# Measurement of Ionizing Radiation

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# *Disclosure Information*
# *Peter Balter, Ph.D.*

I have the following financial relationships to disclose

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Varian Associates

Employee of

University of Texas M.D. Anderson Cancer Center

I will **NOT** include discussion of investigational or off-label use of a product in my presentation.

# 3 useful concepts

Exposure: Roentgen : NOT a measure of dose

Exposure: The ability of Photons to ionize air.

(Defined for air only)

Air Kerma: Energy deposited in the gas inside a chamber

Dose: Energy deposited in matter per unit mass (defined for all materials)

# *Ionizing Radiation*

- Radiation with sufficient energy to break apart air molecules
  - $> 34$ eV
- Allows us to use air-filled ionization based measurement tools
- Only works if we can capture all the ions produced
  - Or if we can cheat

# *Exposure and Dose*

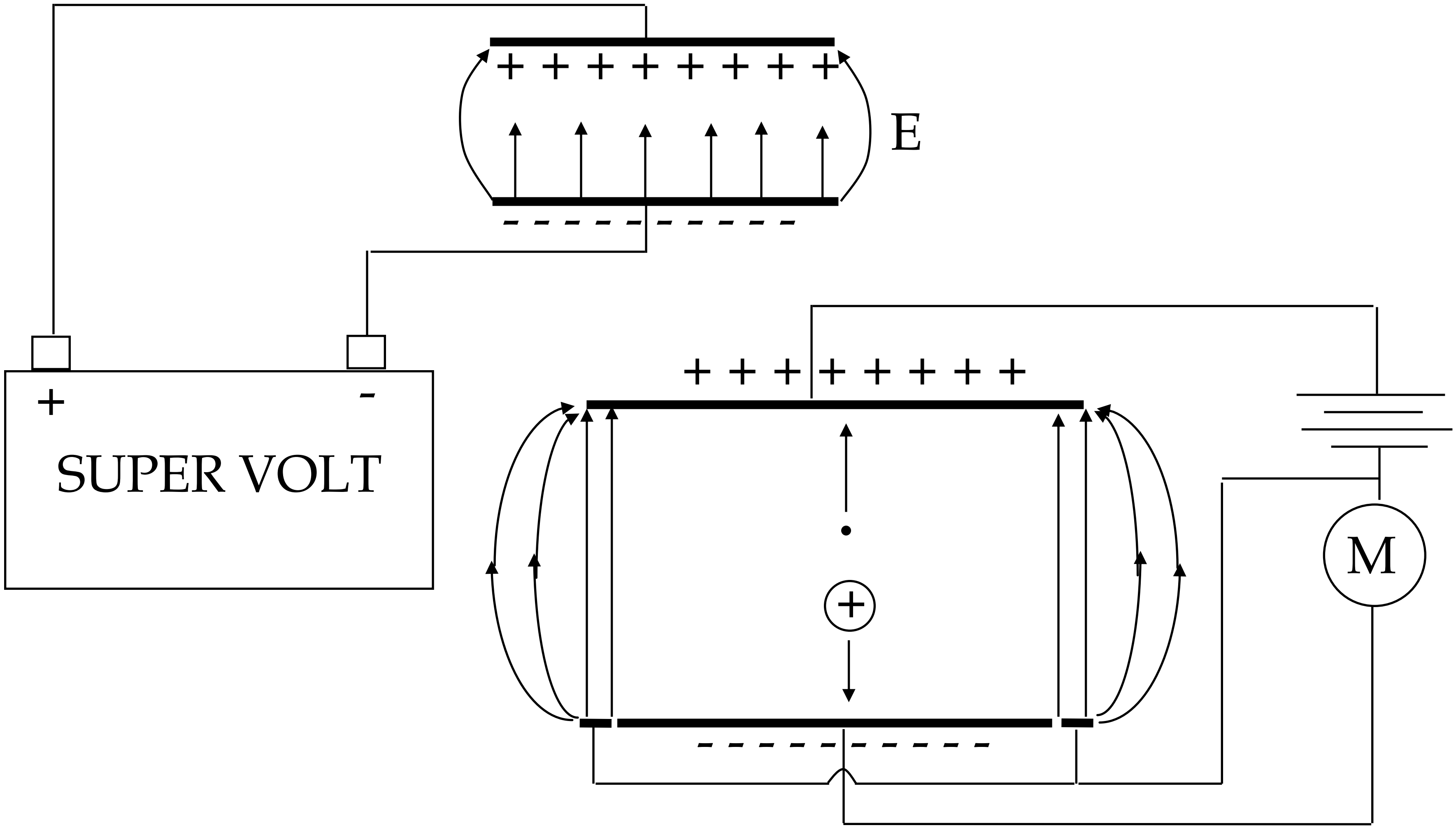
- Exposure is the charge liberated by ionizing radiation per unit mass of air.

  [1 roentgen = 1 R = .000258 C / kg )]
- Dose is energy absorbed from ionizing radiation, per unit mass of any material.

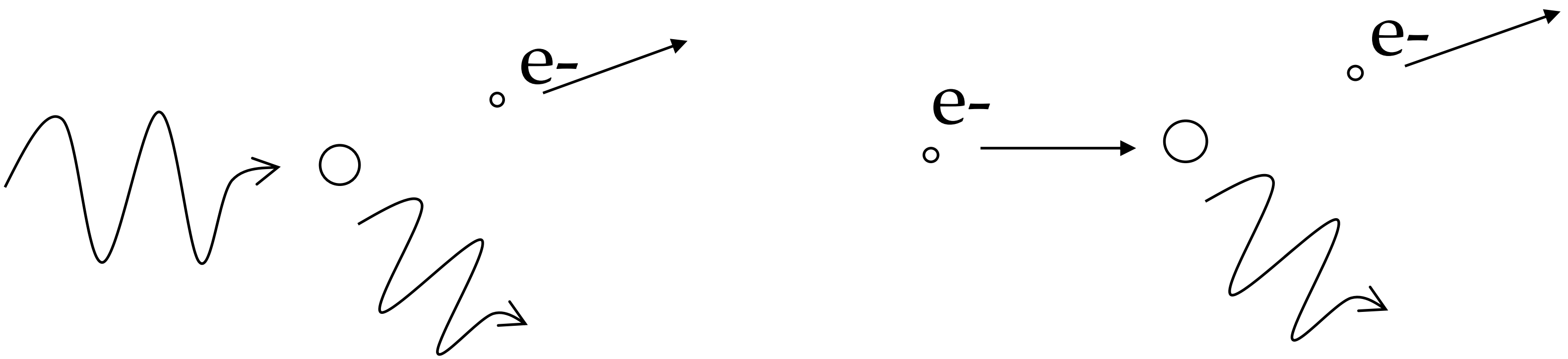
# Useful Units

- Gy: J/Kg : Si unit of dose
- R: <C/Kg> of air (special unit of exposure)
- Coulomb: C :the SI unit of Charge(fundamental)
- Amp: A = C/sec : a unit of current(derived)
- Air Pressure: (measured in units of (force/unit area))
  - kPa: kilopascals (101.33) (SI unit)
  - mm Hg: millimeters of Mercury (760)
  - In Hg: Inches of Mercury (29.92)
    - » In Hg * 25.4(mm/in) = mm Hg

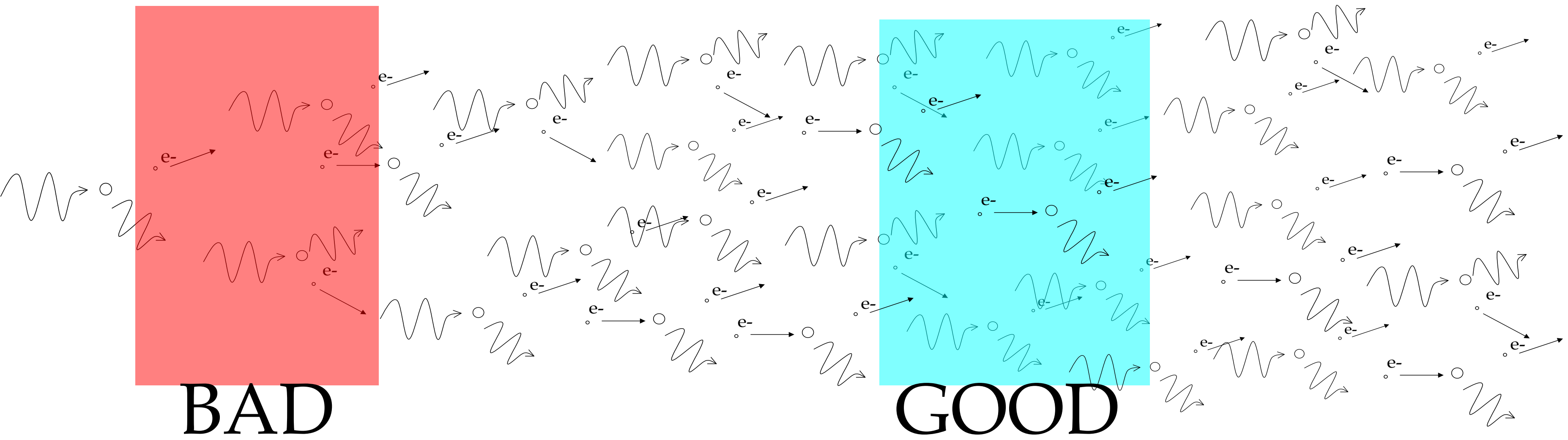
# Review - Electric Fields



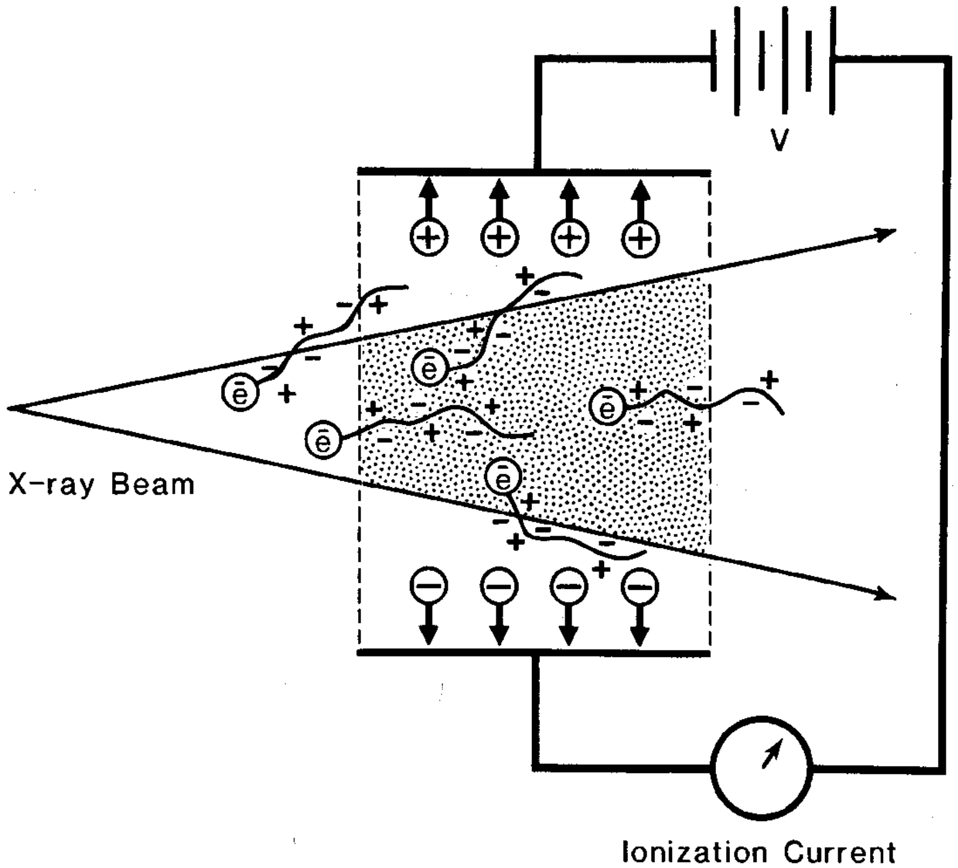
# Electronic Equilibrium




**We want the same number of secondary electrons entering as are leaving our measurement volume**



# The Roentgen




- Roentgen (symbol X) - a measure of the ionization produced in air by photons

1 R =

2.58 x 10 –4 C / kg air

**FIG. 6.1.** Diagram illustrating electronic equilibrium in a free-air chamber.

# The Roentgen

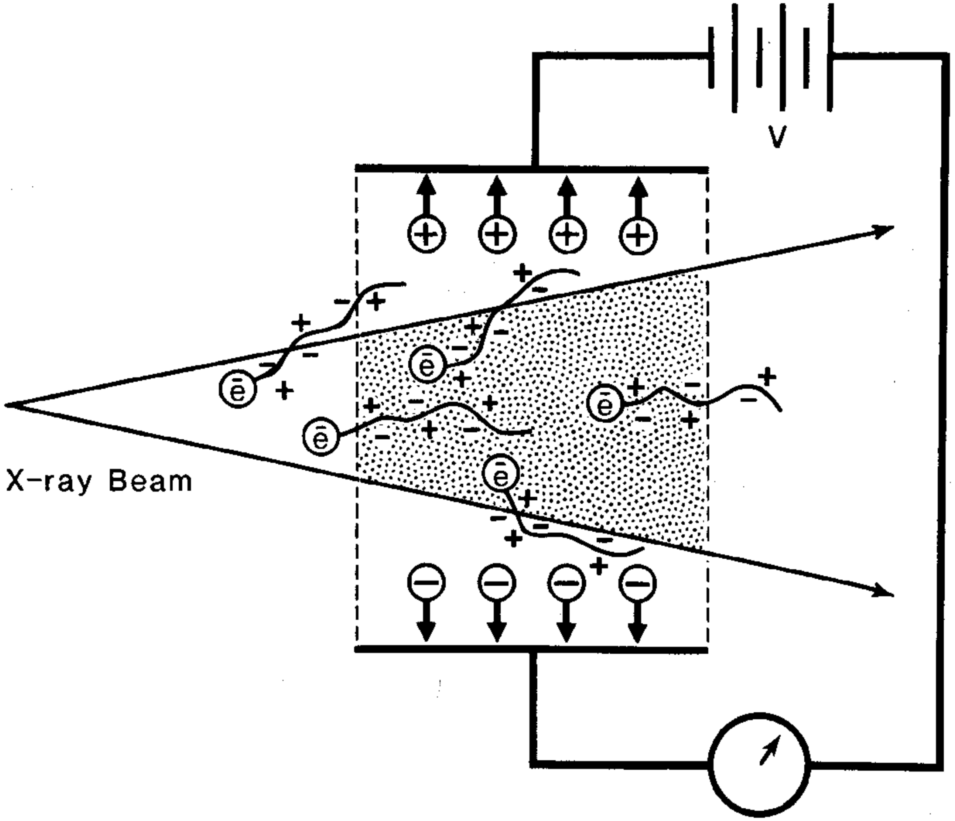
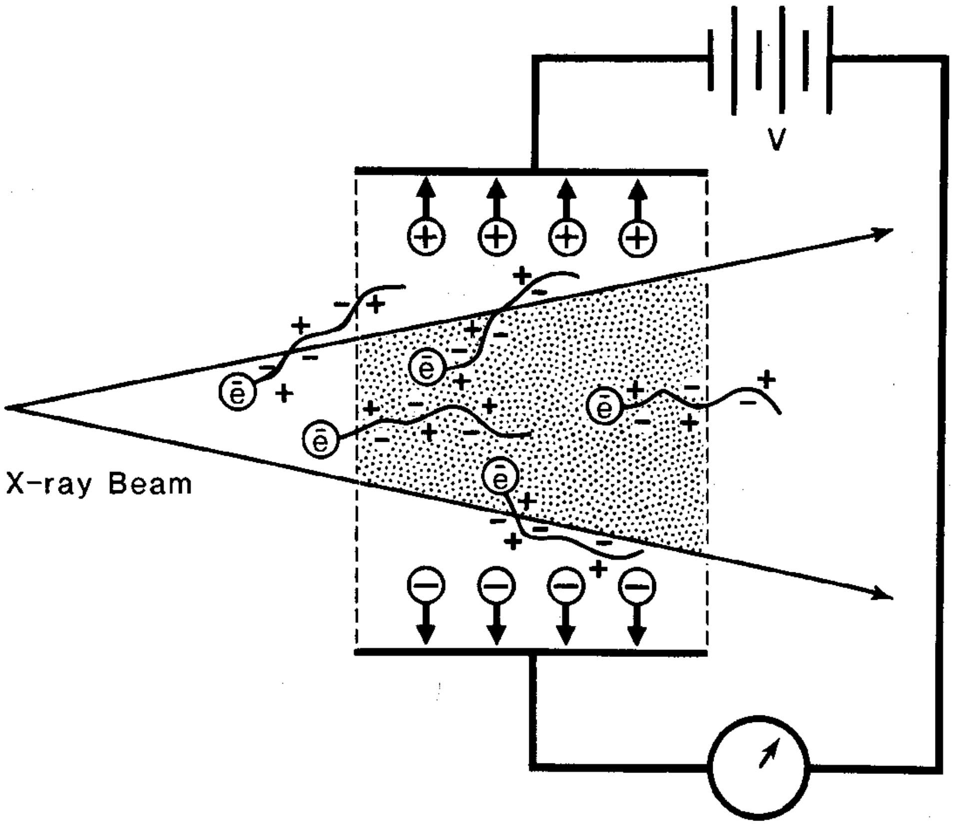



**FIG. 6.1.** Diagram illustrating electronic equilibrium in a free-air chamber.

- All of the energy of the electrons produced by the photons is assumed to be collected. The electrons created cause further ionization in the air.
- Electronic equilibrium

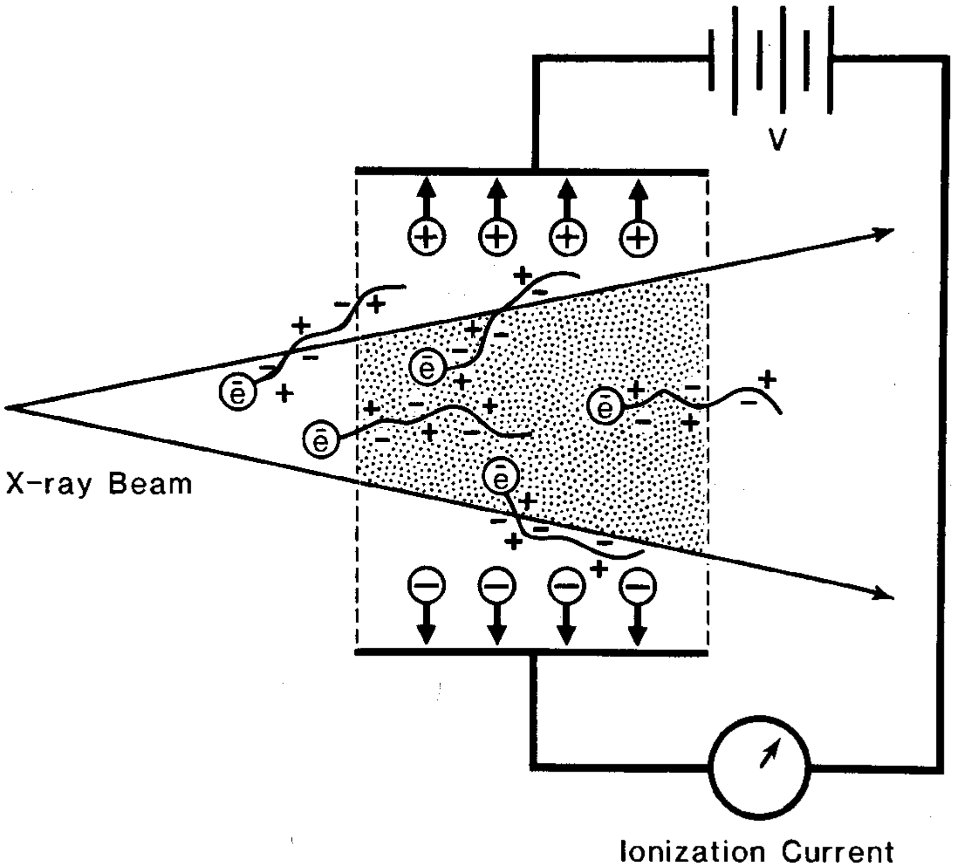
# The Roentgen




- W, is the average energy required to create an ion pair (approx. 34 eV / ion pair) in dry air
- e/W (1C/34J) is charge produced per amount of energy deposited in the air.

