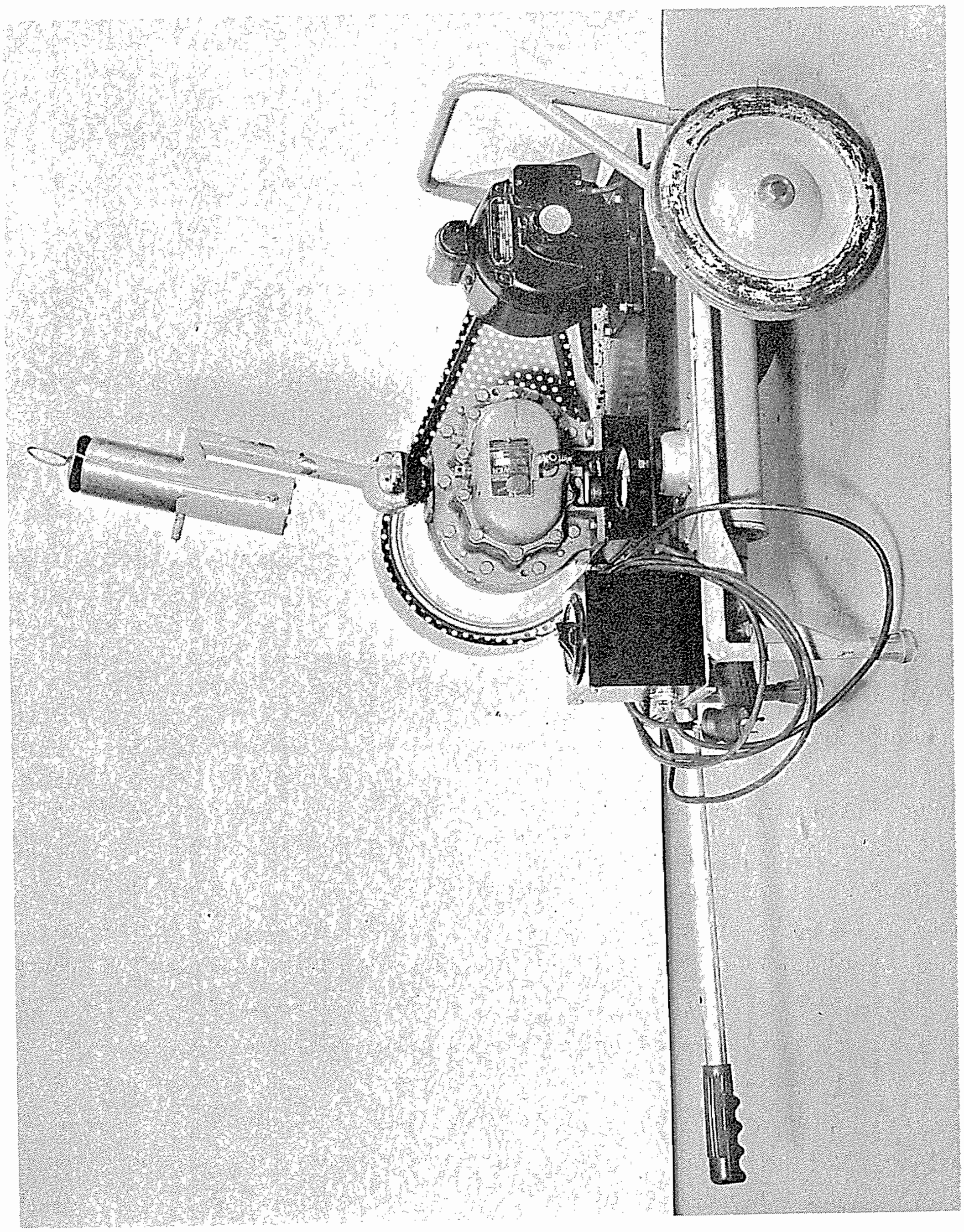
D. Routine Maintenance

Damaged film badges are replaced by new ones. No maintenance, as such, is required.



DuPont Type 533; Typical Response Curves for 1.24 Mev.

ORNL Photo 9913
Unclassified



Filtron

The filtron is a semi-portable instrument used to collect air samples. It consists of an electric motor-blower unit and filter holder. The air flow rate is approximately 5 cu.ft. per minute.

A. Characteristics

1. Operates on 100 to 120 volts AC.

2. Air flow rate: 5 cfm

3. Collection efficiency: >70% for particles greater than 0.5 microns.

4. Complete assembly including motor blower unit and collection head mounted on portable frame.

5. Timer switch regulates collection time.

6. Dimensions: 30" x 18" x 24". Weight: 90 lbs.

B. Application

1. May be used wherever 110 V AC power is available.

2. Filter holder assembly should be snugly seated before operation.

3. Automatic timer, if supplied, may be used.

4. Not recommended for collection of alpha samples.

5. Accuracy of assay depends upon accurate timing and proper air flow rate.

C. Calibration

1. This instrument is calibrated only for air flow rate with U-tube manometers.

D. The routine maintenance of this instrument is beyond the scope of this manual.

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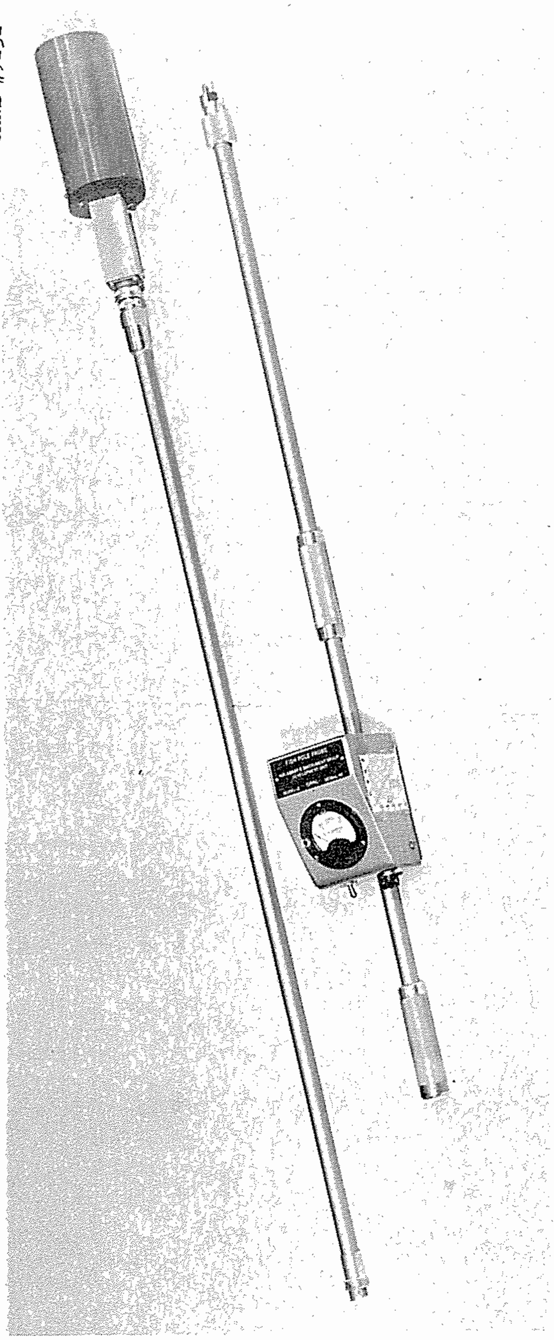


Fish Pole Probe

The Fish Pole Probe is used for detection and measurement of high level X and gamma radiation. The ion chamber is mounted 60 inches from the meter and handle.

Fish Pole Probe

A. Characteristics

1. Measures gamma intensities to 100 r/hr. Will indicate, depending upon sensitivity of instrument and type of ion chamber wall, relative levels of gamma and beta radiation to several hundred rep/hr.

2. Affords protective distance to operator.

3. Ranges: "Lo" and "Hi". The "Hi" range has approximately one-half the sensitivity of the "Lo" range.

4. May be zeroed in field of radiation.

5. Batteries: 4 - 22½ V Eveready 412
   1 - 1.3 V Mallory RM4

6. Length: 7 ft. Weight: 5 lbs.

B. Application

1. Will measure within 10% gamma radiation within the range from 1 r/hr to 100 r/hr.

2. Should be used only for comparison of relative intensities if the dose rate exceeds 100 r/hr.

3. The instrument is calibrated through 100 r/hr.

4. Should be turned on at least two minutes before use.

5. Check switch and meter functions before using.

6. The chamber should not be placed in contact with surfaces which may be contaminated.

C. Calibration

1. Source - 1 curie radium in well (See Section 3).

2. Turn on and allow warm-up for 5 minutes.

3. Adjust zero.

4. Center chamber over source.

5. Adjust source to obtain 1/4, 1/2, 3/4, and full scale readings through range to 100 r/hr. Note and record meter readings and dose rates.

6. Plot a curve of r/hr vs. meter reading and attach to instrument.

7. This instrument should be checked and calibrated every four weeks.

D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, control, meter, and zero function.

3. Check for response to gamma radiation.

4. The more common malfunctions may be due to one or more of the following:

   a. Leakage due to foreign material on insulators, high value resistors, electrometer tube, etc.

   b. Radioactive contamination

   c. Faulty switch

   d. Faulty tube

   e. Faulty meter

   f. Faulty potentiometer

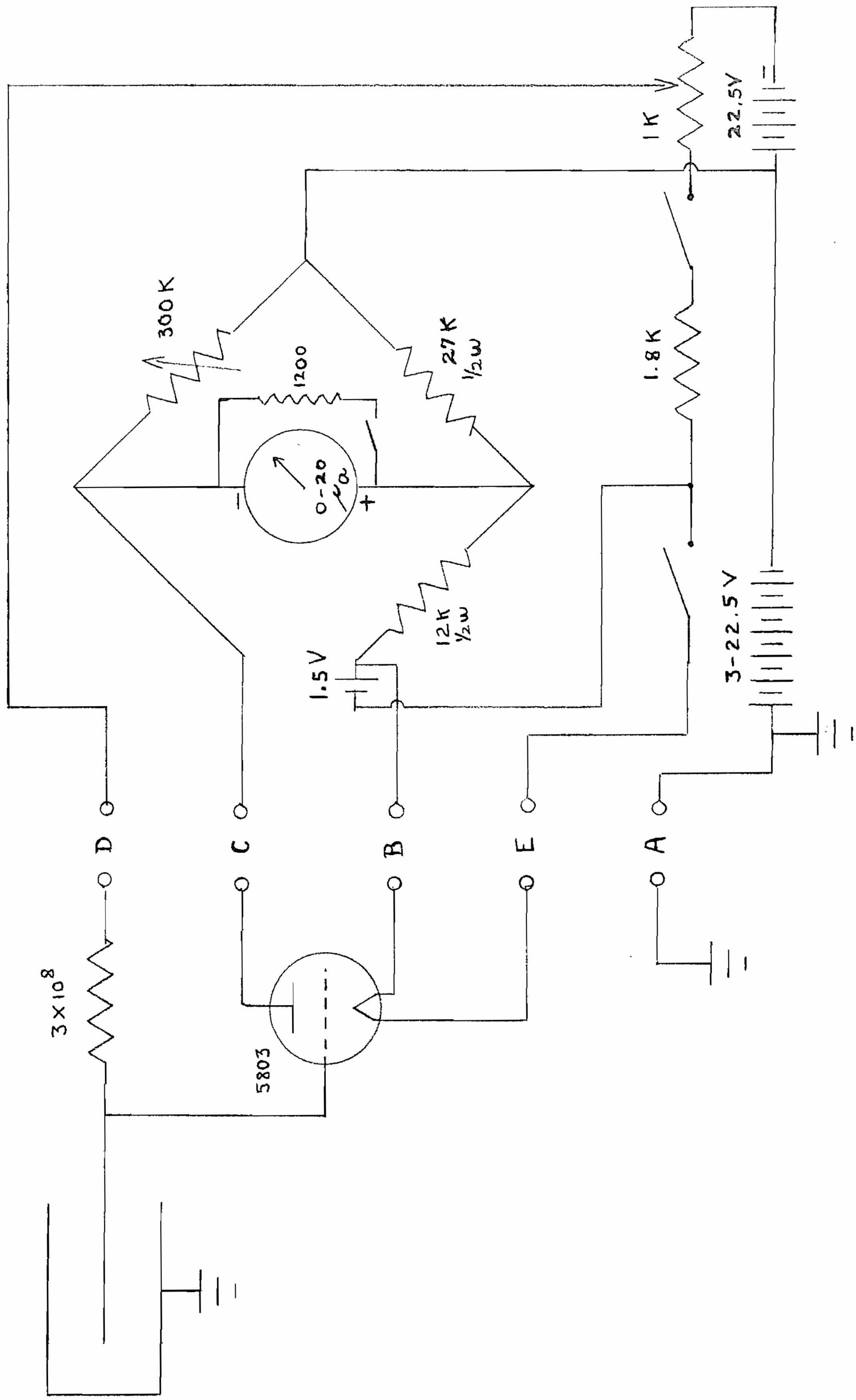
   g. Improper bias adjustment

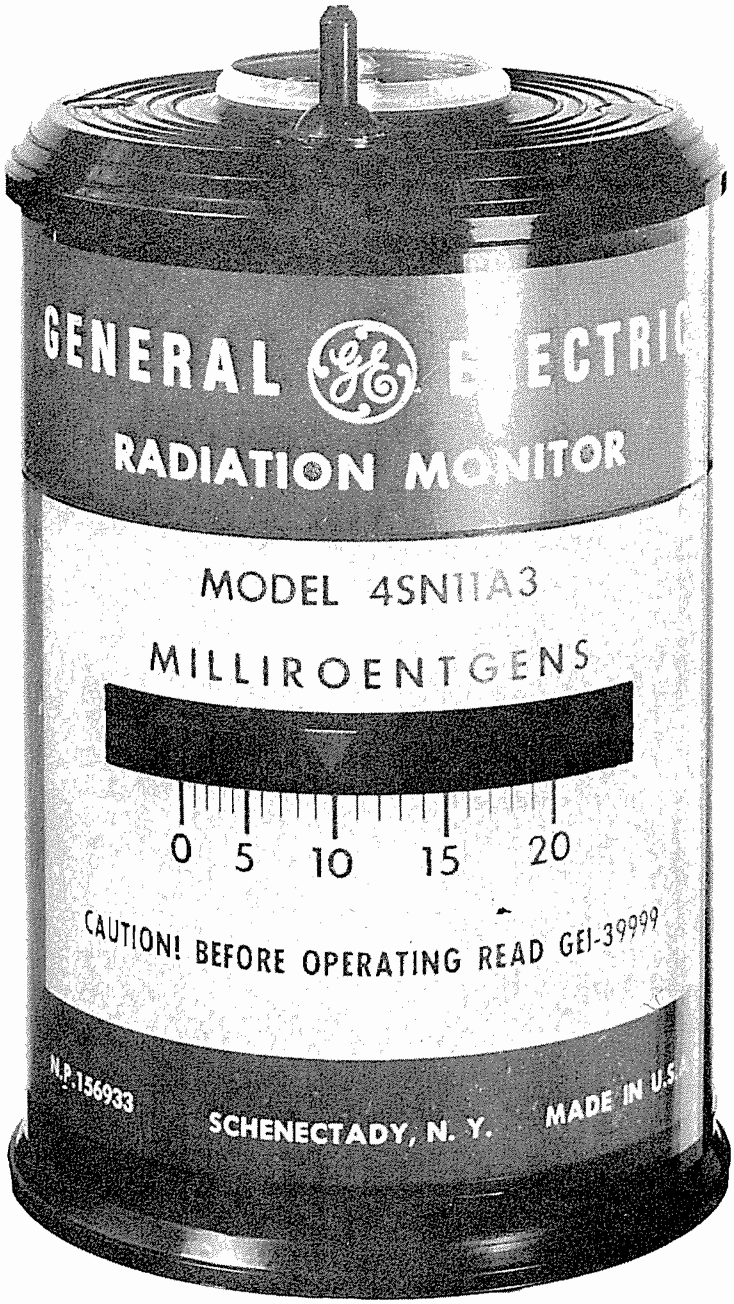
   h. Battery terminals reversed

   i. Intermittent, improperly shorted, or improperly opened connection.

   j. Excessive humidity

Fish Pole Probe





The G-E Radiation Monitor

The G-E Radiation Monitor is a self-contained device for the measurement of X-rays and gamma rays. It consists of an ion chamber, an electrostatic volt meter, and a gravity operated electrostatic generator, in a sealed case. The dose received is indicated by the position of the pointer on the calibrated scale.

The G-E Radiation Monitor

A. Characteristics

1. Completely self-contained - no tubes, batteries or external power supply.

2. Indefinite shelf life.

3. Self-charging - turn equipment upside down, mercury sliding through glass tube generates static charge which powers the device.

4. Sealed to minimize errors due to humidity.

5. High sensitivity: 0 to 20 milliroentgens.

6. Individually calibrated from radium source.

7. Durable construction.

8. Essentially independent of energy level over a wide range.

9. Accuracy: 10% with radium calibration.

10. Energy dependence - varies with gamma radiation from -25% at 50 kv to 0 at its calibration energy of radium in equilibrium with its by-products.

11. Dimensions: 4 inches in diameter, 6 inches high. Weight: 9-3/4 ounces.

B. Application

1. Accurate to within 10% for gamma radiation.

2. Should be operated in accordance with instructions printed on the outer periphery.

3. Will not respond to beta radiation below 1 to 2 Mev.

4. Should not be inverted or roughly handled during operation.

C. Calibration

1. Source - 25 mc Ra and Electroscope set-up (See Section 3).

2. Charge to, or near, zero.

3. Observe after one hour to determine if leakage has occurred.

4. Expose to a dose rate of 100 mr/hr for twelve minutes.

5. Note and record on the instrument the number of divisions per 20 mr/hr.

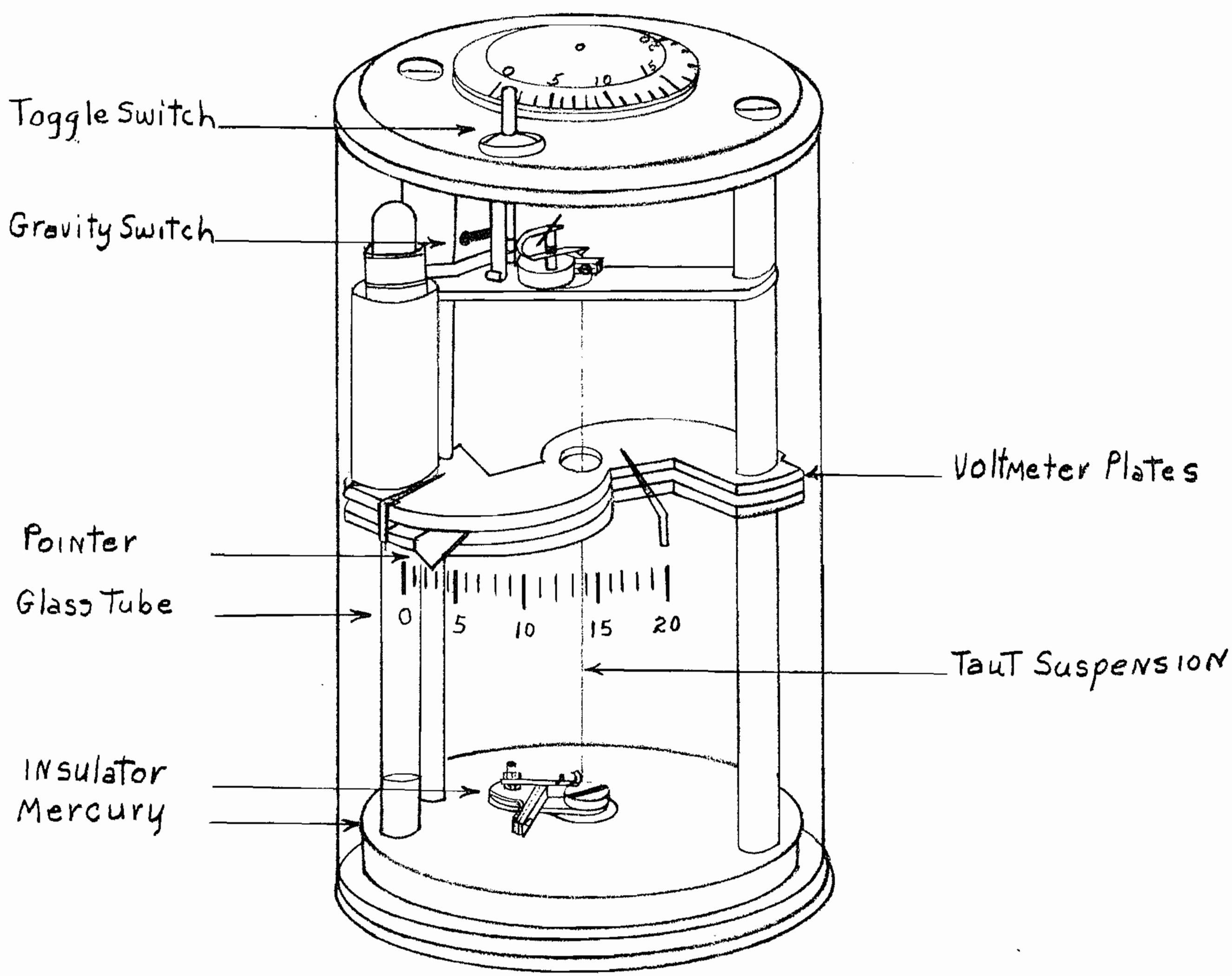
6. Should be checked and calibrated every six to ten weeks.

D. <u>Routine Maintenance</u>

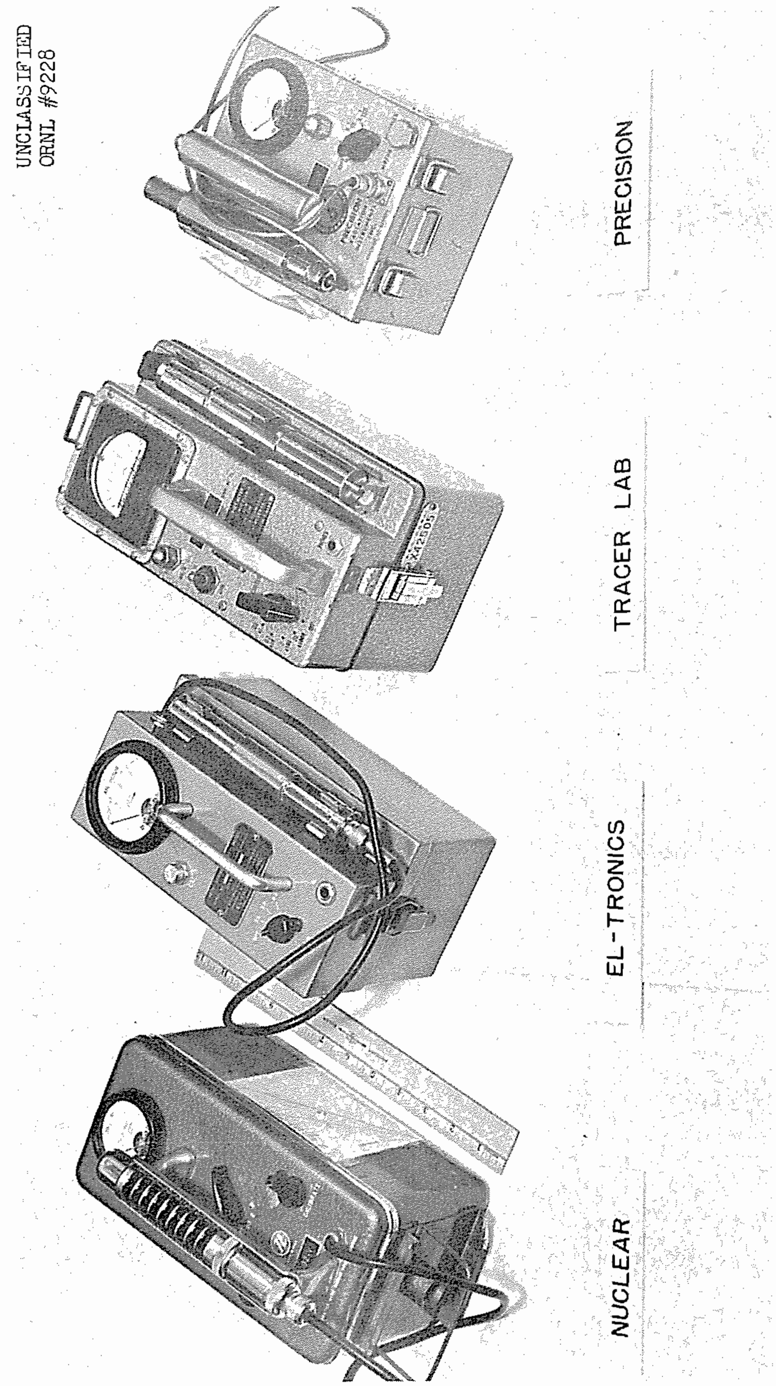
1. Check charging functions.

2. Check for leakage.

3. If any malfunction is apparent, repairs should be attempted only by persons experienced in this delicate type work.



Radiation Monitor - General Electric



G-M Survey Meter

The G-M (Geiger-Mueller) Survey Meter is a medium weight, portable, beta-gamma indicating survey instrument. Aural or visual indication of radiation is afforded by means of ear phones and count rate meter.

G-M Survey Meter
Nuclear 2610A

A. Characteristics

1. Detects gamma rays. Detects betas of 200 KEV energy and greater.

2. Full scale readings:

Beta	Gamma
600 c/m	.2 mr/hr
6,000 c/m	2.0 mr/hr
60,000 c/m	20.0 mr/hr

3. Headphones supplied.

4. Sliding beta shield 1600 mg/cm^2 thickness.

5. Dimensions: 10" x 4-3/4" x 5-3/4". Weight: 9 lbs.

B. Application

1. Indicates approximately the magnitude of gamma radiation between intensities of approximately .05 mr/hr and 20 mr/hr.

2. With shield open indicates beta radiation above approximately .2 Mev.

3. Should not be used in measuring dosage rates, but rather as a detection instrument.

4. Should be used in conjunction with earphones, since earphones respond more quickly to pulses than the count rate meter.

5. Care should be exercised to prevent contamination of probe.

6. Instrument is adjusted to read 10 mr/hr with shield closed in a gamma radiation field of 10 mr/hr.

C. Calibration

1. Source - 1 millicurie radium (See Section 3).

2. Turn instrument on at least one minute before calibration.

3. Place probe, with shield closed, in clamp on the calibration stand.

4. Switch to the 20 mr/hr scale, adjust source to give a dose rate of 10 mr/hr. Adjust sensitivity control so that meter reads 10 mr/hr.

5. Check the meter reading at dose rate positions of 2, 5, and 20 mr/hr and note if the variation of the meter is greater than 10% from these dose rates. If variations do not exceed 10% instrument may be returned to service.

D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, meter, and zero functions.

3. Check for response to gamma radiation.

4. The more common malfunctions may be due to one or more of the following:

    a. Radioactive contamination

    b. Faulty switch

    c. Faulty GM tube

    d. Faulty electrometer tube

    e. Faulty meter

    f. Faulty potentiometer

    g. Improper bias adjustment

    h. Battery terminals reversed

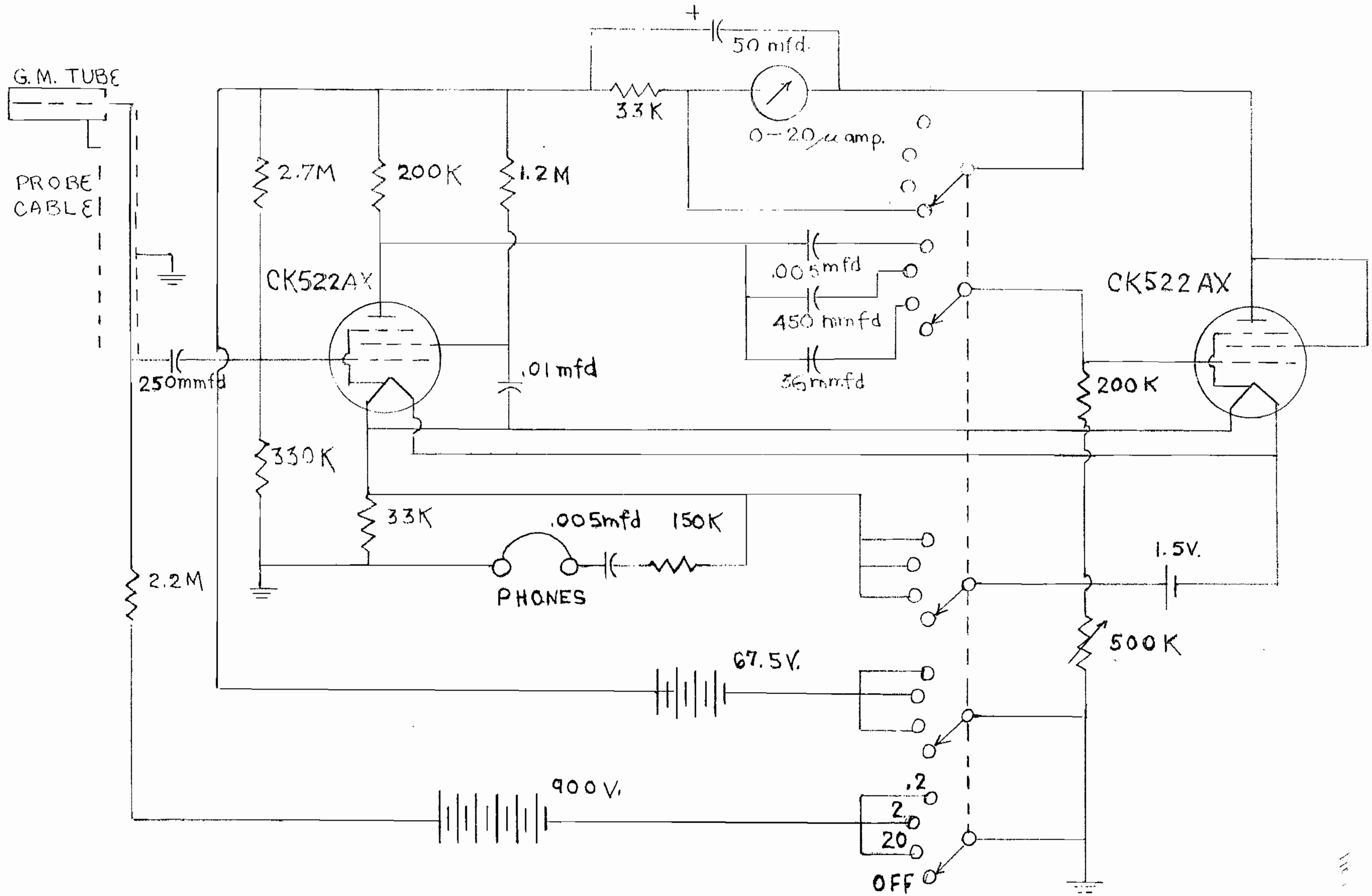
    i. Intermittent, improperly shorted, or improperly opened connection, particularly in input cable from the probe.

5. Inability to zero may be due to any one of the foregoing.

6. Lack of or weak response may be due to b, c, d, e, g, or i.

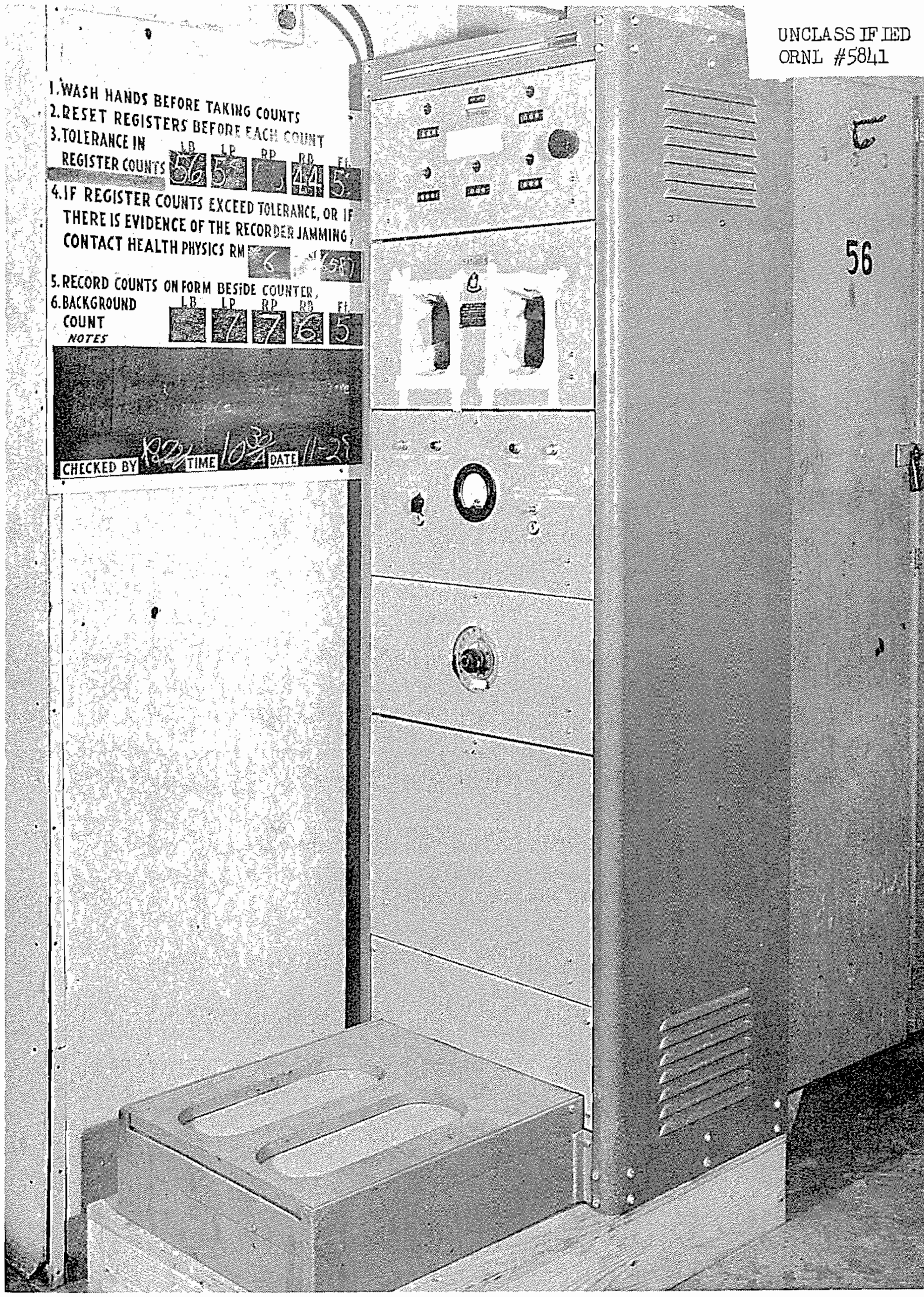
7. Too great response to radiation may be due to a, c, d, or g.

