C4- Calibration, Quality Control and Quality Assurance

Characteristics and use of calibration equipment; measurements of radiation quantity and quality; calibration and evaluation of ionizing and nonionizing radiation sources and installations; calibration and evaluation of measuring, recording and imaging devices; acceptance testing, commissioning, quality control and quality assurance; and related subjects.

Detectors:
TG51: TG51 (+1), my talk slide (+1), question (+1), Wepassed (+1)

C4-A (Detectors)

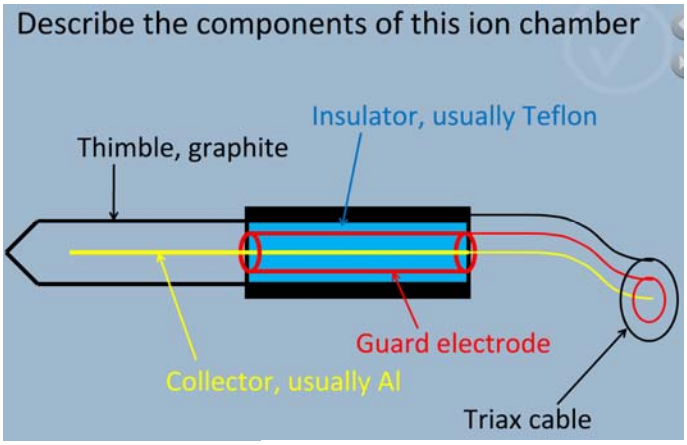
- Describe the general mechanism of how an ion chamber works? (DABR P109)
  K: Physics process defining the **Dose**
  When a charged particle, such as an electron, passes through a medium, it will interact with orbital electron or nucleus (for nucleus, it is Bremsstrahlung interaction) of an atom/molecule through the Coulomb force. While the charged particle interacts with the orbital electron, there will be 2 possible processes, ionization and excitation. Ionization means the charged particle remove an orbital electron and make the atom/molecule become positive in terms of charge; we called this atom/molecule as positive ion, and the removed orbital electron paired to the positive ion is so called as negative ion. This pair positive atom/molecule and negative ion, orbital electron form an "ion pair". This positive ion also called free radical will induce DNA damage and eventually cell death. The negative ion/electron can also further produce ionization on another atom/molecule called secondary ionization. So, the ionization process basically defines the dose. The negative ion or other high LET particles, such as Beta and Alpha particles, can also directly induce cell damage, but for x-ray and electron therapy, it is not the dominant mechanism. If we can measure how many ion pair is produced during the radiation, we can quantify the dose. In this case, we can just measure the total (positive or negative) charge produced by the ionization process.

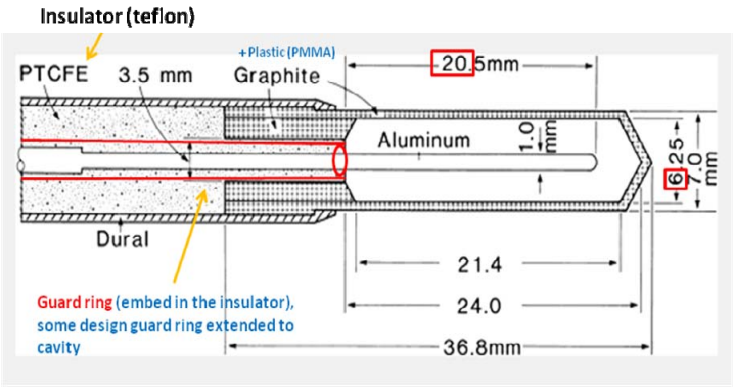
  The excitation process is the charged particle excite/give the energy to the orbital electron to promote it to a higher energy state but the energy given from the charged particle is not enough to remove the orbital electron from the atom. The excited electron will quickly decay back to the original state by emitting photon energy. This excitation process will take some of the incident charged particle energy but it does not contribute to the dose.

  So when we have incident radiation to generate the ion pairs inside the air cavity of the ion chamber, we further apply a bias voltage to collect all the charge generated from the ionization process, and then we can estimate the deposited dose. The average energy to generate 1 ion pair, including the loss energy of excitation process, in the air is 34 eV, so 1 MeV particle can generate approximately 30,000 ion pairs.