**FIG. 6.1.** Diagram illustrating electronic equilibrium in a free-air chamber.

# The Roentgen




- Thus, exposure is simply

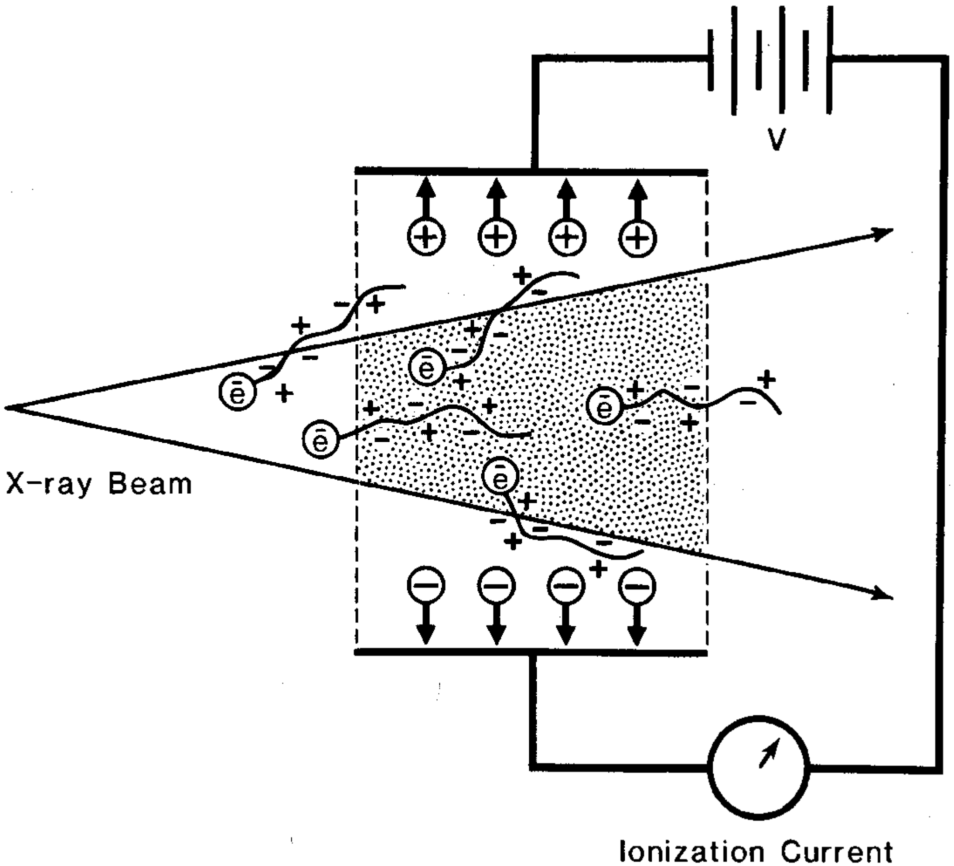
$$X = \Psi_{air}\left(\frac{\bar{\mu}_{en}}{\rho}\right)_{air}\cdot\left(\frac{e}{\overline{W}}\right)_{air}$$

1 R =

2.58 x 10 –4 C / kg air

**FIG. 6.1.** Diagram illustrating electronic equilibrium in a free-air chamber.

# The Roentgen




- We cannot measure how many joules of energy was absorbed by the air, but we can measure the number of ion pairs created in the air. This is what the ion chamber is measuring: the number of ion pairs created in the air

**FIG. 6.1.** Diagram illustrating electronic equilibrium in a free-air chamber.

# *Free-air Ionization Chamber*

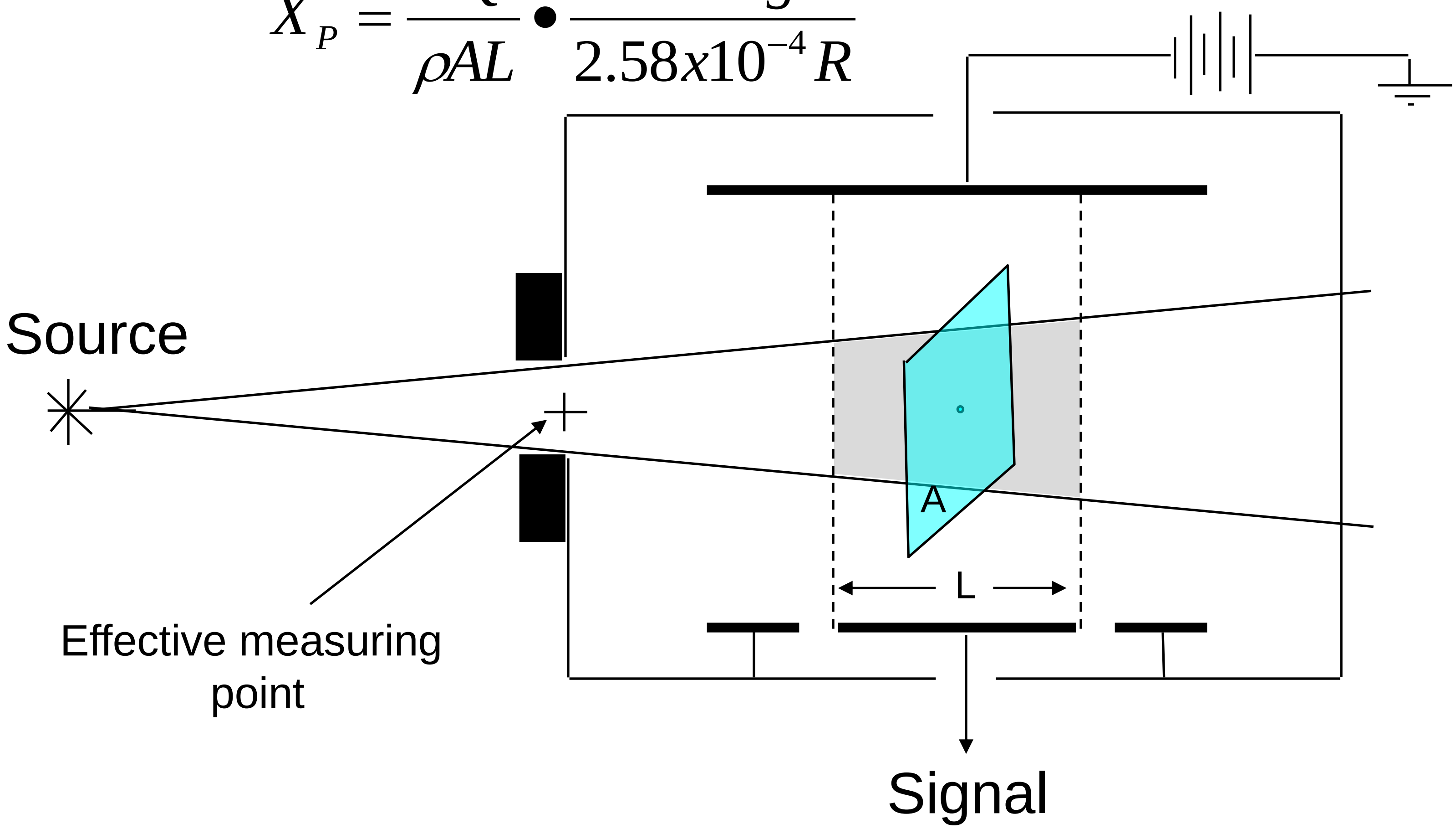
**Photons measured must be below 3 MeV**

- All charge from each created electron must be absorbed within the collecting volume
- As photon energy increases, so does the electron's range
- Large separation of plates designed to collection ions creates nonuniform electric fields and ion recombination

# Free Air Ionization Chamber

Directly measures exposure based on the definition of exposure

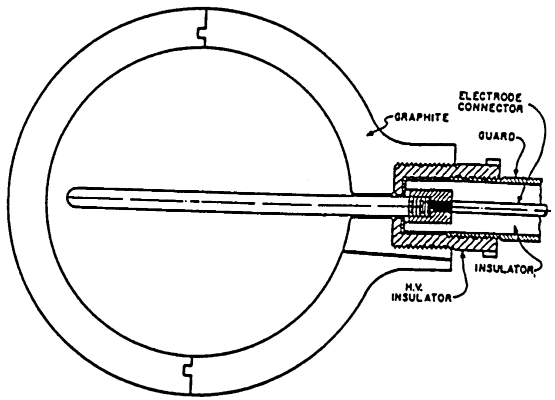
$$X_P = \frac{\Delta Q}{\rho A L} \bullet \frac{1C/Kg}{2.58x10^{-4}R}$$



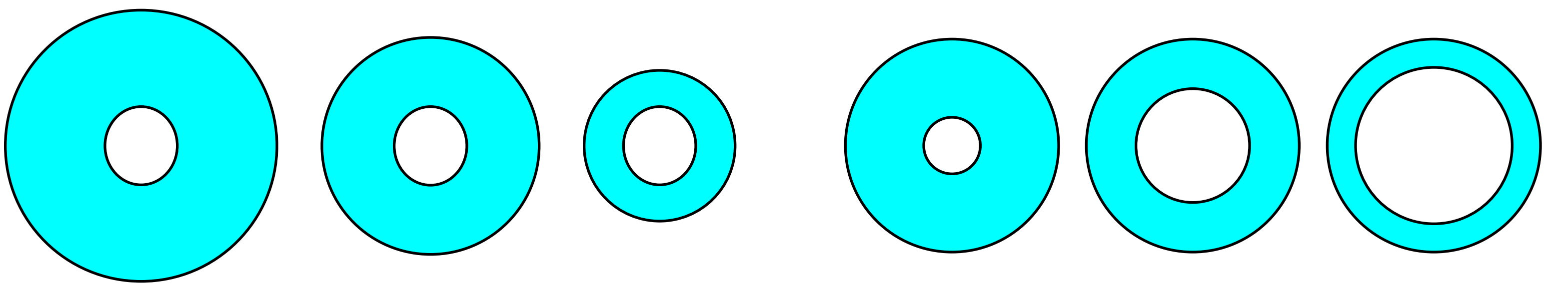
# Effective Atomic Number

- Effective Atomic Number (Z): The atomic number of an element with which photons interact the same way as with the given composite material.
- Is a function of photon energy - dominant interaction.
  - Low Energy Photoelectric effect $\propto Z^3$
  - Medium energy Compton effect (XRT) $\cancel{\propto} Z$
  - High energy Pair Production $\propto Z^2$

# Graphite Chambers




NIST’s Cobalt-60 Standard is a series of spherical graphite chambers

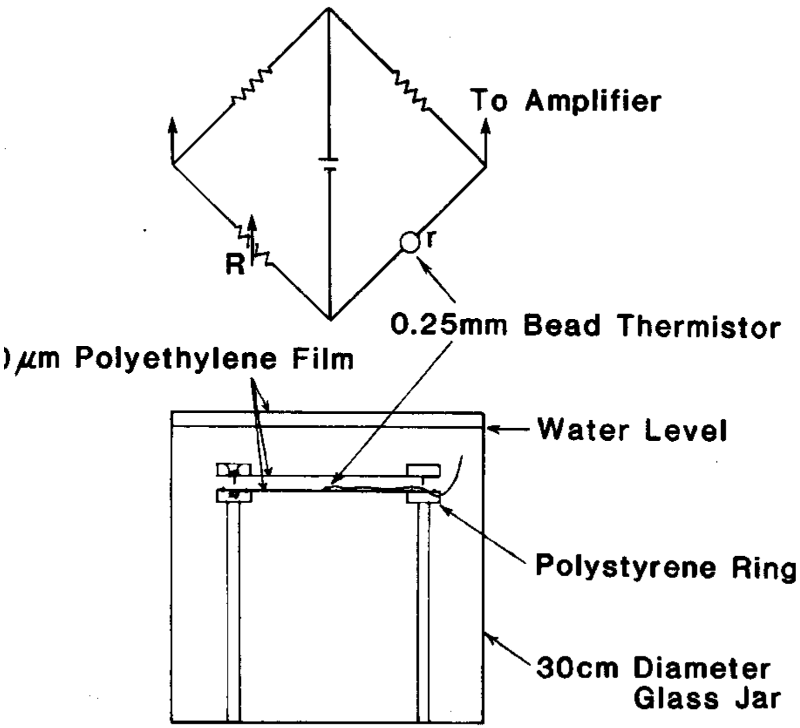


Constant Volume

Constant Outer Diameter

Data from chambers are used to determine exposure rate and wall effects

# Calorimetry




Energy absorbed in the medium from radiation appears as heat energy

Thermistors are semiconductors which show a large change in electrical resistance with a small change in temperature. By measuring the change in resistance with a Wheastone bridge, the dose can be determined.

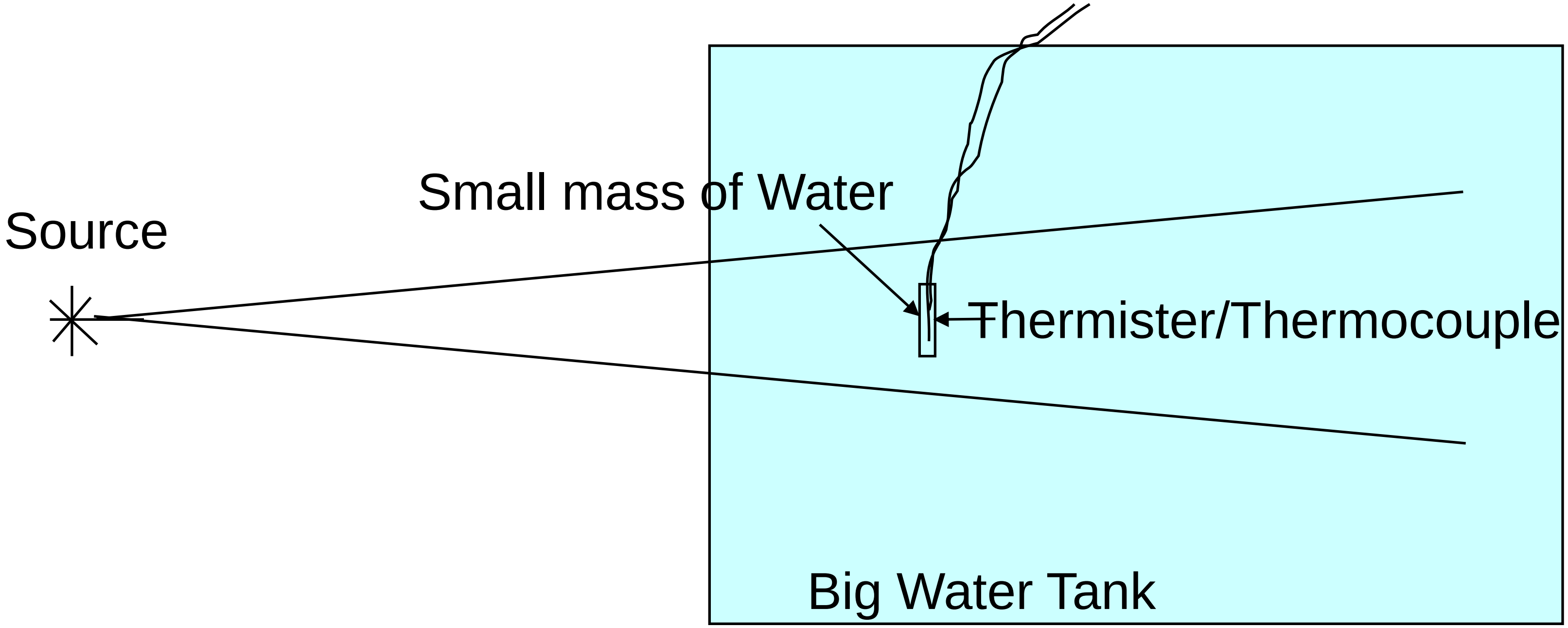
**FIG. 8.9.** Schematic diagram of Domen's calorimeter. (Redrawn from Domen SR. Absorbed dose water calorimeter. *Med Phys* 1980;7:157.)

# Absorbed Dose To Water From $^{60}$Co

NIST measures the the increase in temperature in a small mass of water in a large water tank

All the increase in temperature is due to energy delivery by the $^{60}$Co beam

Remember 1 Gy= 1 J/kg
Specific Heat of Water = 4190 J/kg$^{o}$C
so: 1 Gy = 0.0002387 $^{o}$C change in temp



# *KERMA*

Kinetic energy released in matter

-the sum of the kinetic energies of all the charged particles set into motion by ionizing radiation per unit mass of the material

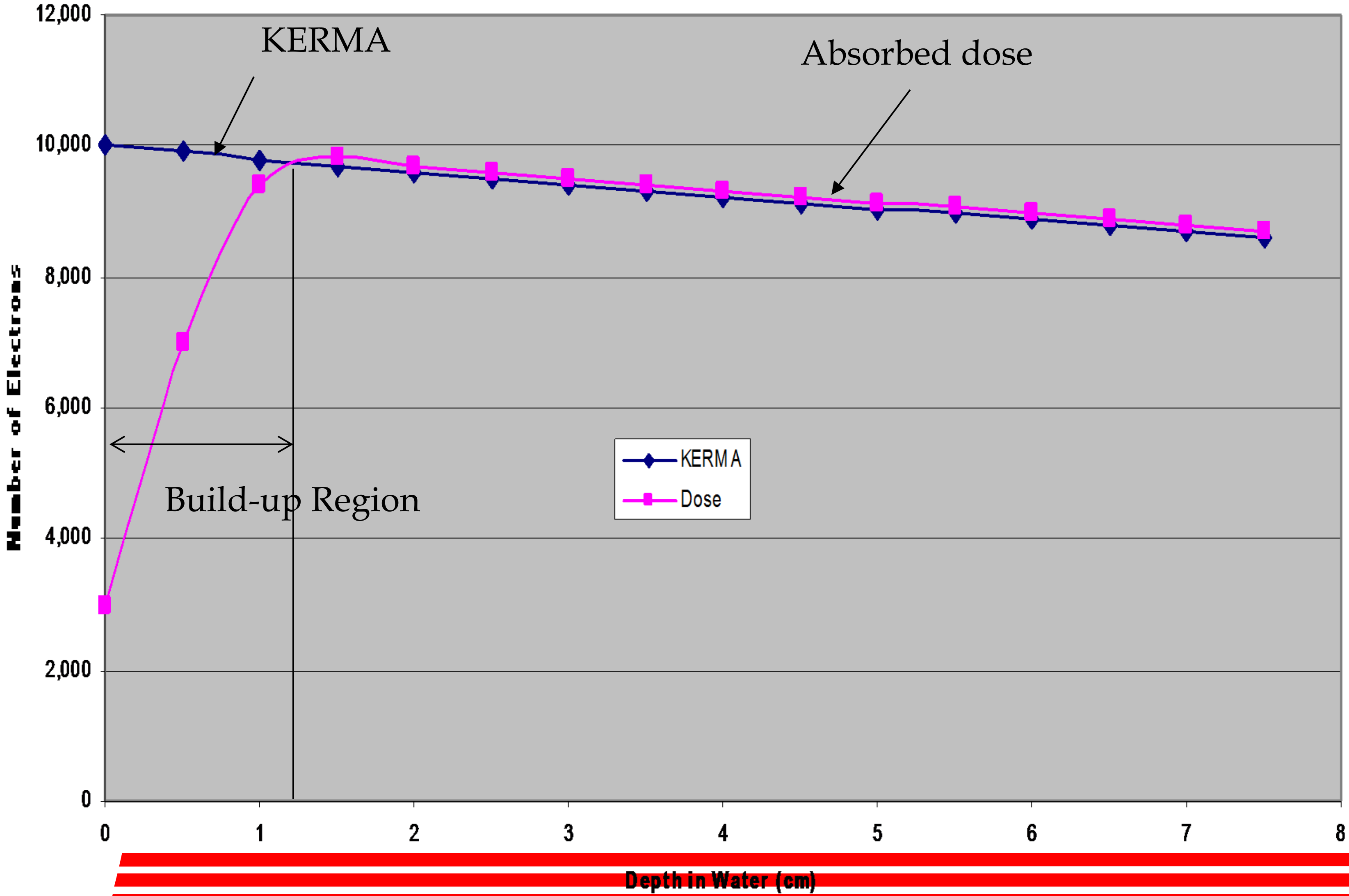
-The relationship between exposure and KERMA is

$$X = K^{col}_{air} \times (e/W)$$

-e/W is the amount of charge liberated per unit energy.

-KERMA is always maximum at the surface of a phantom

# KERMA and Dose



# *Measurement of Dose*

- Exposure is only defined for ionization created in air, air-kerma is a more general term for the energy delivered to the gas in the chamber.
- Air-kerma in a chamber in a medium (water tank) can be used as a proxy for dose at that location.
- For a given energy and chamber type the air-kerma can be related to a dose rate at that location with the chamber removed as determined by Bragg-Gray Theory.

# *Bragg-Gray Cavity Theory (Simplified)*

- *"The ionization produced in a gas-filled cavity placed in a medium is related to the energy absorbed in the surrounding medium"* (KAHN 2nd ed p 140)

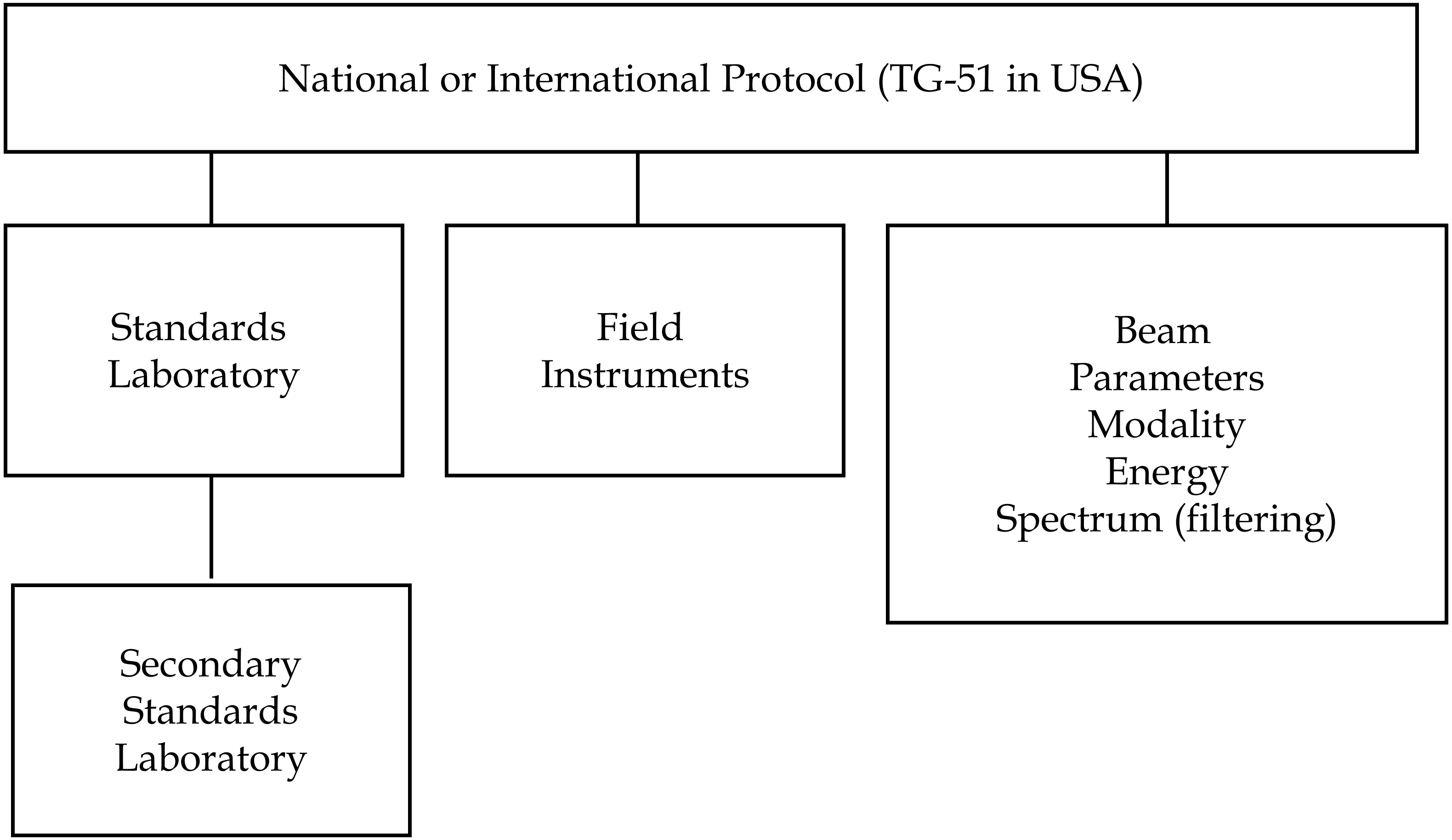
$$D_{med} = \frac{Q}{m_{air}} \cdot \left[\frac{W}{e}\right]_{air} \cdot \bar{\bar{S}}\,{}^{med}_{air}$$

- Gives the absolute dose to the medium at the location of the chamber with the chamber removed.
- Stopping power (S) is a function of the beam energy and the relative response of an air-filled ionization chamber to various photon energies can be determined using ratios of stopping power

# *Conditions of B-G Theory*

- *The size of the gas cavity should be small compared to the range of the charged particles striking it that its presence does not perturb the charged-particle field*
- The size of the gas cavity should be large enough so secondary ionizations created in the cavity stop in the cavity
- *The absorbed dose in the cavity is assumed to be deposited entirely by the charged particles crossing it*
- Electronic equilibrium
- The wall must be the same material as the medium or thin enough so that the charge particles crossing the gas cavity are created in the medium rather than the wall.