8. Erratic readings may be due to b, c, d, g, or i.



G.M. SURVEY METER
NUCLEAR MODEL 2610A

UNCLASSIFIED
ORNL #5841



Hand and Foot Counter

The Hand and Foot Counter is a device for beta-gamma contamination monitoring of feet and hands, simultaneously.

Hand and Foot Counter

A. Characteristics

1. Operates on 100 to 130 volts AC.

2. Type radiation: beta-gamma.

3. Provides 5 channel scaler and power supply system with automatic controls to time the counting operations in proper sequence.

4. One scaling channel is provided for each side of each hand and one for the soles of both feet.

5. Each hand channel is operated by 2 thin wall counting tubes, individually shielded to provide low background.

6. The foot channel is operated by 4 shielded counting tubes, two to each foot.

7. High voltage. 600 to 2000 volts continuously adjustable (read on chassis mounted meter).

8. Manual reset.

9. Minimum beta energy sensitivity is 200 Kev.

10. Dimensions: 76" high, 32" wide, 24" deep. Weight: 600 lbs.

B. Application

1. Background should be noted and recorded on board daily.

2. Should be calibrated with calibration count noted on board daily.

3. To prevent contamination of paper bags, 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 alpha contamination.

6. Hands and feet should not be moved from the time of start of count until count has been completed (24 seconds).

C. Calibration

1. Source - special Hand and Foot Counter sources (See Section 3).

2. Check registers for zero setting.

3. Obtain background count and write this information in space allotted on adjacent board.

4. Place hand sources in counter, as near the center of the slot as possible, and as far to the rear of the slot as possible. Place a foot source in the center over each foot opening.

5. Zero the registers and count for one cycle (the cycle is preset for 24 seconds).

6. Write in the counts obtained in the allotted spaces on the board opposite "Tolerance in Register Counts."

7. The four hand surface counting rates should agree within 20% of each other.

8. The instrument should be checked and calibrated daily.

D. The routine maintenance of this instrument is beyond the scope of this manual.

Juno

The Juno survey meter is an ionization chamber instrument used to measure the intensity of gamma radiation and alpha particle emission, and to indicate the relative intensity of beta particle dose rates. Two manually positioned shields are incorporated to aid in determining types of radiation measured.

Juno

A. Characteristics

1. Radiation detected: alpha, beta and gamma (self-contained filters for rejection of alpha or beta particles). Alpha filter .020 in. acetate, beta filter 3/32" aluminum. The alpha window is of .005" rubber hydrochloride.

2. Sensitivity: Ranges: 50, 500 and 5,000 mr/hr.

3. Zero adjustment for setting meter in the field.

4. Battery life approximately 300 hours in intermittent use.

5. Batteries: Four Eveready No. 412, 22½V, one Burgess No. 2, 1½V, nine Burgess No. Z, 1½V.

6. Dimensions: 2" x 5-1/2" x 3-3/4". Weight: 4 lbs. 8 ozs.

B. Application

1. The Juno will measure within 10% gamma radiation, with the shields closed, between the intensities of 5 mr/hr and 5 r/hr.

2. Will differentiate, by using a shield, among alpha, beta, and gamma radiation.

3. The instrument is calibrated for gamma radiation, for full scale readings of 50 mr/hr on X1 scale, 500 mr/hr on X10 scale, 5000 mr/hr on the X100 scale.

4. The instrument is calibrated for alpha radiation on the X1 and X100 scale through 250,000 disintegrations per minute.

5. Should be turned on 2 minutes before using.

6. Should be carefully zeroed.

7. For accurate gamma measurement, the instrument should be oriented with respect to the source as in the calibration procedure.

C. Calibration

1. Source - 1 curie radium in well and alpha plaques (See Section 3).

2. Turn to "on" and allow to warm up five minutes.

3. Adjust zero.

4. For gamma calibration, place over well.

5. Adjust source to obtain dose rate of 50 mr/hr at the center of the chamber. Switch to X1 scale and adjust calibration potentiometer corresponding to this scale so that meter reads 50 mr/hr.

6. Adjust source to obtain a dose rate of 500 mr/hr. Switch to X10 scale and adjust meter to read full scale.

7. Adjust source to obtain a dose rate of 5000 mr/hr. Switch to X100 scale and adjust meter to read full scale.

8. Both beta and gamma shields should be closed for gamma calibrations.

9. For alpha calibrations, open both shields.

10. Use alpha plaques, center Juno chamber over source, and obtain at least three readings on each of the X1 and X10 scales.

11. Plot a curve of disintegrations per minute versus scale reading for the X1 and X10 scales.

12. This instrument should be checked and calibrated at least once every four weeks.

C. <u>Routine Maintenance</u>

1. Check and replace weak batteries.

2. Check switch, control, meter and zero function.

3. Check for response to gamma radiation.

4. The more common malfunctions may be due to one or more of the following:

    a. Leakage due to foreign material in insulators, high value resistors, electrometer tube, etc.

    b. Radioactive contamination.

    c. Faulty switch

    d. Faulty tube

    e. Faulty meter

    f. Faulty potentiometer

    g. Improper bias adjustment

    h. Battery terminals reversed

i. Intermittent, improperly shorted, or improperly opened connections

j. Alpha window too thick.

k. Excessive humidity

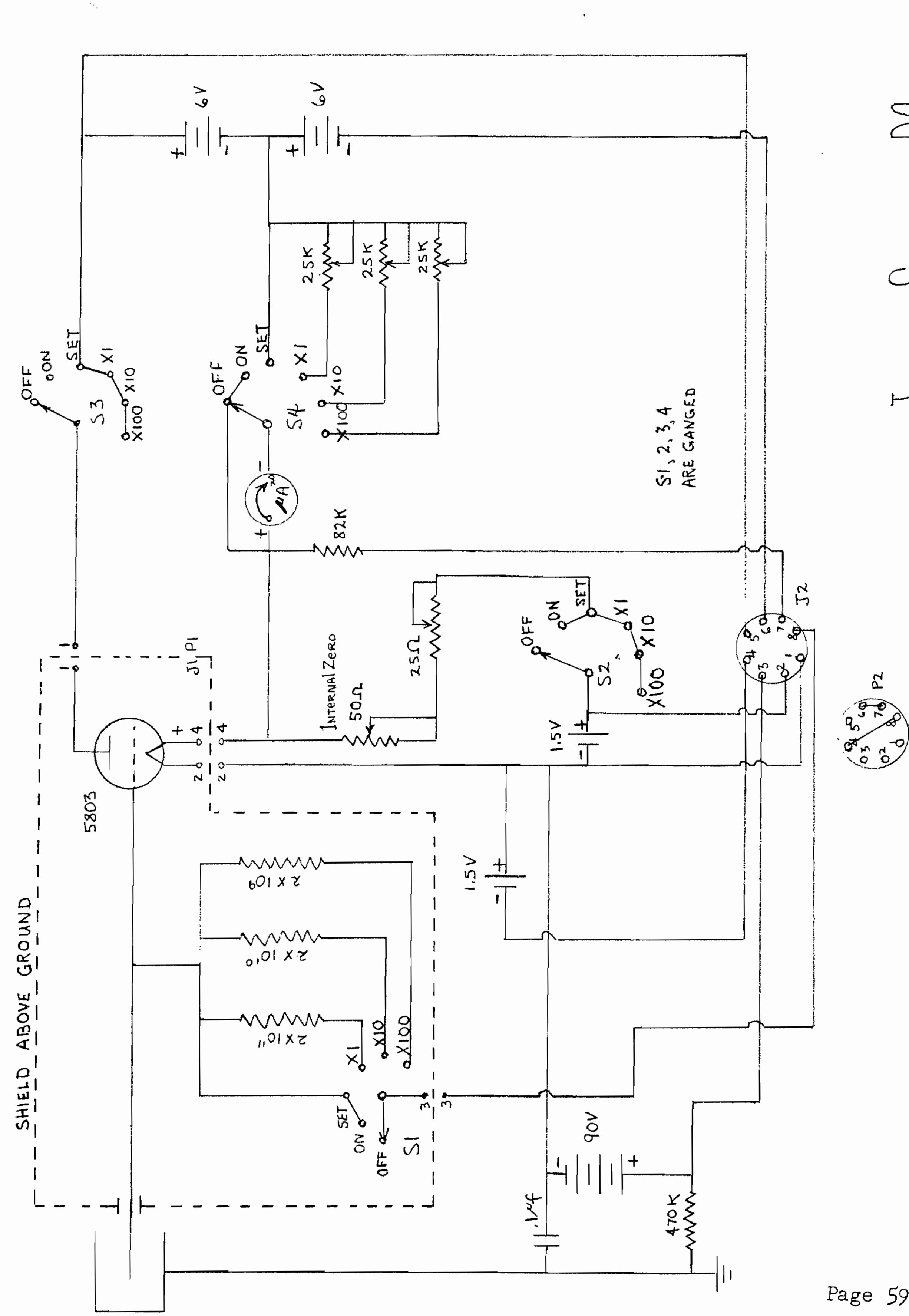
5. Inability to zero may be due to c, d, e, f, g, h, or i.

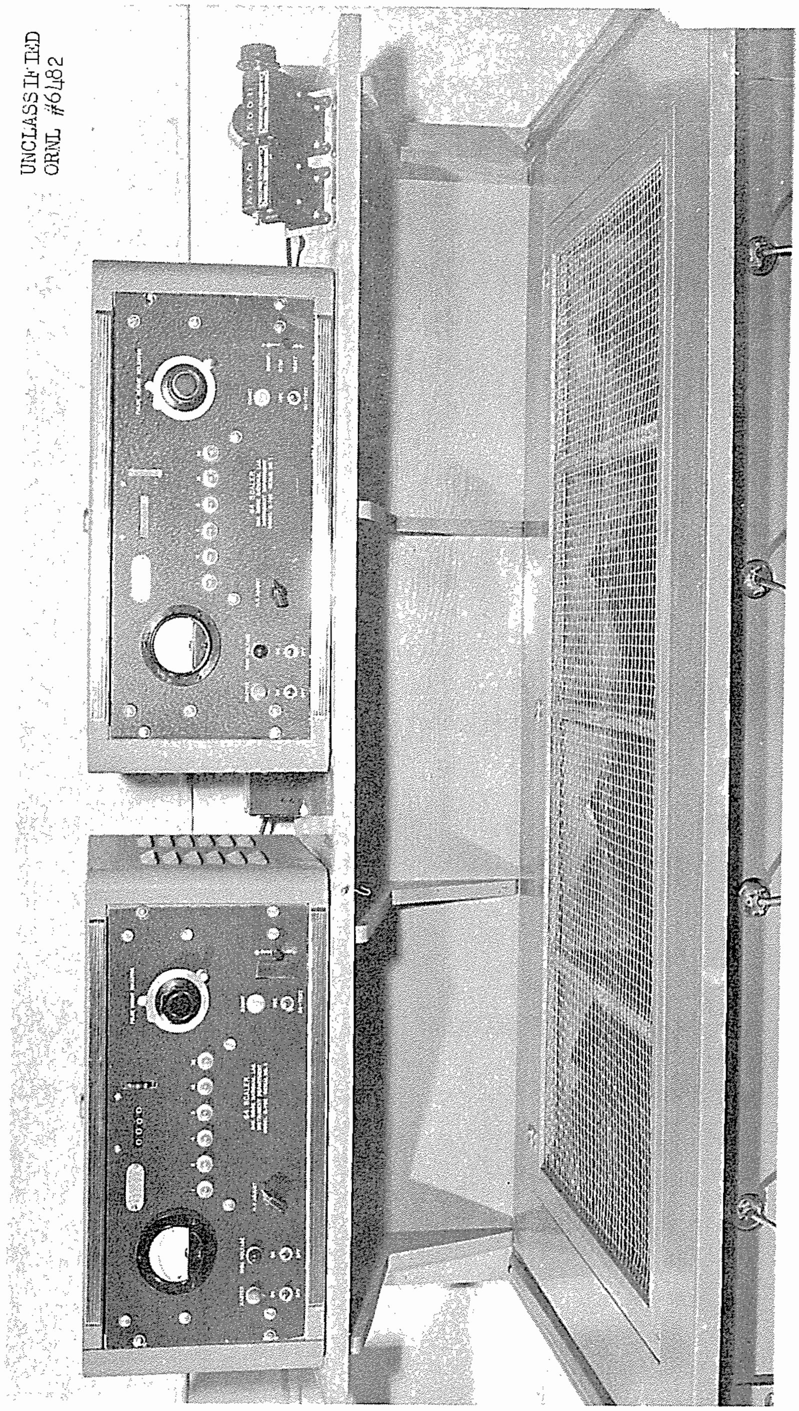
6. Lack of or weak response to radiation may be due to c, d, e, g, j, or i.

7. Too great response to radiation may be due to a, b, d, g, i, or k.

8. Erratic readings may be due to a, c, d, e, f, g, h, or i.

Juno Survey Meter





Laundry Monitor

The laundry monitoring instrument used for beta-gamma detection consists of a standard scaler with four G-M tubes feeding into the scaling unit. The tubes are arranged over a lead lined table, and covered with a wire mesh screen on which clothing is placed for counting.

A. Characteristics

1. Operates on 100 to 130 volts AC.

2. Radiation detected: beta-gamma.

3. Equipped with two scale of 64 scalers and registers.

4. Automatically reset and timed.

5. Timing interval adjustable from 0 to 60 seconds.

6. Four GM tubes feed into each scaler.

7. High voltage to each GM tube individually adjustable.

8. 20" x 20" table-top sensitive area opening over each set of GM tubes. Total sensitive area 800 sq. in.

9. GM tubes mounted in lead lined cavity.

10. Dimensions: 6' x 3' x 3'.

B. Application

1. Will detect beta-gamma contamination on clothing above an average of approximately .1 mrep/hr/100 sq. in.

2. Will not detect alpha contamination.

3. All tubes should be checked for proper operation before use.

4. Clothing should be arranged so that as much surface as possible is exposed to the counting tubes.

5. Clothing should remain stationary throughout the counting interval.

6. Background check should be made before initial operation and after each movement of clothing in the immediate area.

C. Calibration

1. Sources - small Ra source and special laundry monitoring source (See Section 3).

2. Check function and determine if each tube operates properly by placing the Ra source over each tube during a counting cycle.

3. With sources removed from the vicinity of the tube obtain and record the background counting rate.

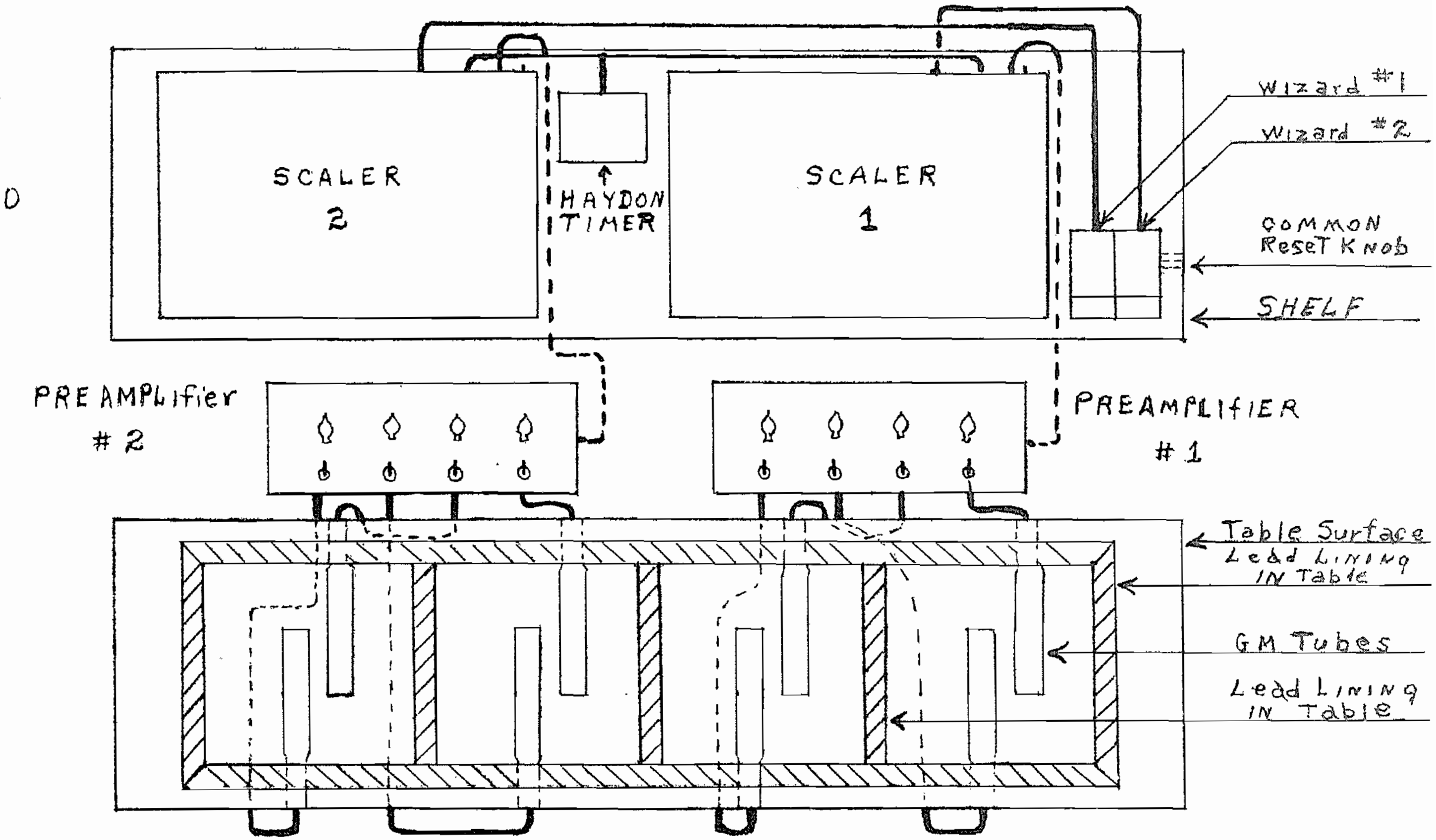
4. Place the laundry monitoring source on the screen opening for one counting cycle. Record register counts. Repeat to obtain counting rates for four different positions of the source.

5. Calculate the average of the counts obtained and subtract from this average the background count. This net counting rate is the tolerance rate for the instrument.

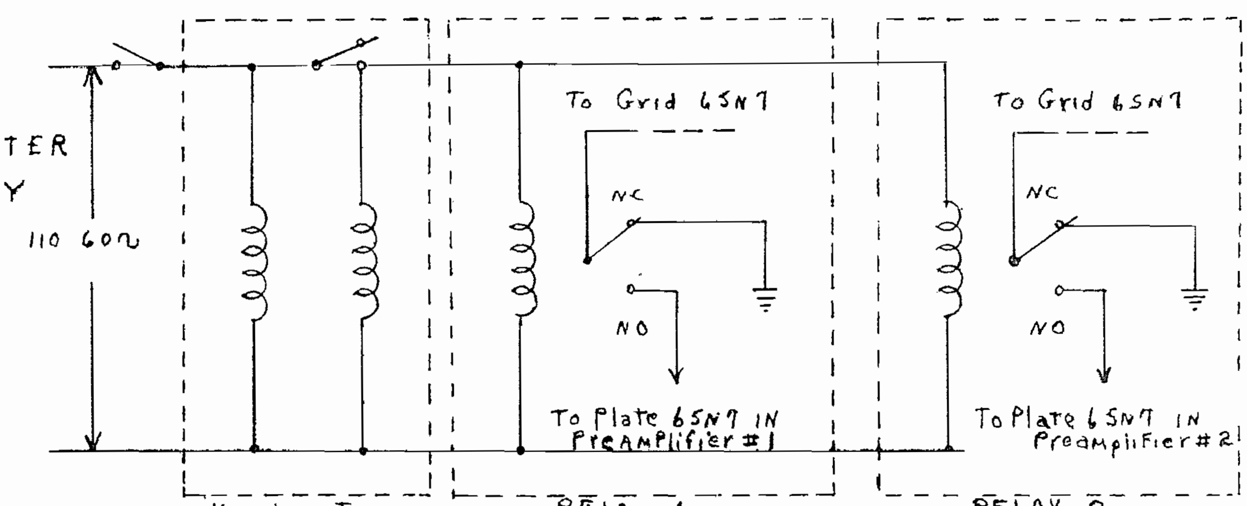
6. The counting rate for the individual tubes should not vary by more than 20%.

7. The instrument should be calibrated weekly; the counter response should be checked daily.

LAYOUT OF LAUNDRY BACKGROUND COUNTER



LAUNDRY COUNTER TIMER RELAY SYSTEM



UNCLASSIFIED
ORNL #12028

Victoreen Minometer

The minometer is a portable string electrometer, connected with a metal well into which a pocket chamber is inserted. The string is viewed by means of a built-in microscope. The displacement of the string is proportional to the voltage on the system. In use, the string and pocket chamber are charged to the same potential, the pocket chamber is removed and used, and then reinserted into the well. Any difference in voltage on the pocket chamber from that on the minometer causes a deflection, proportional to the radiation dose received by the pocket chamber, of the string.

Minometer

A. Characteristics

1. For use with pocket chambers.

2. Zero on scale equals 150 V charge. Full scale reading (200 mr) equals 110 V charge.

3. Power supply: 110 V, 60 cycle AC.

4. Dimensions: 8" x 4" x 6". Weight: 6 lbs.

B. Application

1. Designed to charge and read discharge in terms of mr on pocket ionization chambers.

2. A discharge of approximately 40 volts corresponds to 200 mr.

3. The scale in the minometer is calibrated in mr from zero to 200.

4. The instrument should be turned on for 12 to 24 hours before using.

5. When fully discharged the fiber should rest on the "Z" line.

6. When fully charged the fiber should lie on the zero line of the scale.

7. Leakage check should be made before use.

8. Fiber should be sharply focused.

9. The instrument is calibrated using pocket chambers and a Ra source.

C. Calibration

1. Source - 100 millicuries of Ra and gamma film set-up (See Section 3).

2. Turn minometer on, discharge and adjust "Z".

3. Adjust charge voltage to charge fiber to zero.

4. Select six previously calibrated pocket chambers.

5. Expose the pocket chambers to a dose of 50 mr. Read the meters with the minometer and take an average of the six minometer readings. This average should be within 10% of 50 mr.

6. Repeat the foregoing for doses of 100, 150, and 200 mr.

7. Calibration should be checked every four weeks.

D. Routine Maintenance

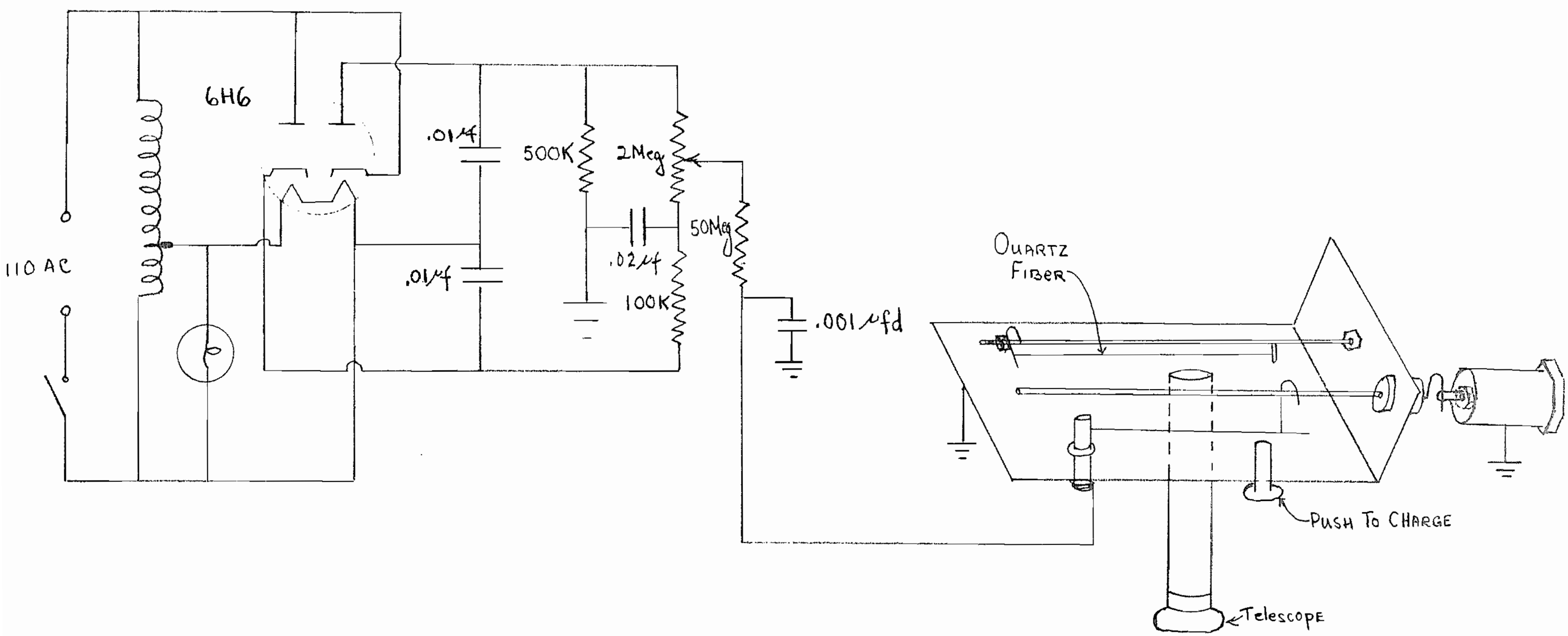
1. Check light source.

2. Check scale and fiber definition and focus. Adjust focus and alignment as may be necessary.

3. Adjust "Z" setting and charge voltage.

4. Check for leakage. If leakage occurs, wipe the well clean with cleansing tissue and blow out lint with a moisture-free air stream.

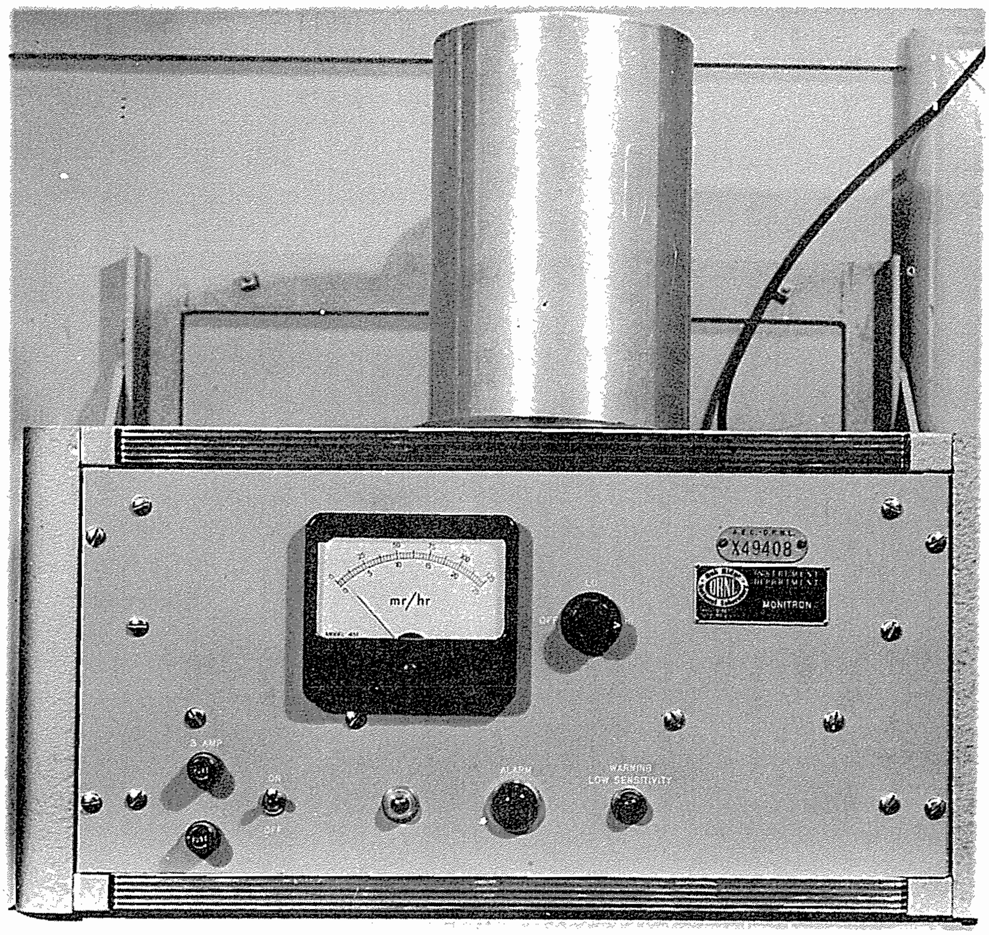
5. Refer to the manufacturer's instruction and maintenance manual before attempting repairs to the fiber mechanism.



6H6
110 AC
.01μf
.01μf
500K
2Meg
50Meg
.02μf
100K
.001μfd
Quartz Fiber
Push To Charge
Telescope

Minometer

UNCLASSIFIED
ORNL #12030



Monitron

The monitron employs a large ionization chamber coated on the inside with enriched boron. It is used for the detection of gamma and thermal neutron radiation. The ionization chamber is connected with an amplifier circuit and a count rate meter which reads directly in mr/hr. A relay circuit, actuating an alarm, may be set to go off at any predetermined gamma radiation level.

Monitron

A. Characteristics

1. Consists of control chassis and a 4000 cc ion chamber which can be located 150 feet or more from the control unit.

2. Chamber may be coated with carbon for gamma only, or with boron coat for gamma and neutron detection.

3. Full scale readings of 25 mr/hr and 125 mr/hr on 3" meter.

4. Zero and calibration settings at control chassis.

5. Both zero setting and calibration drift-free.

6. Reliable condenser modulator with phase sensitive demodulator.

7. External connection for 1 milliampere recording meter or millivolt recorder.

8. Adjustable rate alarm indicator, also external connection for additional alarms.

9. 110 volt, 60 cycle operation: no batteries.

10. Dimensions: Control Chassis 21" x $10\frac{1}{2}$" x 14". Weight: 70 lbs.
    Chamber 20"h, $6\frac{1}{2}$" dia.

B. Application

1. Useful for monitoring background levels of gamma and thermal neutron radiation.

2. Will indicate gamma radiation levels in terms of mr/hr.

3. Does not measure thermal neutron intensities, but will indicate relative levels.

4. Should be checked daily for zero setting.

5. Should operate only on high sensitivity setting. Persons concerned should be duly notified if instrument is set on low sensitivity setting.

6. For monitoring radiation levels for Health Physics purposes, alarm setting should be such that alarm will respond at 7.5 mr/hr.

7. Instruments are calibrated with Ra source in terms of mr/hr.

C. Calibration

1. Source - 1 millicurie Ra and monitron calibration yoke.

2. Check knob and meter functions of instrument.

3. Check zero setting and background counting rate.

4. Attach yoke and mount source.

5. Adjust source and calibration control to obtain indicated dose rates which agree most closely with those dose rates from the source. Perform this operation on both the high and low sensitivity scales.

6. For those instruments which require a calibration chart, plot a curve of dose rate versus meter reading and attach to the instrument.

7. Check alarm function. The alarm should sound at a dose rate of 7.5 mr/hr when the instrument is switched to the high sensitivity range.

8. Should be calibrated every six to eight weeks.

9. The instrument is not calibrated for neutrons but should be checked occasionally for neutron sensitivity.

D. Routine maintenance of this instrument is beyond the scope of this manual.

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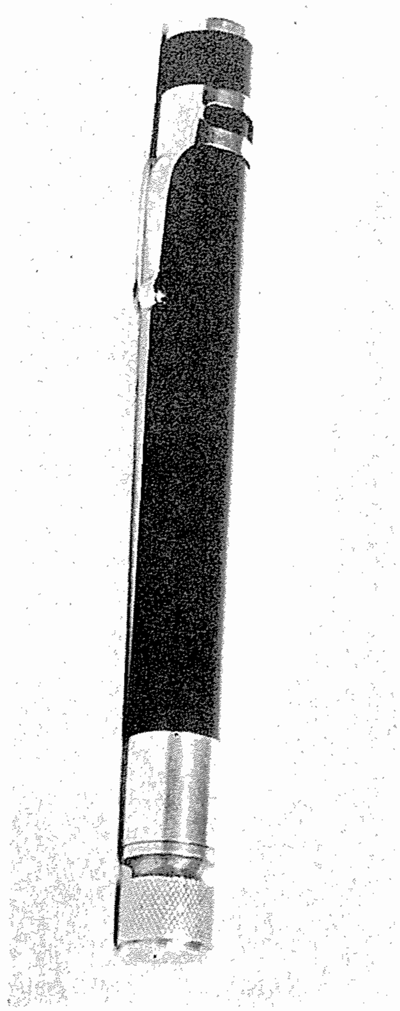


Pocket Chambers

The Victoreen Pocket Chamber is a pencil type ionization chamber. The chamber consists of a barrel, or outer electrode, a core, or inner electrode, an insulator, and a cap. The chamber is used in conjunction with the Victoreen minometer to measure exposure of the chamber to gamma and hard beta radiation. Modifications to the basic chamber allow measurements of thermal neutron exposures and indications of soft beta radiation exposures.