  (Ref: Attix, P339, Eric Hall, P11-12, Hendee P22-23, 82)

  (Thimble/Farmer chamber)
  Cut away view of thimber chamber (Khan Fig 6.3). Discuss Farmer chamber (picture from Kahn 2nd Ed. p107).
- A rudimentary picture of a cylindrical ion chamber is given. Explain this, what type of ion chambers do you use? What is central electrode, guard and wall and their material? What is the purpose of guard? How is this connected to triax cable? Draw a schematic of an ionization chamber. Various parts and function. What are typical values for diameter and volume of an ion chamber?





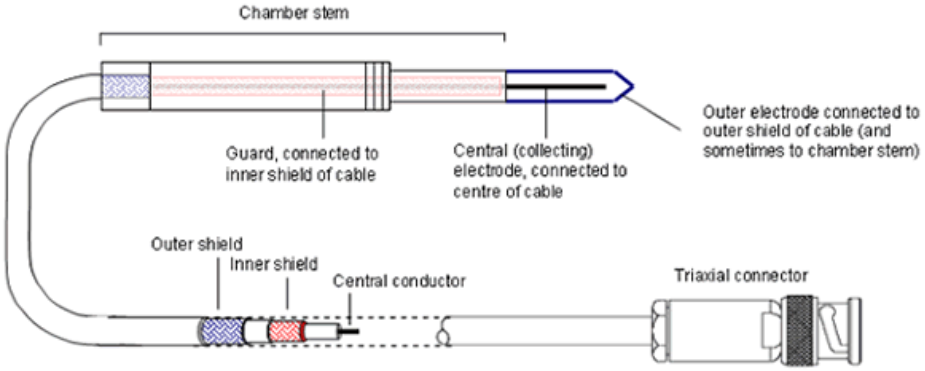


Figure 1: Schematic of a cylindrical ionization chamber showing connections from triaxial cable to chamber electrodes.

Farmer chamber is one kind of thimble chamber

Exradin A12 farmer chamber, collecting vol = 0.65 cc, the central collector, guard ring, and wall material are made by the "air-equivalent conducting plastic", low leakage current 10^{-15} A,

How much leakage is too much?

- Ideally, you want signal-to-noise ratio ≥ 1000
- This ratio depends on the chamber and the application
- A leaking chamber that may be good enough for large dose and high dose rate measurement may not be acceptable for low dose, low dose rate.

An well-guarded IC is basically a gas filled cavity surrounding by a conductive wall with tri-axial connection:

- Central electrode (the collector) ←→ Central conductor of the triax cable
- Guard electrode ←→ go to the inner shield of the triax cable
- Thimble wall ←→ go to the outer shield of the triax cable

Important dimension: The collecting volume of the chamber is nominally 0.6 cm^3 (cc), 6 mm inner diameter, and 20 mm active volume length

(Important concept): After electrometer provides a dual polarity HV source to hold the collector at a high bias voltage (e.g., 300 V), the collector gets the ion generated by electron and then delivers the current to a charge measurement device. The thimble is at ground potential and the guard is kept at the same potential as the collector (+300V setting). In this setting, we get the negative reading/ion through the collector, and the wall gets the positive ion but it will not go into the reading.

- 3 wires: collector, guard electrode, and wall
- Voltage arrangement can be either:
  - Collector and guard gets ± HV, wall gets ground
  - Collector and guard gets ground, wall gets ± HV
- Guard electrode should always be at the same, or almost the same, potential as the collector

Most often the collector is operated with a positive voltage to collect negative charge although either polarity should collect the same magnitude of ionization charge, if the chamber is designed with minimal polarity effects (to be discussed later).

- Why use bias voltage?
- (2011) Something about what ion chambers are used for. Part of the question had to do with polarity and recombination effects in ion chambers. He asked follow-ups like what polarity we used. What voltage? What would happen if you use 50V? Why not 800 V? Asked for details about what exactly happens in proportional region.

What bias voltage do you use for this chamber?