# *The protocol based model for absolute dosimetry*



# Calibration Protocols

- Several exists:
  - TG-21 / TRS-277 (exposure based)
    - » $D_{med} = M \times N_{gas} \times L/\rho)^{med}/_{air} \times P_{ion} \times P_{repl} \times P_{wall}$
  - TG-51 / TRS-398 (water based)
    - » $D_w^Q = M \times k_Q \times N_{D,w}^{Co\text{-}60}$
- All are based on Bragg-Gray cavity theory
  - Exposure based include dose to air to dose to water coversions
  - Dose based only use B-G for relative energy respose
- All measure ionization within an air cavity placed at depth in a phantom, and convert the reading to dose in the medium of the phantom

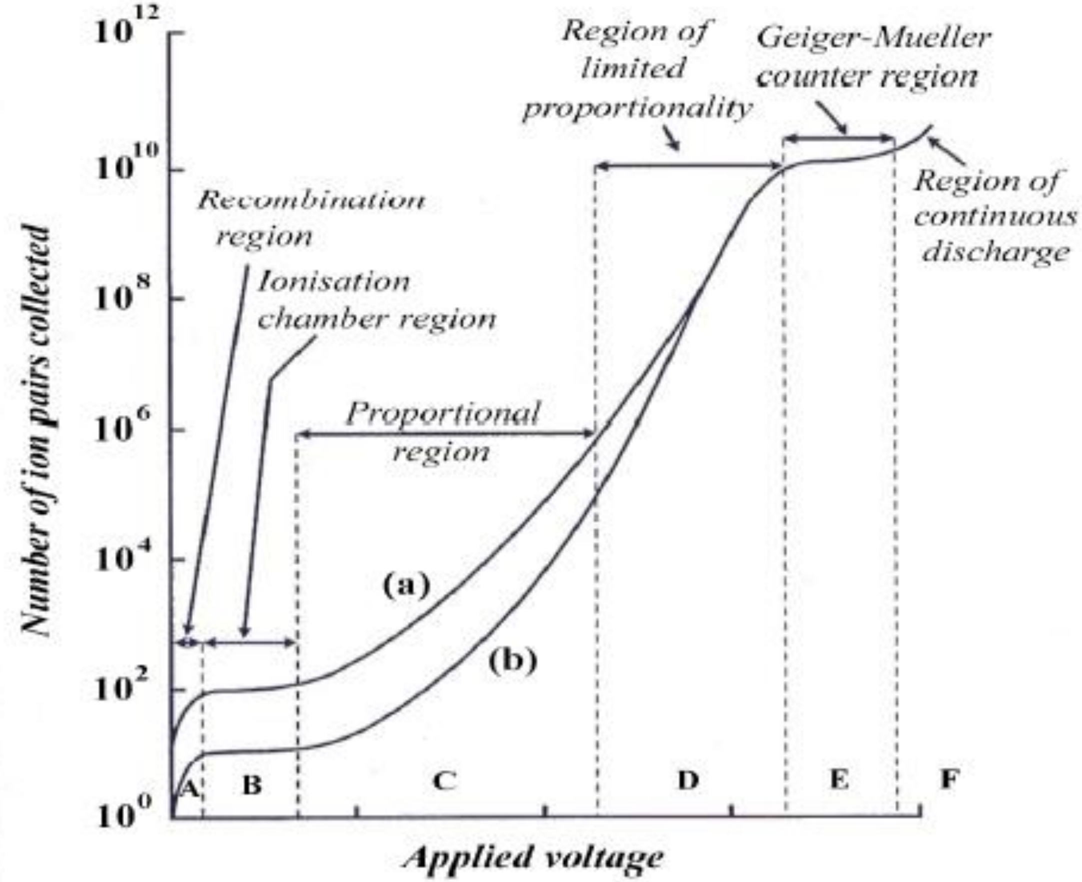
# *Different ionization of air based detectors*

If the collecting voltage in an air based ionization detector is very high the ions will be accelerated fast enough to create 2ndardy ionizations resulting in a higher (but less precise) signal.

Ion Chamber: No multiplication

Proportional Counter: Multiplication that is somewhat predictable

Geiger Counter: Each Ionization event immediately fills the ionization chamber with the maximum signal



# *Different ionization of air based detectors*

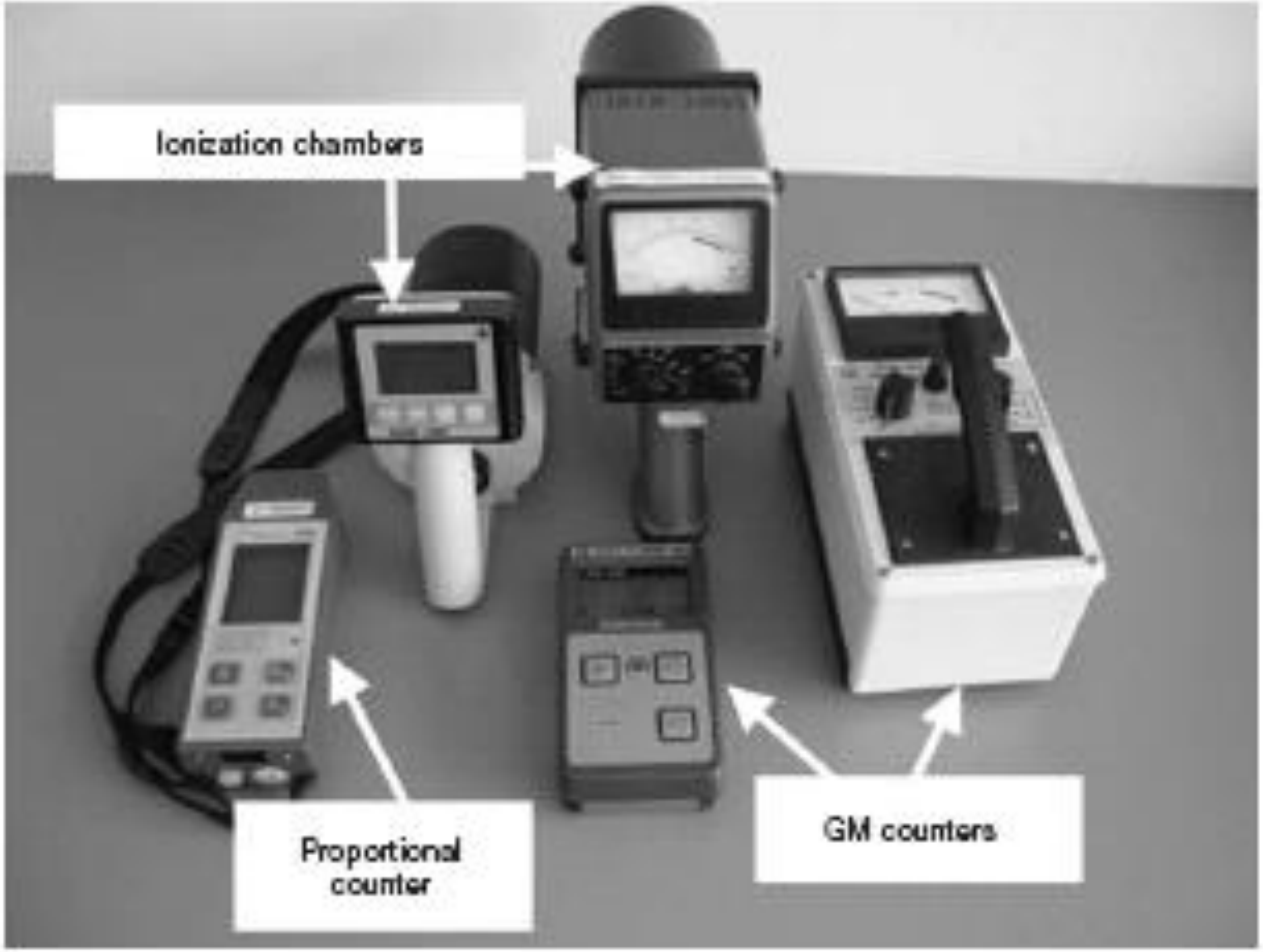
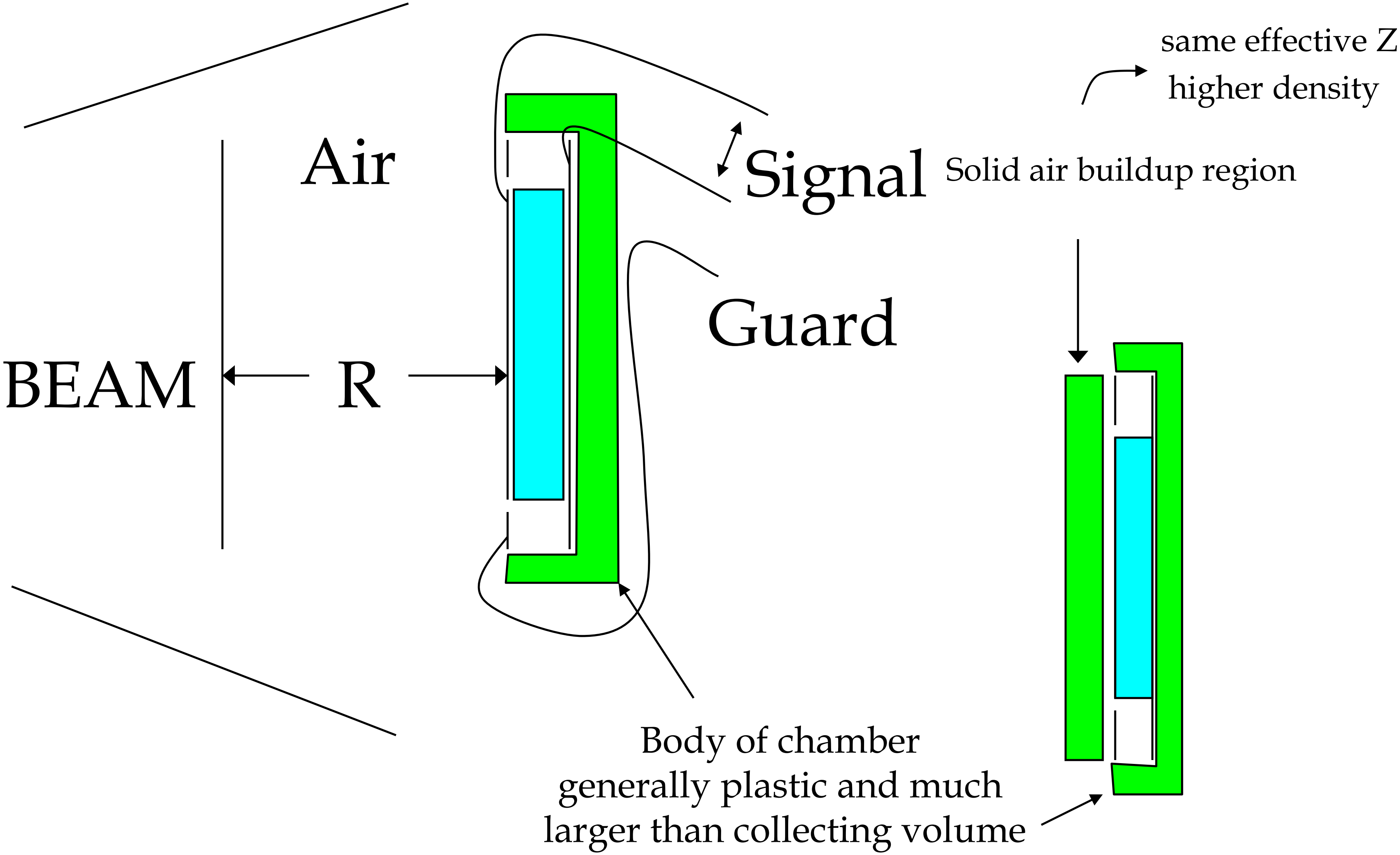


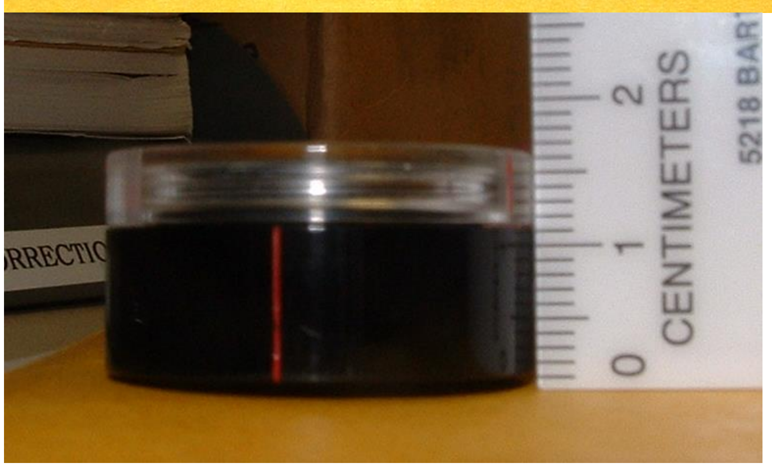

*FIG. 4.2. Area survey meters commonly used for radiation protection level measurements: ionization chambers, a proportional counter and GM counters.*

# Parallel Plate Chambers

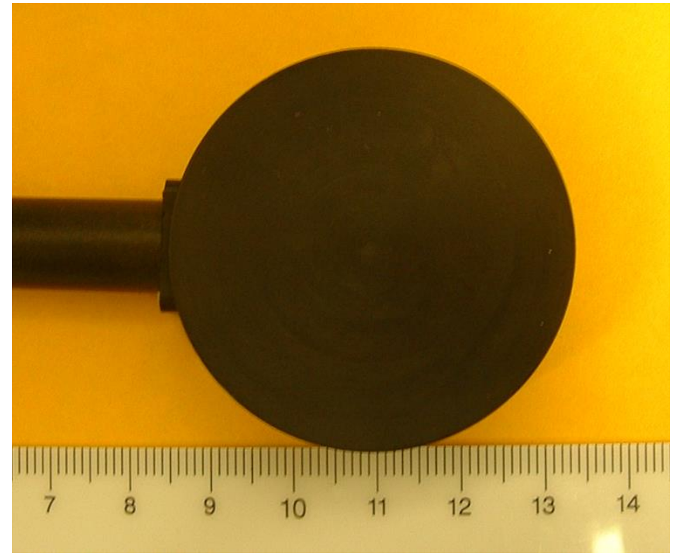


# *Parallel Plate Chambers*

Marcus Chamber



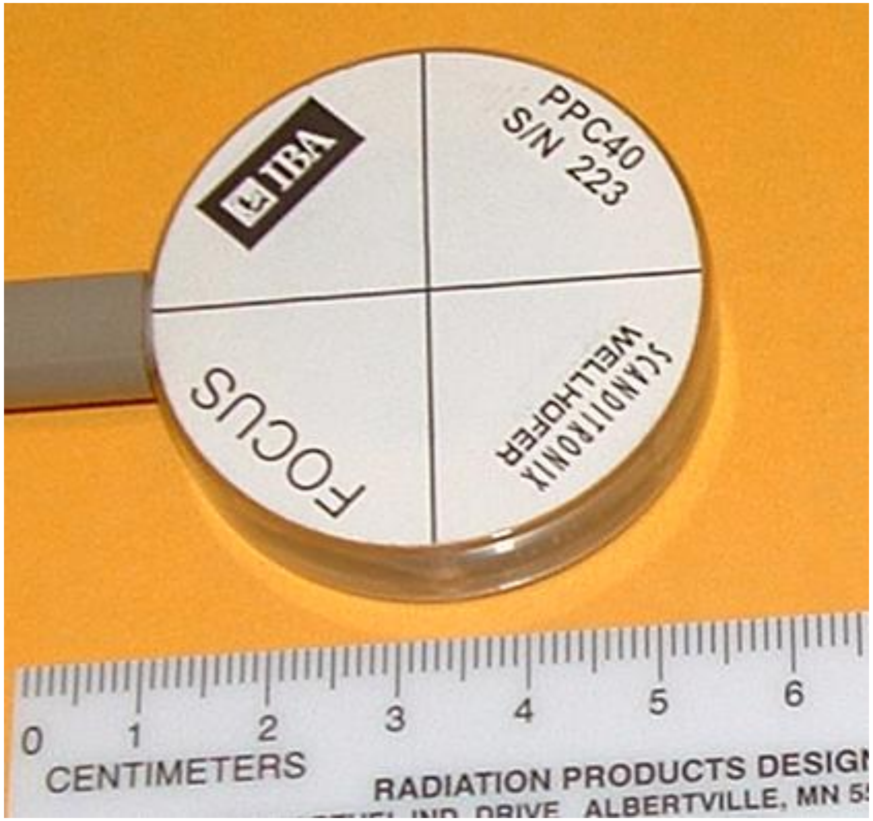

Exradin P11



# *Parallel Plate Chambers*

Roos Chamber

Front




Back

# Parallel Plate Chambers -PTW

Bragg Peak Ionization Chambers

Waterproof plane-parallel chambers for dosimetry in proton beams

more...

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Advanced Markus® Electron Chamber

Plane parallel ion chamber for high-energy electron measurements in water and solid state phantoms

more...

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Roos® Electron Chamber

Precision plane parallel chamber for absolute dosimetry of high-energy electron radiation in water and solid state phantoms

more...

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Soft X-Ray Ionization Chambers

Plane parallel chambers with thin membranes for measuring therapeutic X-rays in air and solid state phantoms

more...

# Parallel Plate Chambers-Exradin

## Parallel Plate Chambers

**Products** - Click on an image below to learn more


**Parallel Plate Chambers**

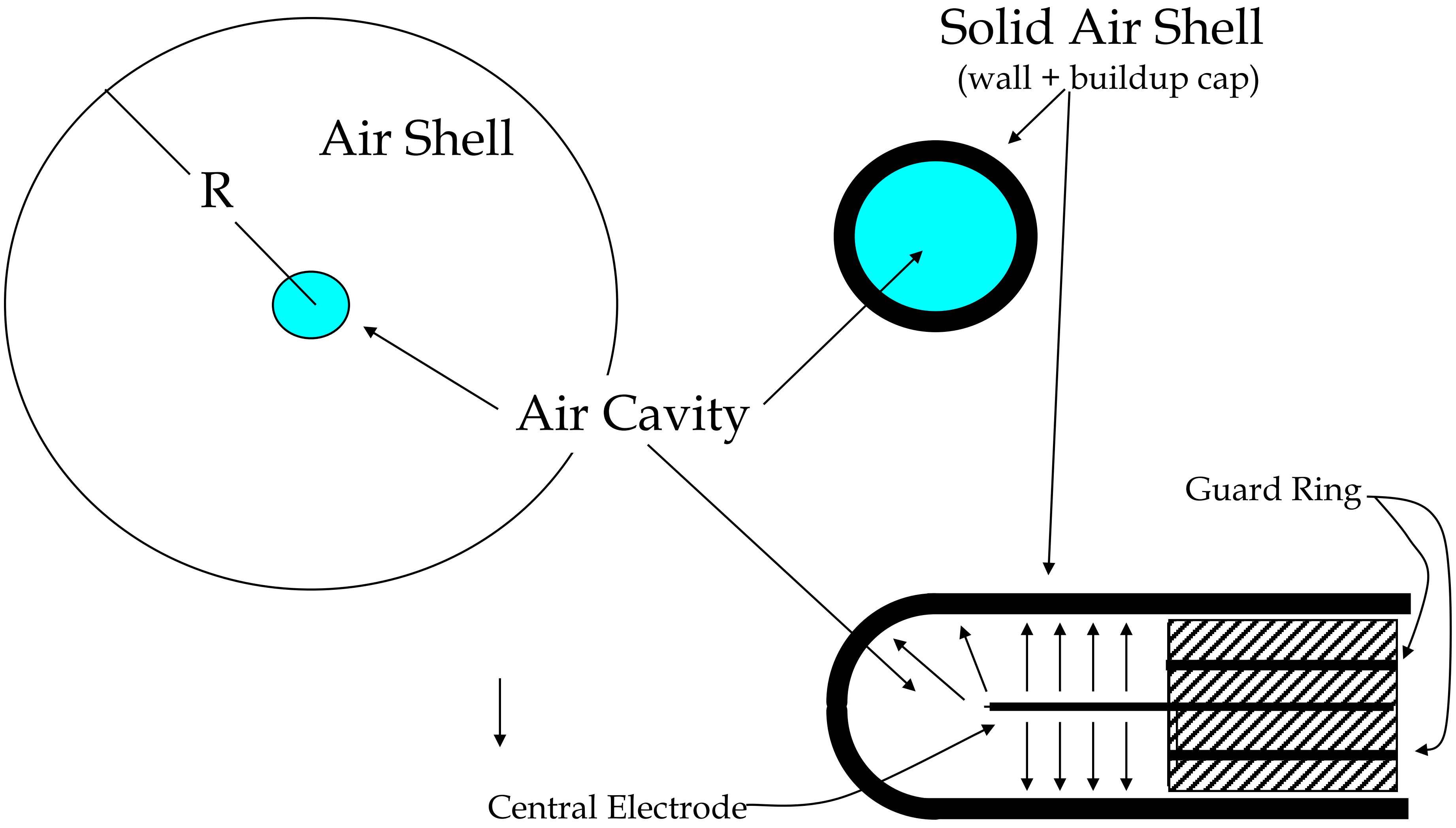
Ideal for use in:

- Routine electron beam measurements and depth-dose studies in electron and high energy photon beams … **Model A10**
- Routine electron beam measurements and depth-dose studies in electron, photon, proton, and neutron beams … **Model A11**
- Superficial therapy and low energy diagnostic beams, as well as routine electron beams and depth-dose studies and photon beams … **Model 11TW**
- All air kerma, absorbed dose, and exposure measurements … **Magna 1cc** and **Magna 3cc**

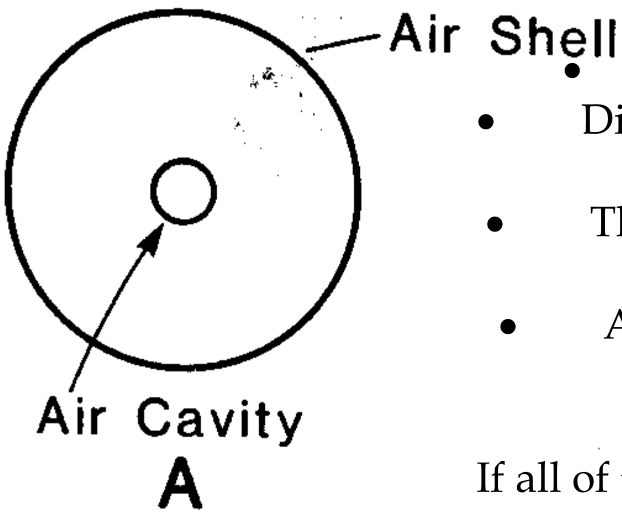
# Parallel Plate Chambers

- Can have very thin entrance windows
  - Can be used to measure very low energy beams
- Can be used near phantom surface
- Air volume (plate separation) can be made very thin, minimizing perturbations.
- Are recommended for electron measurements. Not for photons (TG-51)
  - We don't fully understand the influences of the body of the chamber
- Tend to have a strong directional dependence

# Thimble Chambers



# Thimble Chambers




Assume:

- Uniform beam of photons fully covers the chamber
- Distance between outer wall and air cavity is greater than or equal to the practical range of the electrons
- The number of electrons that enter the cavity is equal to the number that leave the air cavity
- All ions created by the electrons are collected in the cavity
- The mass of the air in the cavity is known

If all of this is true, the amount of charge we collect can be used to calculate the exposure (or dose) in the air

- If we take the “outer” air cavity in 6.3A and compress it into a “solid air shell” shown in Figure 6.3B, we have a thimble chamber. The name comes from a sewing thimble.