A. <u>Characteristics</u>

1. Full scale reading on charger-reader 0.2 r.

2. Chamber: Paper liner coated with "Graphite". Tenite wall 1/16".

3. Accuracy: ± 15%, 40 kev to 1 mev X or gamma radiation.

4. Used with the Victoreen minometer charger-reader.

5. Dimensions: 1/2"D x 5-1/2". Weight: 1/2 ounce.

B. <u>Application</u>

1. Will measure X or gamma radiation exposures between 0 and 200 mr/hr.

2. Measures equally well gamma rays of all energies above .2 Mev.

3. Measures within 10% error gamma rays within energies 0.08 and 0.2 Mev.

4. Is insensitive to beta radiation below 1 Mev.

5. Will not differentiate between beta radiation above 1 Mev and gamma or X radiation.

6. For accurate comparison of film badge meter results the pocket meters should be worn in close proximity with the film badge meter.

7. Orientation of the meter with respect to the source may greatly affect the results.

8. The knowledge of minometer techniques is necessary to properly interpret pocket meter results.

9. These meters are calibrated with a Ra source, and those which deviate more than 10% are rejected.

C. <u>Calibration</u>

1. Source - 100 milligrams of Ra and film calibration setup (See Section 3).

2. Charge chamber and observe after one hour to determine if leakage has occurred.

3. Use adapter ring and expose chamber to 100 mr.

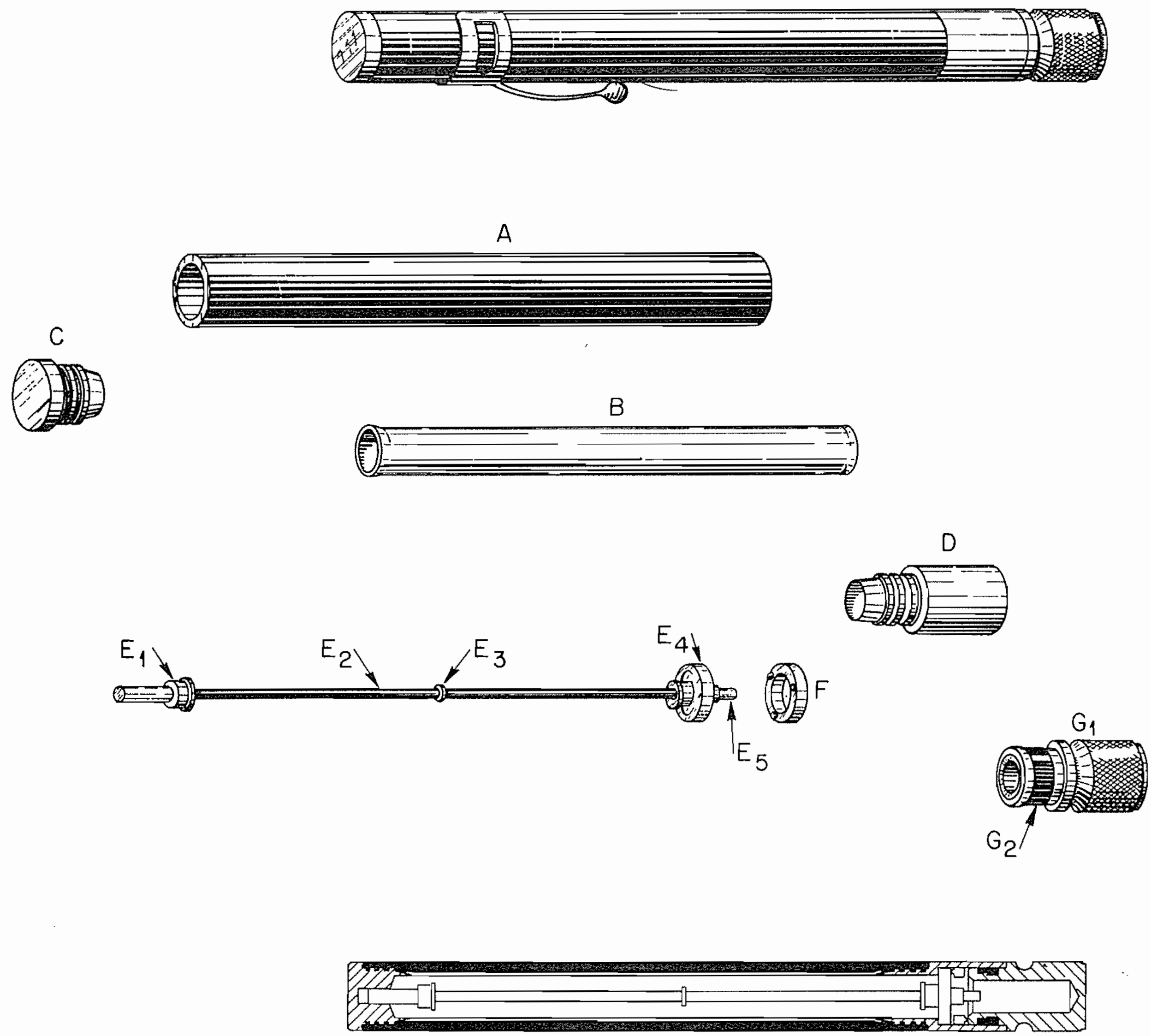
4. Pocket chamber is satisfactory if reading on minometer is within 10% of 100 mr.

D. Routine Maintenance

1. Check for leakage.

2. If leakage occurs, disassemble meter and blow out with clean, dry air; clean insulators, dry, and reassemble.

3. If leakage persists, replace electrode and supporting insulators.



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

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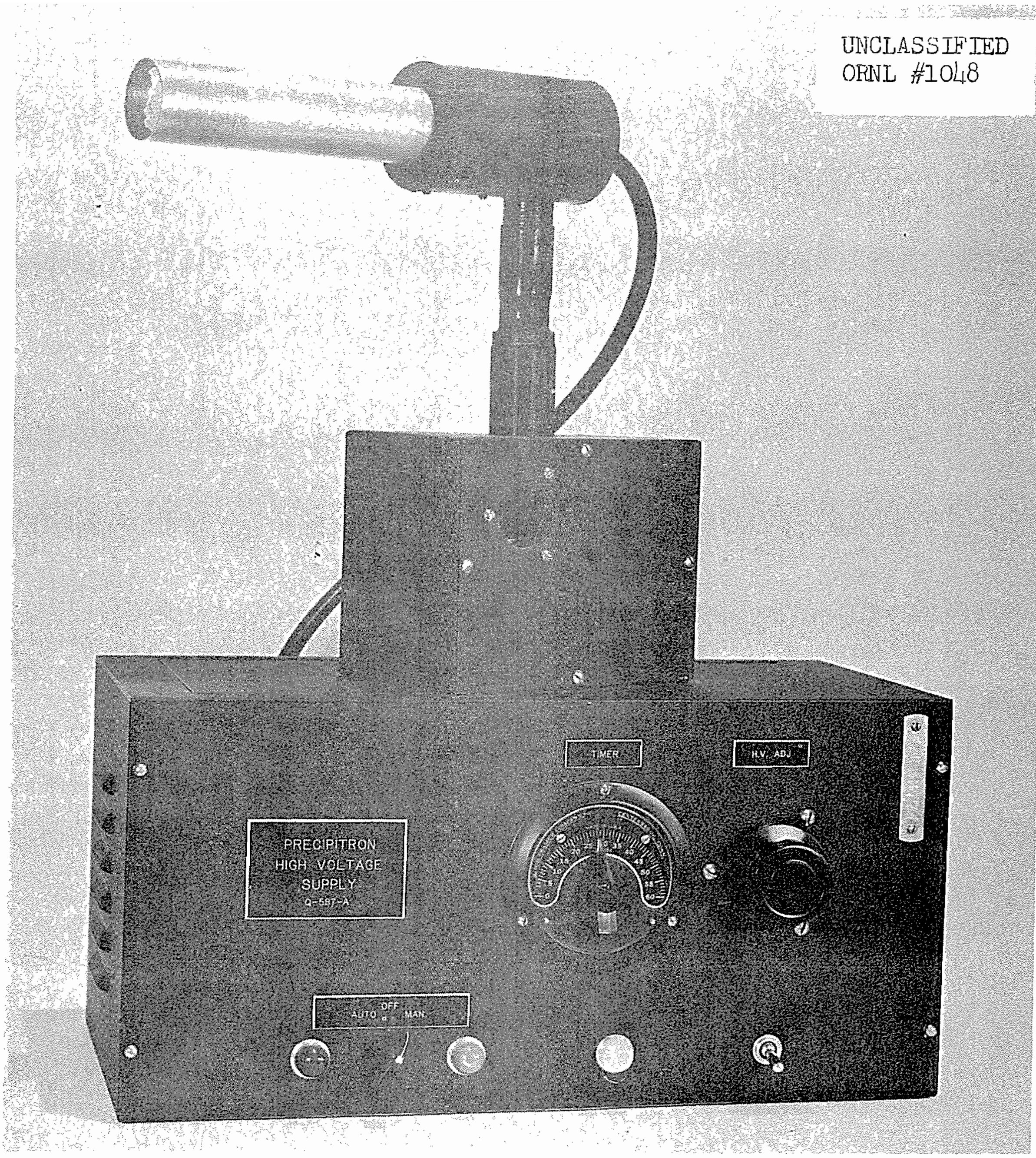

Precipitron

The precipitron is a device for sampling air by the electrostatic precipitation of radioactive particles onto a thin aluminum foil. The principal components of the instrument are a collection head, a small blower unit, to draw air through the filter, and a high voltage power supply.

Precipitron

A. Characteristics

1. Operates on 100 to 120 volts AC.

2. Zero to 60 minute timer incorporated.

3. Blower unit draws 3 cu.ft. of air per minute, through collector.

4. Adjustable high voltage supply.

5. Collection efficiency: 90%.

6. Dimensions: 13" x 8" x 24". Weight: 25 lbs.

B. Application

1. May be used wherever 110 V AC power is available.

2. Extreme caution should be exercised in operating this instrument since from 10 to 20 KV are available from the high voltage supply.

3. Shut off power before inserting or removing collector.

4. When inserting collector, adjust so that electrode wire is centrally located.

5. Collection time is governed by attached timer.

6. Adjust high voltage to 10 KV or above.

7. Air flow rate should be checked routinely.

8. The instrument has a collection efficiency of 90% or greater for all radioactive particles between 0.1 and 10 microns.

9. Recommended for collection of alpha.

C. Calibration

1. This instrument is calibrated only for air flow rate with U-tube manometers.

D. Routine maintenance of this instrument is beyond the scope of this manual.

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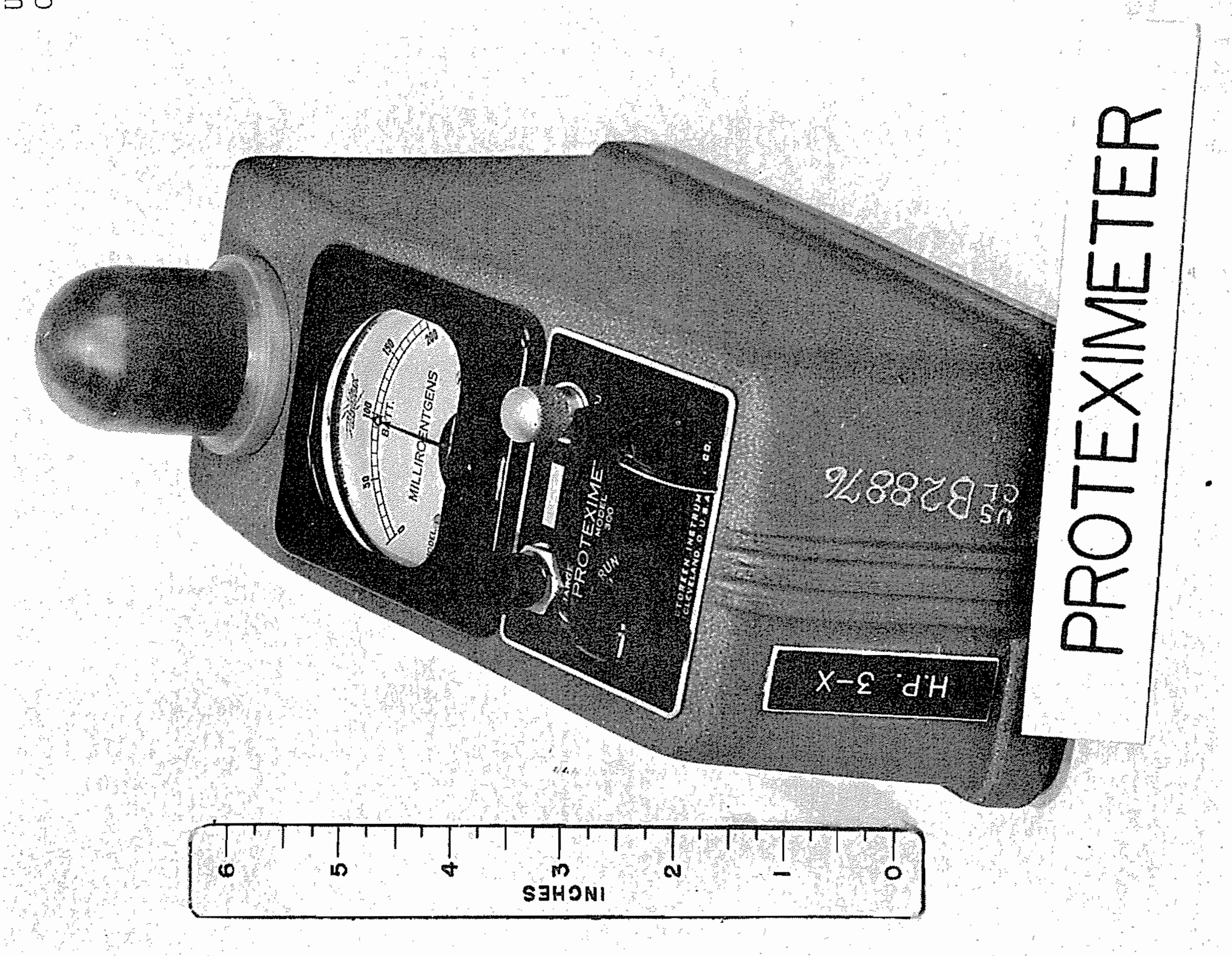


Proteximeter

The Proteximeter reads total accumulated dosage of gamma and X-radiation. The instrument has a self-contained power supply which is used to charge a specially designed ionization chamber. After charging, the reading of the attached meter is an indication of the radiation dose.

Protexímeter

A. Characteristics

1. Radiation detected - Gamma, X-ray.

2. Self contained batteries - 5 Eveready size D - Life: approximately 1 month if used 8 hours a day.

3. Chamber may be discharged by inverting.

4. Range - 0-0.2 roentgens.

5. Dimensions: 9" x 4" x 7". Weight: 5 lbs.

B. Application

1. Accurate within 10% for gamma radiation.

2. Should be operated in accordance with instructions printed on the base of the Proteximeter.

3. Will not respond to beta radiation below 1 to 2 Mev.

4. Should not be inverted or handled roughly during operation.

C. Calibration

1. Source - 25 millicurie Ra and Electroscope set-up (See Section 3).

2. Charge proteximeter to zero.

3. Observe after one hour to determine if leakage has occurred.

4. Expose to dose rate of 100 mr/hr for one hour.

5. Observe and note on instrument number of divisions for 100 mr.

6. Should be checked and calibrated every six to ten weeks.

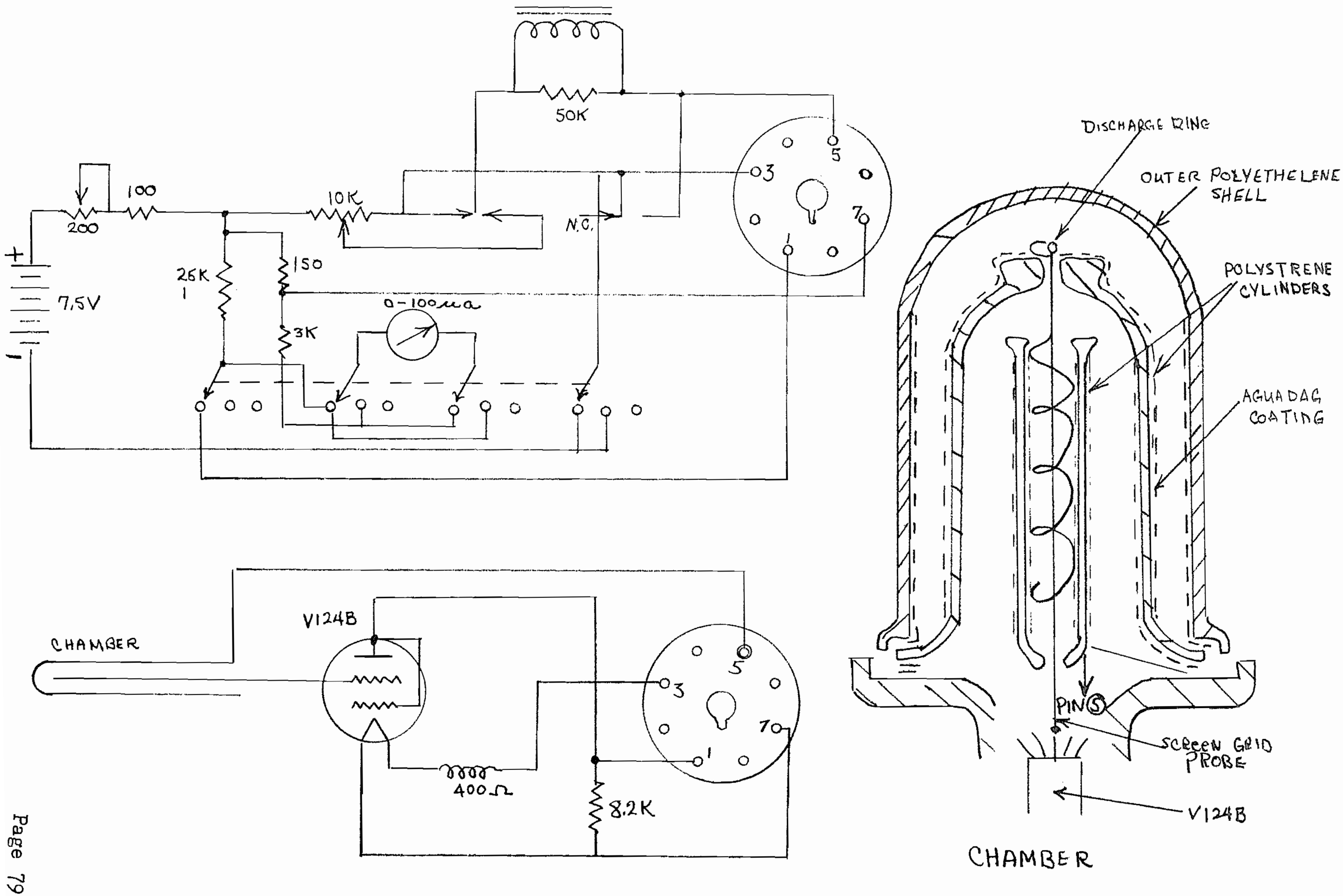
D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, charge, meter, and zero functions.

3. Check for response to gamma radiation.

4. In most cases of malfunction a replacement of the sealed chamber unit is indicated.



PROTEXIMETER

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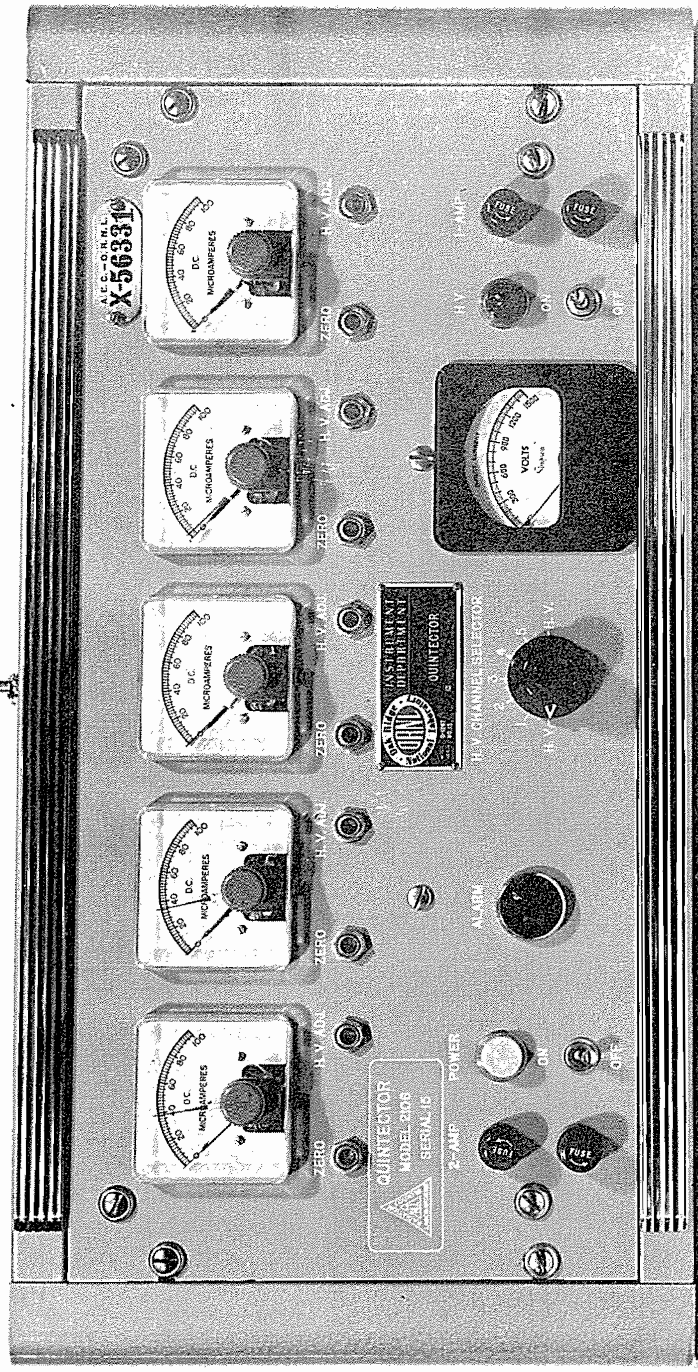

Quintector or Squid

The Quintector affords a method of monitoring for beta and gamma radiation at entrances or exits. Radiation above a predetermined level will cause one or more of five alarms to be sounded.

Quintector (Squid)

A. Characteristics

1. Operates on 100 to 130 volts AC.

2. Type radiation: beta-gamma.

3. Five externally located GM tubes.

4. Individual count rate channel for each tube.

5. Individual adjustment of each channel.

6. Separate rate meter and alarm system for each channel.

7. No thyratron circuit.

8. Special input cables.

9. Dimensions: 21" x 10" x 16". Weight: 50 lbs.

B. Application

1. Alarm contact on meter relay should be set sufficiently above background to reduce spurious readings.

2. A small beta-gamma source should be used to check each tube to determine if operating properly.

3. Will not detect alpha radiation.

4. For indicating relative beta-gamma radiation intensity above background level.

C. Calibration

1. Source - any small beta and/or gamma source.

2. Use source near each tube to determine if counter is operating properly.

D. Routine maintenance of this instrument is beyond the scope of this manual.

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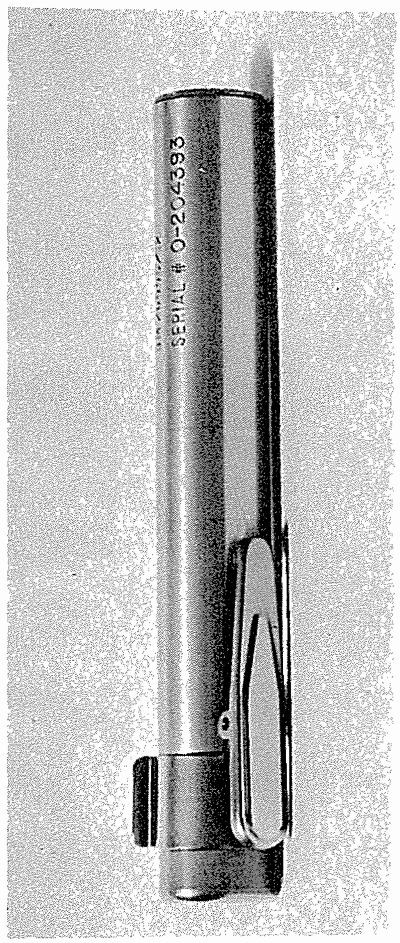


Pocket Dosimeter

The dosimeter is a small, pencil type ionization chamber containing a quartz fiber electrometer unit. The fiber unit is mounted into one end of the instrument and is viewed through a lens from the opposite end. A rectifier circuit or battery supply is used to charge the dosimeter, and the displacement of the fiber after charging indicates the radiation to which the meter has been exposed.

Pocket Dosimeter

A. Characteristics

1. Requires charging unit.
2. Direct reading. Full scale reading is 0.2 r gamma.
3. Hermetically sealed with diaphragm charging switch.
4. Insensitive to beta radiation below approximately 1 Mev.
5. Dimensions: 1/2" d. x 3-5/8". Weight: 1/2 oz.

B. Application

1. The instrument will measure within 10% gamma radiation dosage from 5 to 200 mr.
2. The instrument will not measure beta or soft gamma radiation.
3. The instrument may respond to beta radiation of energies greater than 1 Mev.
4. A separate charging unit is necessary for charging the instrument.
5. The fiber should be charged to exactly zero before using the instrument.
6. The instrument should be checked for leakage.
7. Attention should be given to the position in which the meter is worn and read.
8. The instrument is delicate and should be handled accordingly.
9. Calibrated with Ra gamma and calibration attached to instrument.

C. Calibration

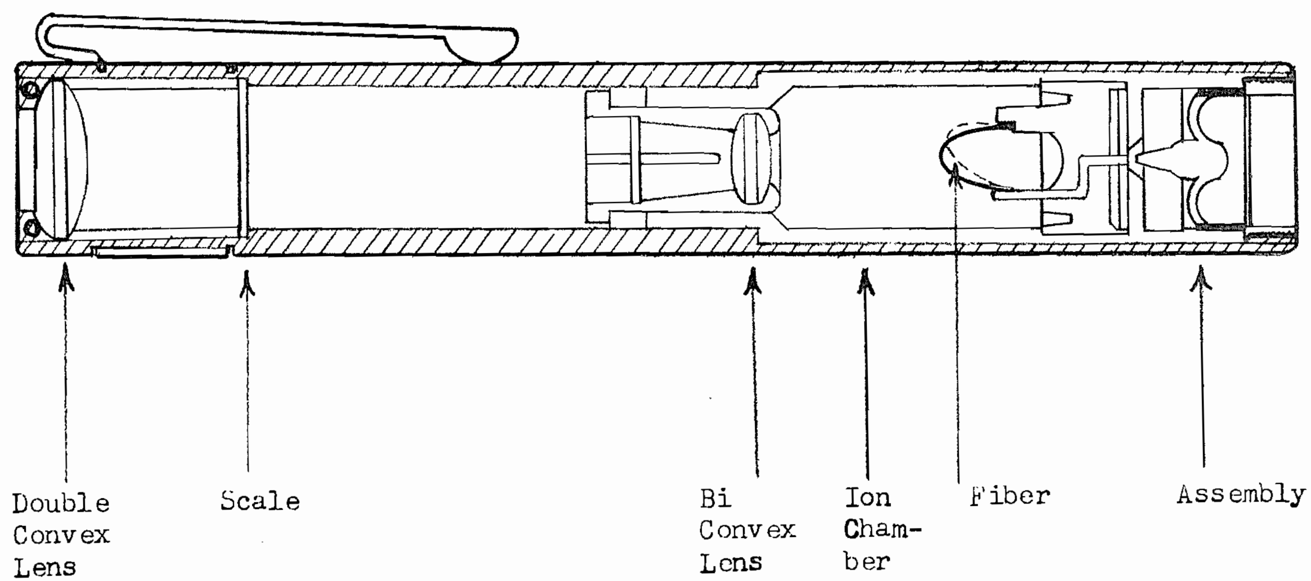
1. Source - 100 millicurie Ra and gamma film calibration set up (see Section 3).
2. Charge instrument and check for leakage.
3. Expose to a dose of 100 mr.
4. Note reading. This reading expressed as the number of divisions equal to 100 mr is attached to the instrument.
5. Should be calibrated once every four weeks.

D. Routine Maintenance

1. Check focus and scale adjustment.

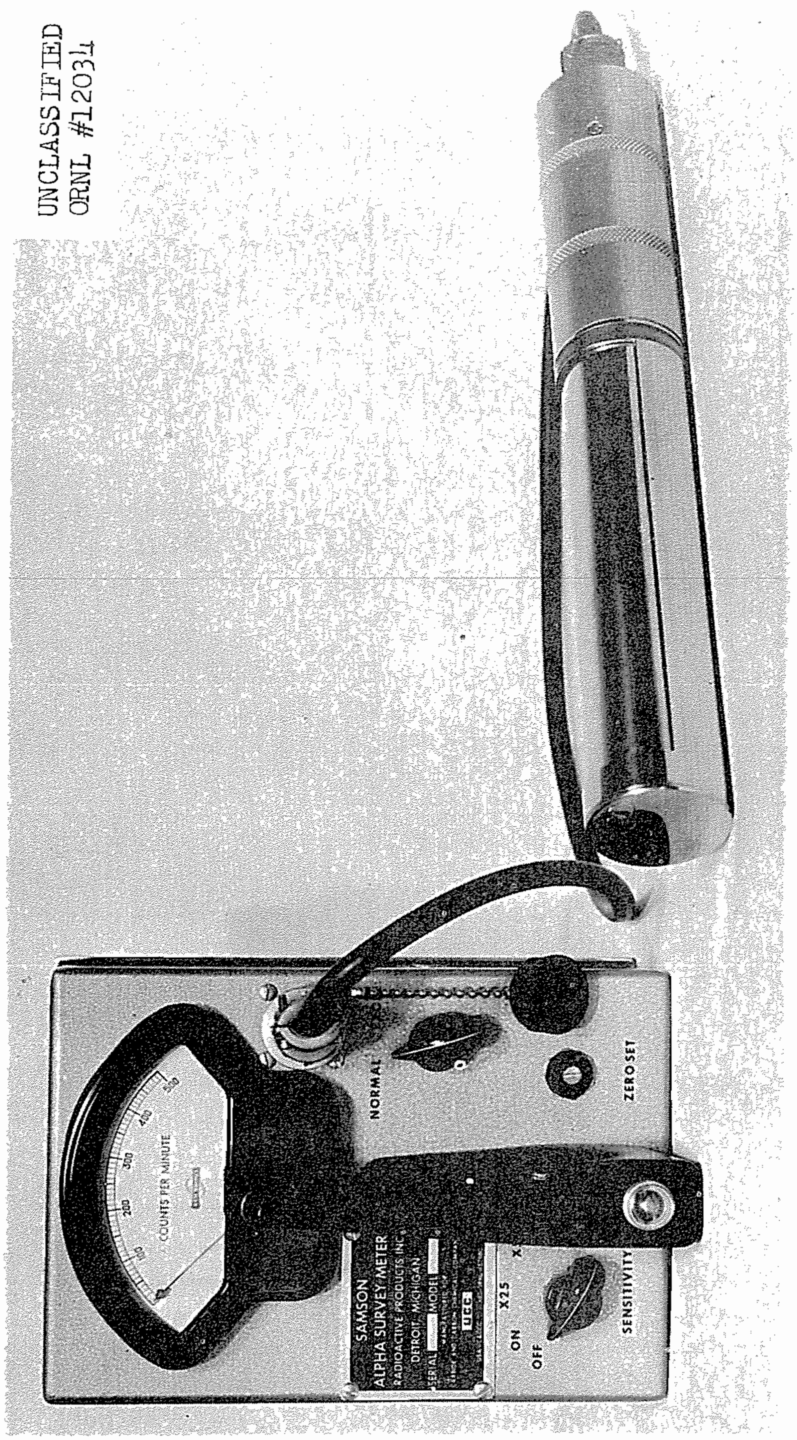
2. Charge and test for leakage. If leakage occurs, clean insulating surfaces near charging electrode with dry cleansing tissue and blow out with clean dry air.

3. Disassembly and repairs of fiber mechanism should be made only in properly equipped laboratory.



Dosimeter (Fiber Type)

CHARGE DOSIMETER



Samson Alpha Survey Meter and Probe

The Samson Alpha Survey Meter is a sensitive, portable ionization type instrument for the quantitative measurement of alpha and qualitative indication of beta and gamma surface contamination. The probe is intended as a contamination monitor for beta and gamma radiation.

Samson Alpha Survey Meter and Probe

A. Characteristics

1. Scale Ranges:

	Alpha Counts	mr/hr
X1	500	0.7
X5	2500	3.5
X25	12500	17.5

2. Will detect alpha particles > 2 Mev and beta particles > .05 Mev.

3. Window 4-3/4" x 5", .0002" pliofilm (rubber hydrochloride) with mass of .66 mg/cm^2. Protected by 80% open area stainless steel screen.

4. Three tube, 100% feedback circuit with electrometer input. Plug-in battery pack.

5. External beta-gamma probe (optional equipment) has freon filled ion chamber, electrometer preamp, and rotating beta shield.

   Gamma Range:

	X1	X100
X1	0.25	25
X5	1.25	125
X25	6.25	625

6. Dimensions: 5-1/8 x 8-1/4 x 7-1/4. Weight: 5 lbs.

7. Batteries: Five Eveready No. 412, 22½V, Four Mallory No. RM-12, 1.3V, one Mallory No. 302437, 9.1V, one Mallory No. 302435, 6.5V.