The Farmer chamber is usually operated at 300 V. Why? Consider the effects of biasing:

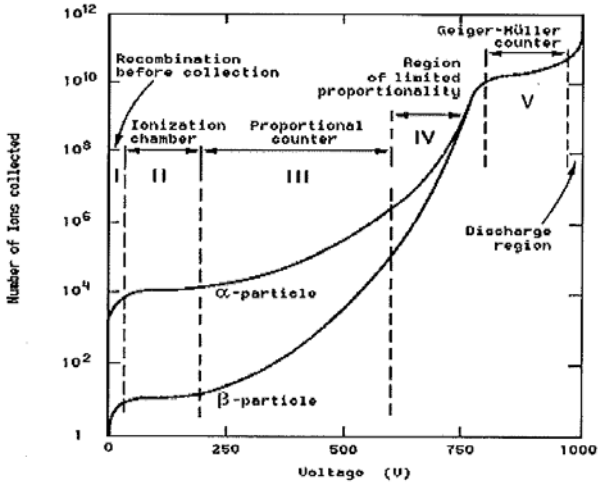
A low bias leads to recombination and therefore poor collection efficiency (< 100 V).

An overly high bias can lead to a collection efficiency > 1 due to gas amplification (> 500 V).

No bias at all will lead to erratic readings.

The bias voltage should be arranged such that the chamber suffers recombination losses less than 1%; that is, has a collection efficiency of 99%. In a 0.6 cc chamber, this is generally achieved if the collection voltage is around 300 V.

We use +300V because it is the same polarity, the chamber was calibrated in ADCL. 300 V is to let the chamber in the saturation zone (100 – 400). If we have too high bias voltage (400-800), we are getting into the proportional zone, the ion itself gains enough energy, and starts to produce secondary ion, and at this region, the larger bias voltage you provided the more secondary ion generated, so it calls proportional region; (the limit proportional zone is simply the voltage is non-linear to the number of ion collected). When V > 800, ion avalanche happened, (one photon ionizing event generates an avalanche of charge). In this case, the # of ion collected does not reflect the energy deposited by the photon.



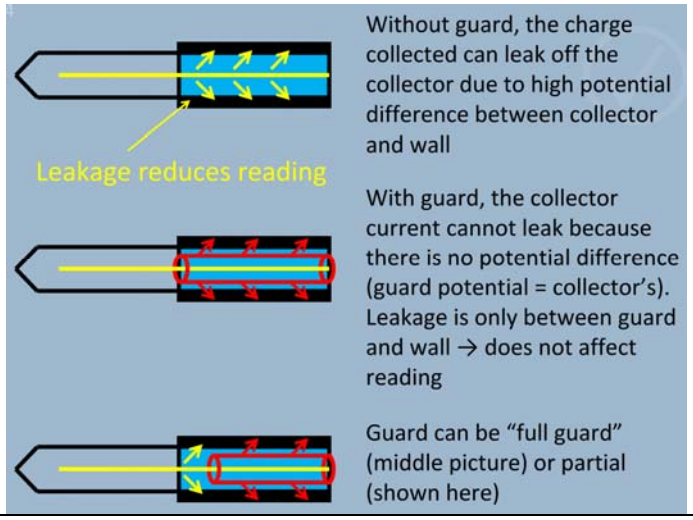
- Central collector (traditionally Al, z = 13): choosing Al (low atomic number material) is to make it close to air.

- Thimble wall (graphite z = 4, air-equivalent wall, Kahn p82-p83): The wall to be coated with graphite is to make it electrically conducting and air-equivalent, and plastic as well to make it waterproof

- Effective atomic number of air = 7.7

- Insulator consists of polytrichlorofluorethylene (Teflon) to reduce the leakage current between the wall and electrode.

- Guard ring (made by either conducting plastic or Al): The guard electrode serves two different purposes. (1). One is to prevent leakage current from the high voltage electrode (the collector) since they are setting as the same voltage and (2). the other is to define the ion collecting volume.



Calculate the amount of charge corresponding to 1 Gy of radiation exposure.

$$D = \frac{E}{m} \Rightarrow E = D \cdot m = D_{air}\left(\rho_{air} V_{chamber}\right) = \left(1\frac{J}{kg}\right)\left(0.00129\frac{g}{cm^3}\right)\left(0.001\frac{kg}{g}\right)\left(0.6\,cm^3\right) = 8\times10^{-7}\,J$$

$$\Rightarrow \frac{8\times10^{-7}\,J}{34\frac{J}{C}} \approx 2\times10^{-8}\,C = 20\,nC$$

Vendors usually specify nominal chamber response as $\frac{20\,nC}{Gy}$. *Remembering a number like this is important so that one can identify gross errors.*