Thimble Central Electrode Stem

# Thimble Chamber

0.6 cc Farmer Chamber (NEL 2505)


0.08, 0.04 and 0.01 cc Chambers

# Farmer Chamber

- Most important ionization chamber used in radiotherapy.
- Construction is a graphite wall and an aluminum electrode. The total volume of the air cavity is 0.6 cc, and the cavity is open to the air.

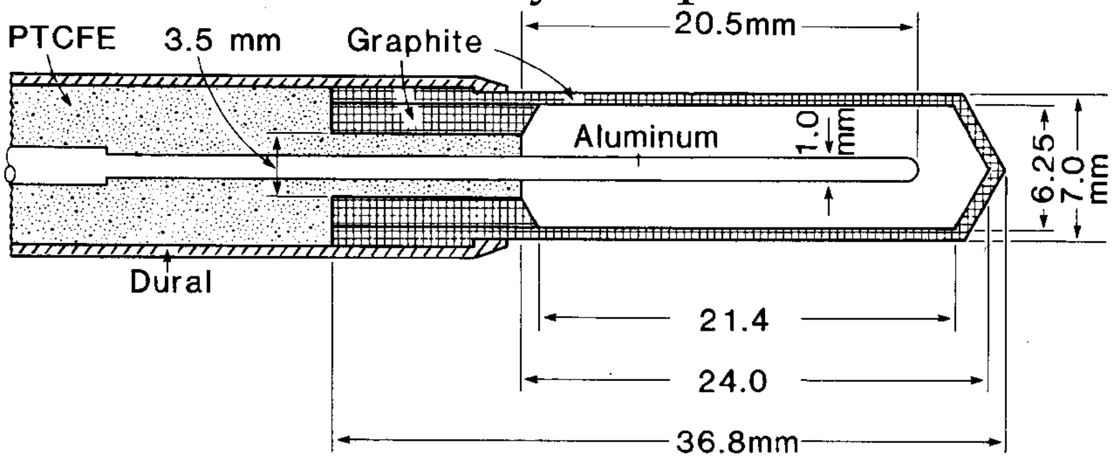



**FIG. 6.10.** Farmer graphite/aluminum chamber. Nominal air volume, 0.6 ml. PTCFE, polytrichlorofluorethylene. (Redrawn from Aird EGA, Farmer FT. The design of a thimble chamber for the Farmer dosimeter. *Phys Med Biol* 1972;17:169.)

## PTW Farmer® Ionization Chambers

**Thimble chambers for measuring high-energy photon and electron radiation in air or in phantom material**

- Vented sensitive volumes of 0.6 $cm^3$
- Suitable as therapy chambers for use in solid phantoms
- Flat energy response
- A variety of different versions is available

The 0.6 $cm^3$ PTW Farmer chambers are designed for absolute photon and electron dosimetry with therapy dosemeters. Three chamber types for measurements in air or in solid state phantom material are available:

- Type 30010 is the standard chamber. The wall material is graphite with a protective acrylic cover, and the electrode is made of Al. The nominal photon energy range is from 30 kV to 50 MV.

- Type 30011 with graphite wall and graphite electrode is used for therapy dosimetry, where a completely graphite-built chamber is required. The nominal photon energy range is from 140 kV to 50 MV.

- Type 30012 is used for therapy dosimetry, where a chamber with graphite wall and Al electrode is required. The nominal photon energy range is from 60 kV to 50 MV. The electron energy range of all chambers is from 6 MeV to 50 MeV. The chambers type 30011 and 30012 with their graphite caps are of delicate construction and should be handled with extreme care. The guard rings of all chamber types are designed up to the measuring volume. An acrylic build-up cap for in-air measurement in 60Co beams is included with each chamber, as well as a calibration certificate.

# MODEL A12 EXRADIN FARMER-TYPE CHAMBER

REF 92700

Add this item to info/quote request cart

Print Product Data Sheet

UNCOMPROMISING QUALITY

For absolute dosimetry calibrations in water, air, or other phantom material

### DESIGNED FOR ABSOLUTE DOSIMETRY CALIBRATION

Exradin Farmer-type Chambers are specifically designed for absolute dosimetry calibrations in water, air, or other phantom material. The Model A12 is completely characterized in TG 51 and TRS 398.

### FAST, PRECISE MEASUREMENTS

Its waterproof construction and two piece removable stem makes it ideal for use in water phantoms. The chamber vents through a flexible tube that surrounds the triaxial cable, ensuring the collecting volume is in pressure equilibrium with the surroundings. The design assures there are no stem or voltage soakage effects, providing precise and reliable measurements.

### DURABLE CONSTRUCTION, BUILT TO LAST

Farmer-type Chambers are constructed of rugged C552 Shonka air-equivalent plastic, providing excellent conductivity and years of reliable use. Rigorous one meter drop test proves ruggedness and reliability.

Model A12 Exradin Farmer-type Chamber

## Features and Benefits

- Proven guard design yields stable, precise measurements and minimizes settling time by creating uniform field lines
- Shell, collector, and guard are made of durable, long lasting Shonka conductive plastic
- Use of homogeneous material throughout the chamber minimizes perturbation of the beam due to the presence of the chamber and optimizes measurements
- Axially symmetric design of the chamber provides an uniform, isotropic response
- Inherent waterproof construction eliminates need for additional protective coverings
- Two separate stem pieces of 5.1 cm and 12.7 cm can be coupled together for ease of use
- A matching 2.8 mm thick $^{60}$Co build-up cap of C552 Shonka air-equivalent plastic is provided for air calibrations and measurements
- Additional build-up caps of Delrin and brass are available
- Ionization collection efficiency is 99.9% or better

## Waterproof PTW Farmer® Chamber

**Waterproof thimble chamber for measuring high-energy photon and electron radiation in water**

- Vented sensitive volume of 0.6 $cm^3$
- Suitable as therapy chamber for use in water
- Flat energy response

The 0.6 $cm^3$ PTW Farmer chamber type 30013 is a waterproof standard chamber for absolute photon and electron dosimetry with therapy dosemeters to be used in water or in solid-state material. The nominal photon energy range is from 30 kV to 50 MV, the electron energy range is from 6 MeV to 50 MeV. This chamber type is of rugged construction, since the wall material is graphite with a protective acrylic cover and the electrode is made of aluminum. The guard ring is designed up to the measuring volume. The chamber is supplied with a cable of 1m length. Different connector types are available. A calibration certificate for calibration in absorbed dose to water or air kerma is included with each chamber. Air density correction is required for each measurement. A radioactive check device is available as an option.

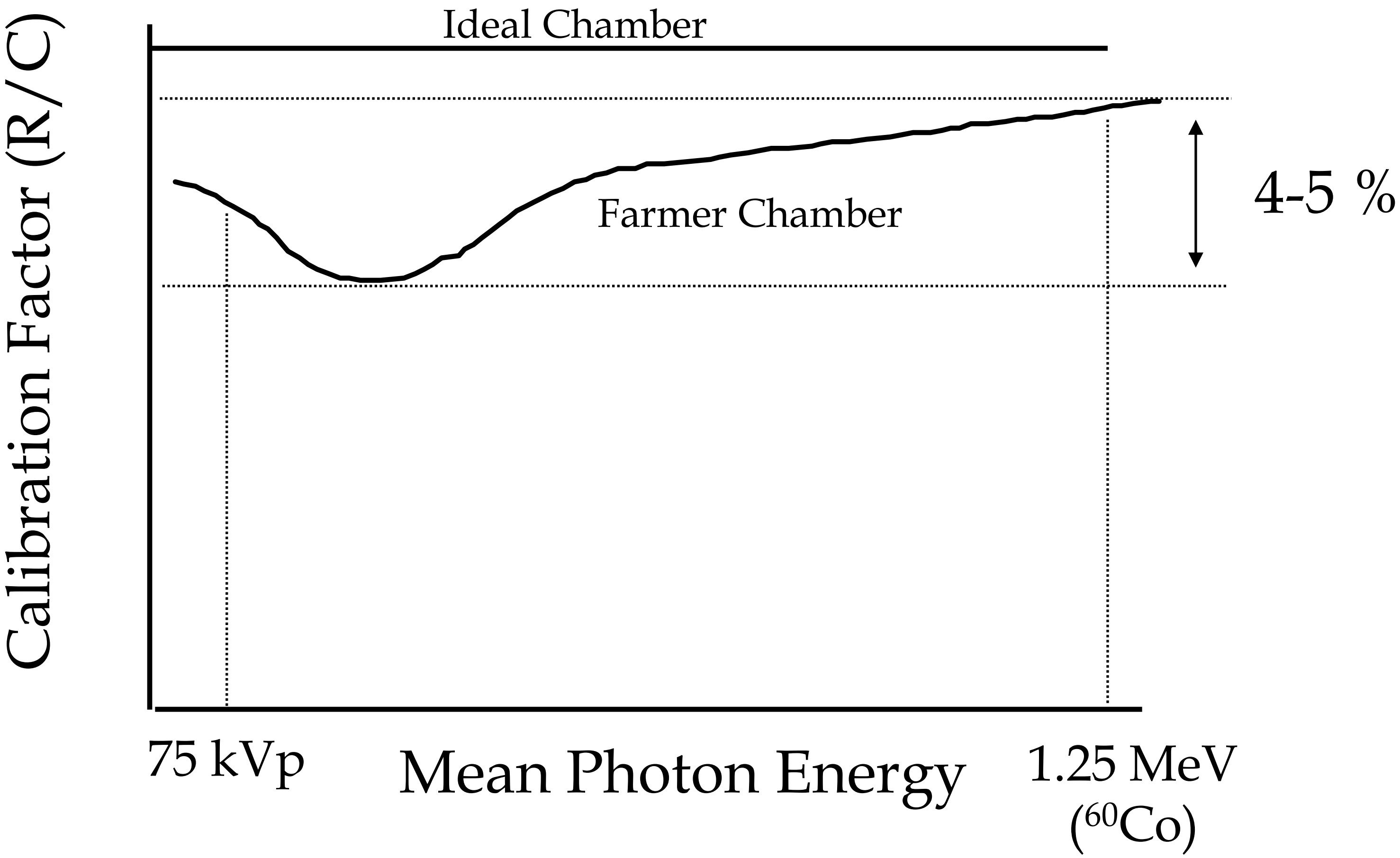
# Operating Characteristics

- energy response
- volume
- directional dependence
- stem leakage
- ion-recombination
- polarity effect

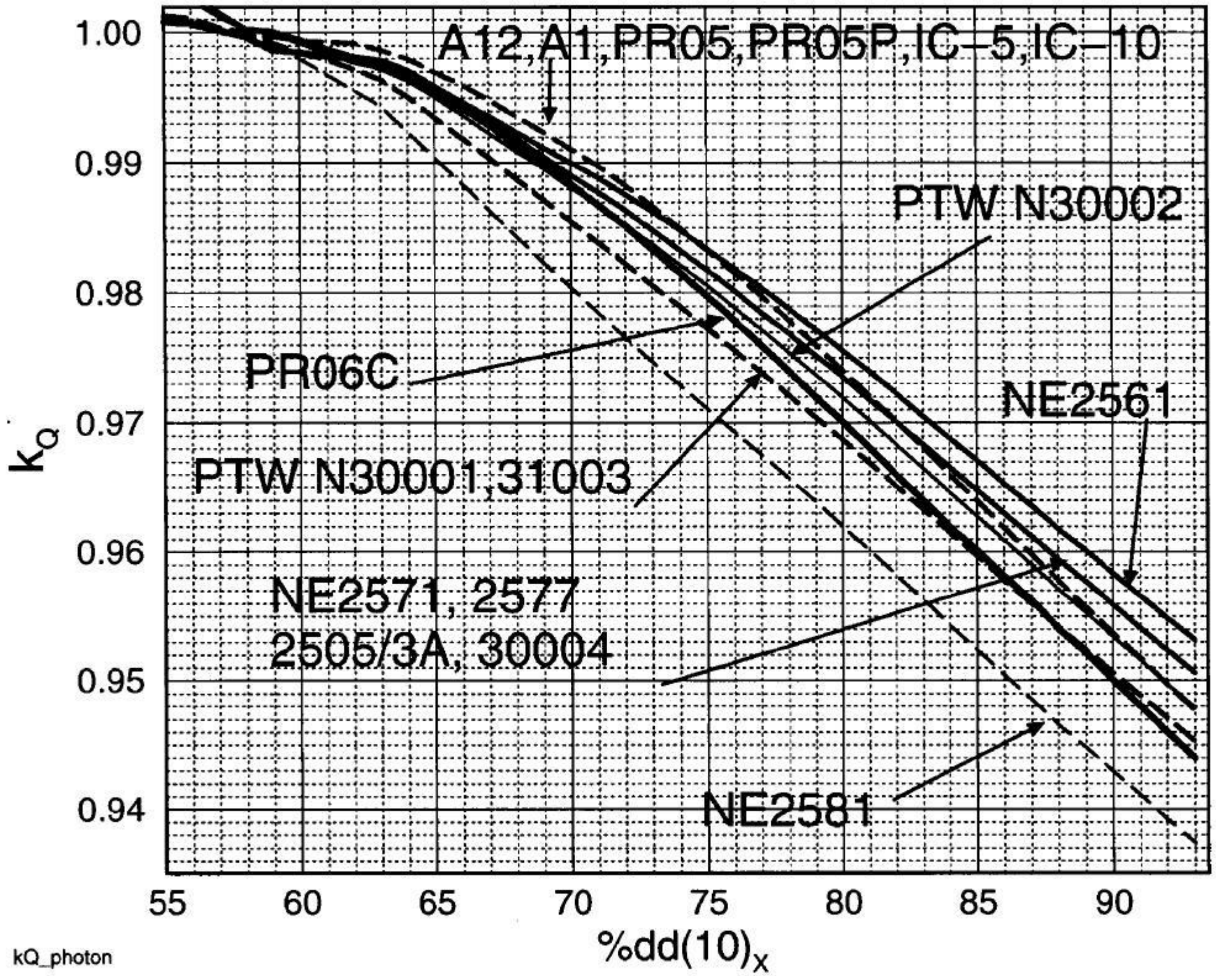
# *Energy Response*

- The ideal chamber will give the same signal per unit R (or Air-Kerma) regardless of the energy of the incoming photons
- Real Chambers respond differently to different energies
  - Due to wall material
  - Due to central electrode material
- Chambers have been designed to minimize these at therapeutic energies

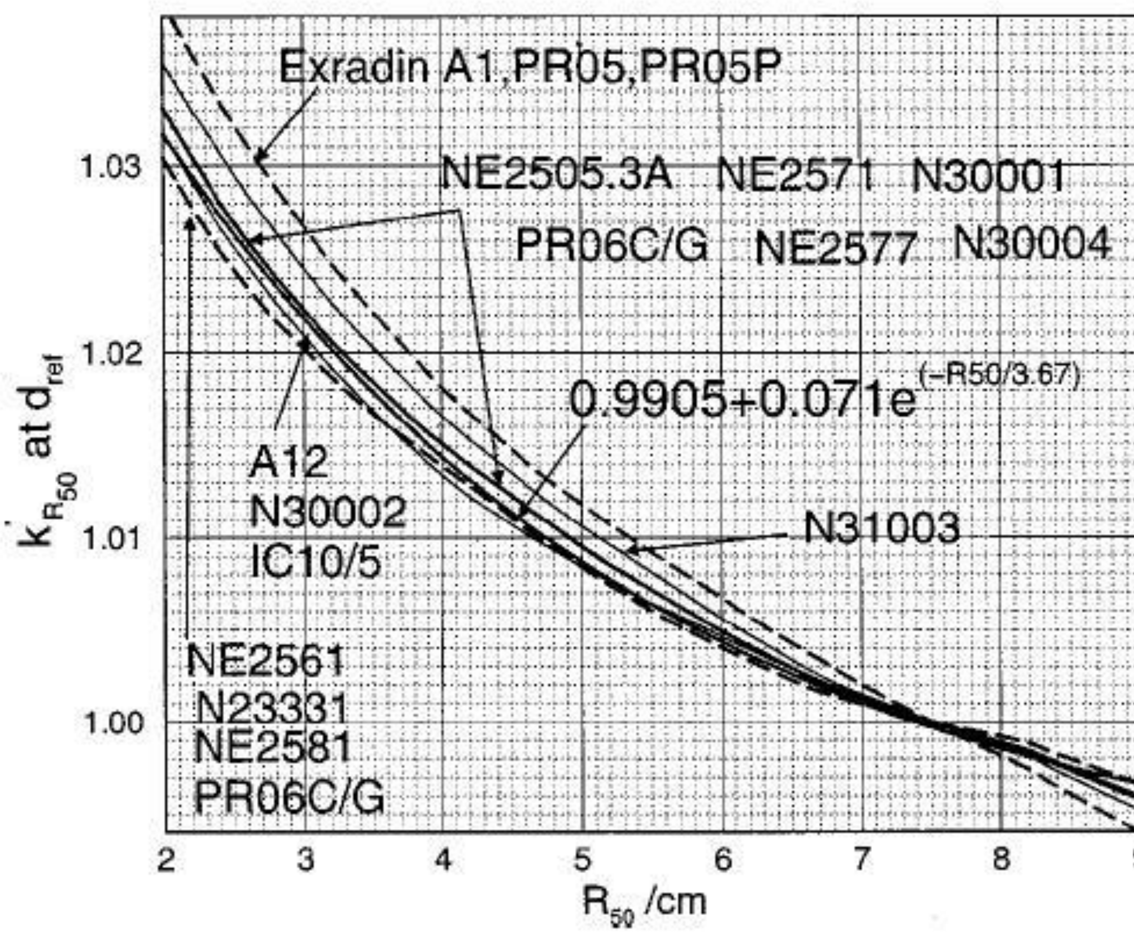
# Photon Energy Response



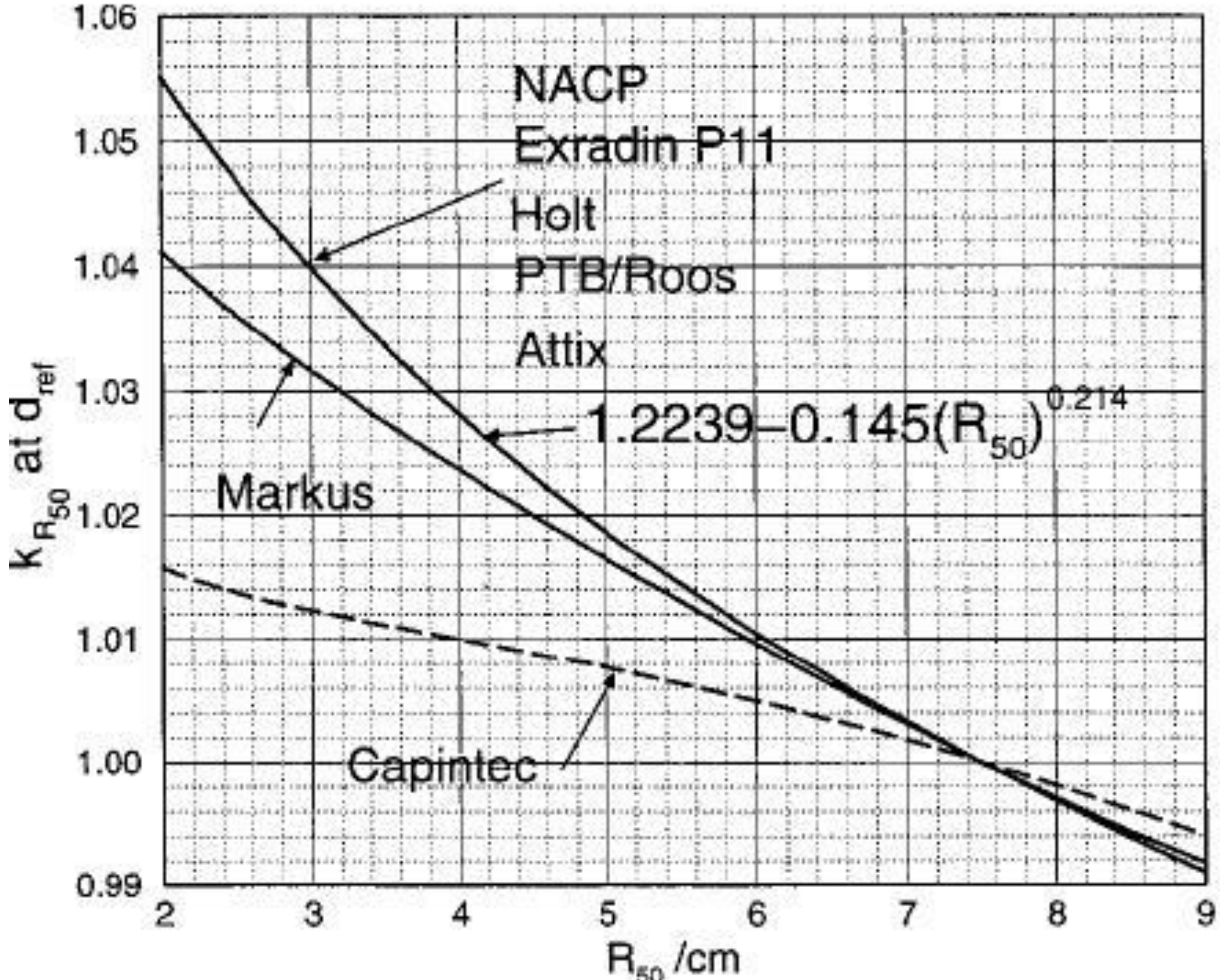
# *Photon Energy Response for cylindrical chamber (TG51)*