B. Application

1. Ionization chamber is sensitive to alpha, beta, and gamma radiation.

2. Instrument is calibrated only for alpha radiation.

3. An external shield should be used to determine if radiation other than alpha is present.

4. Sensitive area of chamber should be in contact with surface being surveyed.

5. Instrument should be properly zeroed before use.

6. Instrument should be turned on for two minutes before use.

7. The probe is sensitive to beta and gamma radiation.

8. The probe is calibrated for gamma radiation.

C. Calibration

1. Sources - alpha plaques and GMSM set-up (see Section 3).

2. Turn instrument on five minutes prior to calibration.

3. Instrument should be properly zeroed.

4. Check dial and meter functions.

5. Make at least 3 observations on each scale with alpha sources. Note and record meter reading in c/m and source strength in d/m.

6. Total the separate c/m readings and divide by the total of the d/m readings. The quotient obtained is the per cent geometry of the instrument.

7. The window of the instrument should be centered over the source and placed as close to the source as possible.

8. To calibrate the probe, place the probe in the holder for the GM Survey Meter probe, and switch selector to "Probe" position.

9. Make observations of meter reading versus mr/hr.

10. Plot curve of c/m versus mr/hr and attach to instrument.

11. Probe should be closed during gamma calibration.

12. Instrument should be checked and recalibrated every four weeks.

D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, control, meter, and zero functions.

3. Check ion chamber for response to alpha radiation and probe for response to gamma radiation.

4. The more common malfunctions may be due to one or more of the following:

   a. Leakage due to foreign material on insulators, high value resistors, electrometer tube, etc.

   b. Radioactive contamination

   c. Faulty switch

d. Faulty tube

e. Faulty meter

f. Faulty potentiometer

g. Improper bias adjustment

h. Battery terminals reversed

i. Intermittent, improperly shorted, or improperly opened connections.

j. Alpha window too thick

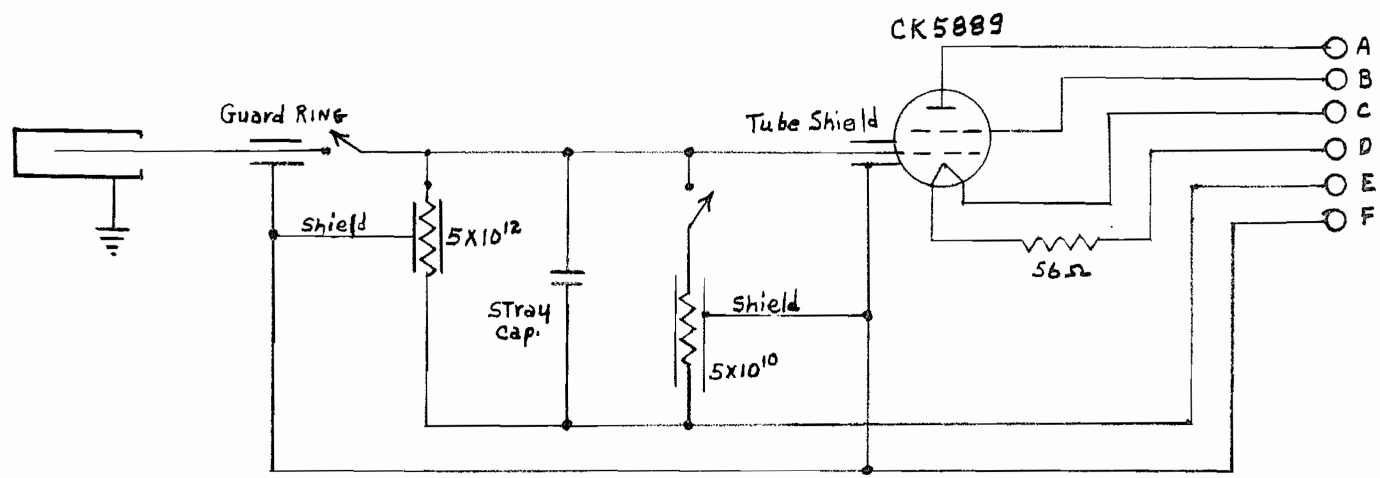
k. Excess humidity

5. Inability to zero may be due to c, d, e, f, g, h, or i.

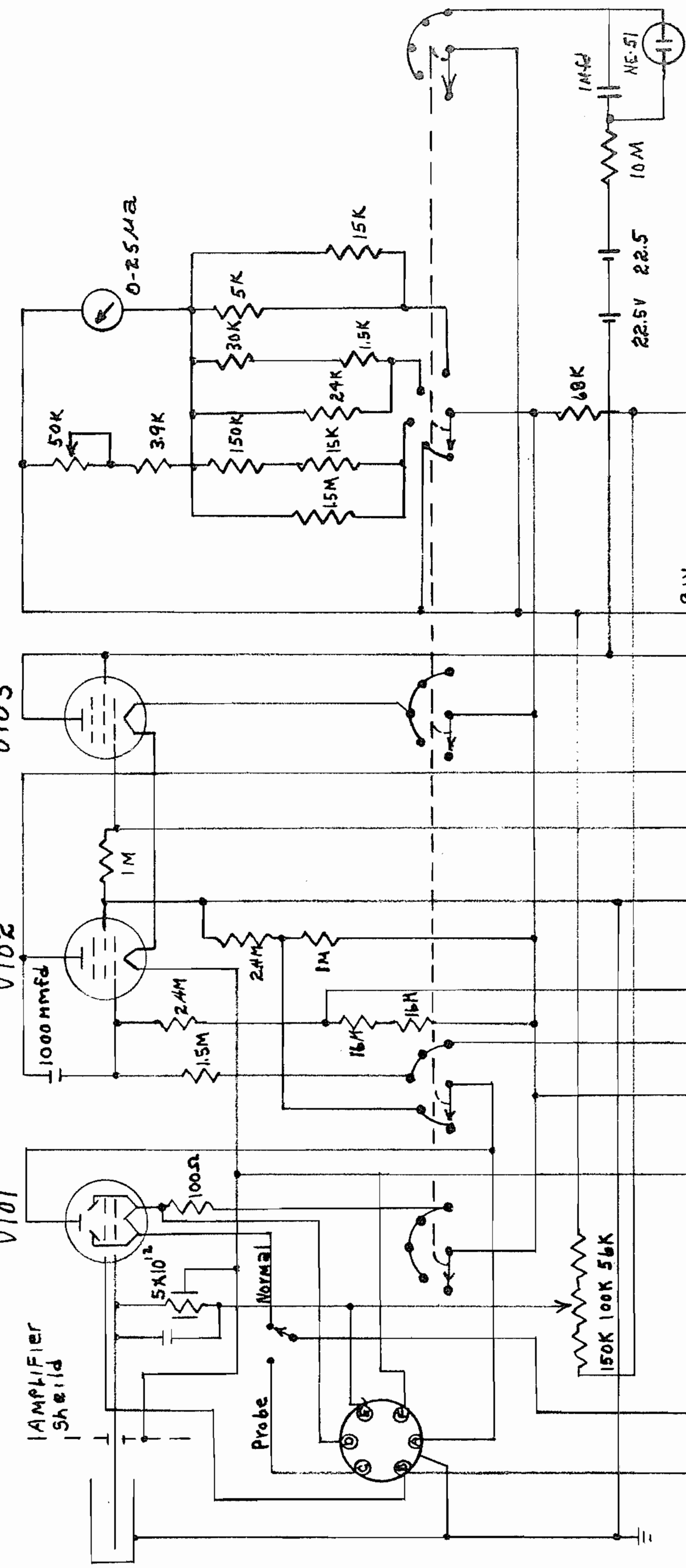
6. Lack of or weak response to radiation may be due to c, d, e, g, j, or i.

7. Too great response to radiation may be due to a, b, d, g, i, or k.

8. Erratic readings may be due to a, c, d, e, f, g, h, or i.



Samson Beta-Gamma Probe



Samson Survey Meter

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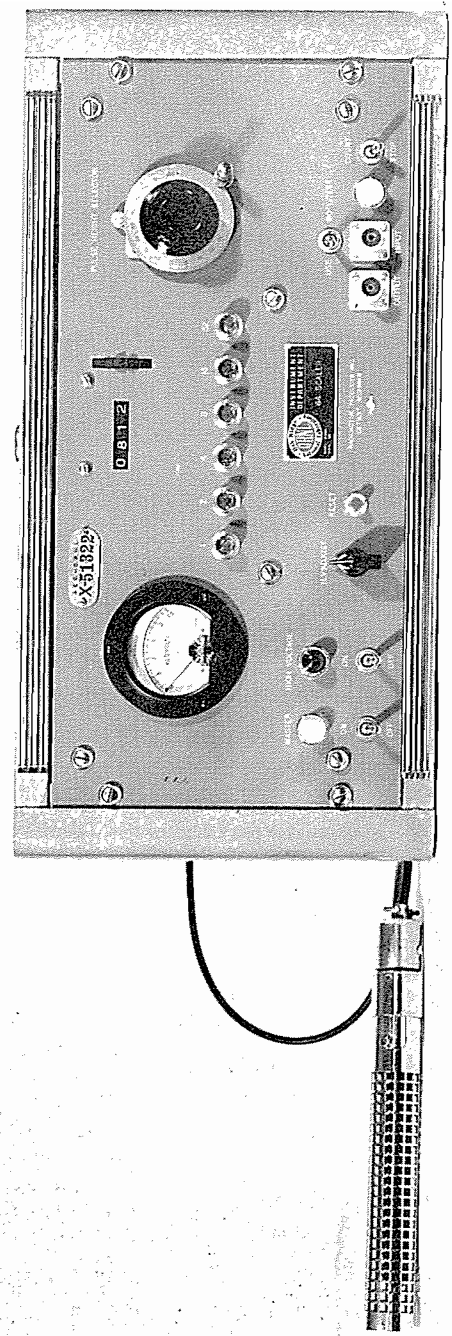

Scaler with Beta-Gamma Probe

Beta-gamma scalers with GM tube probes are used for detection of radiation background and contamination. The counting rate of the scaling device is an indication of the relative intensity of the radiation present.

Scaler with GM Tube Probe

A. Characteristics

1. Operates on 95 to 130 volts power supply.

2. Input sensitivity: 0.25 to 15 volts, negative pulse.

3. Resolving time: 5 microseconds.

4. 600 to 1500 volts GM supply with regulation of 0.01% per percent change in line voltage, less than 0.05% drift.

5. Maximum number of random counts per minute with register: 40,000.

6. Used in conjunction with standard glass GM tube and shield as beta-gamma probe, or with Bismuth GM tube for detection of I^{131} in thyroid.

7. Preamp connection.

8. Dimensions: 22" x 15" x 11". Weight: 60 lbs.

B. Application

1. Useful for detection of gamma and x-radiation and beta radiation of energies greater than .2 Mev.

2. May be calibrated to measure, approximately, mr/hr of gamma or X radiation.

3. Should not be used to measure mrep/hr of beta radiation.

4. Operating voltage with GM tube should be properly adjusted before use.

5. Background count should be noted before using instrument to count other radiation.

6. To prolong tube life, high voltage should be reduced when instrument is not in use.

7. A source should be used to check instrument before use.

8. Counting rate should not be interpreted in terms of mr/hr unless instrument has been so calibrated.

C. Calibration

1. Source - 1 millicurie Ra.

2. Turn scaler on and allow to warm up before operation.

3. Determine proper operating voltage for GM tube.

4. Mount GM tube probe and radium source, as far removed from scattering material as practical, to obtain a dose rate of 1 mr/hr.

5. Take a five minute count and determine c/m versus mr/hr.

6. Remove source and determine background counting rate. Subtract this background rate from the value obtained above to obtain net c/m per mr/hr.

7. To calibrate the Bismuth GM tube for thyroid counting, proceed as above and divide the net c/m by 35 to obtain the net c/m for I^{131} tolerance in the thyroid. This factor of 35 has been previously determined from experiments with a phantom.

D. Routine maintenance of this instrument is beyond the scope of this manual.

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Portable Scintillation Counter

The portable scintillation counter is useful for the detection and measurement of very low level gamma radiation. The instrument incorporates a sensitive crystal, a photomultiplier tube, an amplifier circuit and a count rate meter.

Portable Scintillation Counter

A. Characteristics

1. Switch positions: Off, Zero, 5, .5, .05 mr/hr.
2. Useful only for gamma or X ray.
3. The instrument is accurate to within 5% of full scale reading.
4. Battery life 200 hours.
5. Zero adjust: may be zeroed in field.
6. Crystal: NaI(Tl), 1" x 1", permanently mounted.
7. Batteries: one Burgess 2D, 1½V, one Burgess 4F, 1½V, two Eveready 412, 22½V, one Eveready 467, 67½V.
8. Dimensions: 6" x 3" x 12". Weight: 7 lbs.

B. Application

1. Measures gamma or X radiation from .005 to 5 mr/hr.
2. Insensitive to beta and alpha radiation.
3. Should be turned on 1 minute and zero adjusted in zero position before use.
4. Time constant switch in "1 second" position allows meter to give instantaneous response to pulses. In "10 second" position, meter is damped so that it responds to average of the pulses.
5. Instrument is useful only in regions of low background radiation.

C. Calibration

1. Source - 1 milligram Ra.
2. Turn instrument on and allow to warm up.
3. Switch to the 5 mr/hr scale and adjust source to obtain a dose rate of 5 mr/hr at the center of the sensitive portion of the chamber.
4. Adjust calibration control to obtain a reading of 5 mr/hr.
5. A special calibration should be made if the instrument is to be used to determine dose rates below 2 mr/hr.
6. Should be checked and calibrated once every four weeks.

D. Routine Maintenance

1. Check and replace weak batteries.

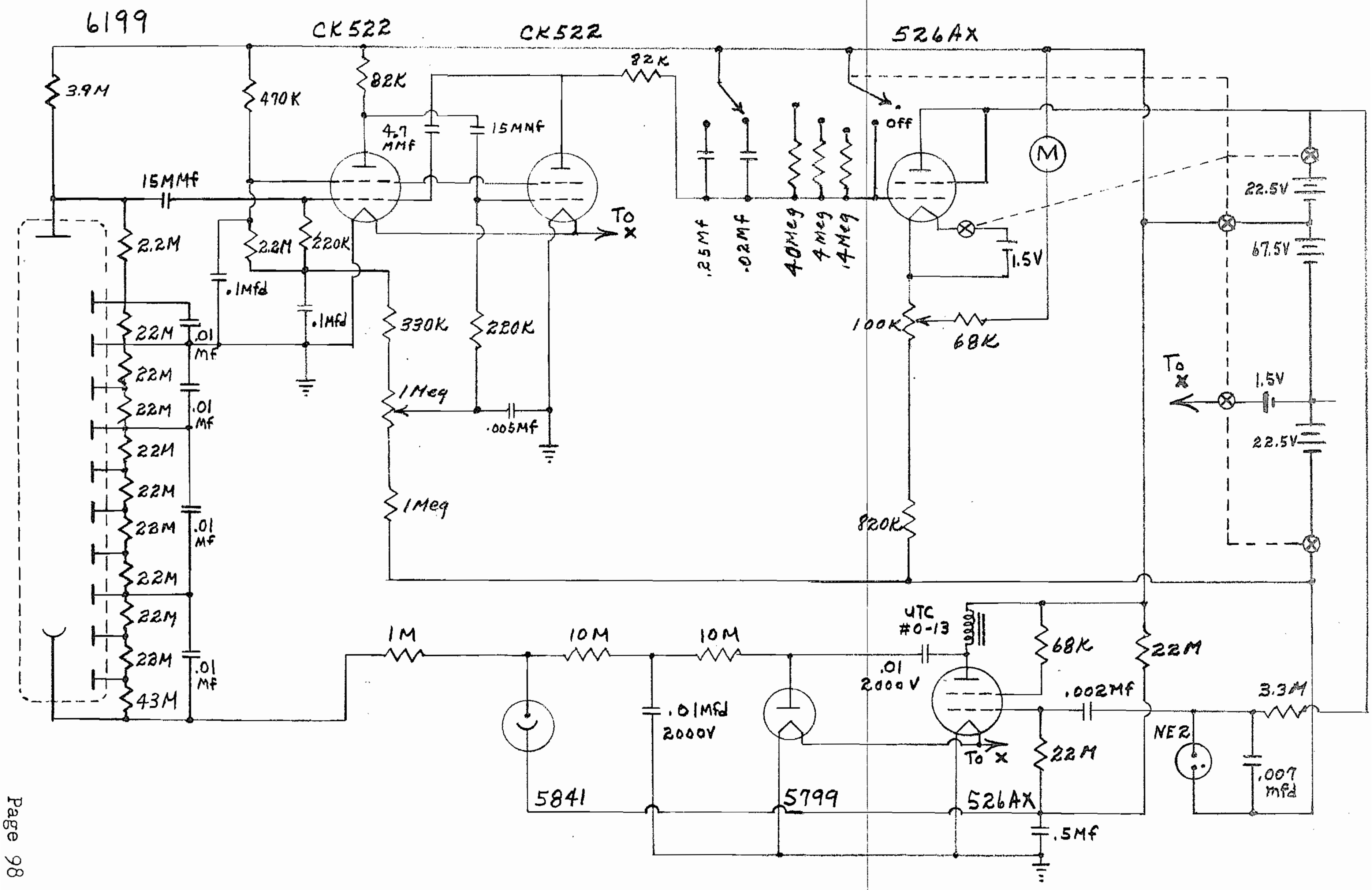
2. Check switch, control, meter, and zero functions.

3. Check for response to appropriate radiation.

4. Inability to zero may be due to faulty output tube and associated components.

5. Lack of, or weak, response to radiation may be due to fault in high voltage circuit, the input amplifier tubes and associated components, faulty photo tube, or excessive light leak.

6. Too great response to radiation may be due to faulty condensers in photo tube circuit, faulty input amplifier tubes, or a small light leak.



Scintillation Survey Meter

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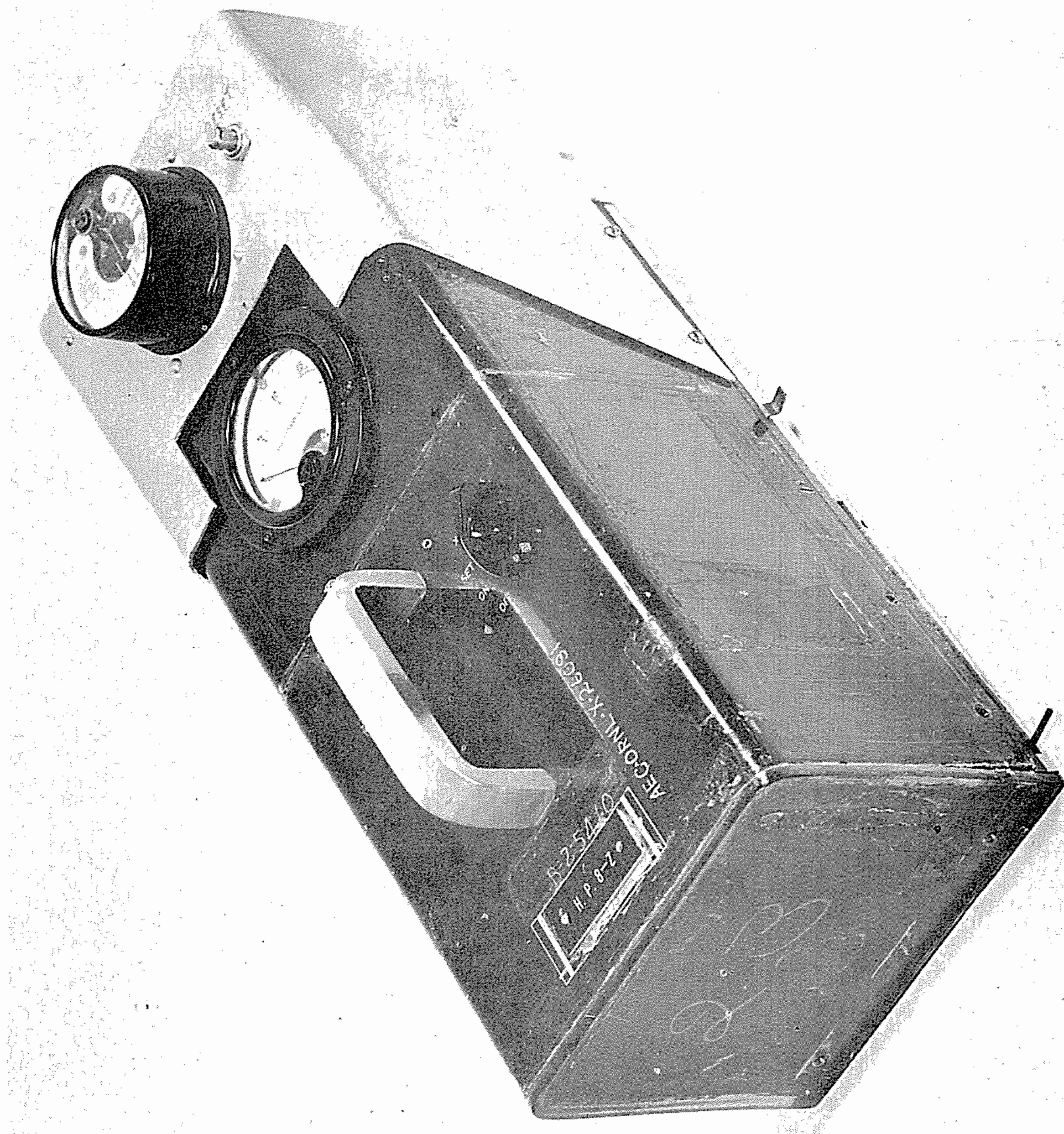


Modified Zeus

The modified Zeus is a medium size, medium weight portable instrument which has been adapted for measuring airborne radioactivity, and particularly gaseous compounds containing H^3 and C^{14}. Indication is accomplished by means of a rate meter and a relay-buzzer system.

A. Characteristics

1. Radiation detected: alpha, beta, and gamma.

2. Absorber: open window to chamber is covered with copper screen. No other shield or covering is used.

3. Use: converted to be used principally for the detection of airborne radioactivity, particularly weak beta radiation.

4. Battery:

   a. Ion chamber circuit: 3 Eveready No. 412, 22½V, 2 Burgess W3BP, 7½V, 2 Burgess B2BP, 3V, 1 Burgess 2FBP, 1½V, and 1 Eveready No. 763, 22½V.

   b. Alarm and relay circuit: 2 Eveready No. 412, 22½V, and 1 Burgess B2BP, 3V.

5. Dimensions: 6-1/2" x 6-1/2" x 17". Weight: 8 lbs.

B. Application

1. The instrument will detect significant amounts of alpha, beta, and gamma airborne radiation.

2. The instrument is also sensitive to direct alpha, beta, and gamma radiation.

3. The instrument is not calibrated in terms of uc/cc and careful interpretation of results obtained should be made.

4. The instrument should be allowed to warm up for 5 minutes before use.

5. The instrument should be properly zeroed in the absence of radiation.

6. Alarm setting should be checked.

7. Airborne activity may contaminate inside of chamber.

C. Calibration

1. Source - 1 millicurie Ra.

2. Turn instrument on 5 minutes before checking.

3. Zero instrument.

4. Switch to most sensitive position, adjust source to give 1.5 mr/hr to chamber, adjust relay to operate at this dose rate.

5. Remove source and reset relay.

D. Routine Maintenance

1. Check and replace weak batteries.

2. Check switch, meter, and zero functions.

3. Check for response to gamma radiation.

4. The more common malfunctions may be due to one or more of the following:

   a. Leakage due to foreign material on insulators, high value resistors, electrometer tube, etc.

   b. Radioactive contamination

   c. Faulty switch

   d. Faulty tube

   e. Faulty meter

   f. Faulty potentiometer

   g. Improper bias adjustment.

   h. Battery terminals reversed

   i. Intermittent, improperly shorted, or improperly opened connection

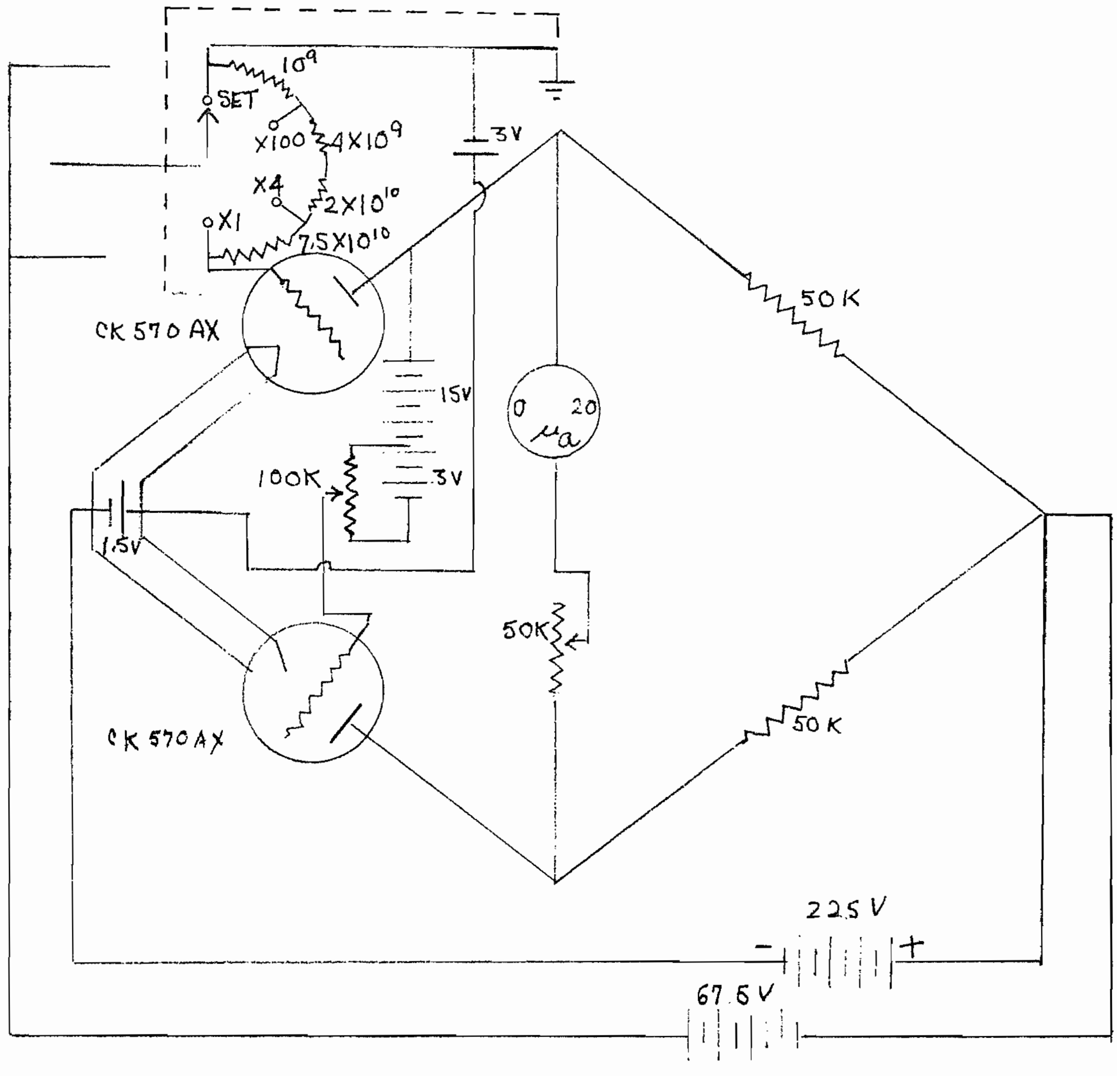
   j. Excess humidity

5. Inability to zero may be due to c, d, e, f, g, h, or i.

6. Lack of, or weak response to radiation may be due to c, d, e, g, or i.

7. Too great response to radiation may be due to a, b, d, g, i, or j.

8. Erratic readings may be due to a, c, d, e, f, g, h, or i.



10^9
SET
X100
4X10^9
X4
2X10^10
X1
7.5X10^10
3V
CK 570 AX
50 K
15V
0
20
μa
100K
3V
1.5V
50K
CK 570AX
50 K
225 V
-
+
67.5 V

ZEUS

SECTION II

Section II -

Radiation - Types, Units, Permissible Exposures

I. Types of Radiation Measurements

A. Alpha

Alpha rays are particles that carry positive charges and have been identified as the nuclei of helium atoms, i.e., two protons and two neutrons held together as a unit. The alpha particle has a mass number four times that of the hydrogen atom and a positive charge two times that of the hydrogen nucleus. Alpha particles may have velocities ranging from nearly 0 to the order of 2×10^9 cm/sec. As they move through air, they produce ionization by interaction with atoms. Each successive interaction reduces the speed of the particle until it is no longer able to produce ions.

Alpha particles have definite ranges, the range depending upon the energy of the particle. The approximate range of the alpha particle may be determined by the formula $R_\alpha = 0.318E^{3/2}$, where

R_α = range in cm of air at 1 atom and 15°C

E = energy, Mev

Example: Find the range in air of a 5 Mev alpha particle.

$$R = 0.318\ E^{3/2}$$

$$R = 0.318 \times 5^{3/2}$$

$$= 0.318 \times 11.18$$

$$= 3.55 \text{ cm}$$

The range-energy relationship of alpha particles is shown in Fig. 1, Page 116.

While the range of alpha particles may be several centimeters in air, or other gases, the range in liquids and solids is extremely short. The range in a solid decreases in a regular manner with increasing atomic number. Aluminum is a light element and can be obtained in a variety of foil thicknesses and is therefore frequently used in absorption studies for alpha particles, results being expressed in range in mg/cm² for Al. The range-energy relationship for aluminum is shown in Fig. 2, Page 117.

Instruments used for detection and measurements of alpha particles utilize thin sheets of low atomic number materials as windows or screens. For example, the window of the Keleket Cutie Pie and Juno are composed of pliofilm approximately .0002" think and the window of the Victoreen Alpha Survey Meter is approximately 5 microns thick (.5 mg/cm). These windows will stop all alphas below approximately 1.0 Mev.

B. Beta

Beta rays are particles that carry negative charges, and are high speed electrons. They have velocities ranging up to 0.99 that of light. Beta particles are much more penetrating than alpha particles. More than the alpha particle, the beta particle (due to its lighter mass) deviates from its path with each collision. Beta particles are emitted from a given isotope with energies ranging continuously from near 0 to a maximum energy characteristic of the isotope. There is a fairly definite path length associated with each energy of beta ray. Since most of the paths are not straight, and only a few rays are emitted with the maximum energy, very few particles will reach the theoretical maximum range for the source in question. As the beta particle slows down, more ionization is produced per unit path length until it reaches a point at which it is no longer capable of producing ionization.

The approximate range of beta particles may be determined by the following formulas:

For energies > 0.8 Mev

$$R = 0.526 E - 0.094$$

For energies < 0.8 Mev

$$R = 0.407E^{1.38}$$

where R = range, gm/cm^2

E = maximum energy, Mev.

The range-energy relationship for beta particles in aluminum is shown in Fig. 3, Page 118.

A rough estimate of the absorbing thickness or range of beta particles in any material may be obtained from the formula:

$$T = \frac{0.546 E_m - 0.16}{P}$$

where T = thickness of absorbing material in cm

E_m = maximum energy of beta particle in Mev

P = density of material in grams/cc.

The following is a list of some of the more common types of radiation survey instruments showing material and thickness of chamber wall and beta energies required to penetrate the chamber wall.

Instrument	Chamber Material	Thickness	Energy of Beta to Penetrate
Cutie Pie	Bakelite	1/16"	0.7 Mev
" "	Paper	6.75 mg/cm^2	0.07 Mev
Electroscope	Aluminum	1/32"	0.6 Mev
Juno	Plastic Window	.0002"	0.15 Mev
"	Aluminum	1/32"	0.6 Mev
G.M.Survey	Glass	30 mg/cm^2	0.3 Mev

C. Gamma

Gamma rays are electromagnetic radiations of the same character as X rays but extend to much higher frequencies. The frequency of the gamma rays is so high that they are best understood by considering them as quanta of energy. The gamma ray has three types of interaction with matter which makes its detection relatively simple. The three types of interaction are:

1. Photoelectric Effect

An incoming photon interacts with an orbital electron in an atom, transferring ALL of its energy to the electron.

$h\nu = \phi + 1/2\ mv^2$

Energy of photon = $h\nu$

Work function = ϕ

Kinetic energy = $1/2\ mv^2$

Since ϕ is usually small: $h\nu = 1/2\ mv^2$

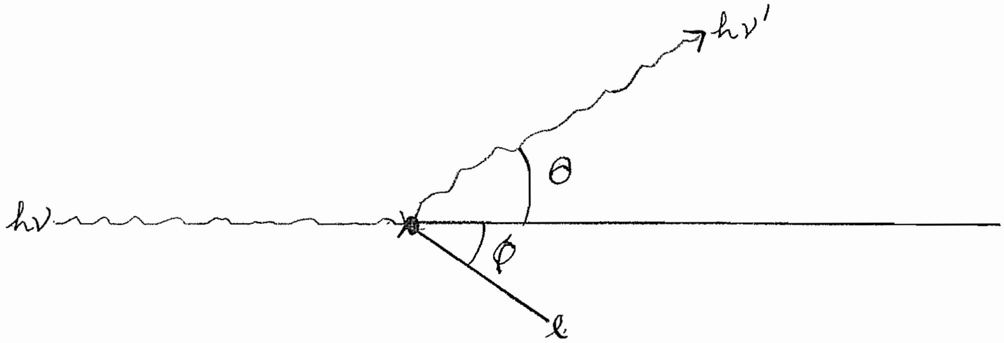
The ejected electron is called a photoelectron. These photoelectrons may produce ionization. This effect is in general small above 1 mev. The effect increases with increasing atomic number (Z) or absorber. Also, the more tightly bound is the electron, the more efficient is the process. For a given K shell the higher the atomic number, the more effective is the process. Production of photoelectrons is proportional to

$$\frac{Z^5}{E^{7/2}}$$

Roughly, we can say this process is important for heavy elements and low energy.