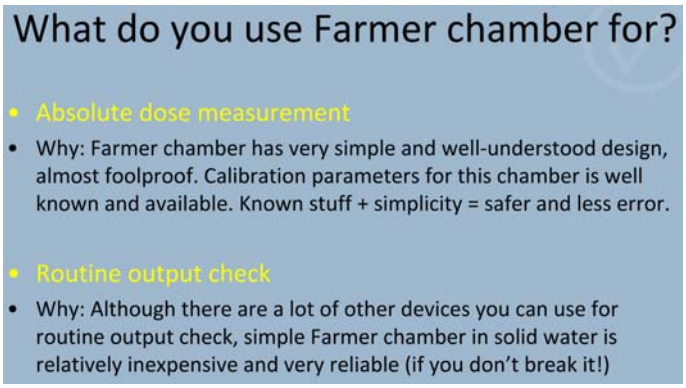
(PAH) We use Exradin A12, for 100 + 10 cm, (photon) we get about 14 nC /67% = 21 nC for 1 Gy at dmax
We use Exradin A12, for 100 + dref (electron), we get about 21 nC /97% = 22 nC for 1 Gy at dmax
(PCAM) We use Exradin A12, for 90 + 10 cm, (photon) we get about 20 nC for 1 Gy at d = 10 cm

What do you use a Farmer chamber for? What shouldn't you use a Farmer chamber for?

The Farmer chamber has a very simple, well-understood design, and is characterized by well known calibration parameters, e.g. response, leakage, energy dependence, wall material, etc. "Simplicity" plus "well-known parameters" make it a perfect device for absolute dose measurement for a wide variety of field sizes and treatment modalities.

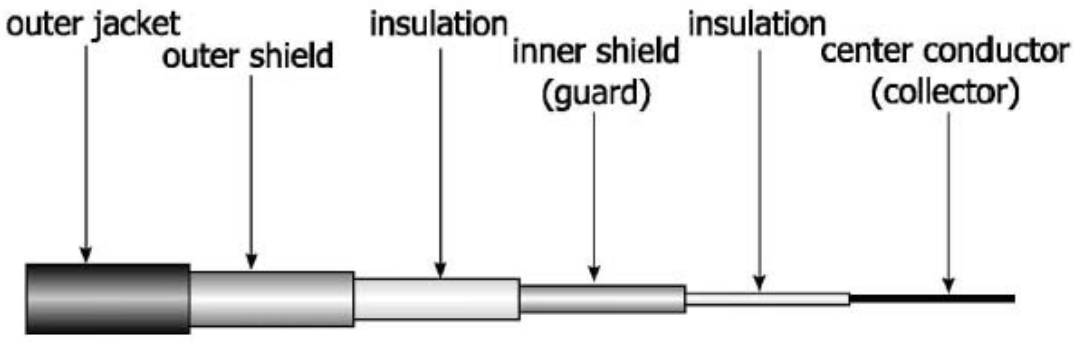
Unfortunately, sharp dose gradients may exist within small target volumes. Considering the fact that a cylindrical chamber has a 0.6 cm resolution in the horizontal direction, but a 2 cm resolution in the longitudinal direction; sticking a relatively bulky dosimeter into a very small target may be unwise for verifying homogeneity. A small pinpoint, or "diamond" chamber may be more appropriate for IMRT QA, for instance.

- What is the difference between ion chamber used for monthly & annual calibration and why? Why use a small ion chamber?
  The chamber used for annual is the chamber with calibration factor traceable to standard lab. It is important to keep that chamber in a good shape and not to break it, so we only use it to perform TG51 and check absolute machine output value in the annual base.
  We use parallel plate chamber in the solid water to perform routine output check because it's relatively solid setup which can be used in a frequent base.



  Use small vol. ion chamber is to avoid vol. averaging effect, and have better spatial resolution.

- Explain triaxial cable?