# *Electron Energy Response for cylindrical chamber (TG51)*



# *Energy Response for parallel plate chamber (TG51)*



# Collecting Volume

The signal produced from a chamber is directly proportional to the volume of the chamber

- 200 cGy delivered to a typical farmer chamber will give a nominal reading of $2 \times 10^{-8}$ C. ($3 \times 10^{-10}$ A) (the current to run a 60 Watt light bulb is one billion times greater)
- 200 cGy Delivered to a 0.1 cc Chamber will give 1/6th the signal
- Trade off
  - Signal vs spatial resolution
  - Signal vs beam perturbation

# Directional Dependence

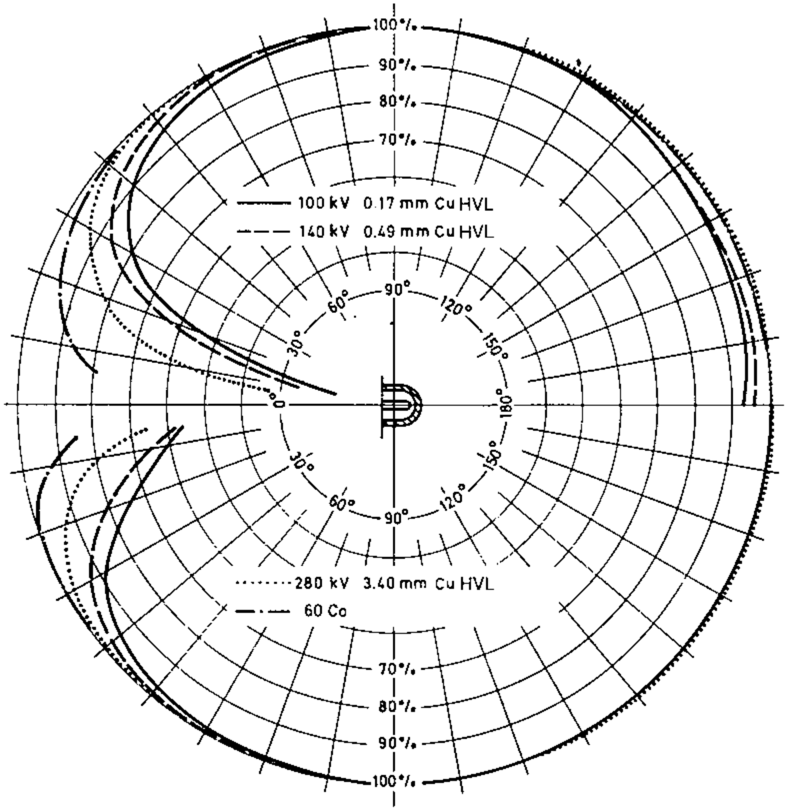
The sensitivity of the chamber as a function of orientation in the beam

- Depends strongly on chamber type
- Nearly all chambers have at least one “bad” orientation
- Is a function of type/energy of radiation
- Provided by the manufacturer of the chamber
- Is often intuitive

# Direction Dependence

Typical Thimble Chamber:

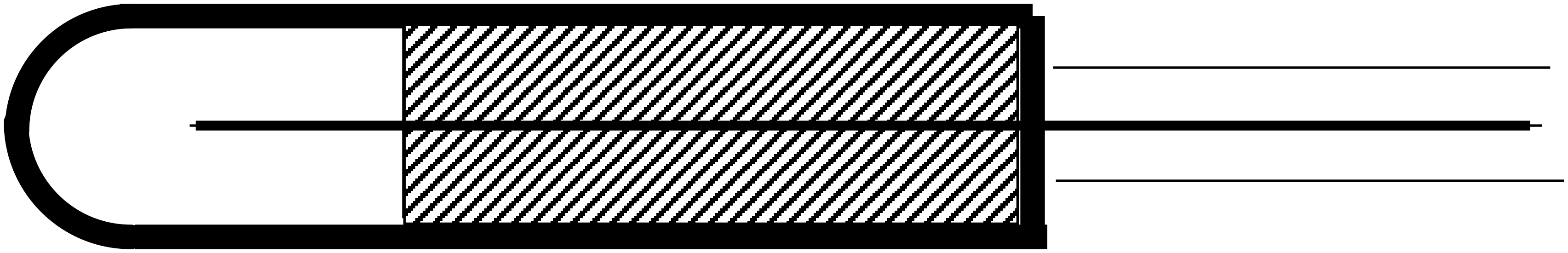
in air




in PMMA

# Stem Effect

Signal produced outside of the active volume



Intentionally Sensitive Volume

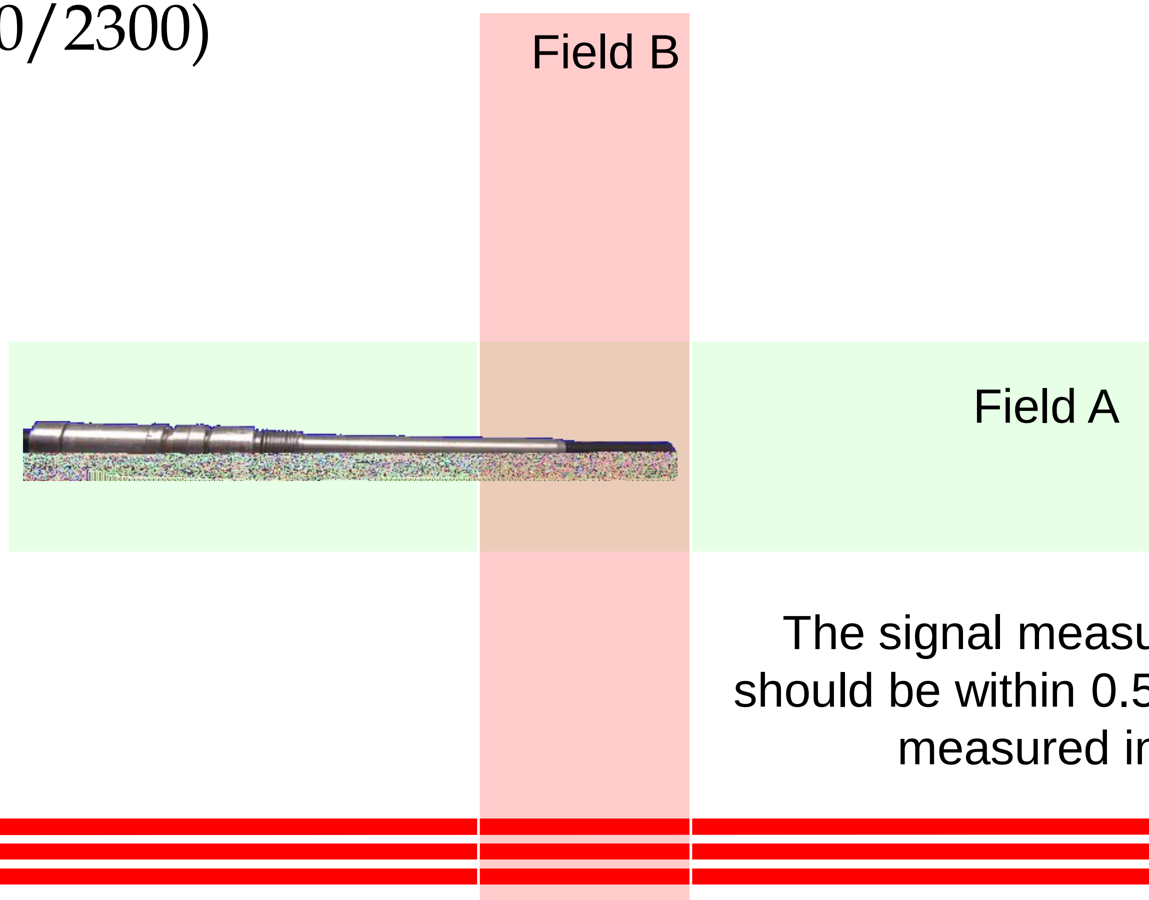
Radiation can induce signal in stem region

Radiation can induce signal in the cable

- Not a problem for most modern dosimetry equipment

# Measurement of Stem Effect

Stem effect can be measured by irradiating the thimble and stem and then rotating the collimator to irradiate only the thimble. Remember to rotate the collimator rather than changing the jaws since changing the jaws can change the output by up to 3% (Varian 2100/2300)




The signal measured in field A should be within 0.5% of the signal measured in field B

# Polarity Effect

The difference in the magnitude of the charge collected when the polarity of the collecting voltage is reversed

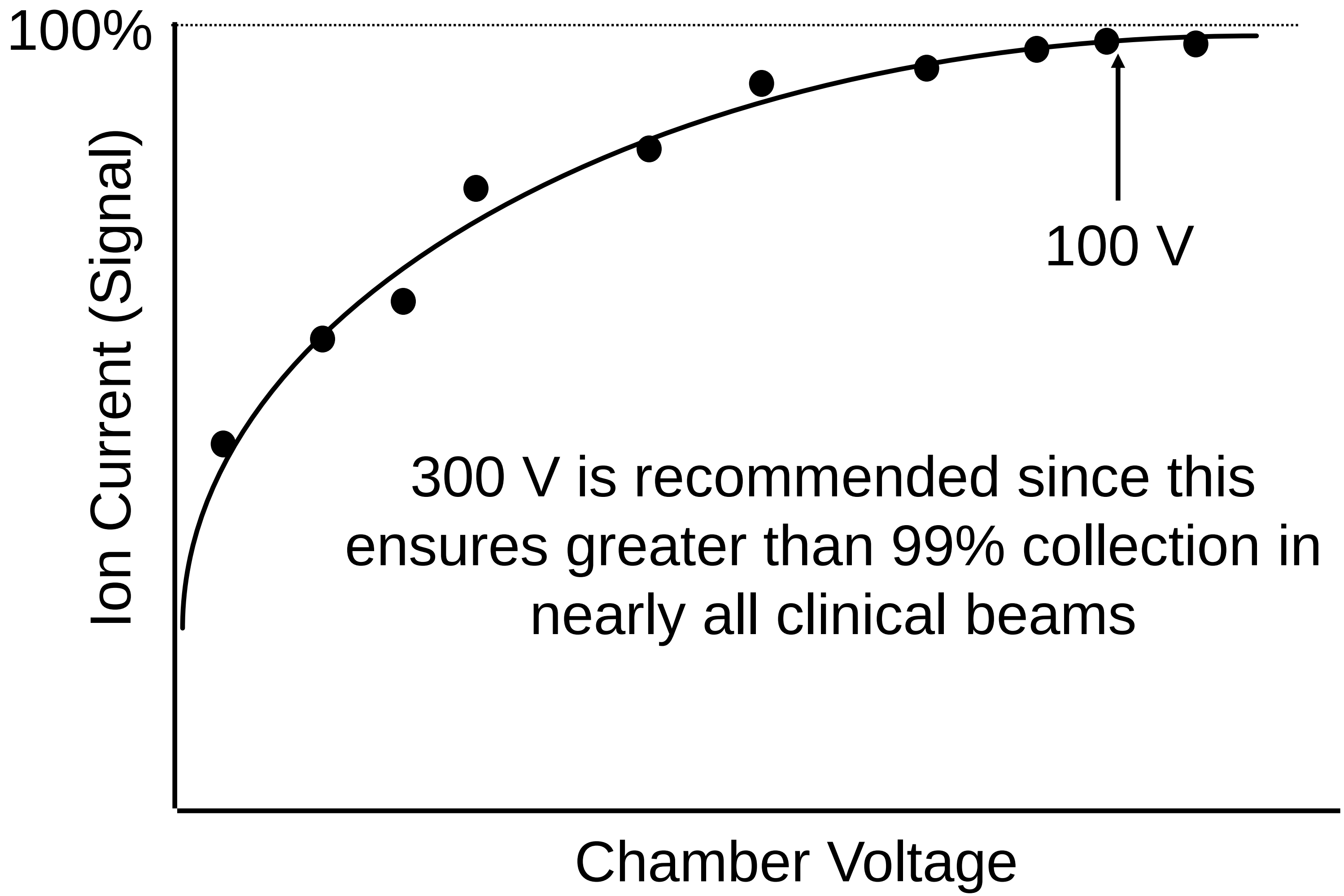
- Caused by electrons stopping in collector
- Extracameral current: (stem effect)
- Tend to be more severe for $e^-$ beams
- Should be measured at the time of calibration, at the location of calibration, in the beam being calibrated
- TG51 says ignore this if it is less than 0.5%
  - For most equipment this means all photon beams and electron beams of 10 MeV or greater.
- Is a large concern in TBI verification where large portions of the cable are irradiated

# Collection Efficiency

The fraction of ions produced in the chamber that are collected before recombination.

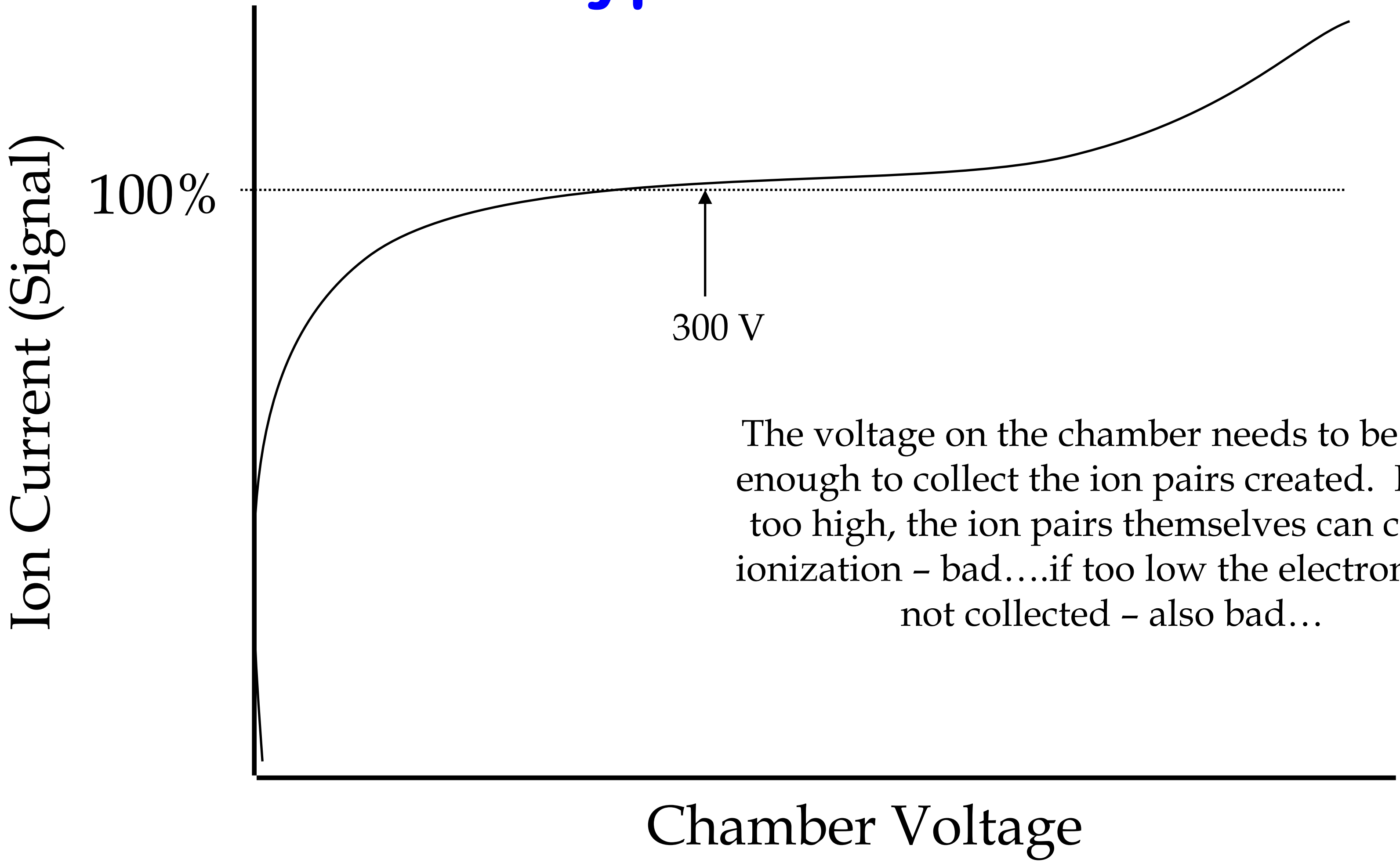
- Is a function of chamber size
- Is a function of chamber geometry
- Is a function of instantaneous exposure rate
  - Continuos Radiation
  - Pulsed radiation
  - Scanned/Pulsed Radiation
- Is a function of bias voltage

# Collection Efficiency



# Collection Efficiency

## typical linac




The voltage on the chamber needs to be high enough to collect the ion pairs created. If it is too high, the ion pairs themselves can cause ionization – bad….if too low the electrons are not collected – also bad…

# Ion recombination

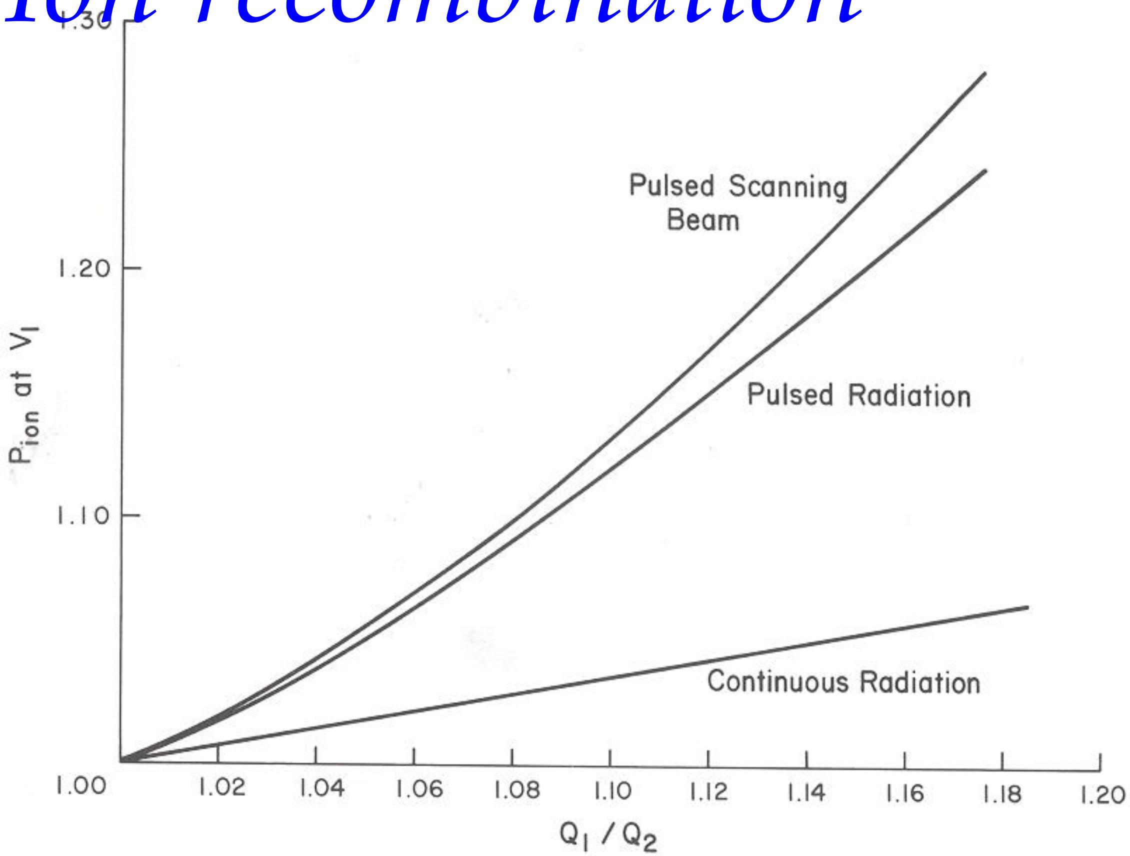



**FIG. 6.17.** Ion recombination correction factors ($P_{ion}$) for continuous radiation ($Co^{60}$, Van de Graaff), pulsed radiation (accelerator-produced x-rays and electron beams), and pulsed scanning beams. These data are applicable when $V_1 = 2V_2$. (From AAPM. A protocol for the determination of absorbed dose from high-energy photon and electron beams. *Med Phys* 1983;10:741, with permission.)