2. Compton Effect

When a quantum of energy collides with an electron, it will project the electron in the general direction of the quantum accordung to the ordinary rules of impact and deflect a new quantum of lower energy. In this way, the recoil electron can acquire enough energy to ionize and be detected.



$$\Delta\lambda = \frac{h}{mc}(1-\cos\theta)$$

$$\Delta\lambda = \frac{6.6\times10^{-27}\,erg\text{-}sec}{9.1\times10^{-28}\,gm\times3\times10^{-10}\frac{cm}{sec}}(1-\cos\theta)$$

$$\frac{gm\,cm^2}{sec^2}\times sec\times\frac{1}{gm}\times\frac{sec}{cm}=cm$$

$$\Delta\lambda = .0241\times10^{-8}(1-\cos\theta)\,cm$$

$$\Delta\lambda = .0241(1-\cos\theta)\,\mathring{A}$$

3. Pair Production

The gamma quantum is transformed into a pair of particles, the particles having the same mass but opposite charges (electron, positron). It is the ionization caused by these particles that may be measured. Pair production accounts for only a small part of the energy loss of low energy (none below 1.02 mev) gamma rays.

$h\nu = e^{+} + e^{-} + KE$

photon energy = positron + electron + kinetic energy

The photon is completely annihilated.

$$E = mc^2 = 9.1 \times 10^{-28} \times 9 \times 10^{20}$$

$$= 81.9 \times 10^{-8} \text{ ergs}$$

Since 1.6×10^{-6} ergs = 1 mev

$$\frac{81.9 \times 10^{-8} \text{ erg}}{1.6 \times 10^{-6} \text{ erg/mev}} = .51 \text{ mev}$$

Therefore $h\nu$ must have at least 1.02 mev.

Important for high energy and high Z.

Gamma radiation is usually evaluated by absorption measurements in which thin sheets of lead are inserted between the gamma emitter and the measuring device. For this reason, absorption of gamma rays are usually expressed in terms of grams per square centimeter of lead. Very often the energy is given in terms of grams per centimeter of lead required to reduce the initial intensity to one-half its value. The "half thickness" is determined by formula

$$X_{\frac{1}{2}} = \frac{0.693}{\mu_m}$$

where μ_m is the mass absorption coefficient.

The mass absorption coefficient is equal to the linear absorption coefficient divided by the density of the material. The half thickness-energy relationship for lead is shown in Fig. 4, Page 119.

The gamma ray absorption for monoenergetic radiation may be determined by the formula

$$I = I_o e^{-\mu x} \quad \text{or } I = I_o e^{-\frac{.693x}{x_{\frac{1}{2}}}}$$

where μ = linear absorption coefficient (cm^{-1})

x = absorber thickness (cm)

$x_{\frac{1}{2}}$ = half-value layer of absorber (cm)

e = base of natural logarithm (2.718)

I_o = original exposure rate

I = radiation exposure rate after passing thru absorber

D. Neutron

The neutron is an uncharged particle with a mass slightly greater than that of a proton - atomic weight 1.0089. The fast neutron does not produce primary ionization but may be detected when it collides with nuclei and imparts energy to them. These moving nuclei, provided they have sufficient energy, secondarily produce ionization which is detectable. A fast neutron may give up one-half (on the average) its energy to a hydrogen nucleus, giving rise to a proton whose range will measure the energy of the original neutron. Slow neutrons may cause nuclear reactions which give rise to fast moving protons, alpha particles, or gamma rays. These secondary radiations can then be measured in the appropriate way and this data will furnish considerable information about the slow neutron flux. A beam of neutrons loses energy exponentially along its path and so is not considered to have a limit to its range. As with the gamma ray, the half range is frequently used. Neutrons are grouped into three categories according to their energy. These are: thermal neutrons 1/40 ev - 10 ev; medium, 10 ev - 0.5 mev; fast neutrons, 0.5 mev - up. Neutrons are stopped effectively thus:

1. Thermal - capture

$${}_1H^1 + {}_0n^1 = {}_1H^2 + h\nu$$

$${}_7N^{14} + {}_0n^1 = {}_6C^{14} + {}_1H^1 + h\nu$$

$${}_6C^{14} \xrightarrow{5100\ \text{yrs.}} {}_7N^{14} + {}_{-1}e^0$$

2. Fast - collisions with protons

II. Units of Measurements

A. Curie

The curie was originally defined as the amount of radon in equilibrium with one gram of radium. Since it is difficult to isolate a given mass of radium or radon, and since the term has been applied to elements other than radon, a more practical definition of the curie has been established. This definition states that a curie is that amount of substance which gives a rate of 3.7×10^{-10} disintegrations per second.

B. Roentgen

The roentgen is that quantity of X or gamma radiation such that the associated corpuscular emission (secondary electron radiation) per 0.001293 grams of air produces, in air, ions carrying one esu of quantity of electricity of either sign.

C. Rep

The rep (roentgen equivalent physical) may be defined as the dose of radiation which will result in the dissipation of 93 ergs per gram of tissue.

D. Rem

The rem (roentgen equivalent man) is that amount of radiation which will produce the same damage to man as a roentgen of X or gamma radiation.

E. RBE - Relative Biological Effectiveness

x or gamma = 1	fast neutron = 10
beta = 1	thermal neutron = 5
alpha = 20	protons = 10

Thus, one rem of alpha $= \frac{93}{20} = 4.7$ ergs/gram of tissue. This produces the same biological damage as 1 rem of beta = 93 ergs/gram of tissue.

1 rem of alphas $= \frac{1}{20}$ rep.

1 rem of betas = 1 rep.

III. Maximum Permissible Exposures (See Note, Page 115)

A. External

Gamma - X rays Beta Neutrons(1)	300 mrem/wk to interior tissues ($>$ 5 cm in depth), 500 mrem/wk to outer layers of tissue, 1500 mrem/wk to hands, feet, forearms, and ankles. To be averaged over 13 weeks, not to exceed 2 times above values in any one week.

(1) Lesser values may be recommended for the exposure of the eyes.

Approximate neutron flux (in neutrons/cm^2/sec for 8 hrs per day)

Fast Neutrons[2] ($\geq$ 0.5 Mev)	50 n/sec/cm^2
Thermal Neutrons ($<$ 5 Kev)	1750 n/sec/cm^2

B. Internal Exposure

1. (a) Ingestion - Average concentration for 1 week in food and water to be less than values given in NBS HB-52 for specific isotopes. Table 2 values in HB-52 for unknown isotopes are:

$$10^{-7}\ \mu c/ml \text{ for } \alpha,\ \beta \text{ or } \gamma.$$

Concentration should not exceed 10 times the maximum permissible concentration (MPC) for any extended period of time even though the average does not exceed limits for the one week period.

(b) Water at X-10 Area

	alpha	Beta-Gamma
Drinking Water	10^{-7} μc/cc	10^{-7} μc/cc
H_2O Leaving Settling basin	10^{-3} μc/cc	10^{-3} μc/cc
H_2O Leaving White Oak Lake	10^{-5} μc/cc	10^{-5} μc/cc
H_2O in Clinch River	10^{-7} μc/cc	10^{-7} μc/cc

2. (a) Inhalation - Average concentration in air for 1 week to be less than values as given in NBS HB-52 for specific isotopes. Table 2 values of HB-52 for unknown isotopes beyond the control area are:

Beta-Gamma	1×10^{-9} μc/cc
Alpha	5×10^{-12} μc/cc

The Table 3, HB-52 inhalation values for specific isotopes may be increased by a factor of 3 to convert from continuous exposure to a 40 hour week. An example of such specific limits are:

Uranium	5.1×10^{-11} μc/cc air $\approx$ 113 d/m/m^3
Plutonium	6×10^{-12} μc/cc air $\approx$ 13.3 d/m/m^3

(2) The flux value for fast neutrons is approximate only, considering the average occurrence of a spectrum or mixture of energies. In practice, the neutron dosimeter is preferred since the reading is in dose rather than flux.

(b) Action Point Limits -

(1) Without Mask[3]

Alpha - 5×10^{-11} μc/cc

Beta-Gamma - 1×10^{-8} μc/cc

(2) With Filter Type Mask[4]

Alpha - 5×10^{-9}

Beta-Gamma - 1×10^{-6}

(3) With Positive Air Supply

Control by external hazard.

C. <u>Contamination Limits</u>

1. Hands -

Alpha (unknown isotope)[5] 150 d/m

Beta-Gamma[6] 0.3 mrep/hr

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(3) These are chosen as 10 times the Table 2 HB-52 values. Average limits must be met.

(4) Assumes 99% effectiveness for mask. This is generally true for normal particulate dispersions.

(5) Basis for this value is Table H in report of subcommittee to Committee on Plant Acceptable Limits, dated August 11, 1953. Members of the committee are K. Z. Morgan, X-10, H. F. Henry, K-25, and E. G. Struxness, Y-12. It is assumed that this would permit 1/10 of daily internal intake tolerance. If isotope is known, value may be adjusted accordingly.

(6) Non-uniform distribution is assumed to increase this up to 3 times this value over local hand areas, thus giving up to 150 mrep/wk or 1/10 of total hand tolerance.

2. Personal Clothing -

Alpha(7) - 150 d/m/100 cm^2

Beta-Gamma(8) - No 100 sq.in. area to average $>$ 0.18 mrep/hr

3. Company Clothing - (Assumed worn up to 40 hr/wk)

Alpha(9) - 150 d/m/100 cm^2

Beta-Gamma - No 100 sq. in. area to average $>$ 0.75 mrep/hr

4. Personal Shoes(10)

Inside - Total -	Alpha(11)	-	300 d/m/100 cm^2
	Beta-Gamma(12)	-	.3 mrep/hr
Transferrable	Alpha(13)	-	30 d/m/100 cm^2
	Beta-Gamma(14)	-	1000 d/m/100 cm^2

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(7) Based on Table H values, see (5) above. Also considered is the possible transfer to the hands and the possible exposure of family members from transfer or other release (as by dusting). Discretion should be used as it is assumed that all areas of 100 cm^2 will not be contaminated to this limit. Since the value is based on 100 cm^2, the average contamination level will be appreciably below 150 d/m/100 cm^2.

(8) Limits are based on the probability that the total contamination may be transferrable. When the limits are exceeded, decontamination by laundering is required to reduce the "fixed" residue to below these limits.

(9) This value to be used in "neutral" or general access plant areas. For administrative purposes, it may become necessary to have other areas defined in such a manner that higher levels of contamination may be permitted. In such areas, other restrictions should apply to counteract the higher levels of contamination - i.e., no smoking, no eating, etc.

(10) The limits for both inside and outside must be met, and either may be controlling.

(11) This limit is based on the transferrable limit; thus, the major part of the total is "fixed" contamination, of which 10% is considered released currently for possible intake.

(12) Assumed worn up to 128 hrs/wk. Possible 3-fold increase in exposure may follow from non-uniform distribution of activity giving 0.9 mrep/hr locally. Socks worn with shoes contribute additionally when contaminated.

(13) Estimated from Table H values (see (5) above) and possible exposure to family members. Related to total contamination by a release factor.

(14) Estimated from Table H values weighted for probability of transfer and intake, note the units.

Outside - Total -	Alpha[15] -	300 d/m/100 cm^2
	Beta-Gamma[16] -	.6 mrep/hr
Transferrable -	Alpha[13] -	30 d/m/100 cm^2
	Beta-Gamma[14] -	1000 d/m/100 cm^2

5. Company Issued Shoes

Inside - Total -	Alpha[17] -	300 d/m/100 cm^2
	Beta-Gamma[21] -	1.0 mrep/hr
Transferrable -	Alpha[19] -	30 d/m/100 cm^2
	Beta-Gamma[20] -	1000 d/m/100 cm^2
Outside - Total -	Alpha[17] -	300 d/m/100 cm^2
	Beta-Gamma[21] -	2.5 mrep/hr
Transferrable -	Alpha[19] -	30 d/m/100 cm^2
	Beta-Gamma[20]	1000 d/m/100 cm^2

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(15) This limit is based on the transferrable limit; thus, the major part of the total is "fixed" contamination, of which 10% is considered released currently for possible intake.

(16) Home exposure from possibly several pairs of such shoes is the basis. Also considered is the exposures in shoe shops from shoes of many workers.

(17) This limit is based on the transferrable limit; thus, the major part of the total is "fixed", of which 10% is considered released currently for possible intake.

(18) Possible 3-fold increase in exposure may result to local areas as a result of non-uniform distribution giving up to 3 mrep/hr for 40 hrs. Company issue socks may contribute an additional 30 mrep/wk. It is assumed that if company issued shoes are worn, the personal shoes will not get contaminated; if this be not so, a lower limit should apply.

(19) Estimated from Table H values. Basic limit for general plant area surfaces considering buildup, etc. This is related to "total" contamination by a release factor.

(20) Estimated from Table H values weighted for probability of transfer and intake. Note the units.

(21) Considering a factor of 3 for non-uniform distribution the shoe surface could give local exposure of 300 mrep/wk rate to adjacent tissues (as sitting on one's foot, etc.)

6. General Plant Surfaces[26]

Total Activity - Alpha[22] -	300 d/m/100 cm^2
Beta-Gamma[23] -	.25 mrep/hr
Transferrable Activity - Alpha[24] -	30 d/m/100 cm^2
Beta-Gamma[25] -	1000 d/m/100 cm^2

NOTE: The above tolerance values are based on Supplementary Report by X-10 Subcommittee members. The report was submitted to the Committee on Plant Acceptable Limits on August 12, 1953. Members of the X-10 Subcommittee are T. J. Burnett and D. M. Davis.

(22) This limit is based on the transferrable limit; thus, the major part of the total is "fixed", of which 10% is considered released currently for possible intake.

(23) This value is chosen to limit direct exposure to 1/3 the 30 mrep/wk and allow for possible internal exposure. This is desirable to insure adequate safety to the young and those who may be pregnant.

(24) Estimated from Table H values. Basic limit for general plant area surfaces considering buildup, etc. This is related to "total" contamination by a release factor.

(25) Estimated from Table H values weighted for probability of transfer and intake. Note the units.

(26) Includes tools, furniture, floors, tables, etc. in all areas of unrestricted access, such as offices, shops, corridors, etc., where no special precautions are taken due to work with active materials. For administrative and/or technical reasons zoning of certain areas may be desirable to exclude activity above background levels, or permit work with active materials under conditions of higher contamination levels. Such higher levels in the "hot" zones do not imply over conservativeness of the levels for general areas since other precautions are taken. No recommended values are given for such zoned areas as they will depend on the work in progress, etc., and should be set by the individual installation.

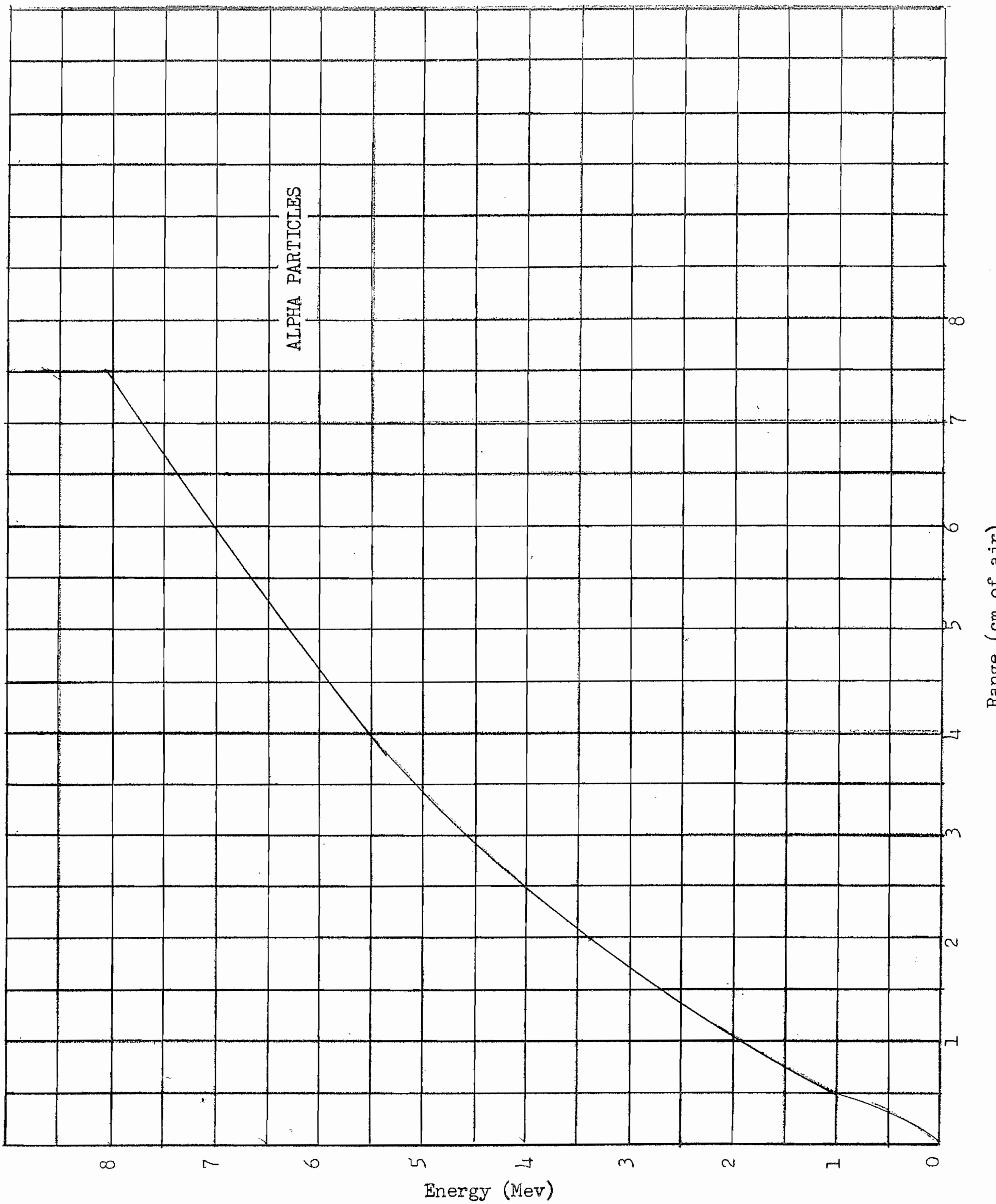


Figure 1

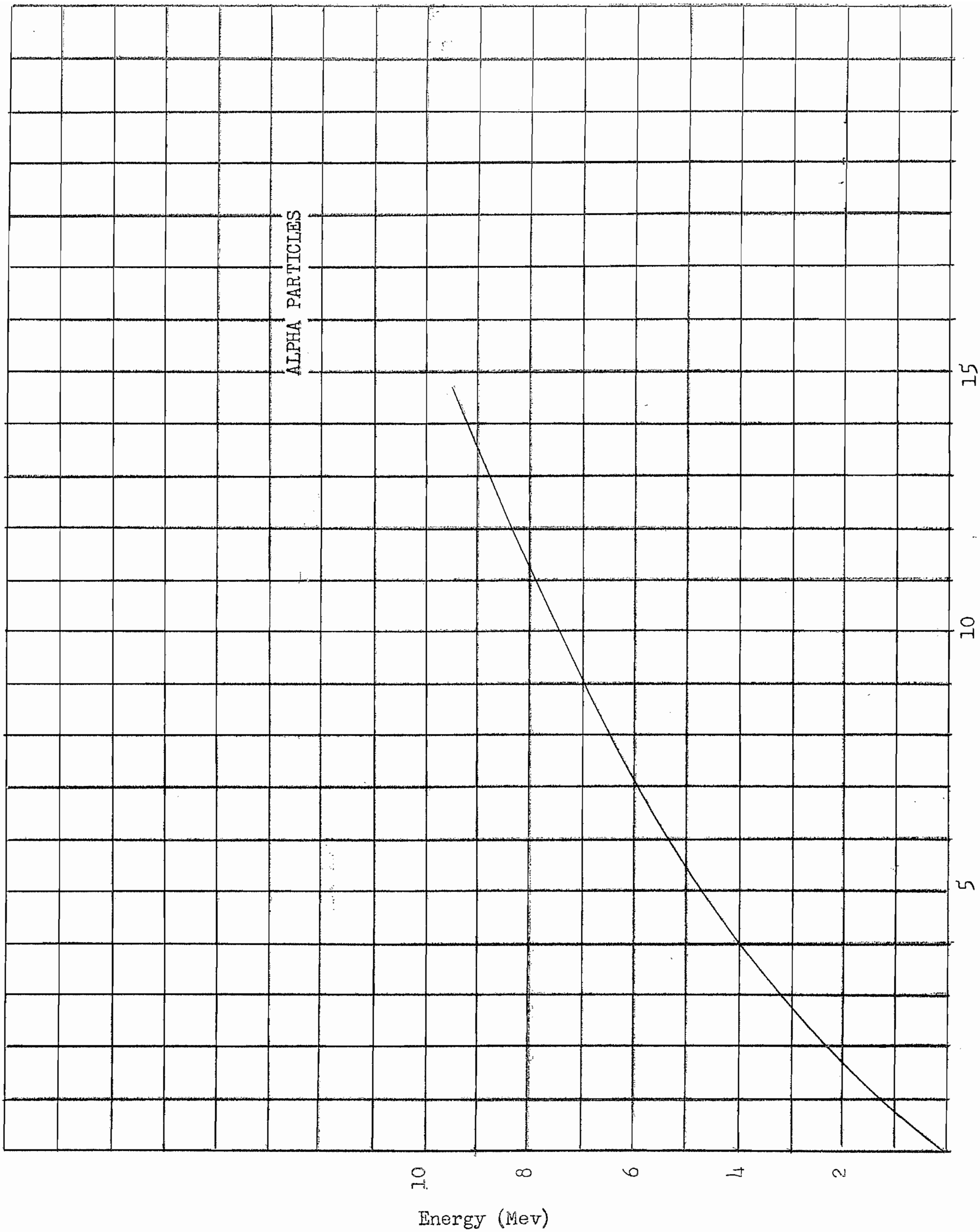


Figure 2

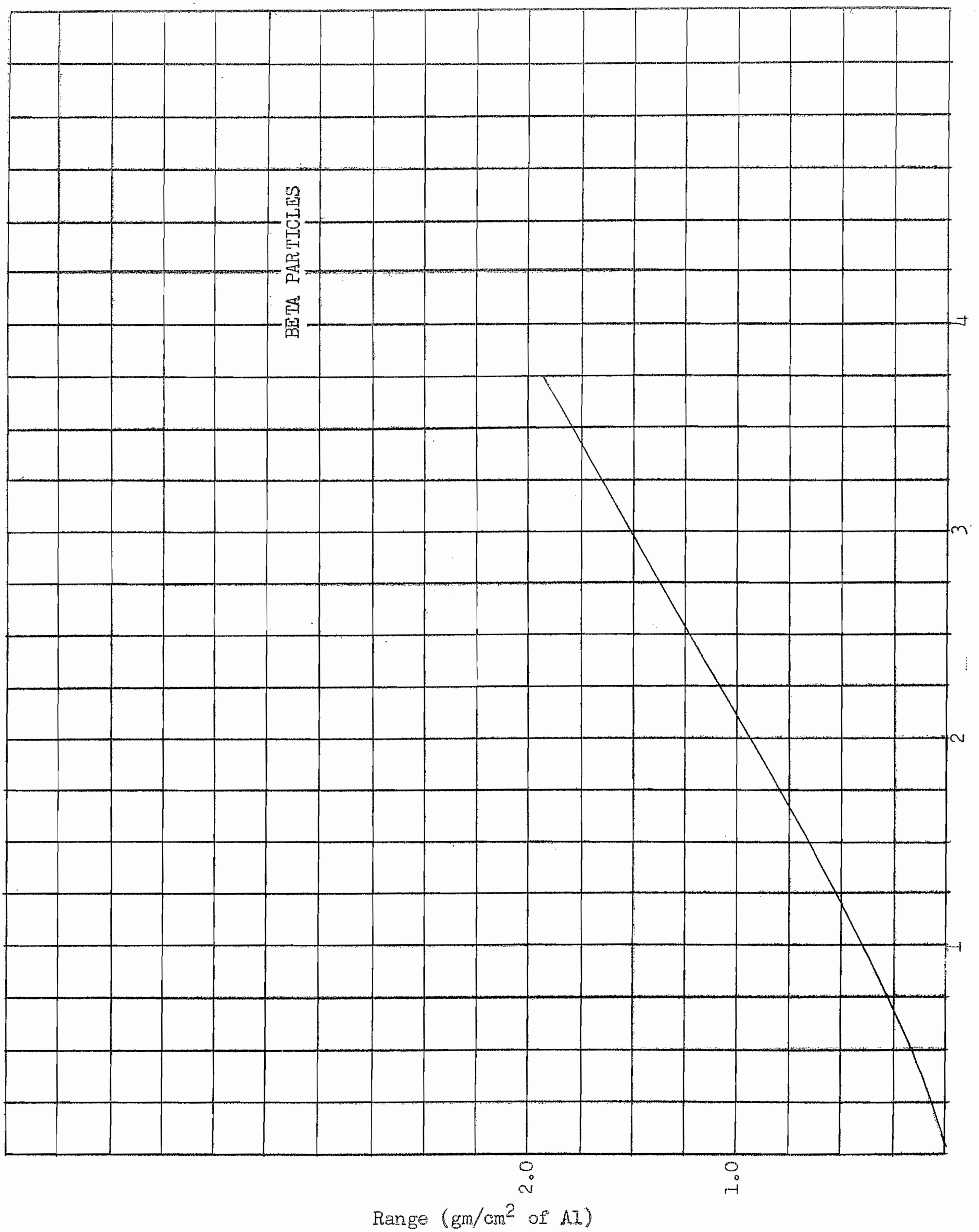


Figure 3

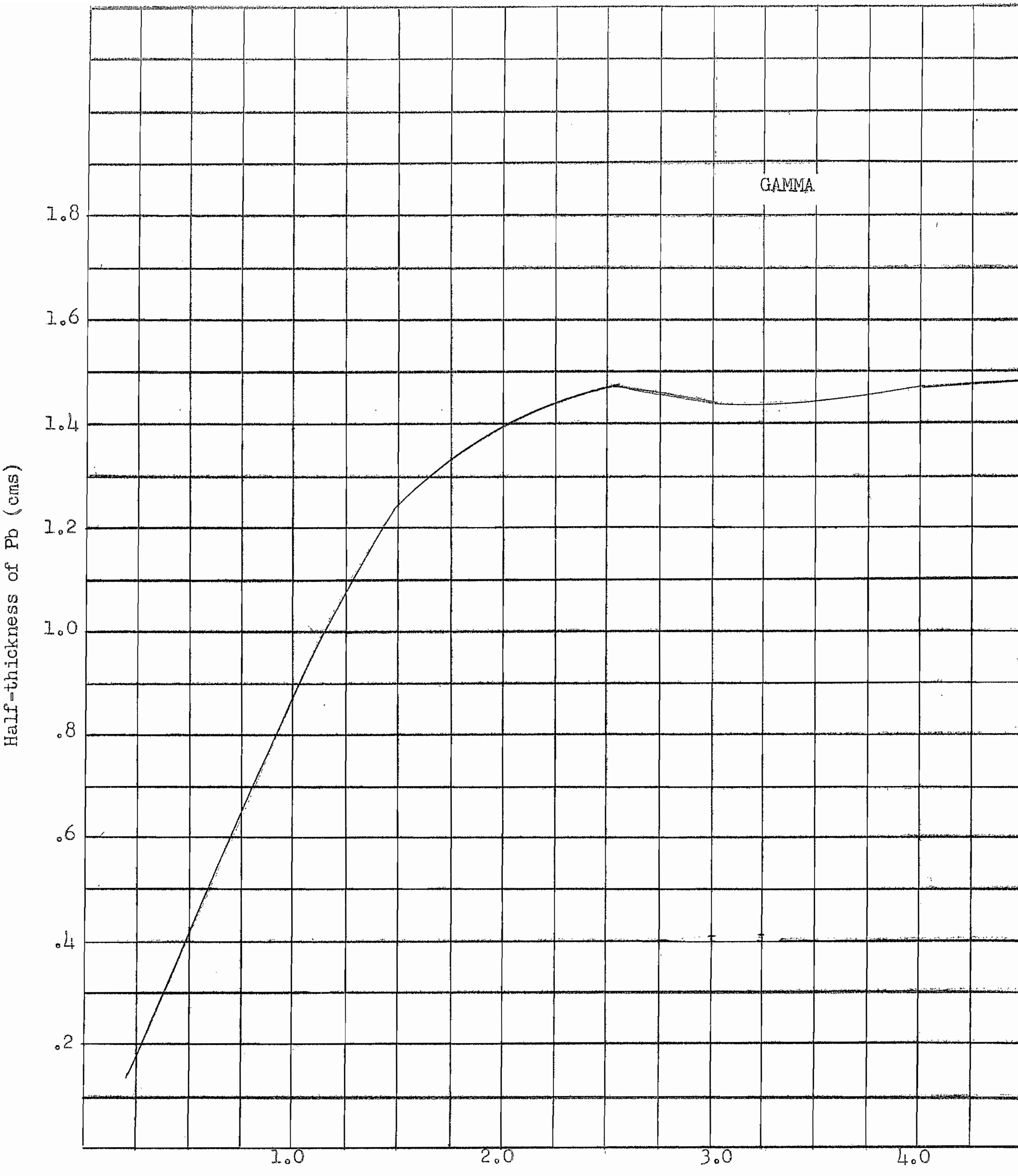

GAMMA
Half-thickness of Pb (cms)
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
1.0
2.0
3.0
4.0
Energy (Mev)

Figure 4

SECTION III

Section III -

Sources, Procedures, Calibration Devices

I. Gamma Sources

A. 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 years, 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 one gram of Radium. This definition has been extended such that a curie of any radioactive material is that quantity which has a disintegration rate of 3.7×10^{10} dis/sec, since this is the recommended value of the disintegration rate of one gram of radium.

4. The gamma radiation from a radium source is almost entirely from its equilibrium products, Ra B and Ra C. The gamma ray spectrum of radium and its equilibrium decay products is shown approximately in the following table:

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	

The effective average energy of the filtered radiation is approximately 0.7 Mev.

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

$$Ra^{226}(1590\ yrs) \xrightarrow{\alpha} Rn^{222}(3.825\ d) \xrightarrow{\alpha} \underset{(Ra\ A)}{Po^{218}}(3.05\ m) \xrightarrow{\alpha}$$

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

$$\underset{(Ra\ D)}{Pb^{210}}(22\ yrs) \xrightarrow{\beta} \underset{(Ra\ E)}{Bi^{210}}(5\ d) \xrightarrow{\beta} \underset{(Ra\ F)}{Po^{210}}(140\ d) \xrightarrow{\alpha} \underset{(Ra\ G)}{Pb^{206}}(Stable)$$

It may be noted that the transitions of interest in gamma ray production 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, for attenuation 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 a "half-value layer".

7. Radium sources are most commonly radium salt solutions in glass ampules or 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 U. S. Bureau of Standards or by the Canadian National Research Laboratories. A sample of a report supplied is shown in Fig. 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 instrument for measuring the radiation, and the geometry all being the same.

10. The equivalent value in milligrams of radium, named in the body of the report, 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 order to apply the formulae 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 end of the report. 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 formulae:

(1) $R = \frac{9.3\, M\, e^{-ux}}{d^2}$, where

R = roentgens per hour.
u = 1.9 cm^{-1} for platinum. Varies with atomic number.
x = Platinum wall thickness in cm.
d = distance from source in cm.

or

(2) $mr/hr = \frac{K\, M}{d^2}$, where

d = distance from source in cm.
K = factor as follows:

Material of Source Container	Thickness in mm	K
Platinum	0.2	8900
"	0.5	8400
"	1.0	7800
Monel	1.0	8800
"	1.5	8500

Formula (2) is more flexible for calibration purposes.

13. At the ORNL Health Physics Calibration Unit all standard sources used for gamma calibration are of the radium salt in Platinum-Iridium (10%) or Monel cylinders. These have been placed in an additional cylinder of aluminum which has a wall thickness of 1/8 inch. To facilitate handling, by means of an electromagnet, thin inserts of iron have been placed in the ends of these cylinders.

14. In order to prepare information for calibration purposes,

a. Increase the value named in the body of the report by the amount designated in the note at the end of the report.

b. Calculate the dosage rate, using formula (2) preceding, at each of at least three convenient distances.

c. If the radium source is enclosed in an additional container, reduce the dosage rates obtained in b. by the percent attenuation of the cylinder. (The 1/8 inch wall aluminum cylinder has an attenuation, through the side wall, of approximately 4% for sources contained in 0.5 or 1 mm of platinum, or 1 or 1.5 mm of monel.)

d. Plot a curve, which should be a straight line, on log log paper of mr/hr vs. cm.

15. EXAMPLE:

a. Refer to Fig. 1 to obtain corrected value of M:

$$M = 9.78 \text{ mg} - \frac{1.5}{100}(9.78 \text{ mg}) = 9.78 - 0.147 = 9.93 \text{ mg Ra.}$$

b. Calculate the dosage rate at 10, 30, and 100 cm., using formula (2).

Note that the source, E-859, is contained in a platinum cell of wall thickness 0.2 mm. K for this wall is 8900.

(1) At 10 cm,

$$\text{mr/hr} = \frac{(8900)(9.93)}{10^2} = 884 \text{ mr/hr}$$

(2) At 30 cm,

$$\text{mr/hr} = \frac{(8900)(9.93)}{30^2} = 98.3 \text{ mr/hr}$$

(3) At 100 cm,

$$\text{mr/hr} = \frac{(8900)(9.93)}{100^2} = 8.84 \text{ mr/hr}$$

c. Plot the values as indicated in Fig. 2.