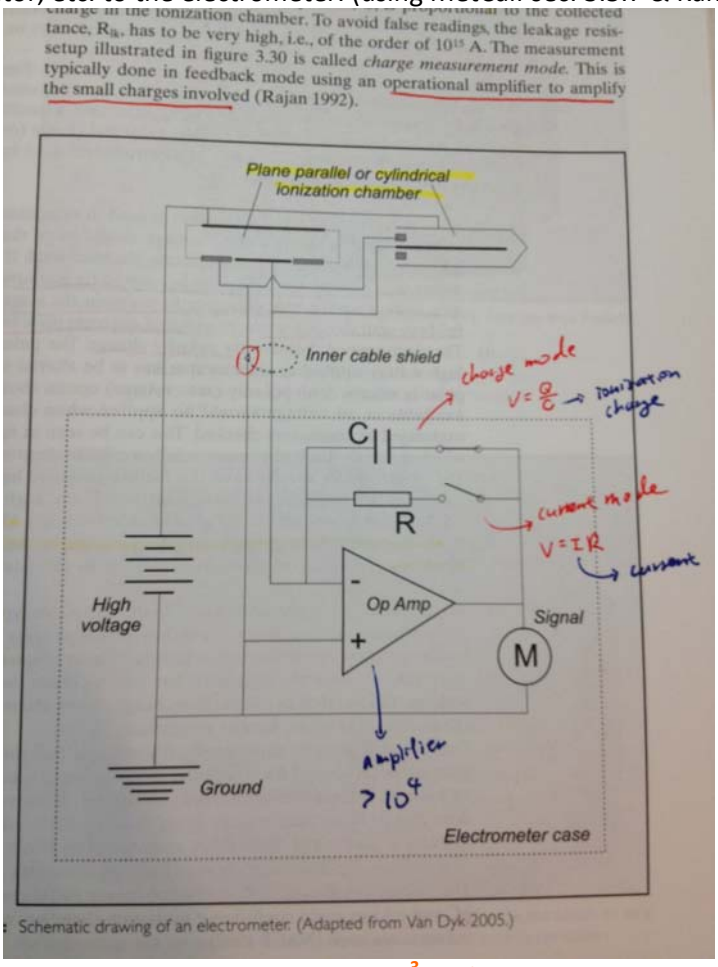
'igure 6-8. Schematic of triaxial cable.

(AAPM summer school 2009 Ch6)

A low-noise triaxial cable has insulating qualities that reduce electronic noise from mechanical stress from the cable. The cable should be positioned in a relaxed state, avoiding twisted coils and sharp bends that induce mechanical stress. The guard connector provides a contiguous guard throughout the length of the cable. Connections for the cable have to be secure with good insulation between layers. Also the cleanliness of the connectors is of extreme importance, since one of the major causes of leakage is a dirty connector. Generally, good quality cables and connectors have very low leakage (generally $\leq 10^{-15}$ A, when 300 V is applied). Also desirable for a good triaxial cable is a low capacitance per meter. Cables and ionization chambers should have a fast equilibration time following any change in applied voltage to prevent continually increasing or decreasing readings after a change in voltage.

- Shown a graph of a Farmer's chamber. Why do we design the shape as cylinder rather than something else?
  Cylindrical chamber is 2D symmetrical in its longitudinal axis. Because of this design, chamber shows less directional dependence compared to other shape such as cube or rectangular.

- Given on a piece of paper an electrometer and the same chamber. Know to draw the triaxial cable connections through the resistors, capacitor, etc. to the electrometer. (using MetCalf sec. 3.5.7 & Kahn p90-91)



Electrometer leakage current should be as low as **10^{-3} pA** (ex: The LDR reading is pretty low **2 pA**)

- **(Parallel plate)**Parallel plate chamber and identify the different parts and explain where and why you would use them?
- A very poor diagram of parallel plate chamber. What is it? Basics of operation. Why you would use it? Makes and models used in clinic.

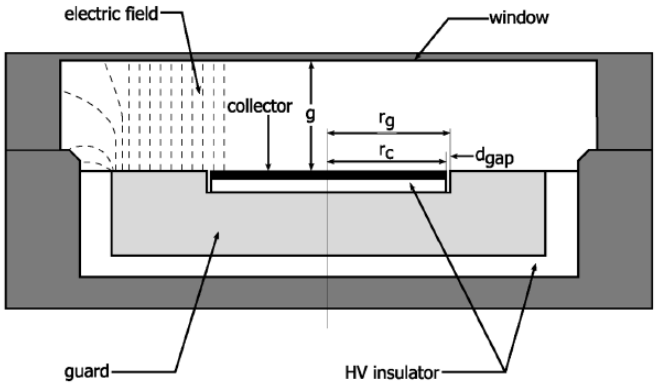
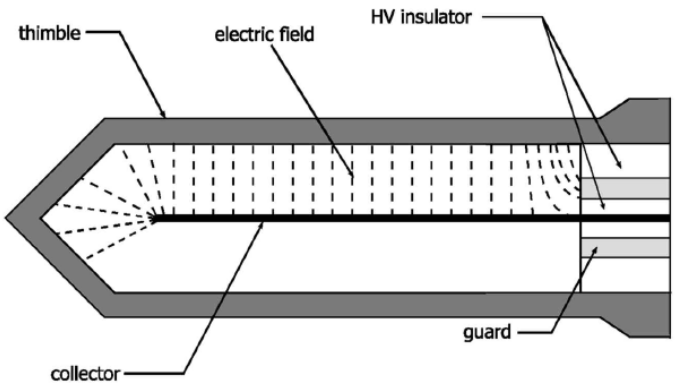