Even if the voltage is properly set, some ions may find a mate and undergo recombina-tion. The collection efficiency is the ratio of the number of ions collected to the number produced. This effect should be less than 0.5%

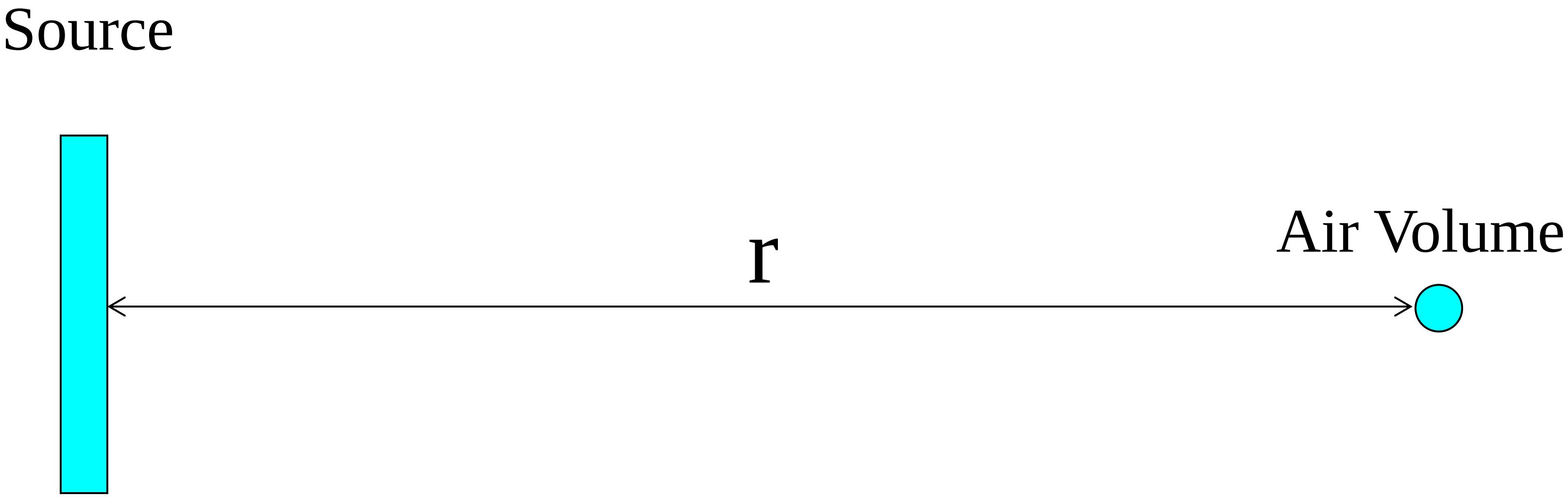
$$P_{ion}(V_H) = 1 - \frac{V_H / V_L}{M_{raw}^H / M_{raw}^L - (V_H / V_L)}$$

# *Brachytherapy Equipment*

# Reminder : Air Kerma Strength

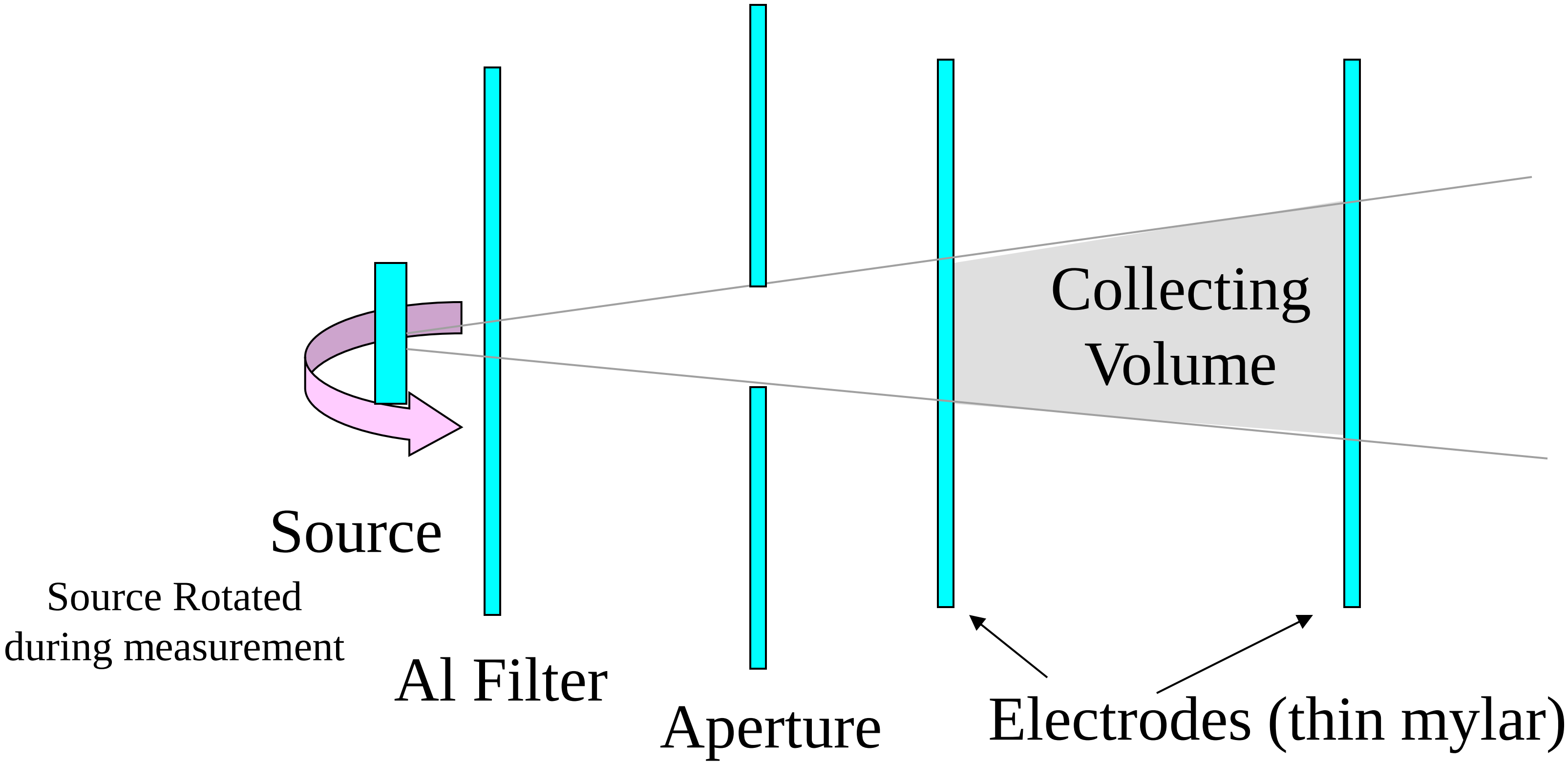
$$S_k = r^2 \, (dK(r)/dt) < \mu Gy \; m^2/h >$$

The product of the Air-Kerma Rate and the square of the calibration distance assumed in vacuum and measured along the transverse bisector of the source.



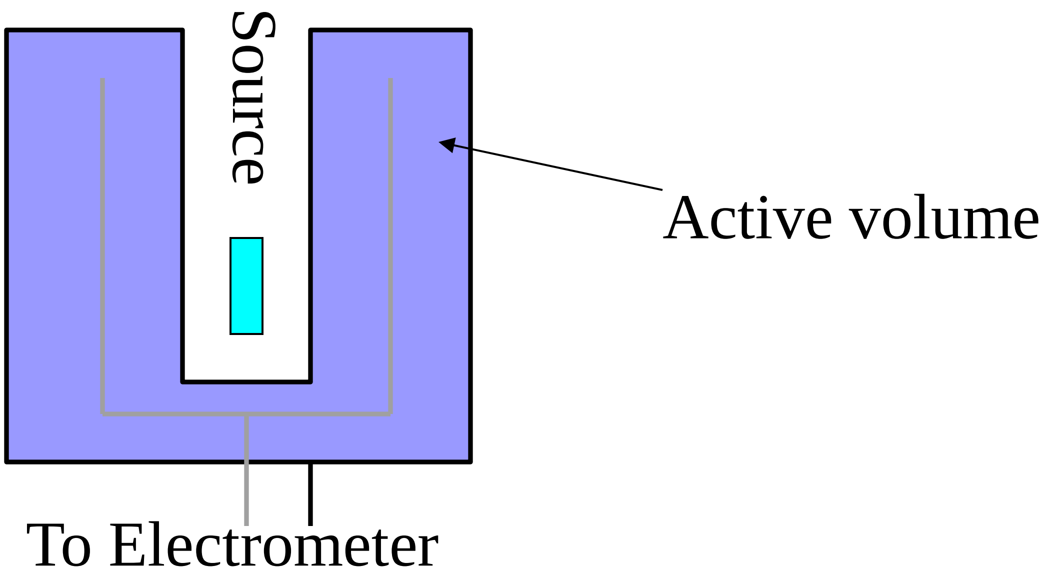
# How NIST Measures Air Kerma Strength

## Wide Angle Free Air Chamber (WAFAC NIST99)



# How we measure Air Kerma Strength

We use a transfer standard, for low energy, nearly always a well chamber, calibrated by an ADCL or by the end users with a seed calibrated by the ADCL. The ADCL uses a well chamber to transfer calibrations from the WAFAC at NIST. NIST calibrations are transferred using at least three seeds of a given design. The calibration is transferred to a customer using a single seed. All U.S. low energy calibrations start at NIST.



# Standard Imaging HDR-1000+

Very common chamber, big well, single seed or batch calibration, Seed holders available, relatively poor signal to noise.

Capintec Nuclear medicine Dose Calibrator: lots of signal, big well, lots of choices for check geometry (batch calibration), Not designed for high precision work. If shared with Nuc Med can become contaminated, can have high background.

# *Desirable Chamber Characteristics*

1. Response is independent of photon energy for a given dose
2. Chamber volume should be large enough to give a good signal
3. Response is independent of the direction of the photon beam on the active volume
4. No response should be observed when the non-active volume is irradiated
5. All of the ion pairs created in the chamber should be measured

# Electrometers

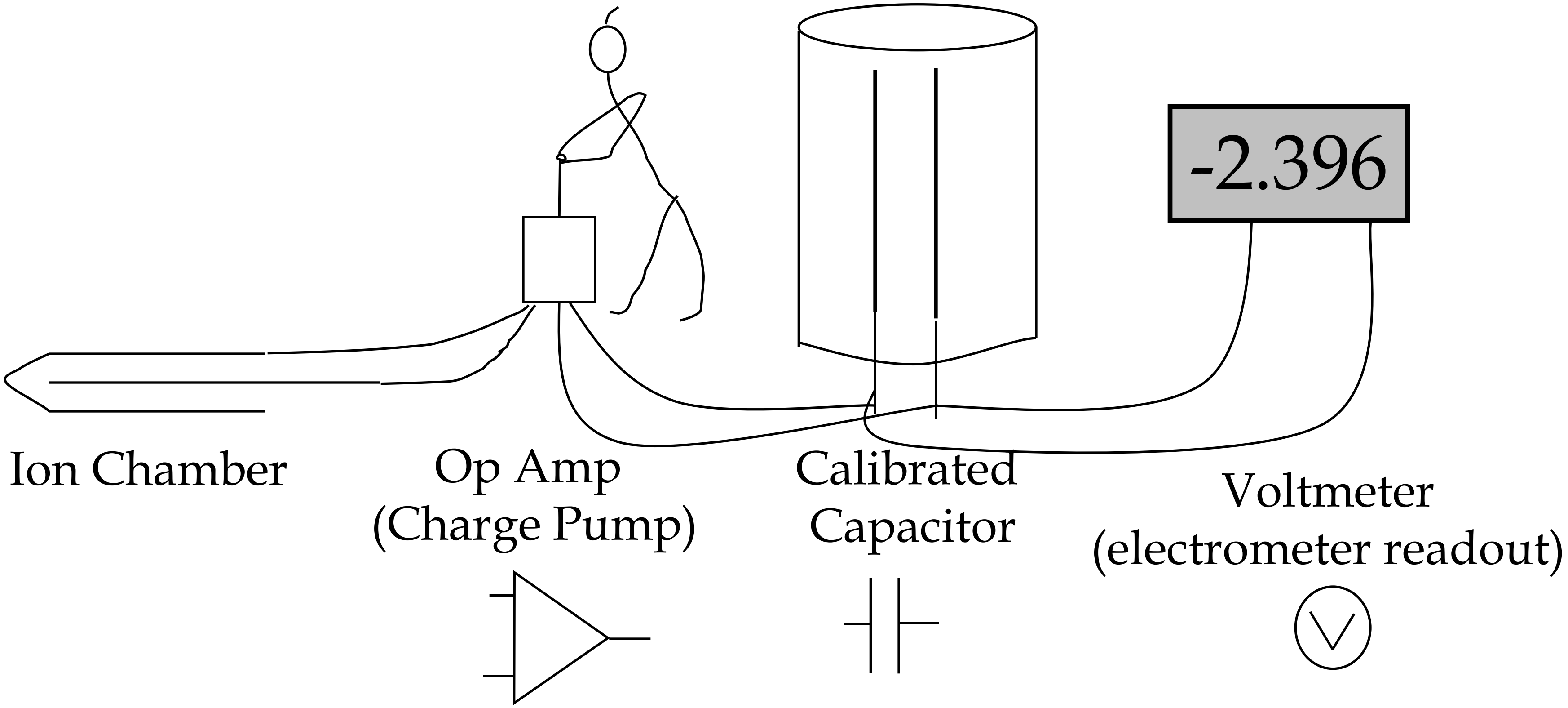


# Electrometers (Op-Amp)

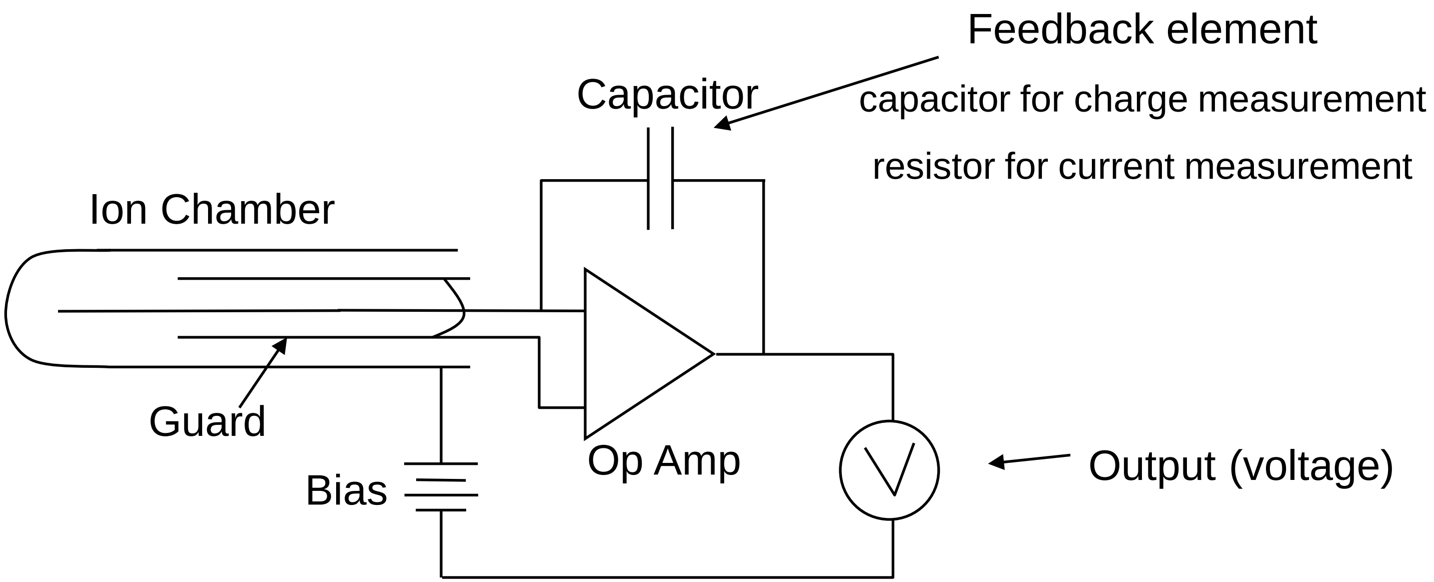
- All modern electrometers are Op-Amp feedback type
- Electrometer calibrations are NIST traceable, electrometers need to be calibrated at least as often as ion-chambers.
- Cost doesn’t = Quality

# Electrometers (Op-Amp)

Capacitor equation: $Q = C \cdot V$



# Electrometers (Op-Amp)



# Environmental Conditions

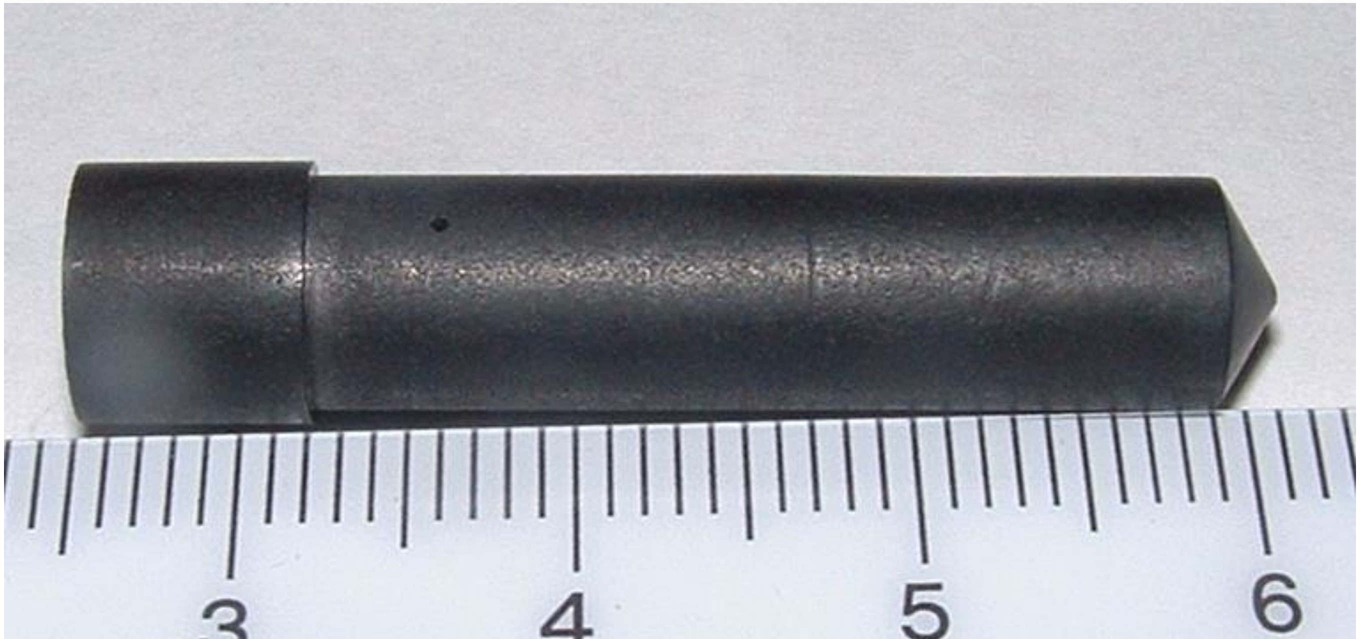
- Exposure is Charge/unit mass of air
- chamber volume is fixed
- density of air is a function of temperature, pressure and humidity
- the mass of air in the chamber is a function of temperature pressure and humidity

# Environmental Conditions

- If humidity is high enough to cause a significant problem chamber leakage will result
- We correct for temperature and pressure using the ideal gas law to correct the signal from the chamber to the signal that would be present at $22^{o}$ C, 760 mm Hg

# Temperature Pressure Correction

$$K_{T,P} = \left(\frac{760mmHg}{\mathrm{Pressure}}\right) \bullet \left(\frac{273.15 + Temp}{295.15Kelvin}\right)$$



scale in centimeters

# Barometers


Aneroid

convenient but need to be calibrated/verified at least every 6 months

Mercury

Absolute standard but require gravity and temperature corrections

# Digital Barometers

**$ 2,290.00** DPI740-KIT

- Two Cases Standard
- NIST Traceable Calibration Standard
- Very High Accuracy, 0.02% FS
- Absolute or Sea Level Reference Barometric Pressure
- Altitude Mode with Local Height and Temperature Corrections
- Stability Better than 100 PPM per Year
- Standard RS-232 Communications

View related products - Pressure Transducers

- Must be traceable
- Must have adequate resolution and accuracy
- Should be designed as a standard instrument
- Resolution ≠ Accuracy

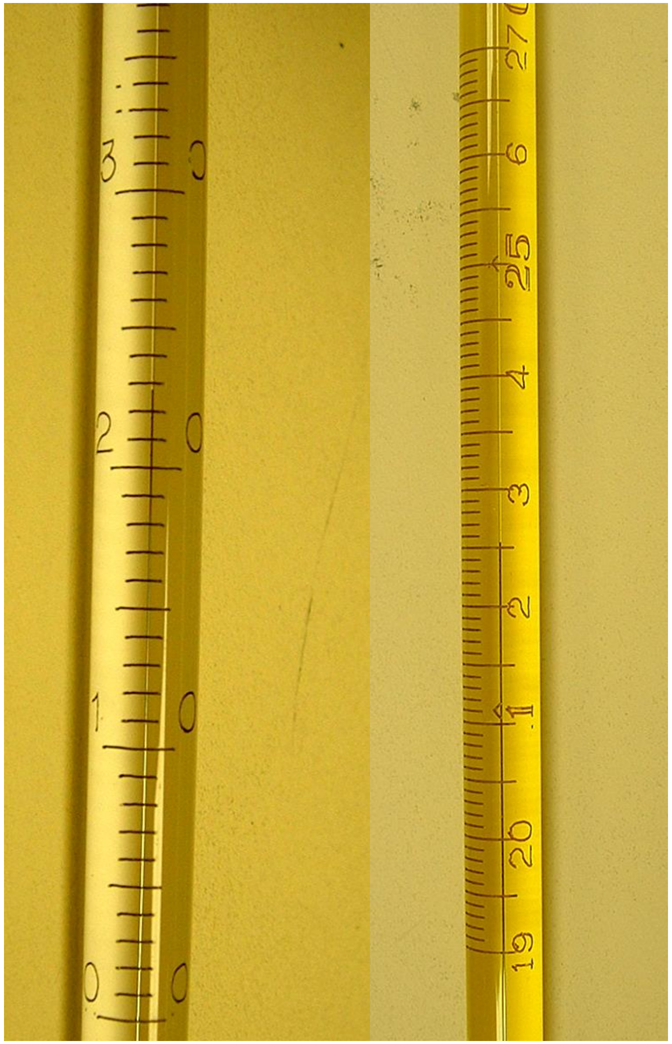
| TRACEABLE® HANDHELD DIGITAL BAROMETER | |
|---|---|
| Item # | Description |
| 469-005 | Traceable® Handheld Digital Barometer |

The Handheld Digital Barometer measures altitude, temperature, and barometric pressure. It also has a stopwatch/time-of-day clock and graphically displays the barometric pressure trend. A Traceable Certificate is provided to indicate instrument traceability to NIST (National Institute of Standards and Technology).

Barometer
Measures barometric pressure from 15.90 to 31.01 in inches of mercury (inHg) with a resolution of 0.03 inHg and from 400 to 1070 millibars (mbar) with a resolution of 1 mbar. Accuracy is ±0.1477 inHG (± 5 mbar). Display may be switched to inHg or mbar.

Barometric pressure trend shows present readings and previous 2, 4, 6, 8, 10, and 12 hours in bar-chart format. Barometric pressure reading is updated every 15 minutes.

# Thermometers



- Mercury are the best
- Other thermometers should be compared to a Hg at least every 6 months
- Should be NIST traceable
- Should be selected for the temperature range and precision necessary to accomplish your task

remember 1$^{o}$ C = 0.3% change in calibration

# Digital Thermometer

### Traceable® Mini Digital Thermometer with NIST Certificate

Item #: T100-4045
Manufacturer: Control Company
Manufacturer Item #: 4045
Product Type: Digital Thermometers
Price: $49.95
**In Stock**

BUY NOW

Product Rating:
Read 1 Review / Write a Review

**Traceable® Mini Digital Thermometer With NIST Certificate**

### Features & Applications:

The Traceable® Mini Digital Thermometer monitors temperature up to 500.8°F around the clock. One AAA battery runs continuously for 1 year. A rang alarm can be set to monitor temperature measurement and will alert when the temperature falls or climbs out of range. The one-half-inch display is readable from 10 feet.

All Traceable® Thermometers are provided with an individually serial-numbered Traceable® Certificate indicating instrument traceability to standards provided by NIST.