16. Any discussion of radium should include an admonishment with regard to the serious hazards to health and property if the source material should leak or spill from the container. Every precaution should be taken in order to reduce breakage of and leakage from the container.

The 1/8 inch wall thickness aluminum cylinder is employed to reduce the potential hazards due to leakage.

Surgical cotton is placed in close proximity with each radium source once each week for a period of at least 24 hours, then removed and placed near a G-M counter. If any radon has leaked from the source, a significant count will be obtained due to absorption by the cotton of the radon.

Special precautionary measures are taken where conditions warranting them exist.

B. Artificially Produced Radioisotopes

1. Source Material

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

a. A relatively long half-life, so that too frequent decay corrections are not necessary.

b. Photon energies within the range 0.1 to 2 Mev, so that simplified calculations may be used.

c. A simple, accurately known decay scheme.

d. High specific activity. This permits sources of small physical dimensions.

e. Relatively short activation time in available fluxes. This increases availability and reduces cost.

2. Source Production

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

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

a. The amount of the stable isotope (target material) present before irradiation.

b. The density of the activating flux.

c. The time exposed to the activating flux.

d. The activation cross section of the target material.

e. The amount of contaminant present in the target material, either as chemically compounded or as impurity. These may greatly decrease the effective activation cross section by "soaking up" neutrons which might otherwise activate the target material.

f. 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. Thus, for a target irradiated in a neutron flux there may be very few of the total atoms which are radioactive.

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

$$S = \frac{1.64\,\sigma F}{10^{11}\,A}\left(1 - e^{-0.693t/T}\right), \text{ where}$$

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

After irradiation for approximately six 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 formula may be used:

$$S = \frac{1.136\,\sigma F t}{10^{11}\,AT}$$ where the units are the same as above.

3. Dosage Rate Determinations

a. Geometry considerations which apply to radium sources, apply also to other gamma ray sources.

b. By neglecting scattering, shielding, and self-absorption, the dosage rate produced by gamma rays from a point source may be estimated by calculation.

c. For gamma ray energies between 0.1 and 2 Mev the air absorption coefficient is approximately 3.5×10^{-5} cm^{-1}. Therefore within this range of energies the dosage rate is directly proportional to the curie content of the source and to the total gamma ray energy per disintegration.

The formula for this approximation,

$$R_f = 6CE,$$

is derived as follows:[1]

Let d = distance in centimeters
F = gamma flux in photons/cm^2-sec
K = fraction of incident energy absorbed per cm in air (the absorption coefficient)

---

[1] Morgan, G. W., Some Practical Considerations in Radiation Shielding, USAEC, Isotopes Div., 1948

The gamma flux in photons/cm^2-sec is

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

The energy absorbed per cm^3 =

KFE

K is a function of E. In the range from 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 one esu is 2.08×10^9.

Collecting these values the dosage rate, in roentgens per hour, is:

$$R_f = \frac{3.5 \times 10^{-5} \text{ cm}^{-1} \times 3.7 \times 10^{10} \text{ dis/sec-curie} \times 10^6 \text{ ev/Mev} \times 3600 \text{ sec/hr} \times CE}{32.5 \text{ ev/ion pr.} \times 2.08 \times 10^9 \text{ ion pr. per cm}^3/R \times 4\pi \times 929 \text{ cm}^2/\text{ft}^2}$$

R_f = 6CE, where

R_f = Roentgens per hour at a distance of one foot.
C = Curie content of the source.
E = Total gamma ray energy per disintegration, in Mev.

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

R_m = 0.56CE, where

R_m = Roentgens per hour at one meter.
C and E are the same as above.

d. Applications of these formulae are:

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

(a) Refer to Fig. 3, the decay scheme of Co^{60}, where it is indicated that for each disintegration of Co^{60} there are emitted two gamma rays of 1.1 and 1.3 Mev respectively.

(b) Apply the formula

R_m = 0.56 CE where

C = 1 curie
E = (1.1 + 1.3) and
R_m = (0.56)(1)(2.4) = 1.3 Roentgens/hr @ 1 meter

(2) To determine the gamma dose rate at a distance of one foot from a 2.6 curie Au^{198} source:

(a) Refer to Fig. 4, the decay scheme of Au^{198}. 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

$R_f = 6\ (2.6)(0.41 + 0.024 + 0.0315)$

$R_f = 6\ (2.6)(0.466)$

$R_f = 7.3$ Roentgens per hour at one foot.

e. If the curie content of the source is not known, or if the attenuation of the source container or other shielding agent is not known, the dosage rate may be determined by comparison with a standard source under "open air" conditions.

4. Dosage rates at any distance may be calculated if the dosage rate at some one distance is known, and if the proper geometric conditions are involved.

a. The rule used to calculate the dosage rates is referred to as the "inverse square law", and is written

$$\frac{R_1}{R_2} = \frac{d_2^2}{d_1^2}, \text{ where}$$

R_1 and R_2 are the dosage rates at distances d_1 and d_2, respectively.

b. The inverse square law is derived from

(1) $R_1 = k\ F/4\pi d^2$, and

(2) $R_2 = k\ F/4\pi d^2$, where

F = the total photon flux from the source
k = a constant (for a given source) involving the energy removed per cm of path of the photons.

Dividing (1) by (2) one obtains,

$$\frac{R_1}{R_2} = \frac{\dfrac{kF}{4\pi d_1^2}}{\dfrac{kF}{4\pi d_2^2}} = \frac{\dfrac{1}{d_1^2}}{\dfrac{1}{d_2^2}} = \frac{d_2^2}{d_1^2}$$

c. The inverse square law applies, if R involves 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.

d. A straight line curve of dose rate vs. distance from the source may be plotted on log, log paper.

(1) Calculate or measure the dosage rate at one distance from the source.

(2) Calculate the dosage rate at a second convenient distance.

(3) Plot a curve as shown in Fig. 2.

5. The half-life of the radioactive element must be taken into account when the source is used after the initial curie content determination.

The radiation from a radioisotope at a fixed distance varies with time as follows.

$$R = R_o e^{-\lambda t} = R_o e^{-\frac{0.693t}{T}}, \text{ where}$$

R = dose rate at time t
R_o = initial dose rate
t = time since initial dose rate determination
λ = decay constant, in same units as t
T = half-life, in same units as t

A 2% reduction in dose rate is obtained when t = 1/35 of T; Thus there is a 2% reduction in the dose rate from:

a. Radium in $^{1600}/_{35} \approx 46$ yrs

b. Co^{60} in $^{60}/_{35} \approx$ 2 months

c. Au^{198} in $^{2.7 \times 24}/_{35} \approx$ 2 hours

A curve of % intensity vs. time may be plotted as a straight line on semi-log paper by letting the slope equal 50% over one half-life. Fig. 5 is a half-life curve for Co^{60}.

II. Beta Sources

A. Normal uranium is the only material used as a source of beta particles for dose rate calibration.

1. The beta dose rate at the surface of an infinite slab of uranium is 240 mrep/hr.[2] In practice, this dose rate is obtained if the uranium slab is at least 1/8 inch thick and has an area which extends beyond the area being exposed.

2. The following approximate dose rates are obtained also at the surface of uranium.[2]

a. 140 acre per hour due to alpha particles

b. 3 mr/hr due to gamma rays

c. 15 macre/hr due to secondary electrons

d. 12 mr/hr due to Bremsstrahlung.

3. The uranium slab or sheet should be used only in such a manner that the exposure is measured at the surface of the uranium. These conditions imply that only measuring devices of zero thickness and of surface area small with respect to the uranium surface area be used.

4. The above conditions may be closely approximated if the exposed device is a photographic emulsion. The normally present opaque covering of the emulsion will exclude the alpha particles and most of the secondary electrons.

B. Beta emitting isotopes may be used for calibration applications if:

1. Absolute dose rate involving the beta emitter as a primary standard is used.

2. The source and the indicating device have the same geometry in all cases.

3. The beta emitter is used as a secondary standard.

4. The radioactive decay rate is taken into account.

---

[2] Morgan, K. Z., Health Control and Nuclear Research, (Pre-publication copy)

III. Alpha Sources

A. Alpha sources are prepared by electroplating an alpha particle emitting metal, usually uranium or plutonium, onto a disc of silver or platinum.

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

IV. Neutron Sources

A. Neutron sources may be:

1. Polonium-Beryllium

2. Radium-Beryllium

3. Polonium-Boron

4. Other

The first three emit neutrons due to nuclear reactions between the beryllium or boron and the alpha particles emitted by the polonium or radium.

B. The source activity, in terms of total neutron flux, is usually given in information accompanying the source. If such information is not available, a comparison with a source of known activity may be performed.

C. The principal radiation from neutron sources consists of fast, intermediate and thermal neutrons, and gamma rays - particularly in the cases where radium is the source of the alpha particles. In calibration, allowance should be made for this gamma radiation. Shielding must be provided, also, for gamma as well as neutron radiation.

D. Fast neutron fluxes may be determined from the source activity data as follows:

$$N_f/cm^2\text{-sec} = N(\text{total flux})/4\pi r^2, \text{ where}$$

r is the distance at which the flux is to be determined.

E. Fast neutron dosage rates are a non-linear function of the energies of the fast neutrons, but, in most cases, using the first three sources named above, the following may be used:

$$50\ N_f/cm^2\text{-sec} = 0.75\ \text{mrep/hr} = 7.5\ \text{mrem/hr}.$$

F. Thermal neutrons may be obtained by placing the neutron source within a layer of apraffin.

1. If the neutron source has small physical dimensions, it may best be placed at the center of a cylinder of paraffin such that the wall and end thicknesses of paraffin are 4 inches, i.e., such that the source is surrounded by a minimum of 4" of paraffin. If the paraffin thickness is much less than 4 inches, the ratio of thermal to fast neutrons decreases. If the paraffin thickness is increased beyond 4 inches, there is no increase in the thermal to fast neutron ratio.

2. By means of the Indium Foil method outlined below, it has been determined that 4 inches of paraffin thermalizes the fast flux such that the thermal flux, at any point within a range of 2 meters from the source, is 40% ± 3% of the fast flux which would be obtained if the paraffin were removed.

3. The following is a method for determining the thermal neutron flux in an unknown field by use of indium foils and the ORNL standard pile.

a. Expose a bare indium foil to the unknown flux of thermal neutrons for a short time and determine the saturated activity due to all neutrons in flux by the following formula:

$$A_S = \frac{\lambda}{(1-n)\ n\ (1-n)} \times t_c =$$ the maximum activity which may be induced in the foil by all neutrons in the flux.

λ = indium decay factor (0.012836)

1-n = exposure time factor

n = factor for time between exposure and count

1-n = count time factor

t_c = total counts of foil

b. Expose a Cd (cadmium) covered (30 mil Cd) indium foil to the unknown flux of thermal neutrons for a short time and determine the saturated activity by above formula:

c. Determine the Cd ratio:

$$\text{Cd ratio} = \frac{\text{saturated activity of bare foil}}{\text{saturated activity of Cd covered foil}}$$

d. Determine the saturated activity due to thermal neutrons (A_{th}) by the following formula:

A_{th} = saturated activity of bare foil x $\left(1 - \frac{1.14}{\text{Cd ratio}}\right)$

1.14 is the factor for 30 mil Cd.

The factor for 20 mil Cd is 1.10.

The factor for 40 mil Cd is 1.17.

e. Place a bare foil in the standard pile and determine the K factor:

K factor $= \frac{nv}{A_{th}}$

nv for third slot in the ORNL standard pile is 9210 $n_{th}/cm^2/sec$.

Cd ratio for the third slot is 9.32.

Data for other slots may be obtained.

f. Neutron flux in the unknown field is equal to the saturated activity due to thermal neutrons multiplied by the K factor determined from the standard pile.

Example:

Foil #1 - Cd covered foil:

Exposed to thermals for 5 minutes

Waited 3 minutes before starting count

Counted for 8 minutes

Total count was 608 counts

$$A_s = \frac{.012836}{.06216 \times .96222 \times .09759} \times 608 = 1,337$$

Foil #2 - bare foil:

Exposed to thermals for 5 minutes

Waited 12 minutes before starting count

Counted for 11 minutes

Total count was 2400 counts

$$A_s = \frac{.012836}{.06216 \times .85724 \times .13168} \times 2400 = 4392$$

$$\text{Cd ratio} = \frac{4392}{1337} = 3.28$$

$$A_{th} = 4392\ (1 - \frac{1.14}{3.28}) = 2825$$

Foil from standard pile:

Exposed for 6 minutes

Waited 12 minutes to start count

Counted for 6 minutes

Total count was 14,369

$$A_s = \frac{.012836}{.07413 \times .85724 \times .07413} \times 14,369 = 3.92 \times 10^4$$

$$A_{th} = 3.92 \times 10^4\ (1 - \frac{1.14}{9.32}) = 3.44 \times 10^4$$

$$K = \frac{9910}{3.44 \times 10^4} = 0.268$$

Neutron flux in unknown field =

2825 x .268 = 756 $n/cm^2/sec$.

Indium Foil Half Life = 54 minutes = .012836

T (minutes)	n	1-n	T (minutes)	n	1-n
1	.08725	.02175	14	.83551	.16449
2	.97465	.02535	15	.82486	.17514
3	.96222	.03778	16	.84134	.18566
4	.94995	.05005	17	.80395	.19605
5	.93784	.06216	18	.79370	.20630
6	.92587	.07413	19	.78358	.21642
7	.91407	.08593	20	.77358	.22642
8	.90241	.09759	21	.76372	.23628
9	.89089	.10911	22	.75398	.24602
10	.87954	.12046	23	.74436	.25564
11	.86832	.13168	24	.73487	.26513
12	.85724	.14276	25	.72549	.27451
13	.84631	.15369			

G. The thermal neutron dosage rate is

$1750\ n_t/cm^2\text{-sec} = 1.5$ mrep/hr = 7.5 mrem/hr

H. For sources containing Polonium, which has a half-life of 140 days, it is convenient to provide a curve of per cent of initial flux vs. time in days. Such a curve would be similar to that shown in Fig. 5.

Form 301—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—45037-3

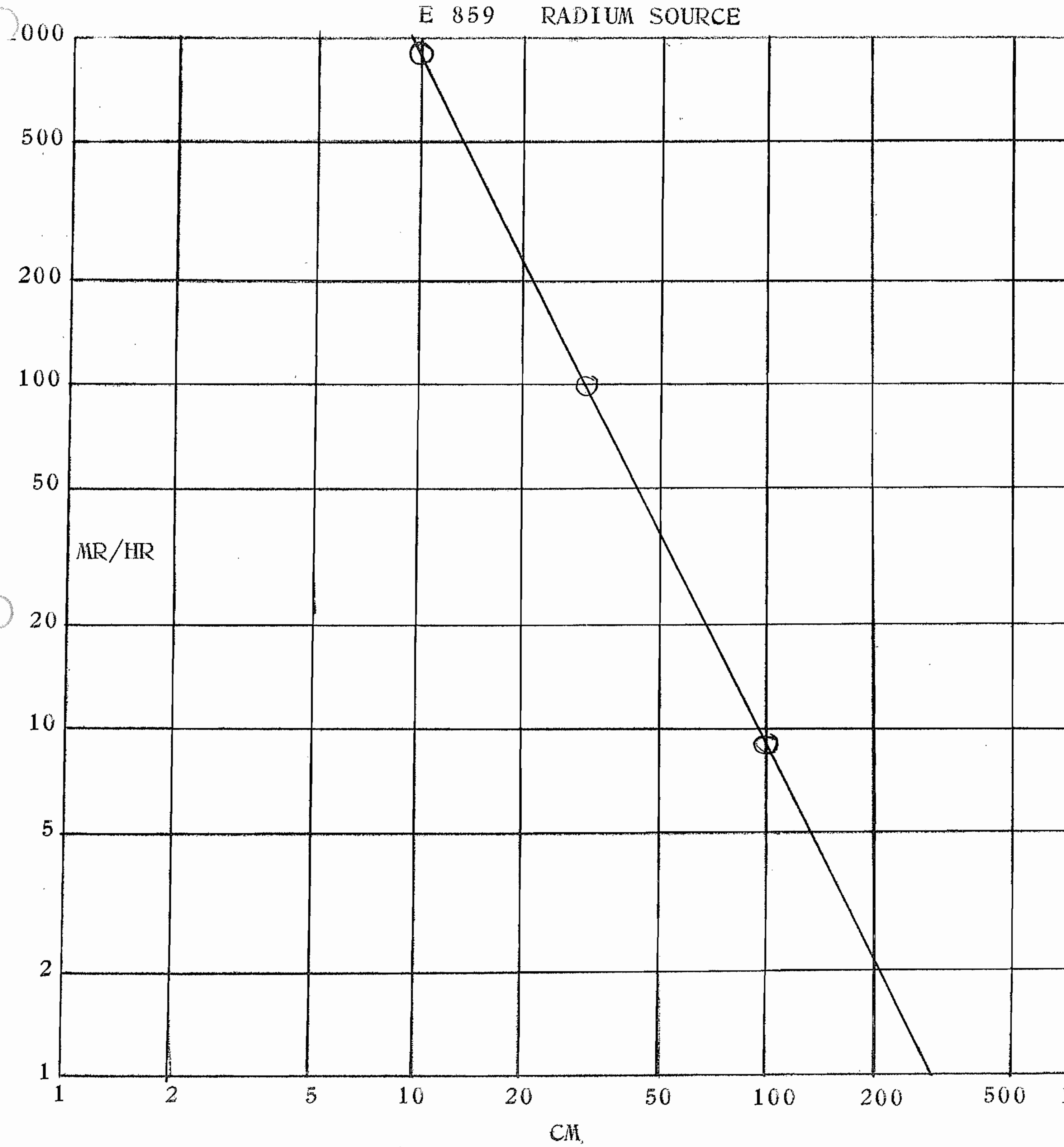

E 859 RADIUM SOURCE
1000
500
200
100
50
MR/HR
20
10
5
2
1
1
2
5
10
20
50
100
200
500
CM.

Figure 2

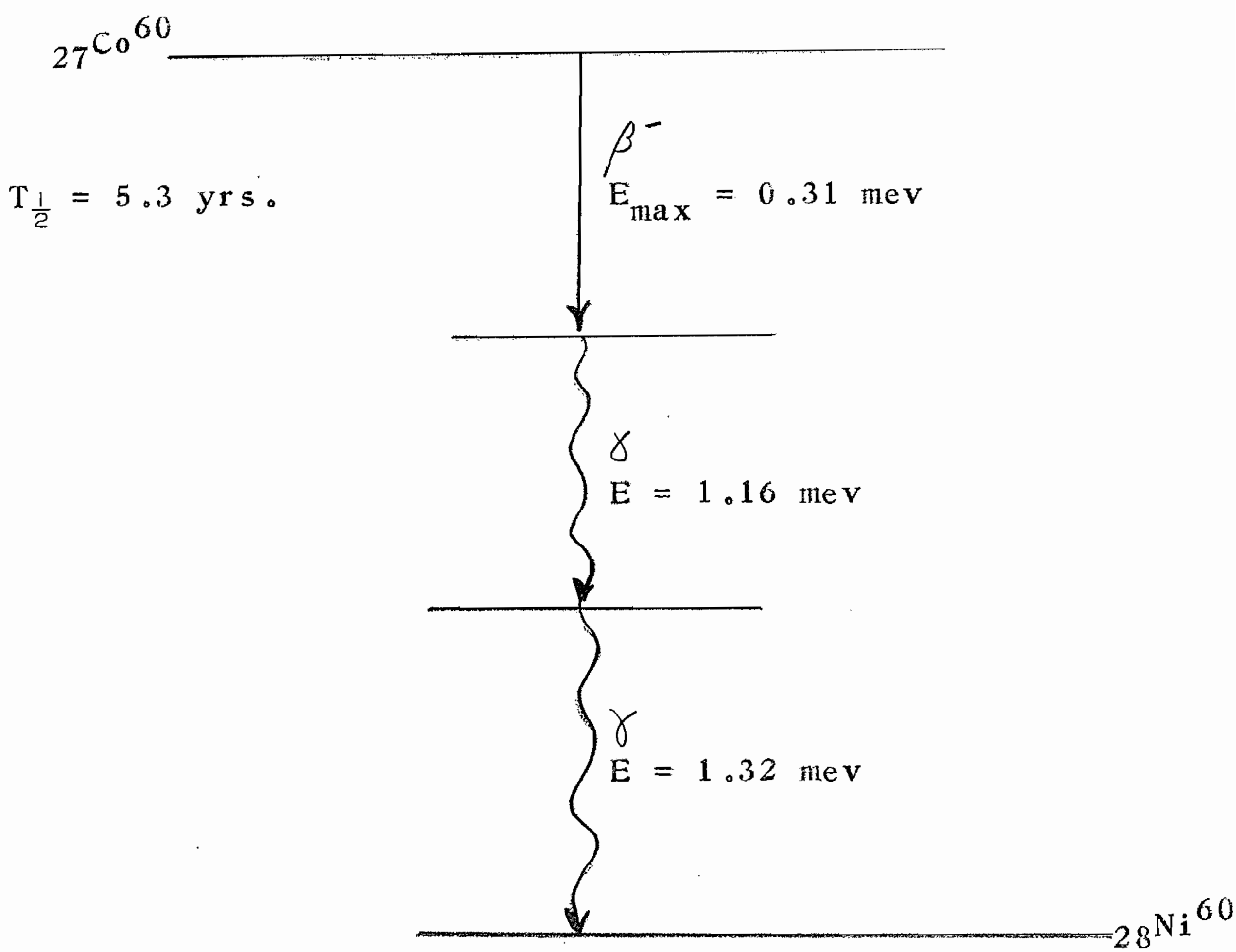


Figure 3

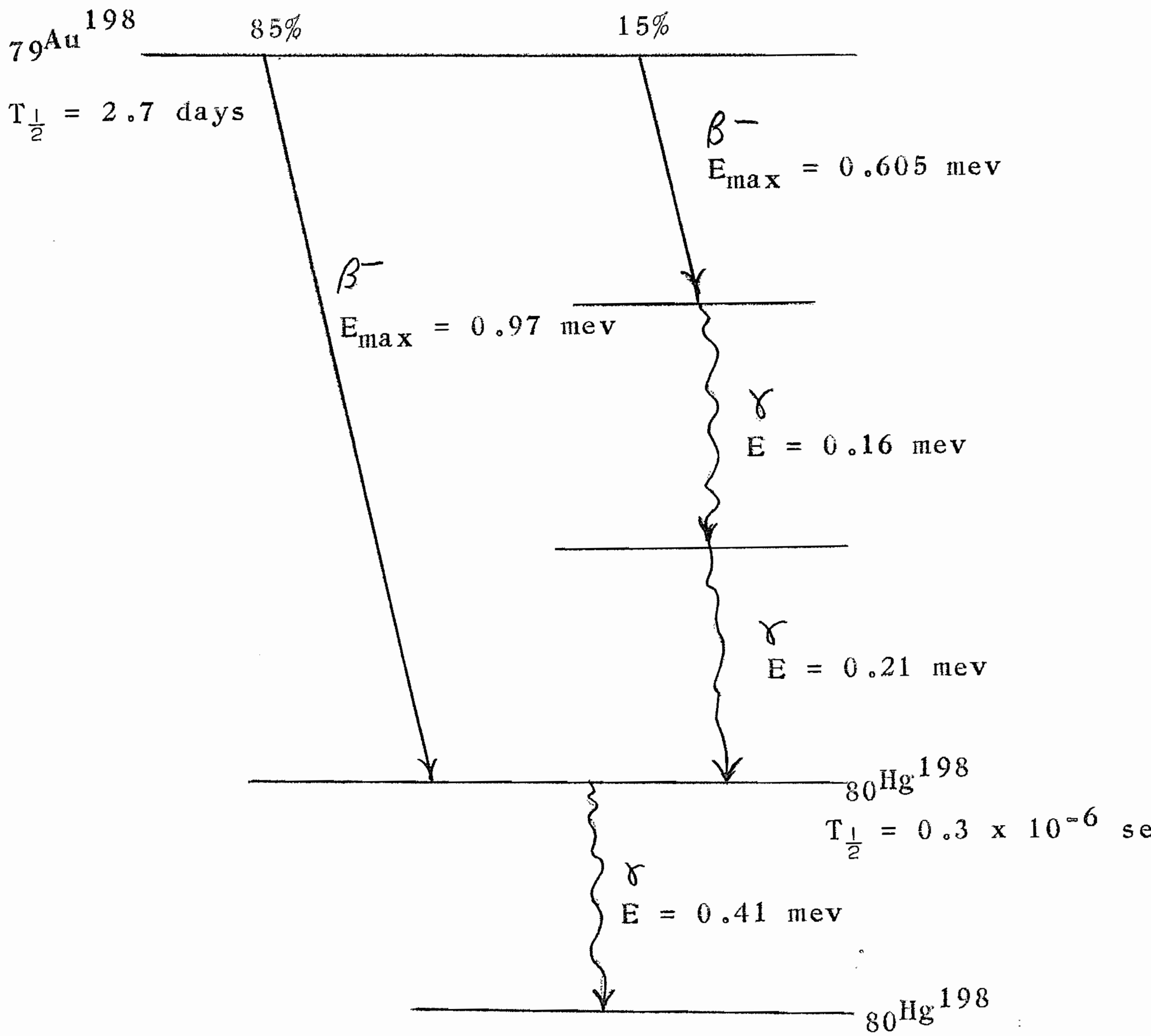

$_{79}Au^{198}$
85%
15%
$T_{\frac{1}{2}}$ = 2.7 days
β⁻
E_{max} = 0.605 mev
β⁻
E_{max} = 0.97 mev
γ
E = 0.16 mev
γ
E = 0.21 mev
$_{80}Hg^{198}$
$T_{\frac{1}{2}}$ = 0.3 x 10^{-6} se
γ
E = 0.41 mev
$_{80}Hg^{198}$

Figure 4

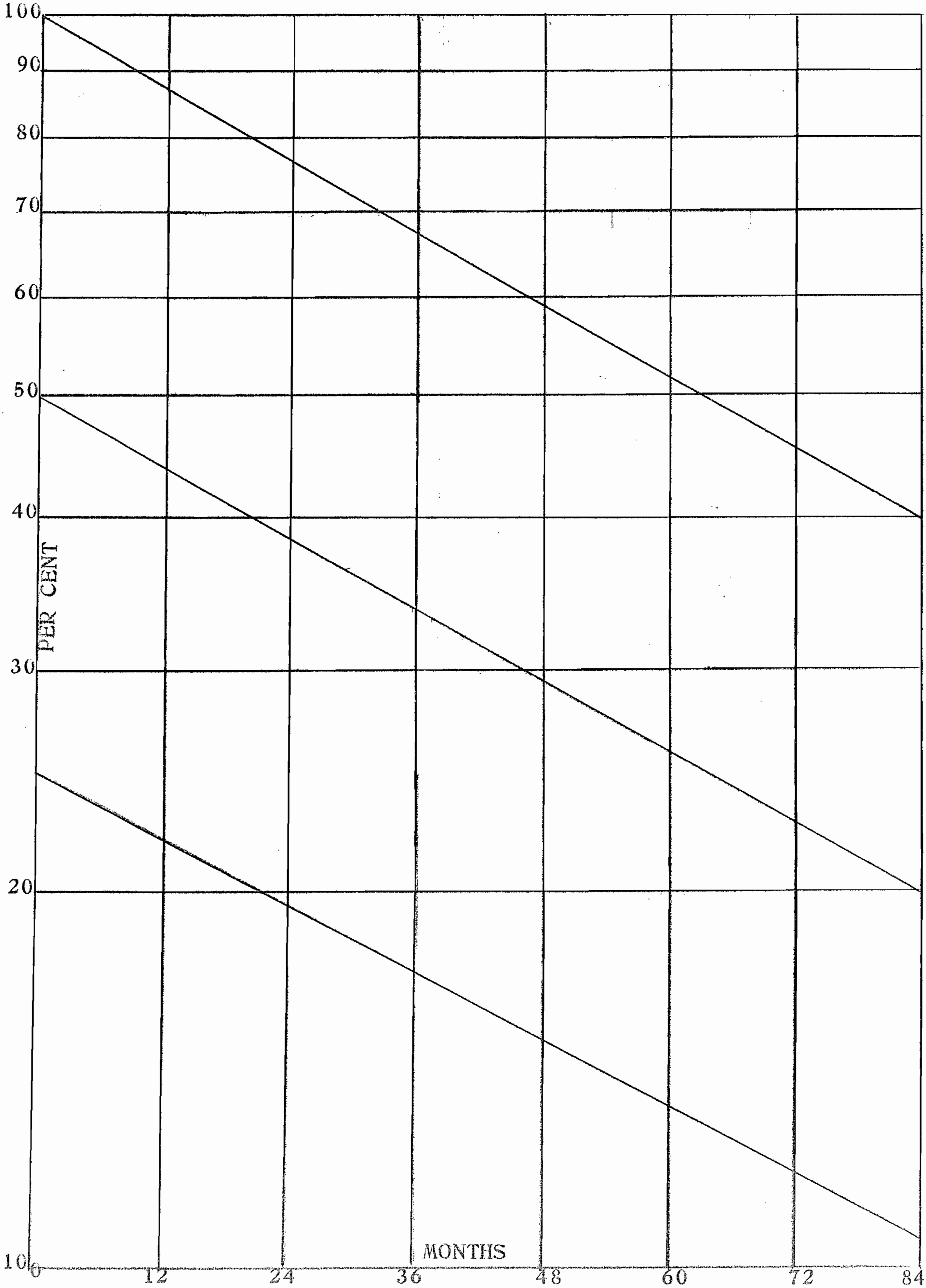


Figure 5

V. Special Sources

A. Hand-Foot Counter Sources

1. Hand Counter Source

Figure 6 is a photograph of a hand counter source.

The construction of the hand counter source is based on a tolerance value of 50 mrep/wk per square inch to an average hand of 21 sq.in., and a dose rate of 240 mrep/hr at the surface of normal uranium.

If one square inch of uranium gives a dose of 240 mrep in one hour to one square inch of a surface with which it is in contact, then

$$\frac{50}{240 \times 168}\left(\frac{\frac{\text{mrep}}{\text{wk} \times \text{in}^2}}{\frac{\text{mrep}}{\text{hr} \times \text{in}^2 \times \text{in}^2 \text{ of U}} \times \frac{\text{hr}}{\text{wk}}}\right) = 1.24 \times 10^{-3} \text{ in}^2 \text{ U}$$

$\therefore$ A dose of 50 mrep/week will be received by one square inch of area exposed to 1.24×10^{-3} square inches of U.

An area of 21 sq.in. will receive an average dose of 50 mrep/wk per square inch if exposed to 2.625×10^{-2} square inches of uranium.

Thus, an area of 0.02625 in^2 of U would give, at contact, tolerance dosage to the hand.

The hand counter sources expose an area of 0.02625 in^2 of normal U .020" thick.

2. Foot Counter Source

Figure 7 is a photograph of a foot counter source.

The foot counter source is constructed similarly to the hand counter source as follows:

a. Tolerance is taken as 0.6 mrep/hr = 100 mrep/wk.

b. The area of a shoe bottom is assumed to be 40 in^2.

c. The area of uranium exposed in each foot source is:

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

B. <u>CAM Source</u>

Figure 8 is a photograph of a CAM source.

The preparation of the source is based upon the following factors:

1. Collection for air containing 10^{-8} μc/cc of particulate beta-gamma activity.

2. A collection period of 30 minutes.

3. An air flow rate of 5 cu.ft./min.

4. A collection efficiency of 70%.

These factors may be used to obtain the following:

70% x 28,320 cc/cu.ft. x 5 cu.ft./min. x 30 min/sample x 10^{-8} μc/cc x 3.7×10^{-4} dis/sec - μc = 1108 dis/sec per sample.

The preparation of the source consists of adjusting the area of a portion of sheet uranium such that the counting rate when mounted within the plastic holder is equivalent to 1100 dis/sec.

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

C. <u>Laundry Monitor Source</u>

Figure 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, based on the following factors:

1. Area of source face = 100 in^2 (10 in x 10 in)

2. Tolerance value of 0.75 mrep/in^2 per 100 in^2.

3. Beta dosage rate at the surface of normal uranium = 240 mrep/hr per in^2.

   The area of uranium exposed is

$$\frac{75 \text{ mrep}}{240 \text{ mrep/in}^2} = .313 \text{ in}^2$$

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

VI. Device for Calibrating Monitoring Film with Beta Particles

Film packets are calibrated with beta particles from normal uranium. The uranium is machined into discs 1-1/8" in diameter and 1/8" thick. (The beta particle dosage rate at the surface of such a disc is 240 mrep/hr.) These discs are mounted in 40 recesses in an aluminum plate (Figure 10). The same absorbers as employed in the film badge meter are interposed between the uranium and the film packet.

A hinged bakelite cover plate and an automatically timed, solenoid operated latch are employed to release the film packets from the sources after the exposure period.

Operation (Figures 11, 12, and 13) steps are:

1. Set the timer for the exposure period.

2. Zero the elapsed time indicator.

3. Turn the plate upward and insert the film packets.

4. Close the cover and depress the push-button switch.

5. Rotate the plate assembly to the downward position.

When the exposure is completed, the film packets are released and slide downward into the drawer.

UNCLASSIFIED
ORNL #12042

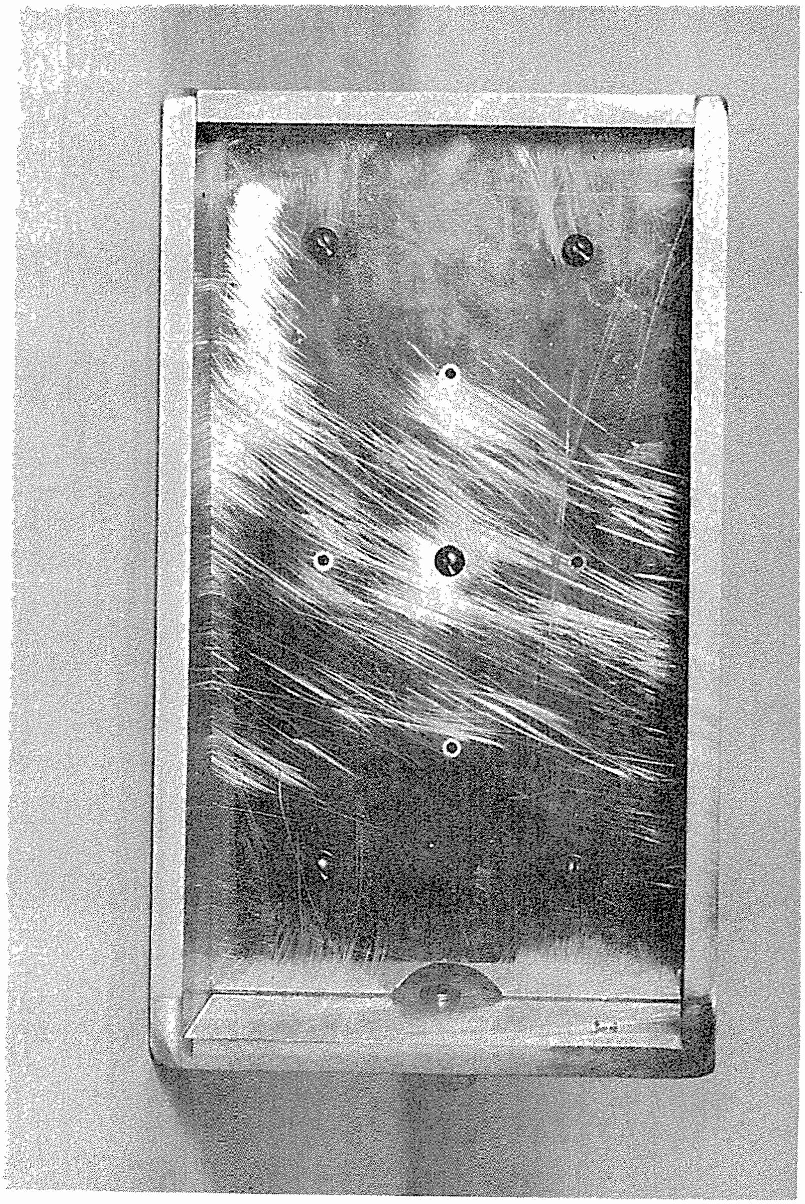


Figure 6

UNCLASSIFIED
ORNL #12043

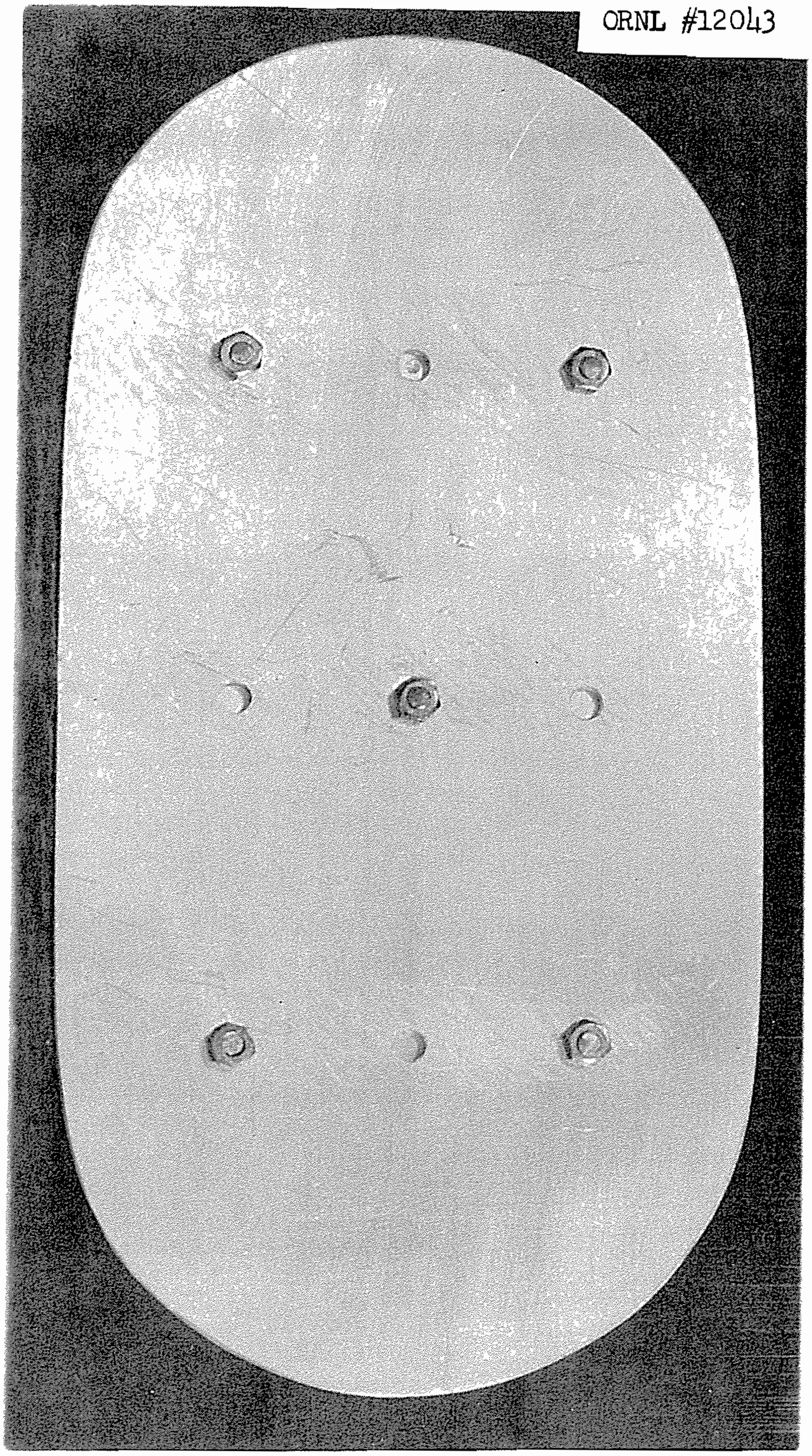


Figure 7

UNCLASSIFIED
ORNL #12045

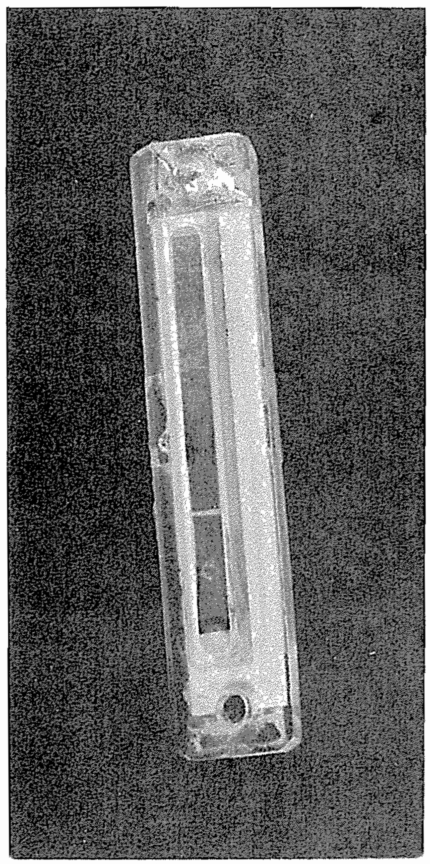


Figure 8

UNCLASSIFIED
ORNL #12037

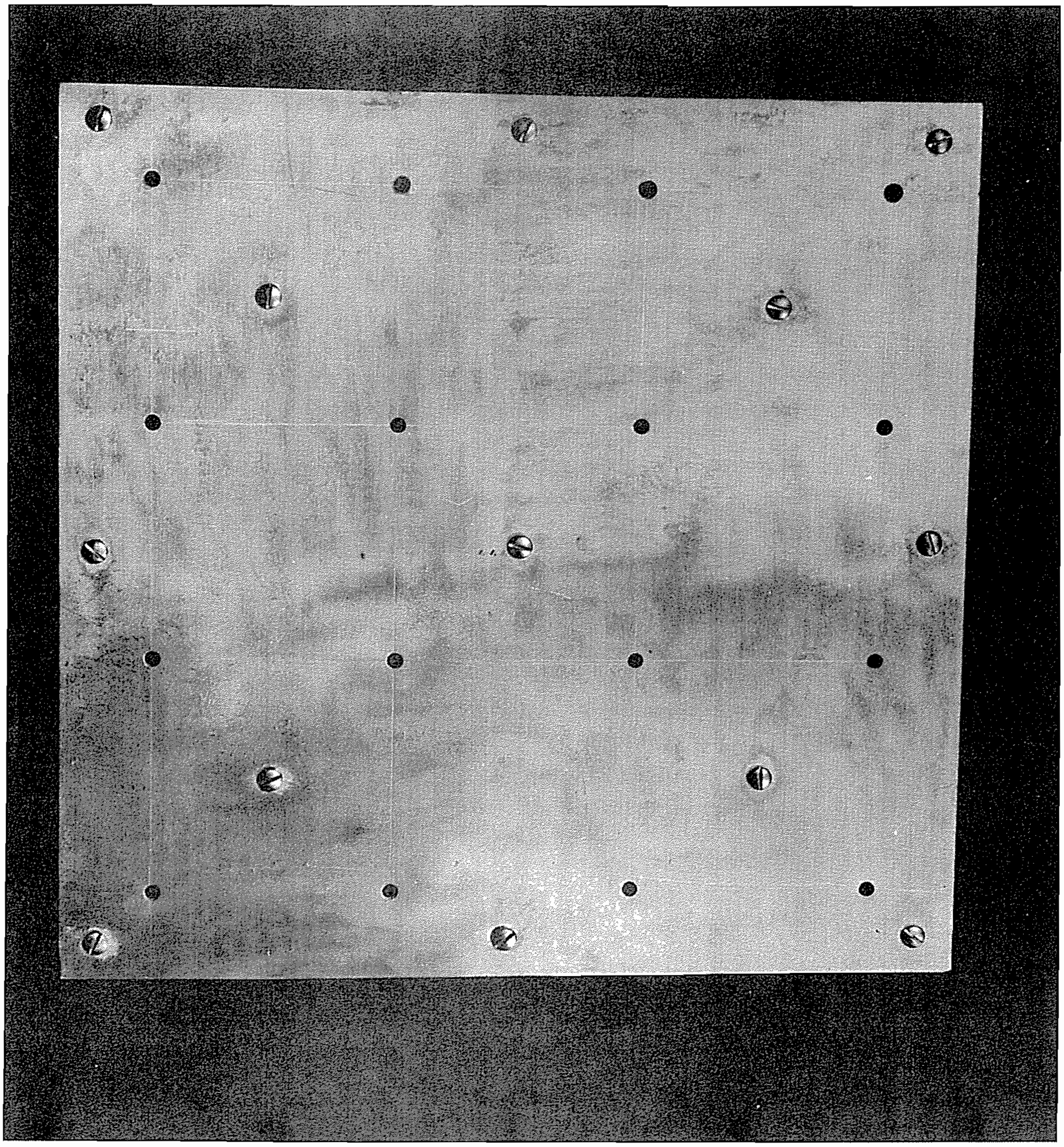


Figure 9

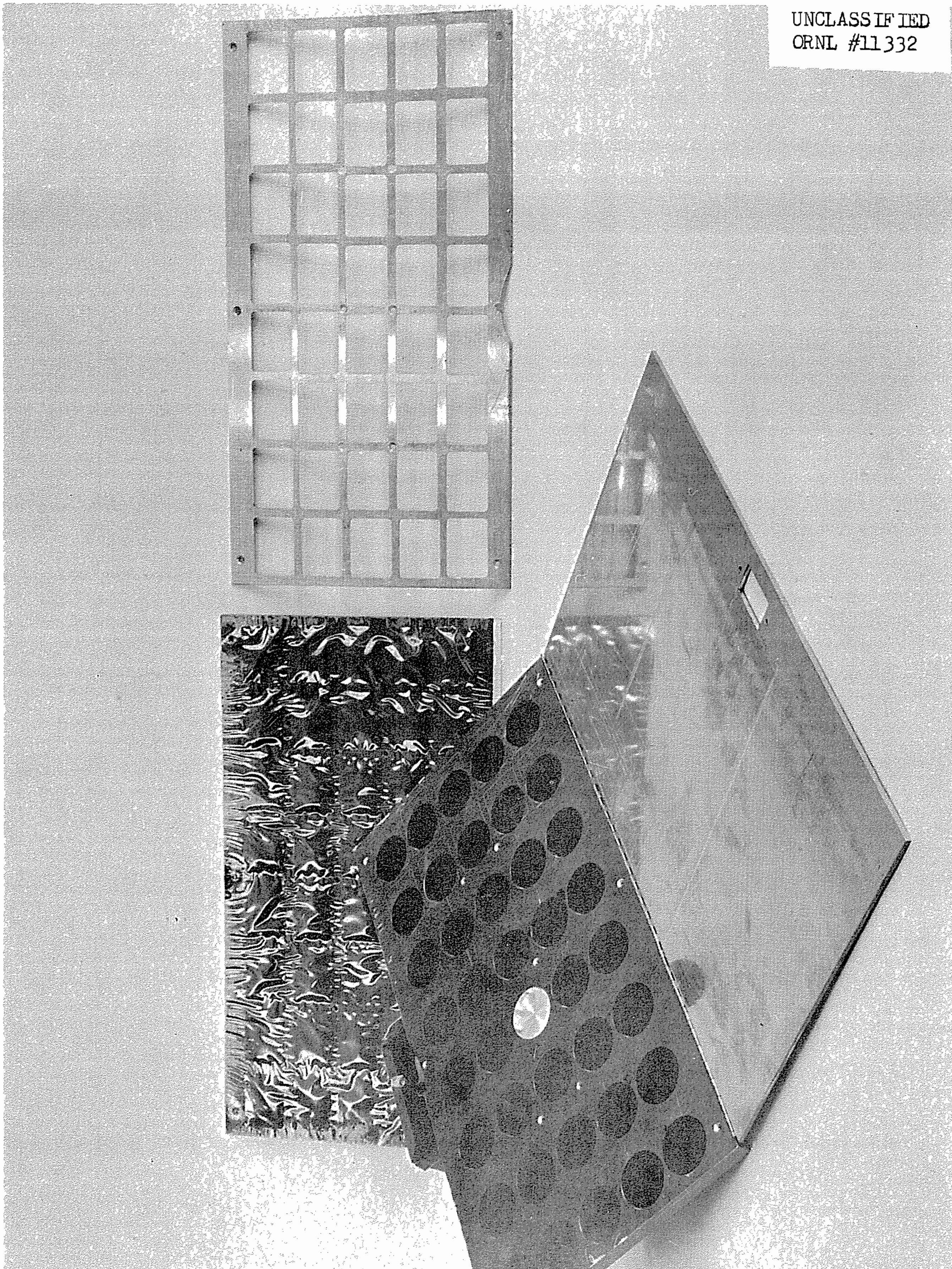


Figure 10

UNCLASSIFIED
ORNL #11331

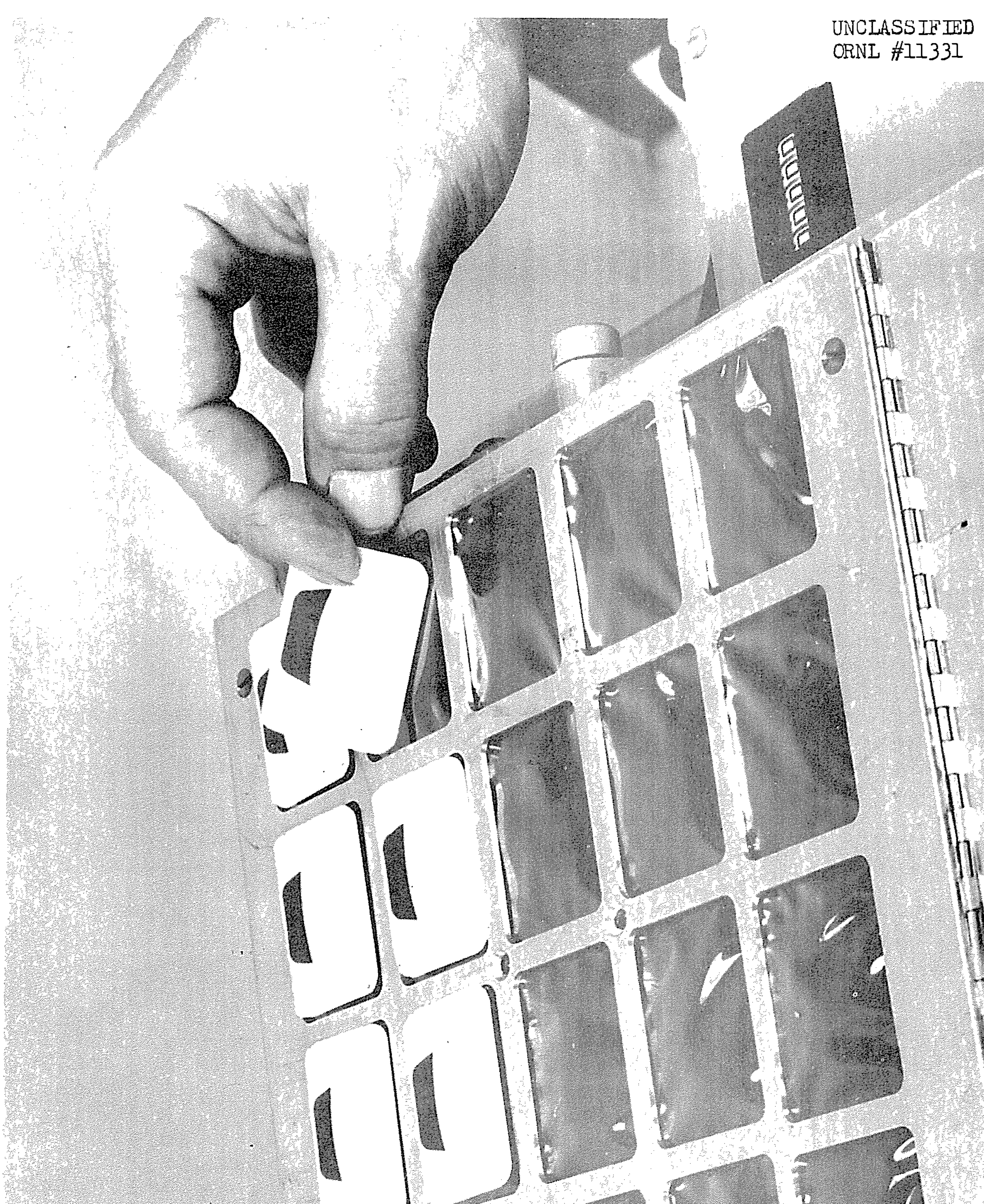


Figure 11

UNCLASSIFIED
ORNL #11333

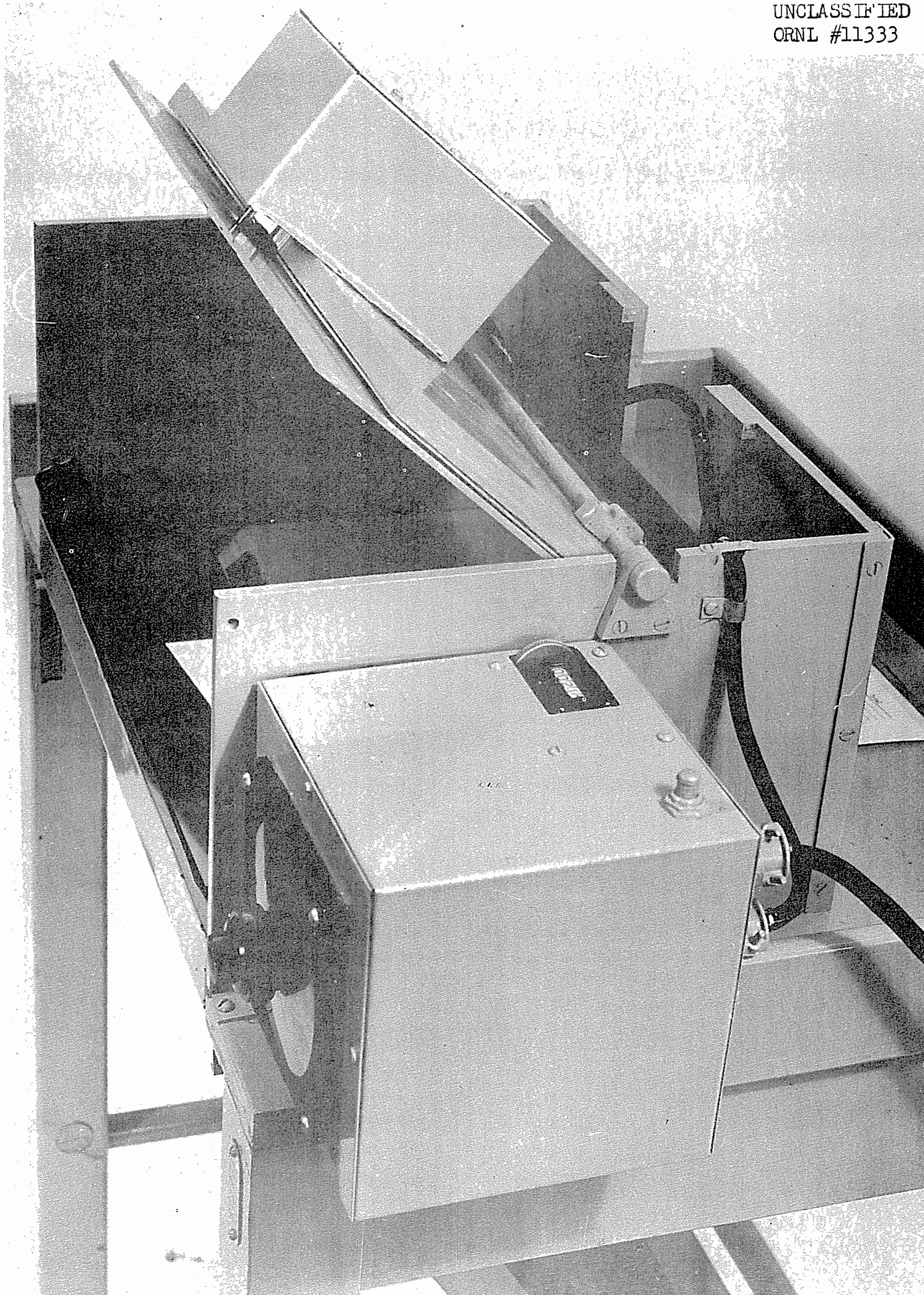


Figure 12

UNCLASSIFIED
ORNL #11329

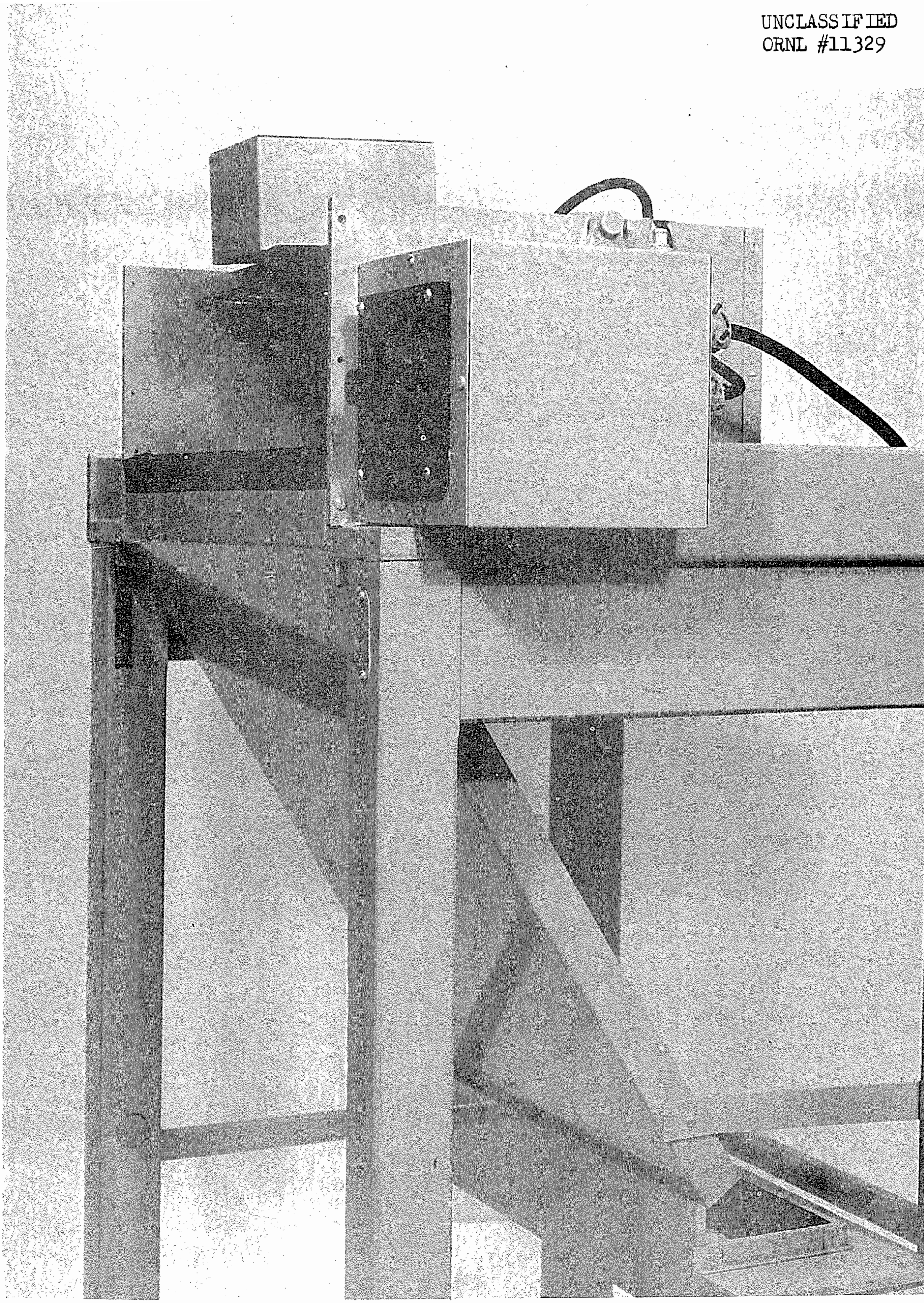


Figure 13

UNCLASSIFIED
ORNL #11330

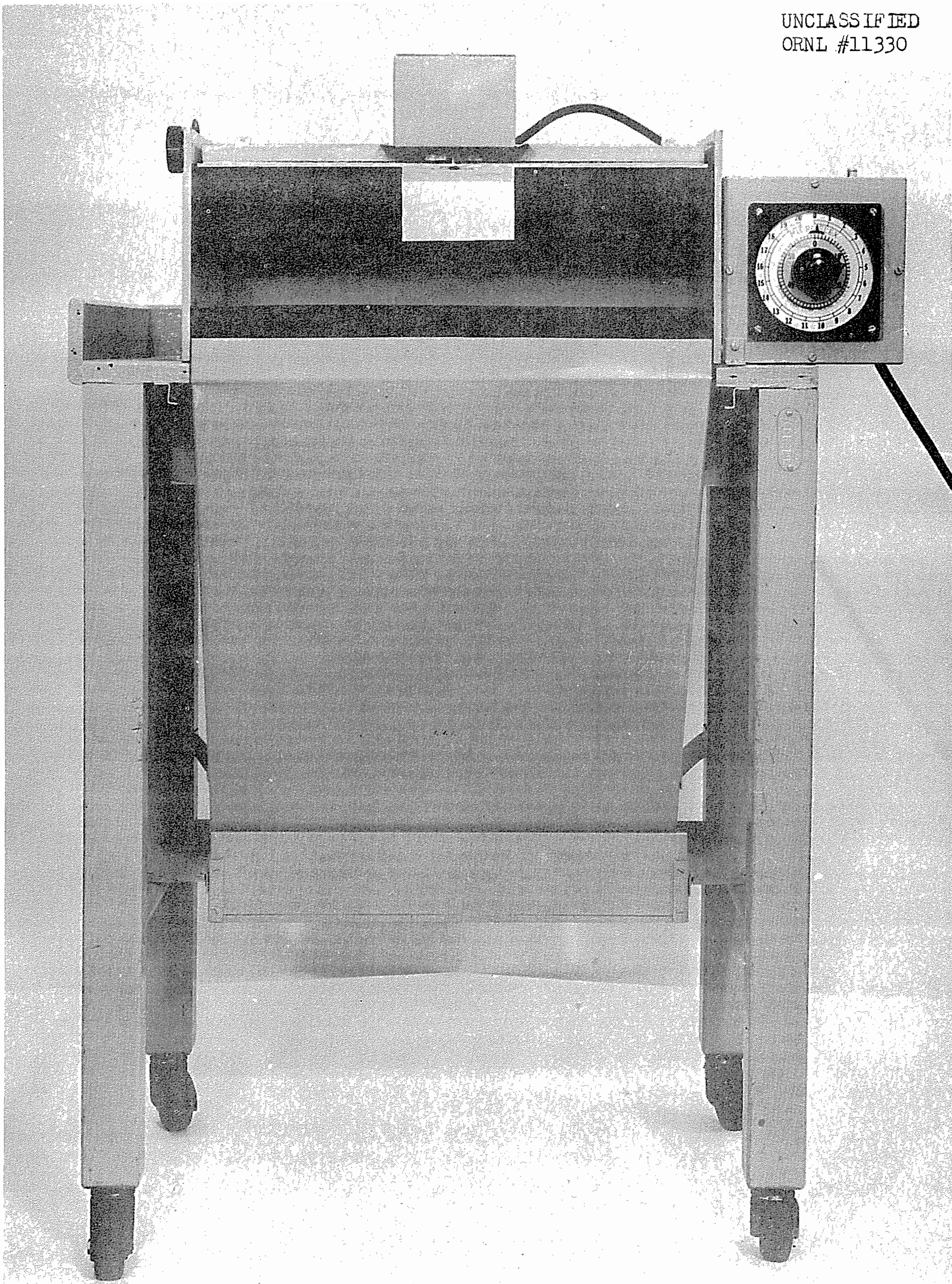


Figure 14

VII. Gamma Calibration Device for Monitoring Film

Figure 15 is a photograph of the film badge mounting ring, source tube and source storage shield. Figure 16 is a photograph of the operating console. Figure 17 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 minute to 24 hours. At the end of the exposure period, the vacuum pump is shut-off automatically, and the source drops into the shield.

The exhaust gas from the pump is filtered through two oil and wool fiber filters, then passes through a paper filter which is situated at the window of a GM tube. This GM 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 pre-set level.