**Features:**

- NIST Traceable Certificate
- Always ON monitoring
- °F or °C temperature conversion
- Programmable Range Alarm
- Stainless steel probe clips to unit for handy storage
- Flip-open stand for bench use
- AAA battery

- Resolution ≠ Accuracy

# *Notes on Temperature and Pressure Measurements*

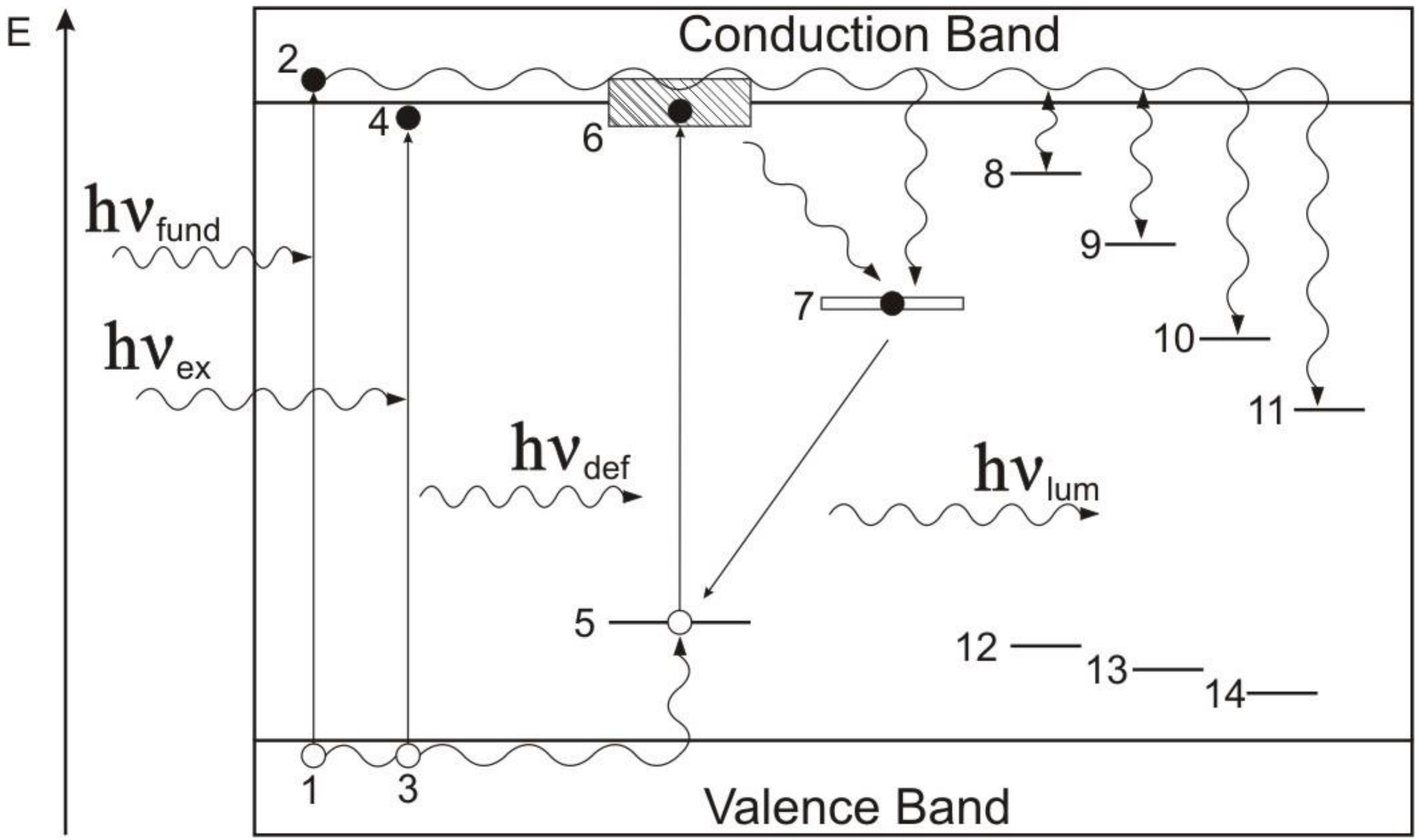
- Temperature should be measured in phantom
  - Plastic phantoms left in a radiation room are at the long term average temperature of the room, it is not uncommon for this to be greater than
    3$^{o}$C (1 %) different from air temperature
  - The air in the chamber will be at phantom temperature within 5 minutes of the chamber being placed in the phantom.
  - Digital thermometers should be calibrated at least annually against a “standard” thermometer
- Pressure reading should be verified at least annually against a mercury barometer, the mercury barometer readings should be corrected for temperature and gravity.

# *OTHER RADIATION DETECTORS*

# *Semi-conductor based trapped energy dosimeters*

- When a semiconductor is irradiated electrons are elevated from the Valence band to the conduction band.
- Most of the electrons fall back to the valance band emitting a photon of the energy difference between the conduction and valance band (generally in the visible light range)
- Some of these electrons get caught in energy traps rather than immediately falling back to the valance band.
- These electrons can be raised back to the conduction band at a later time
  - Requires less energy than raising from Valance Band
  - The fall from the conduction band emits photons
  - Measuring these photons tells us how much radiation the semiconductor was exposed to

# Semi-conductor based trapped energy dosimeters




**Luminescence Properties of AlN Ceramics and Its Potential Application for Solid State Dosimetry**

*By Laima Trinkler and Baiba Berzina*

*DOI: 10.5772/18658*

# Thermo-luminescent Dosimter (TLD)

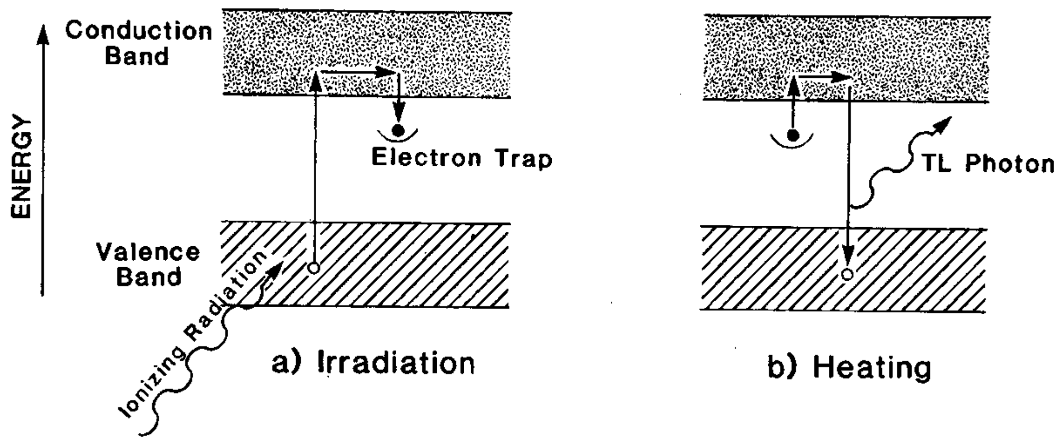



**FIG. 8.11.** A simplified energy-level diagram to illustrate thermoluminescence process.

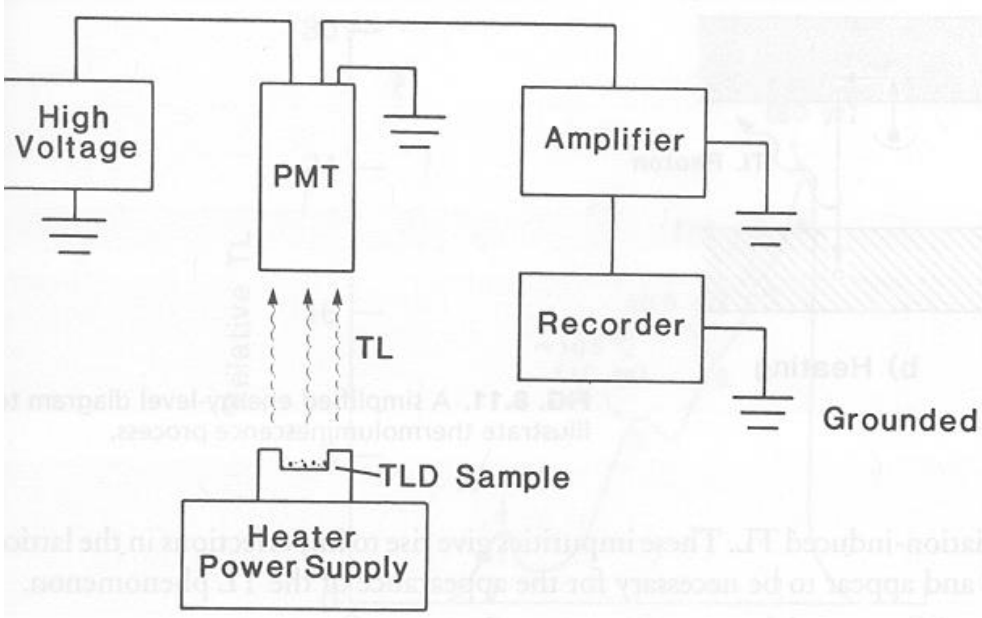
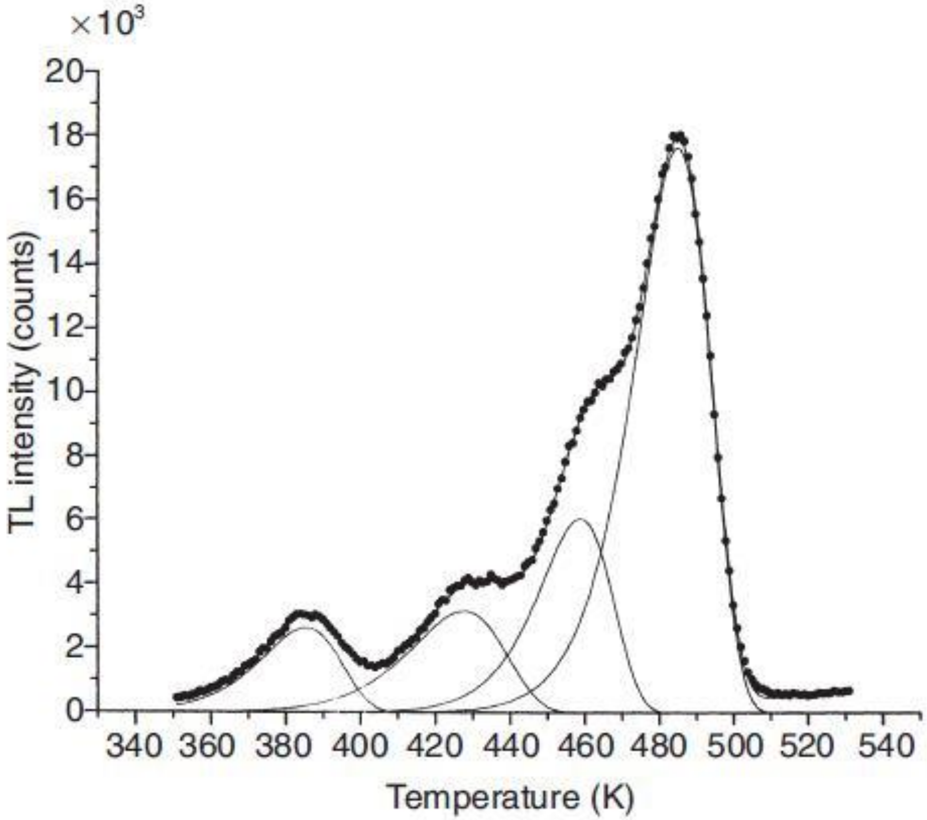



**FIG. 8.10.** Schematic diagram showing apparatus for measuring thermoluminescence.

# TLD glow curve

Dose response relationship for TLD



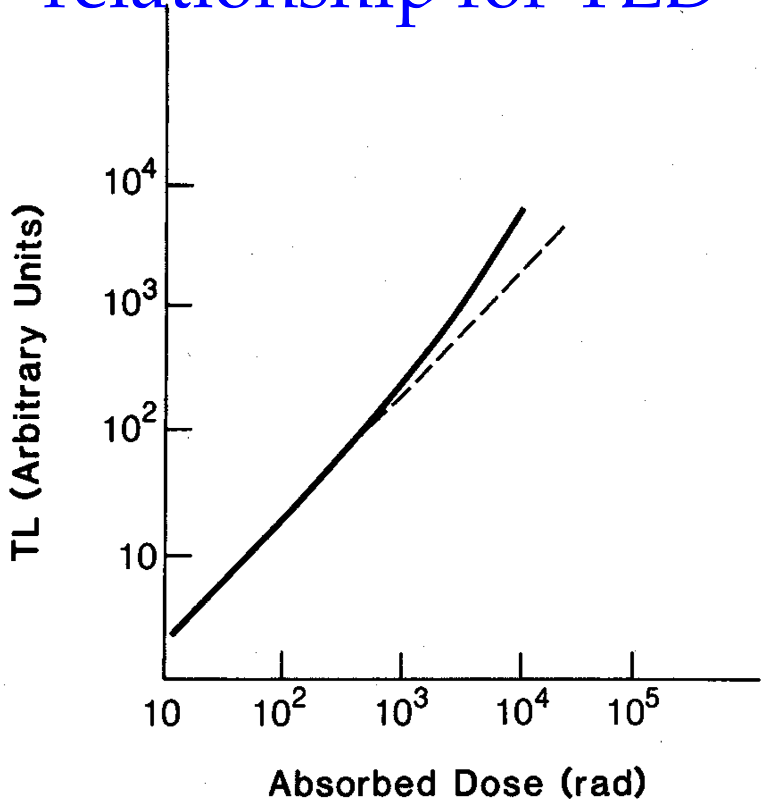




**FIG. 8.13.** An example of TL versus absorbed dose curve for TLD-100 powder (schematic).

# Optically Stimulated Luminescence Dosimeters(OSL)

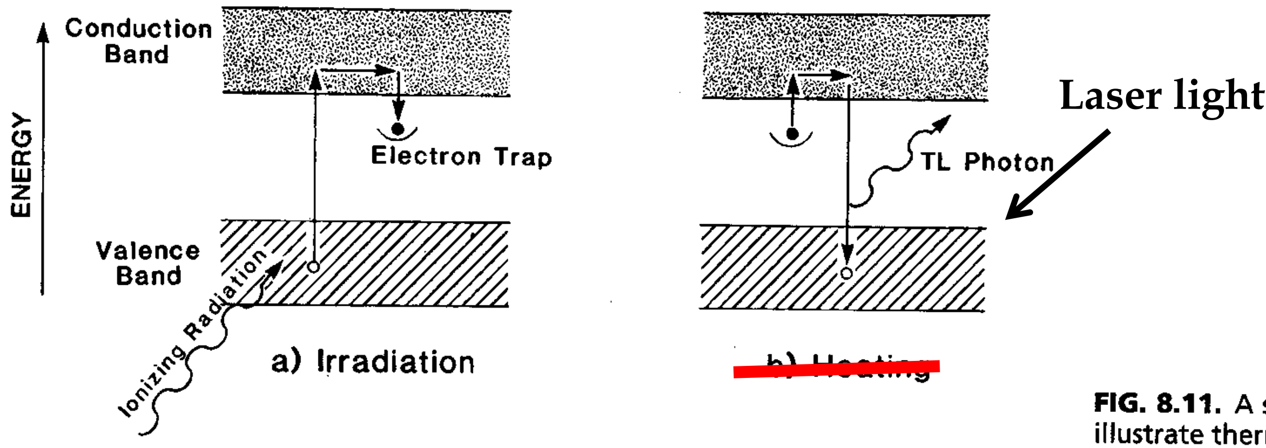



**FIG. 8.11.** A simplified energy-level diagram to illustrate thermoluminescence process.

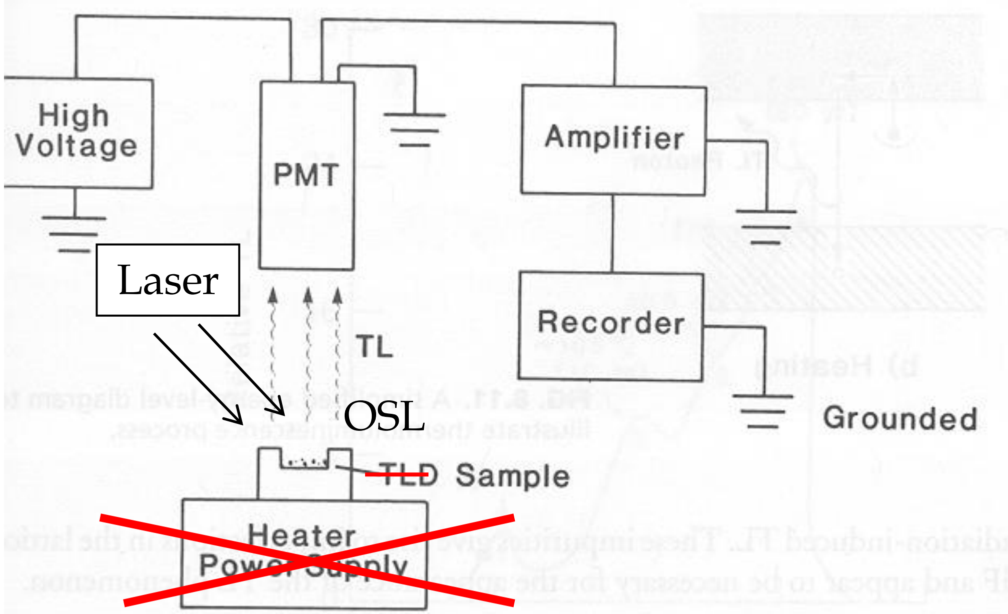
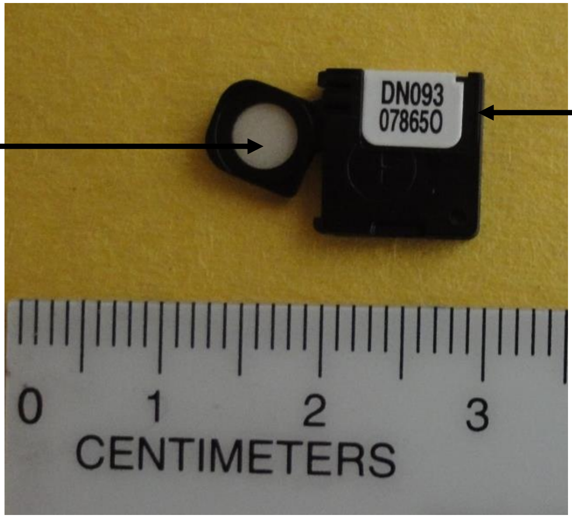



**FIG. 8.10.** Schematic diagram showing apparatus for measuring thermoluminescence.

# Optically Stimulated Luminescence Dosimeters

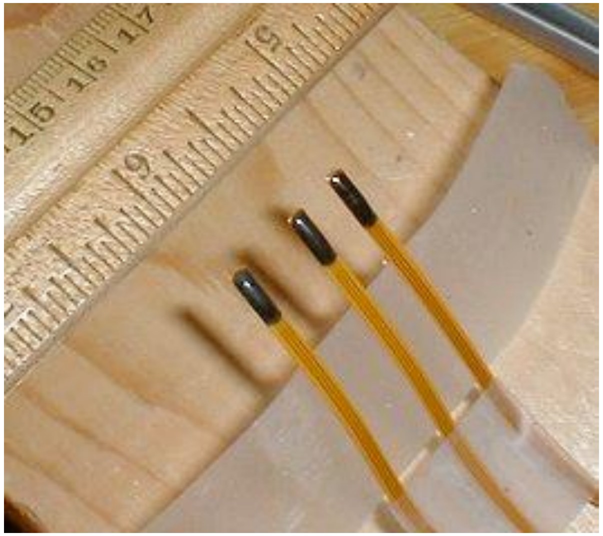
- **AL2O3 (aluminum oxide)**

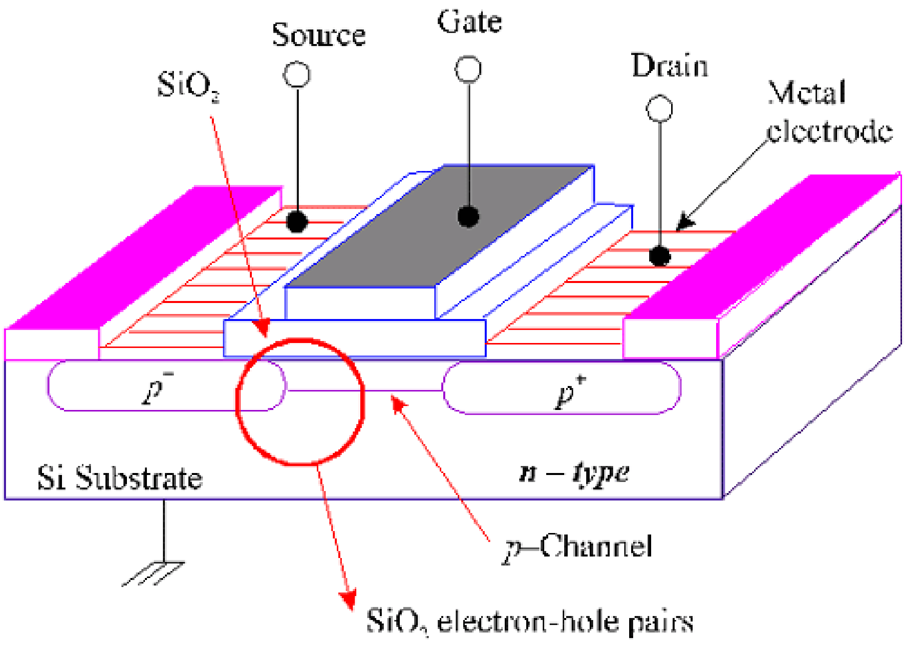
Dosimeter



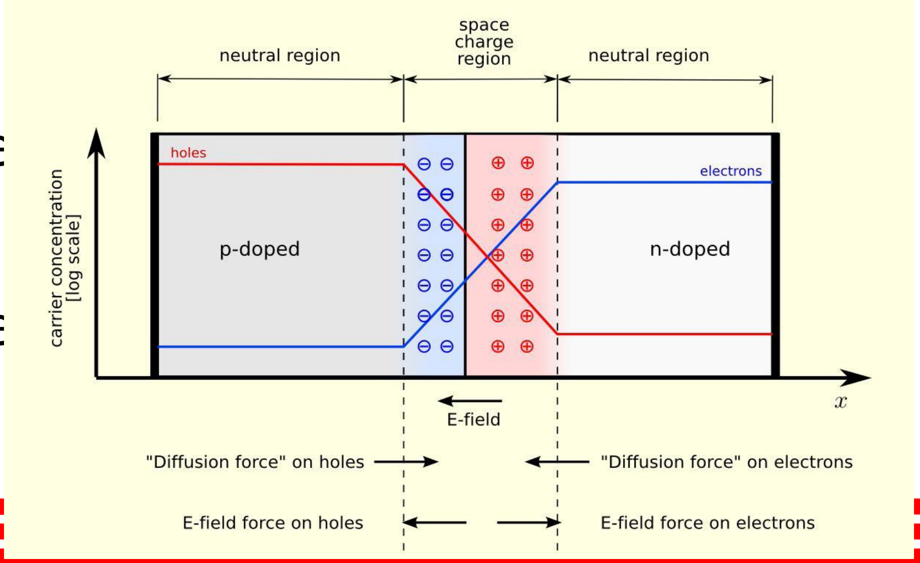

ID

# MOSFETS



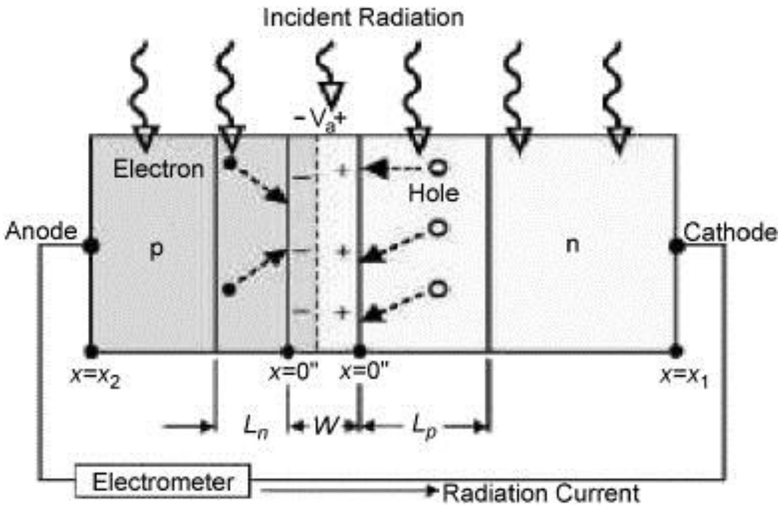



- MOSFET - Metal Oxide Semiconductor Field Effect Transistor
  - active area 0.2 mm x 0.2 mm at the end of the flexible cable
- Diodes
  - Energy/angular dependence