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

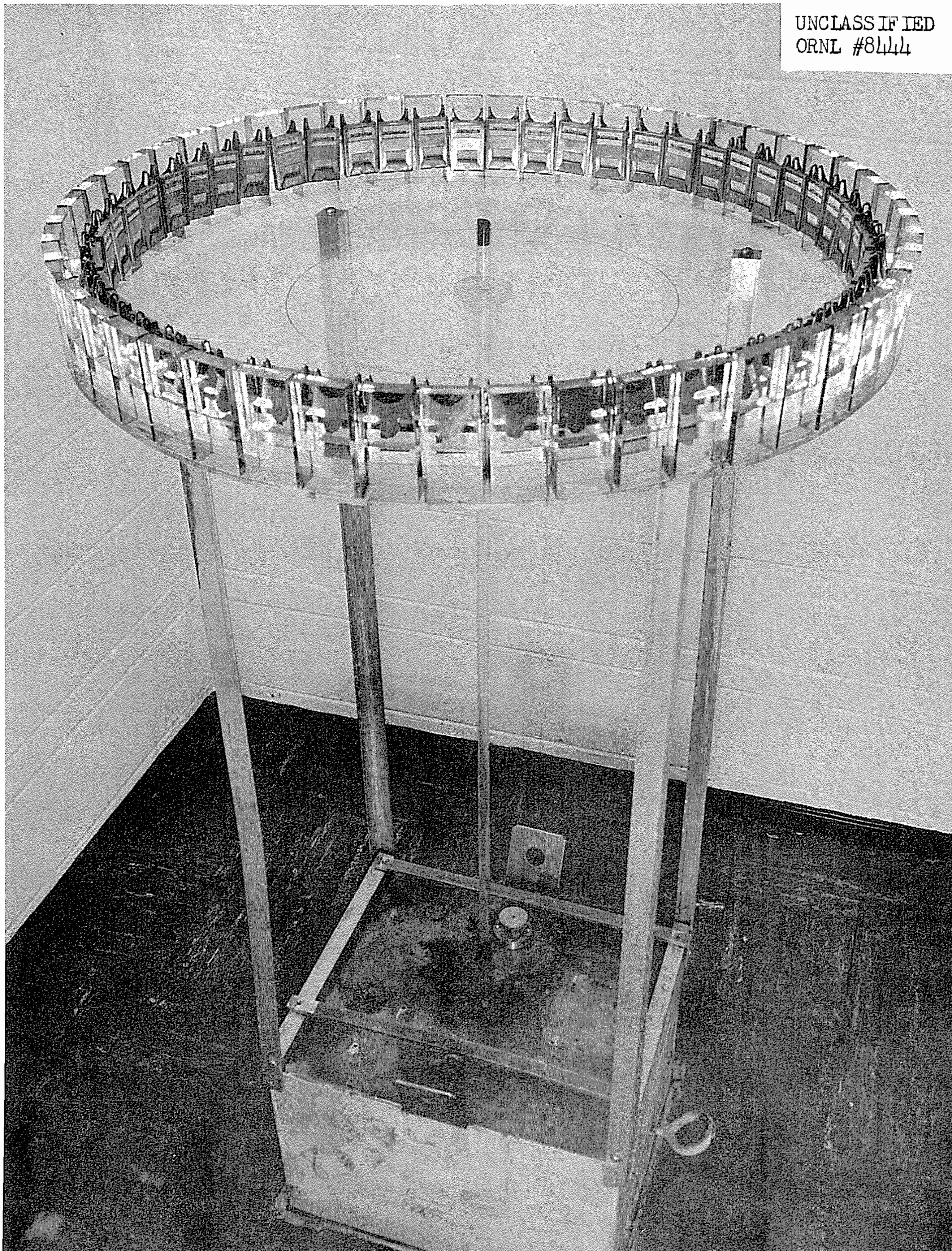


Figure 15

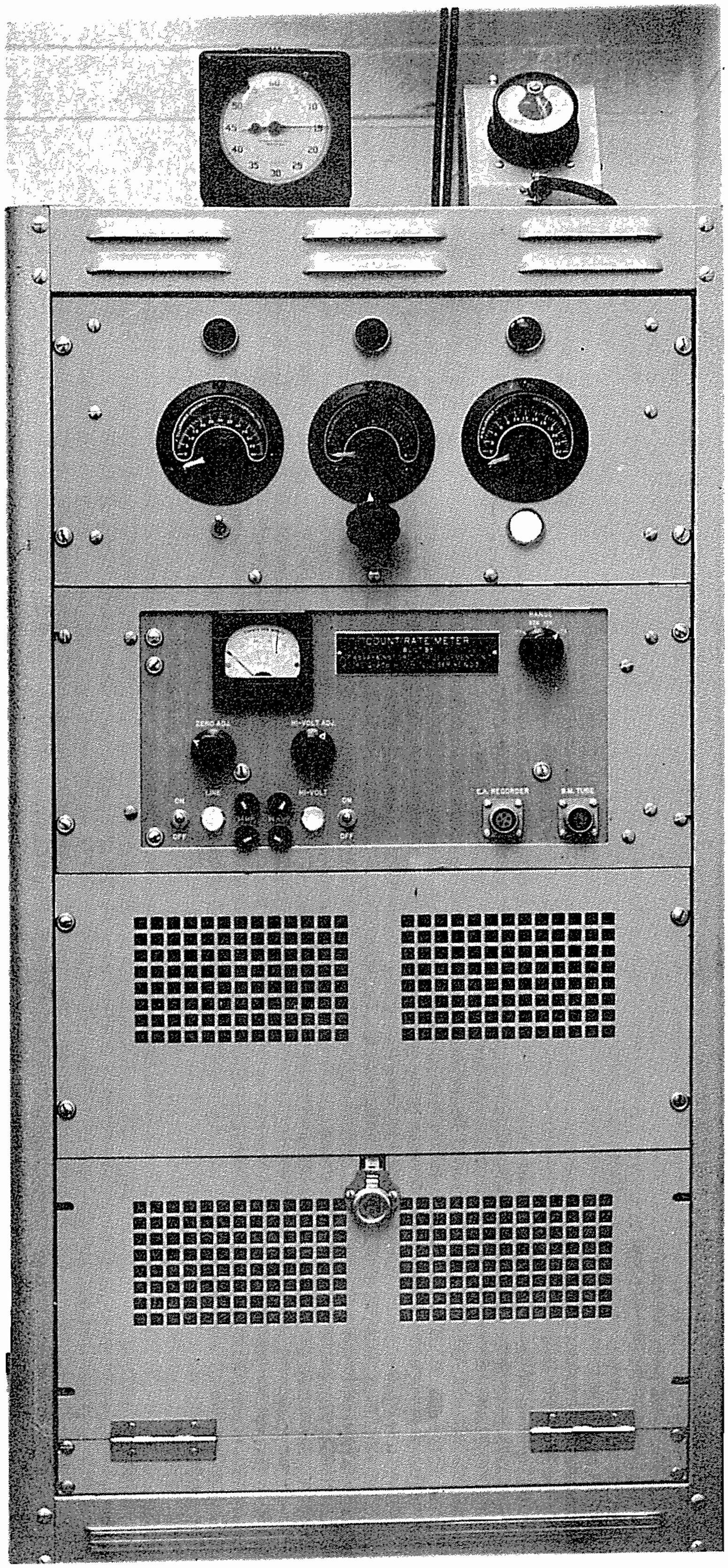
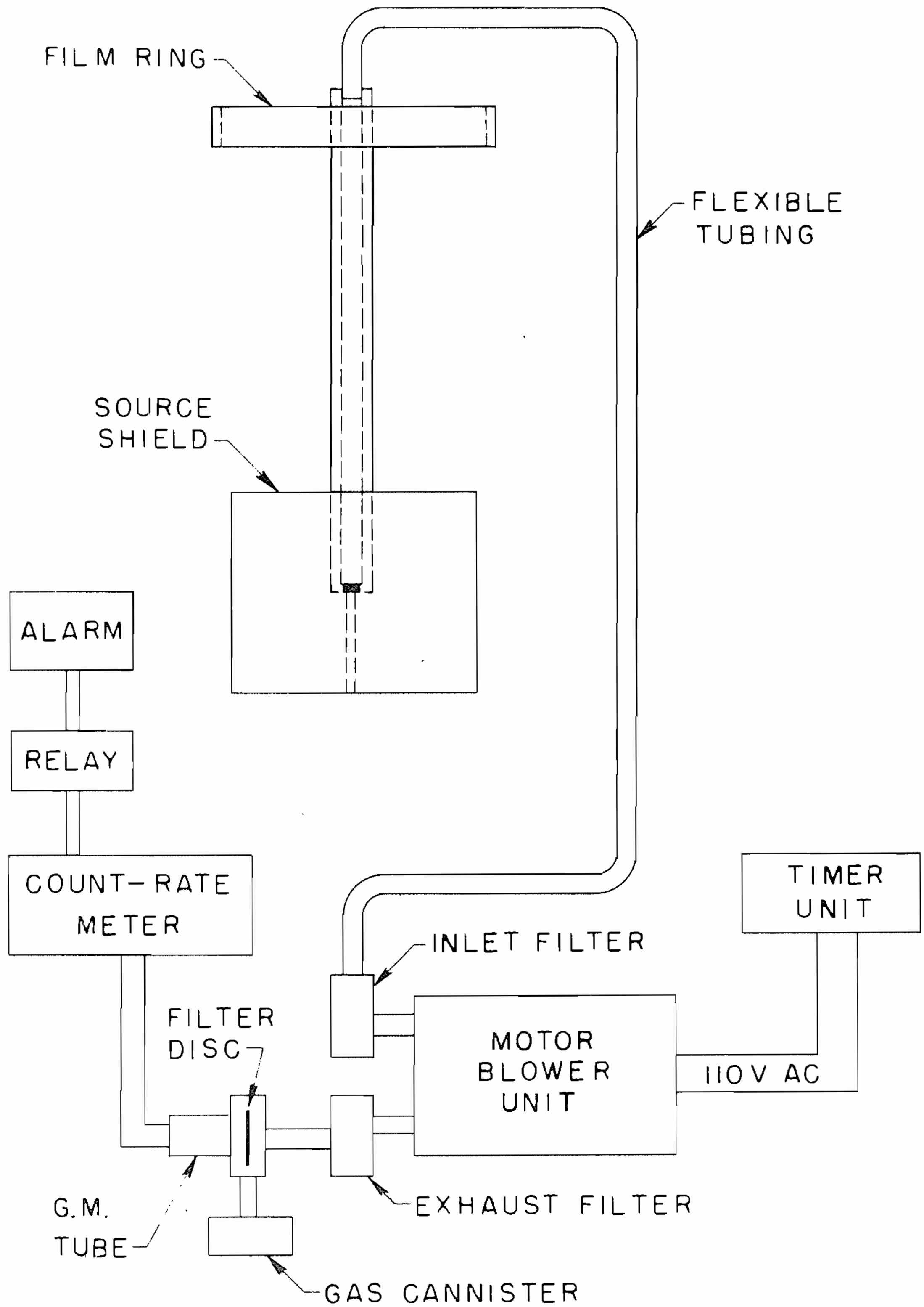

COUNT RATE METER
ZERO ADJ.
HI-VOLT ADJ.
ON
OFF
HI-VOLT
ON
OFF
G.M. TUBE

Figure 16



GAMMA FILM CALIBRATION DEVICE

Figure 17

VIII. Well

Figure 18 is a photograph of the device (termed the "well") used for gamma calibration of ionization chambers. The radiation intensity 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.

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 $\pm$ 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 feet deep, serves to minimize the time required for calibration and to reduce the radiation exposure to personnel.

A one gram 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. 19).

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.

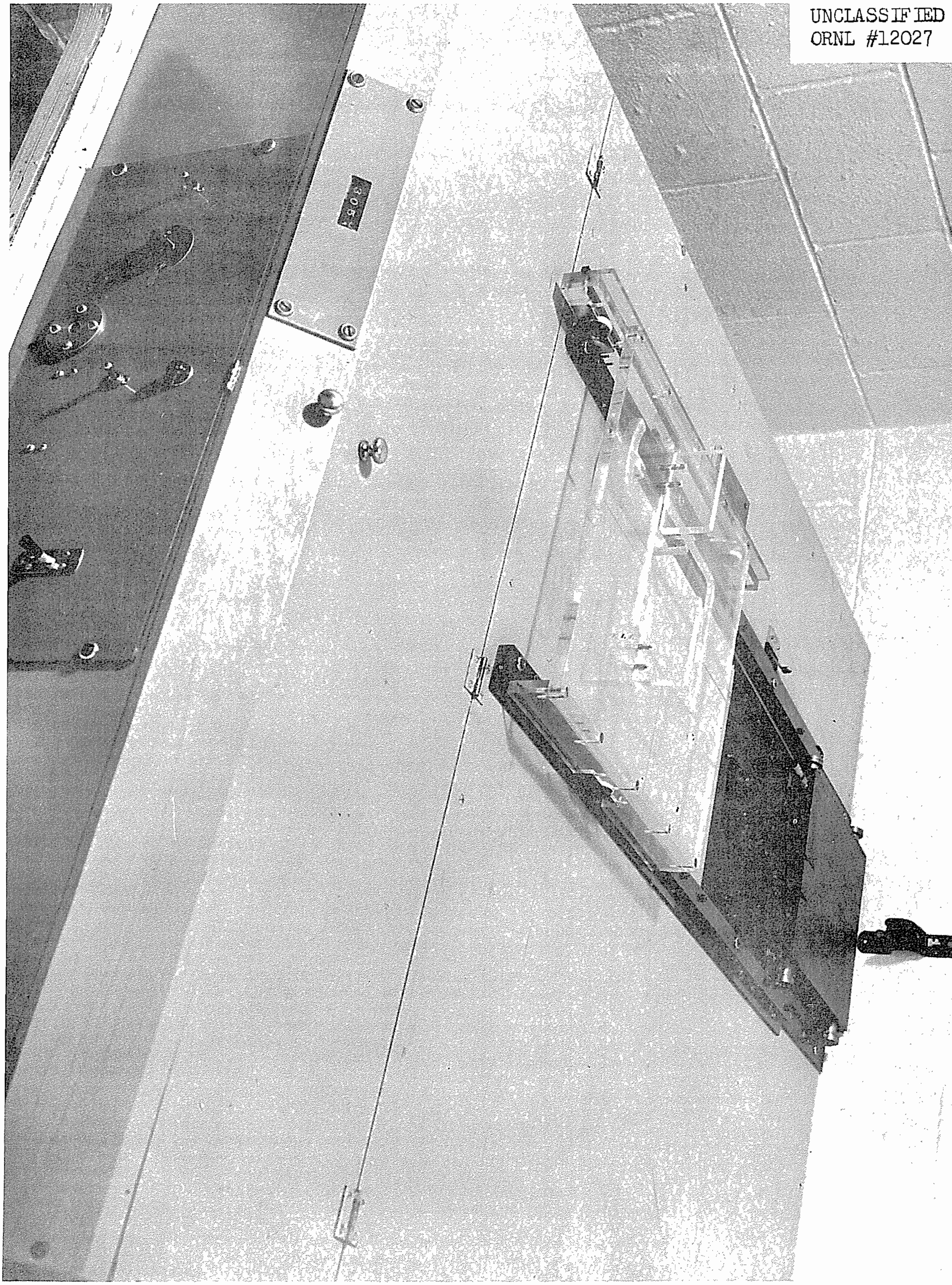


Figure 18

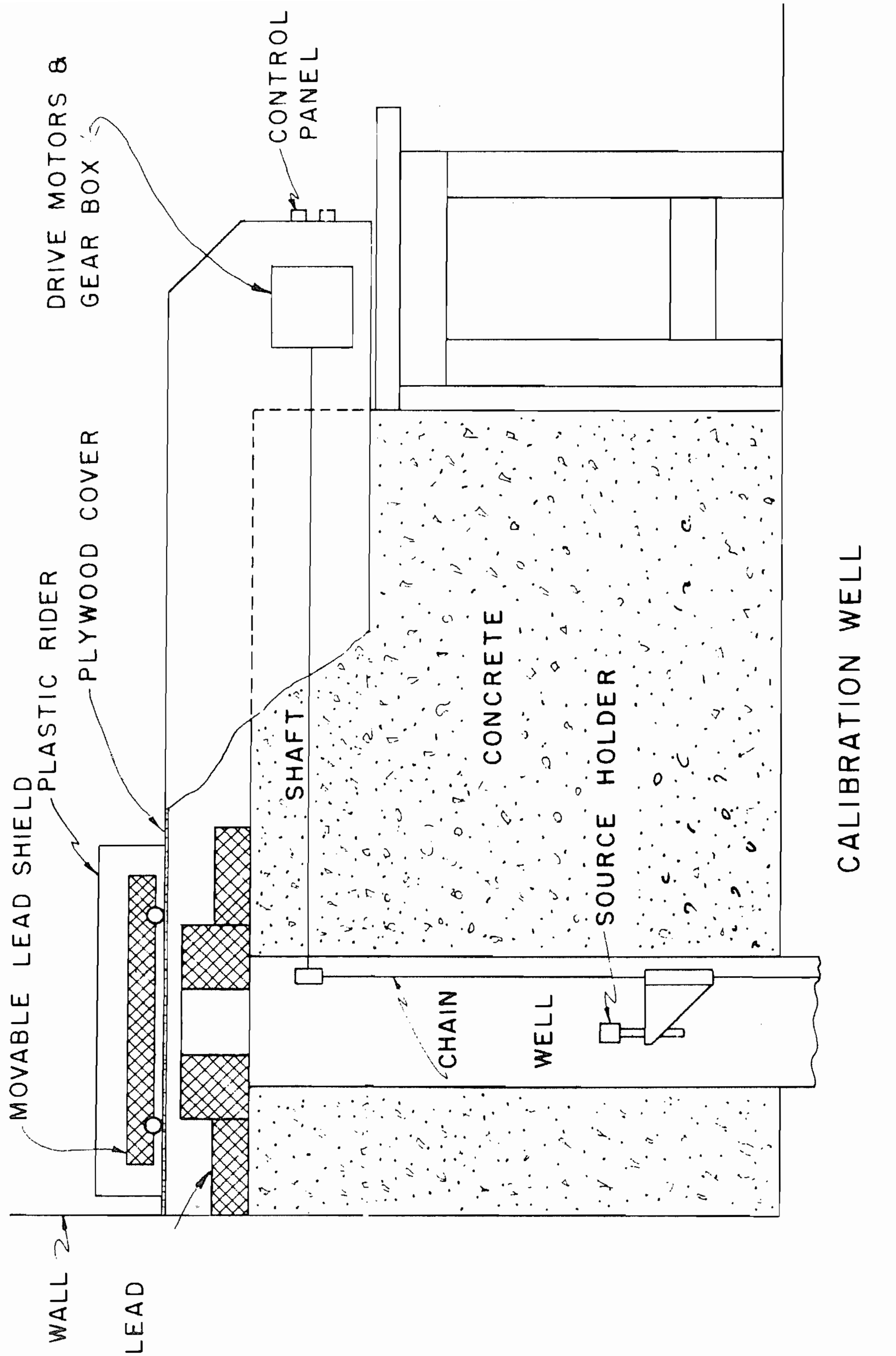

DRIVE MOTORS &
GEAR BOX
CONTROL
PANEL
PLASTIC RIDER
PLYWOOD COVER
MOVABLE LEAD SHIELD
SHAFT
CONCRETE
SOURCE HOLDER
CHAIN
WELL
CALIBRATION WELL
WALL
LEAD

Figure 19

IX. <u>GMSM Calibration Set-Up</u>

Figure 20 is a photograph of the calibration set-up for G.M. Survey Meters. Distance vs. dosage rate is determined by a primary calibration. The source used is 1 mc of Radium. The distances are indicated for dosage rates of 1, 2, 5, 10, 15, and 20 mr/hr.

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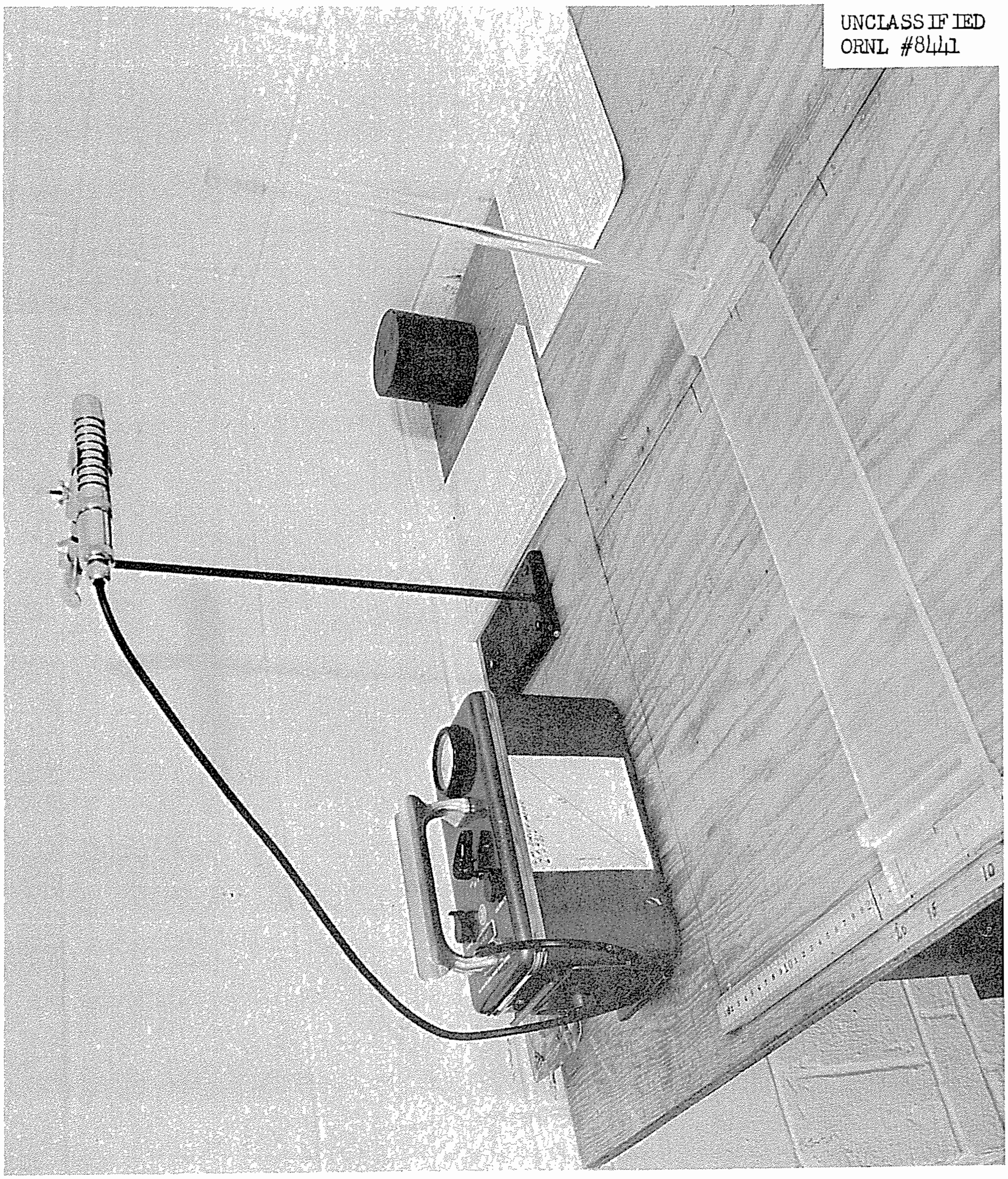

Figure 20

X. Electroscope Calibration Set-up

Figure 21 is a photograph of the calibration set-up for electroscopes. Distance vs. dosage rate is determined by a primary calibration. The lead door serves both to reduce the dosage rate for calibration purposes and to shield the source when not in use. Dosage rates within the range from 1 to 1000 mr/hr are obtained within the 5 foot length of the table with a 25 mc Radium source mounted within the lead box.

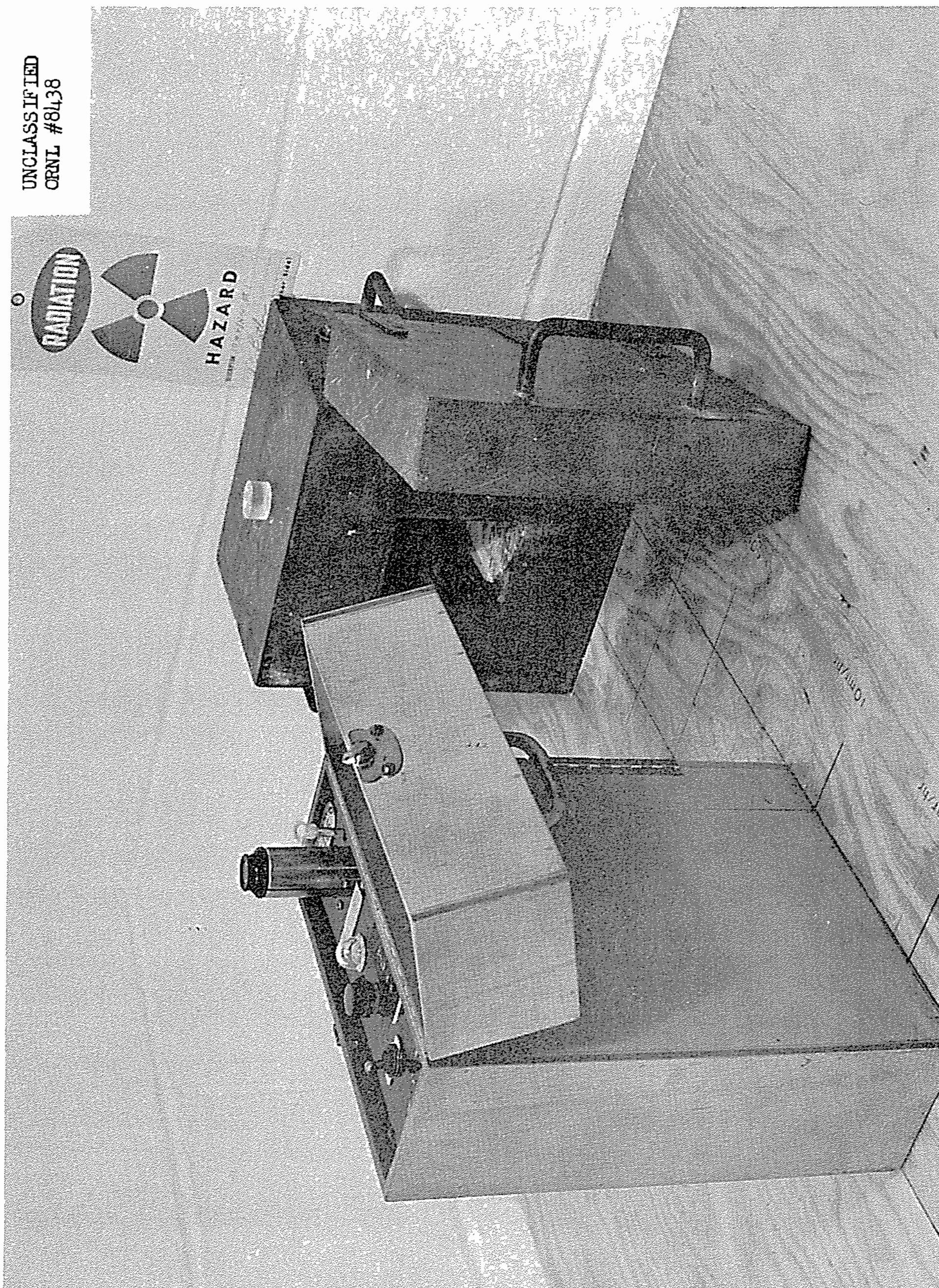

Figure 21

XI. Alpha Sources

Figure 22 is a photograph of one of the sources used for alpha particle calibration. The source is prepared by electro-depositing plutonium on a stainless steel disc. The disc is mounted on a bakelite placque to facilitate handling. The sources used cover the range from 250 d/m to 250,000 d/m.

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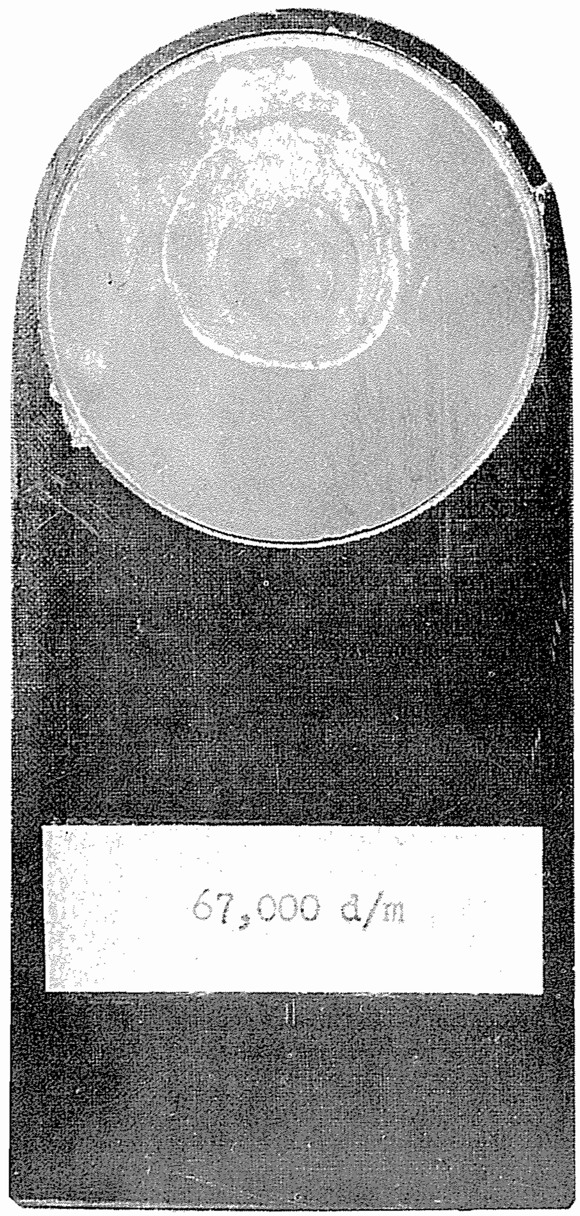

Figure 22

XII. Thermal Neutron Set-Up

Figure 23 is a photograph of the paraffin filled container used for for thermalization of neutrons from a Po-Be source. In use, the source is situated at the center of the paraffin cylinder such that at least 4 inches of paraffin are interposed between the source and the point of measurement. Thermalization is approximately 40% for the distances used.

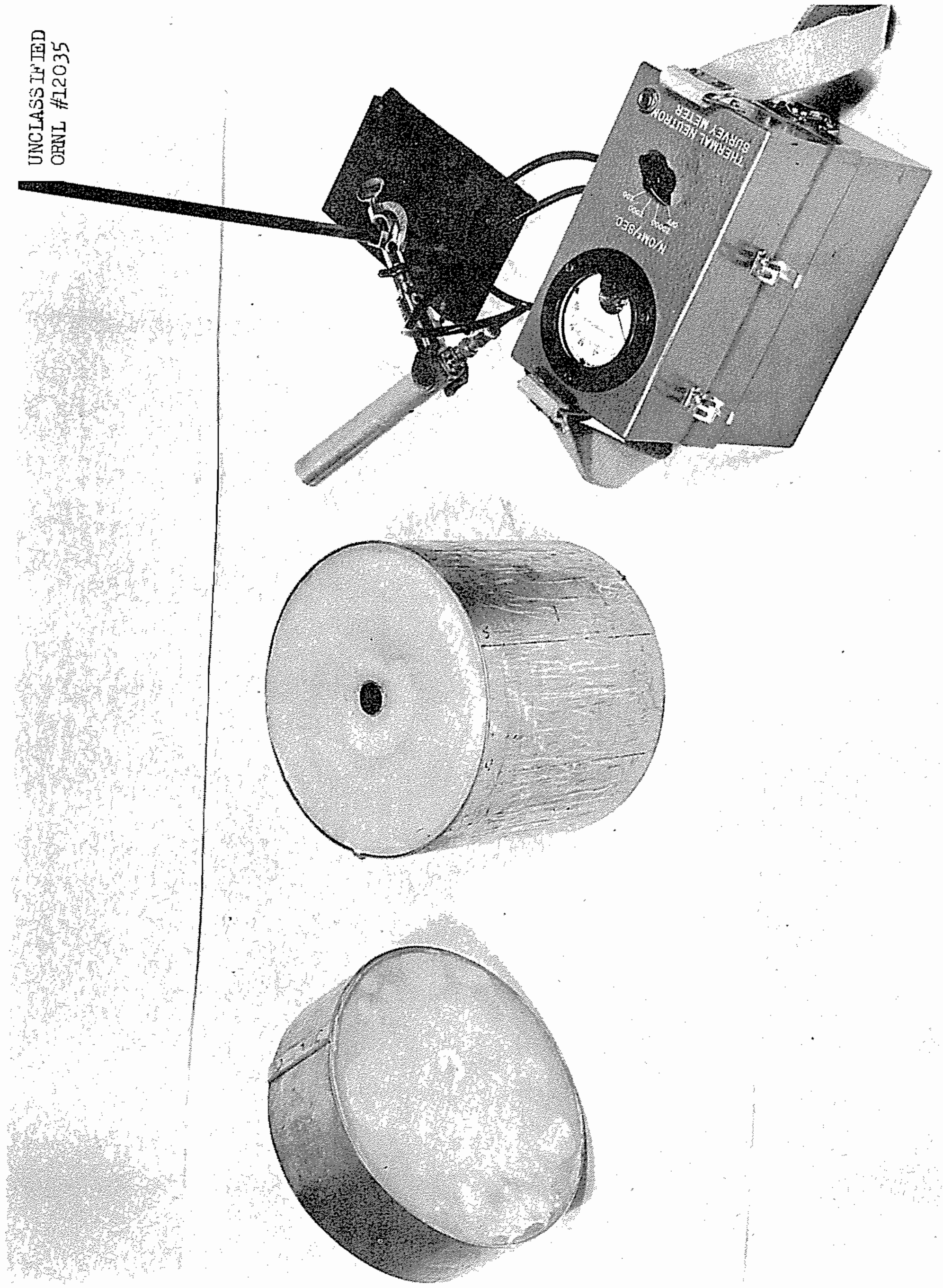

Figure 23

XIII. <u>Fast Neutron Set-up</u>

Figure 24 is a photograph of the set-up for calibration of fast neutron dosimeters. The dosimeter probe is mounted in the jig provided at one end; the gamma or neutron source is seated on the source mount. The source mount may be moved along the track. The distance from the center of the source to the center of the counter is read directly from the attached metric measure.

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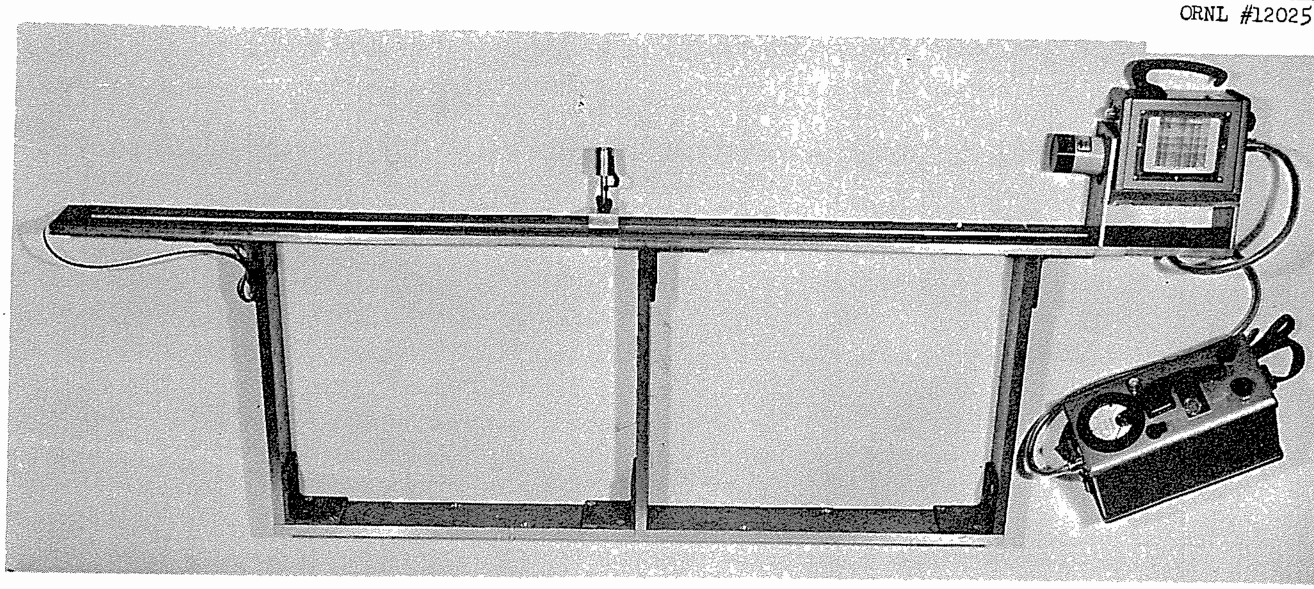

Figure 24