# Diodes

- A diode is a one-way valve, electricity (electrons) will only flow in one direction
- Radiation can create ionizations in the diode material
- Since the electrons can only flow one way this creates a current to allow recombination
- Measuring this current gives a measure of the radiation delivered
- Since there is no air many of the ion chamber uncertainties go away.
- Diodes are very sensitive an thus can be very small
- Radiation damages these devices so their sensitivity changes over time
- Can have significant energy dependence



# *Film based dosimeters*

- A thin a plastic backer layer
- A sensitive layer containing a chemical that changes characteristics when irradiated
  - Silver based films
    - » Chemical changes require developing to bring out
    - » Effective atomic number greater than tissue
      - Energy dependence
  - Radio chromic films
    - » Changes color when exposed to radiation with no external processing
    - » Effective atomic number close to tissue

# Silver based films: Dose Response Hurter and Driffield (H&D) curve

OD is defined as OD = log10 $(I_0/I)$

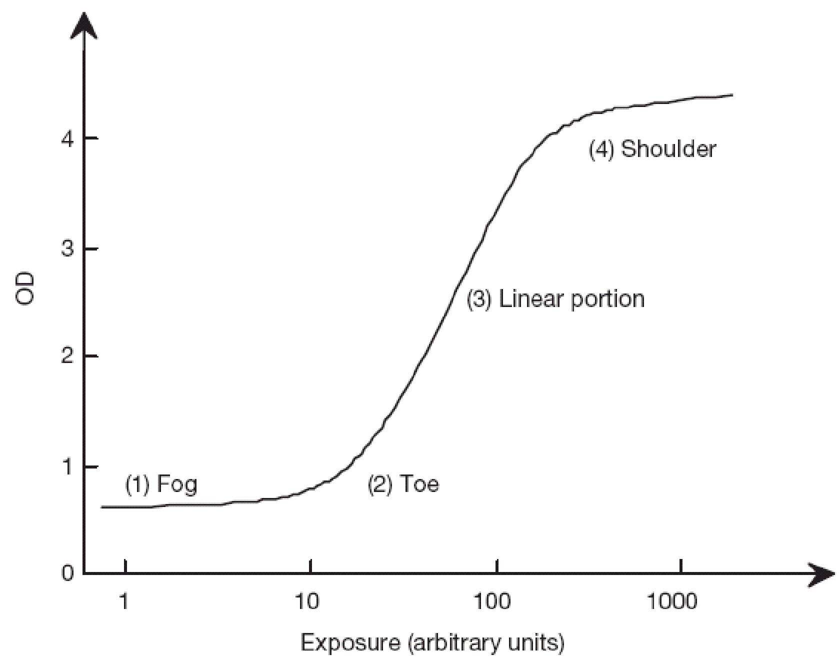



*FIG. 3.7. Typical sensitometric (characteristic H&D) curve for a radiographic film.*

# *Silver based films: Film Speed & Sensitivity*

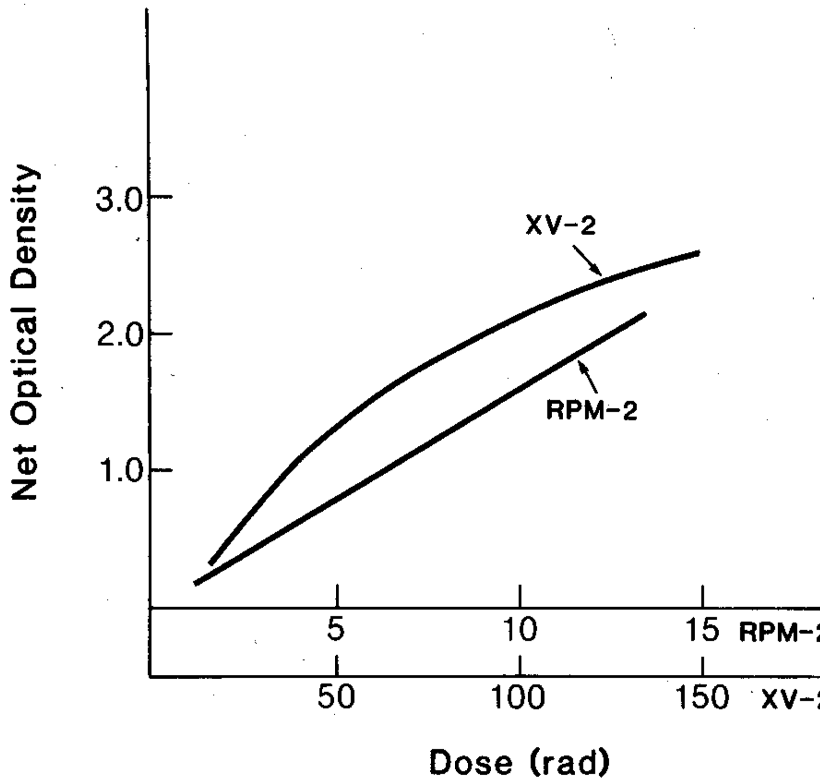



**FIG. 8.17.** Sensitometric curve of Kodak XV-2 film and K
RPM-2 (Type M) film.

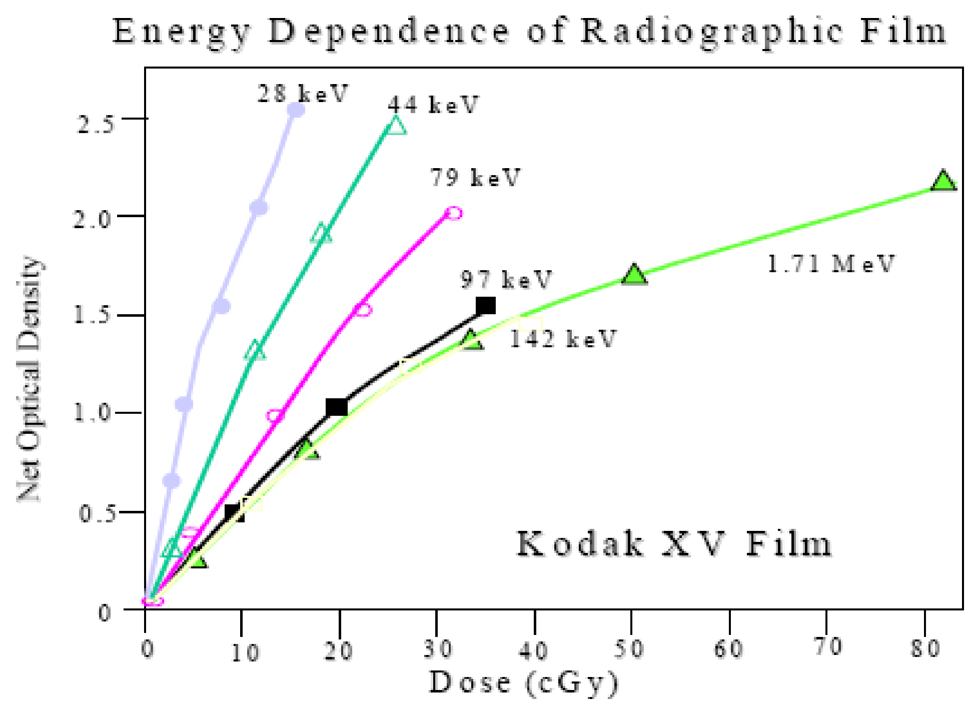



*Figure 23.* Energy dependence of the optical density of XV film from TG-69

# *Radiochromc film: Dose Response*

- Color changes with time after irradiation
- Signal depends on "color' used to measure
- Signal depends on scanning direction
- Still a "works in progress'

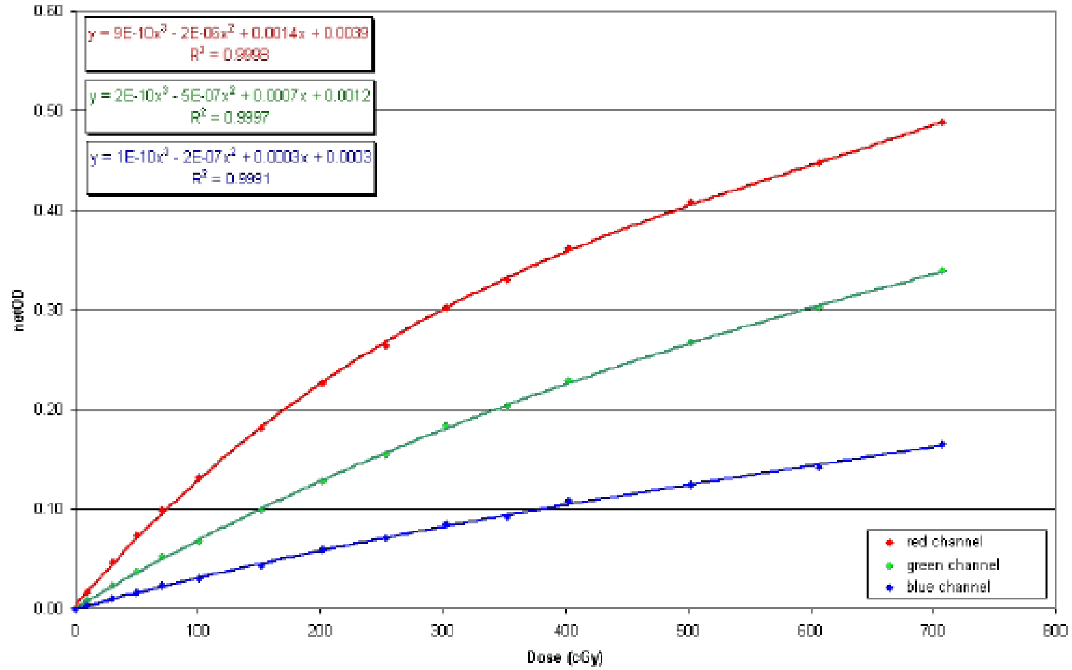


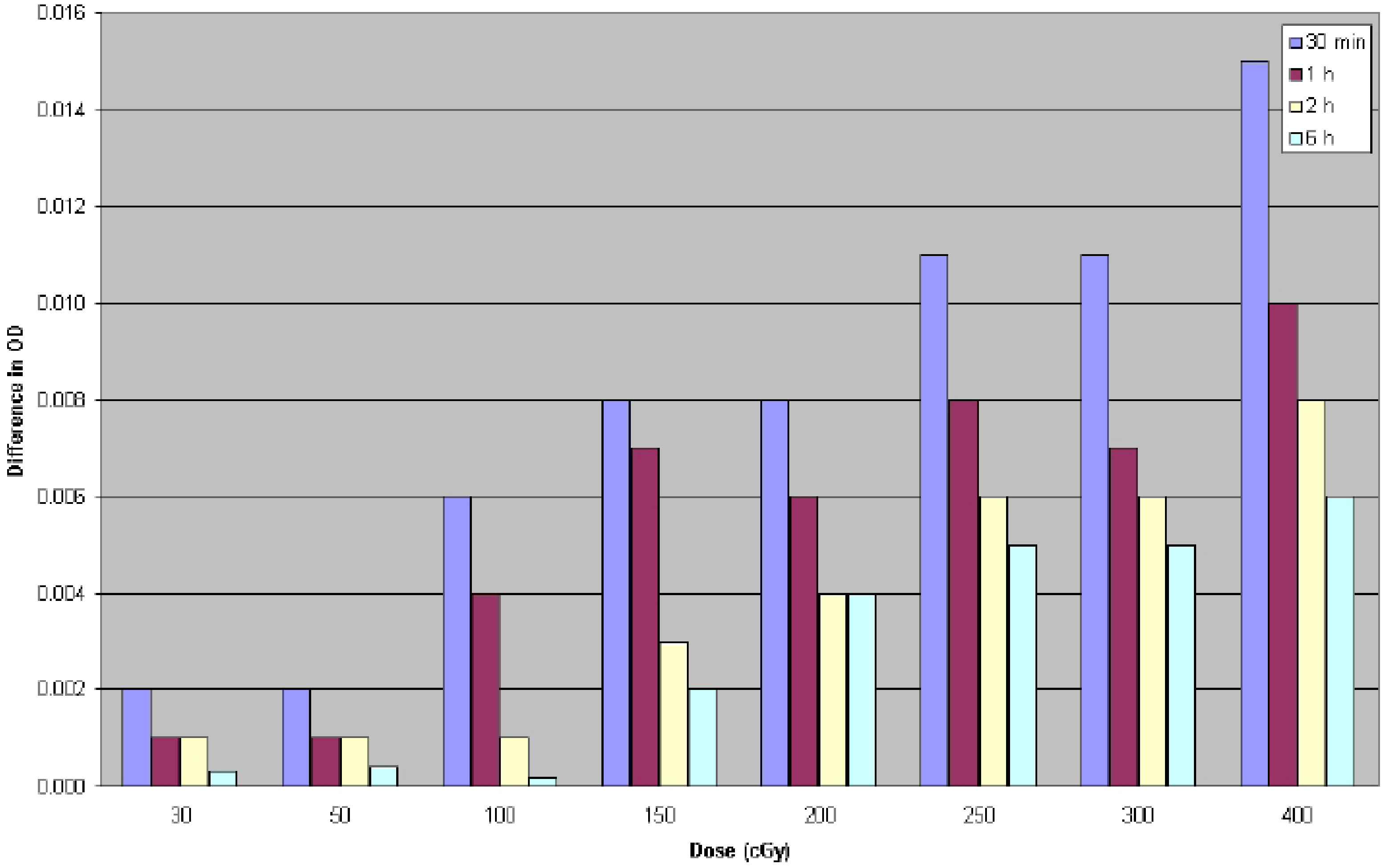

FIG. 1. EBT3 film multichannel calibration curves up to 7 Gy.

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 14, NUMBER 2, 2013

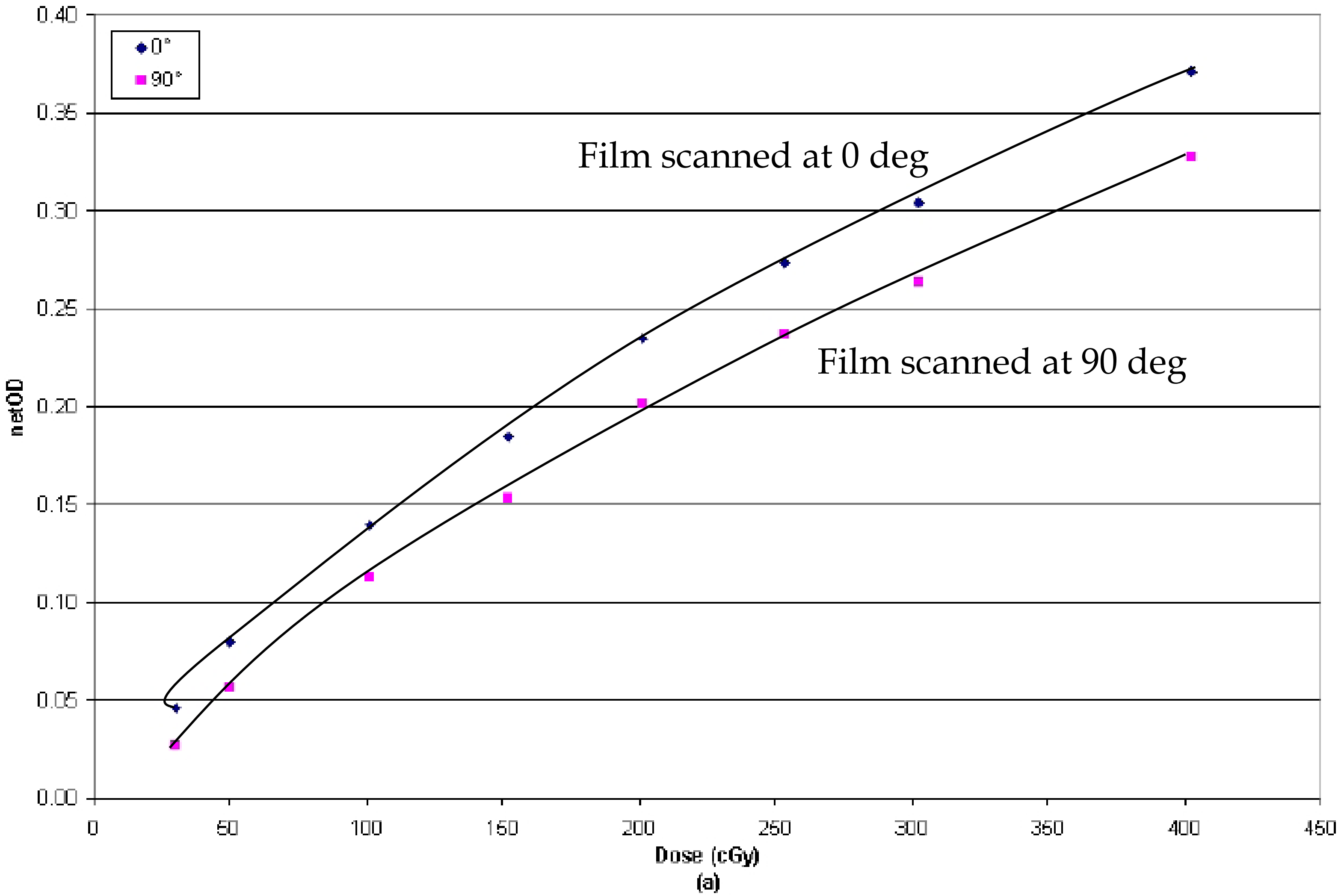
**Dosimetric characterization and use of GAFCHROMIC EBT3 film for IMRT dose verification**

Valeria Casanova Borca, Massimo Pasquino,[a] Giuliana Russo, Pierangelo Grosso, Domenico Cante, Piera Sciacero, Giuseppe Girelli, Maria Rosa La Porta, Santi Tofani
*Azienda Sanitaria Locale TO 4, S.C. Fisica Sanitaria, Ivrea (TO), Italy*
*mpasquino@aslto4.piemonte.it*

# GAF chromic film: Time dependent signal



# GAF chromic film- dependent signal



# Conclusion

TABLE 3.1. MAIN ADVANTAGES AND DISADVANTAGES OF THE FOUR COMMONLY USED DOSIMETRIC SYSTEMS

| | Advantage | Disadvantage |
|---|---|---|
| Ionization chamber | Accurate and precise<br>Recommended for beam calibration<br>Necessary corrections well understood<br>Instant readout | Connecting cables required<br>High voltage supply required<br>Many corrections required for high energy beam dosimetry |
| Film | 2-D spatial resolution<br>Very thin: does not perturb the beam | Darkroom and processing facilities required<br>Processing difficult to control<br>Variation between films and batches<br>Needs proper calibration against ionization chamber measurements<br>Energy dependence problems<br>Cannot be used for beam calibration |
| TLD | Small in size: point dose measurements possible<br>Many TLDs can be exposed in a single exposure<br>Available in various forms<br>Some are reasonably tissue equivalent<br>Not expensive | Signal erased during readout<br>Easy to lose reading<br>No instant readout<br>Accurate results require care<br>Readout and calibration time consuming<br>Not recommended for beam calibration |
| Diode | Small size<br>High sensitivity<br>Instant readout<br>No external bias voltage<br>Simple instrumentation | Requires connecting cables<br>Variability of calibration with temperature<br>Change in sensitivity with accumulated dose<br>Special care needed to ensure constancy of response<br>Cannot be used for beam calibration |

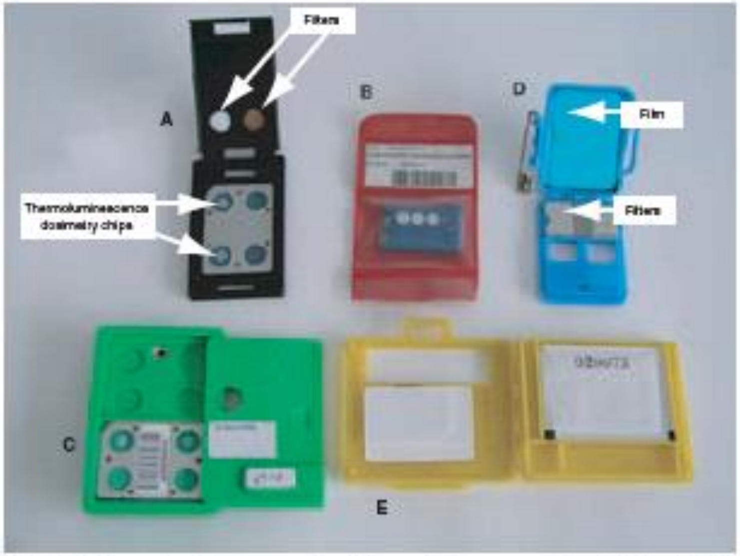



*FIG. 4.5. Personal dosimeters: examples of thermoluminescence dosimetry badges (A, B, C) and film badges (D, E).*

*FIG. 4.3. Neutron dose equivalent rate meter with a thermalizing polyethylene sphere with a diameter of 20 cm.*

*Thank You*