Figure 6-3. Schematic of parallel-plate chamber with field lines shown.



gure 6-4. Schematic of a classic Farmer chamber with field lines shown.

(AAPM summer school 2009 Ch6)

In a parallel-plate ionization chamber, an electric field is generated between the window and the guard and the window and the collector. The separation of the collector and the window defines a volume that is filled with air.

The guard ring, which provides a uniform electric field and a defined volume is a donut-shaped ring with high voltage applied between the guard and the inner surface of the window.

Collector will collect charge from all the ions that are generated in the gas between the plates. Generally, these chambers have a thin window usually composed of a few microns of conductive MylarR or KaptonR.

Most measurement protocols recommend parallel-plate ionization chambers for electron with energies < 10 MeV. The plate separation for most of the parallel-plate ionization chambers used for electrons falls between 1 and 2 mm, resulting in a negligible change in beam intensity across the sensitive volume. The small plate separation gives better spatial and depth resolution than cylindrical chambers in beams with large gradients, i.e., such as buildup region and electron beam.

& $P_{gr} = 1$, $P_{fl} = 1$, $P_{wall} = 1$ for parallel plate chamber.

We use **PPC40 from IBA**. The
Specifications
Ngas/(NxAIon) (cGy/R): 0.8547
Volume: ..... **0.4 cc nominal, vented to the atmosphere**
Sensitivity: ..... 0.13 nC/cy, nominal
Leakage current: ..... $< \pm 4 \times 10^{-15}$ A
Entrance window: ..... acrylic (PMMA), graphite coated, 1 mm thick, 1.18 g/cm2
Ion collector: ..... 16.0 mm diameter graphite coated acrylic (PMMA) 1.18 g/cm2
Body material: ..... acrylic (PMMA)
Electrode separation: ..... 2.0 mm
Guard ring width: ..... 3.8 mm wide
Reference point in water: ..... 1 mm from entrance plane
Bias voltage: ..... ±300 V
Polarity effect: ..... <1%
Perturbation effect: ..... approximate unity, (Prepl = 1)
External dimensions: ..... 44 mm diameter x 10 mm
Cable: ..... 1 meter, low-noise triaxial, BNC male

- Picture of a parallel plate chamber, know how to draw one. Describe each of the parts. What is the size of the spacing? What is a well guarded chamber? Is a Markus chamber well guarded? Is it vented? Where/how?

For Parallel-Place Chambers:

- Without guard, there is field inhomogeneity, esp. at the edges
- Effective collecting volume < Geometric volume between plates

- With guard ring, field is uniform inside the collecting volume
- Effective volume ≈ Geometric vol.

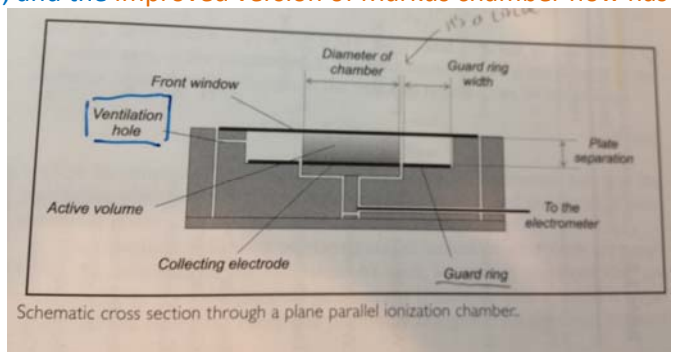
As a rule of thumb, the width of the guard ring should be ≥ 3 times the gap width

Guard

- Desire is to collect charge from a known and well maintained volume. Not random amounts of ionization outside the chamber.
- Added advantage is reduction of leakage and other effects

Guard ring is also used to avoid secondary e scattered from the wall being counted in the chamber.

(MetCalf p155) The original version of Markus chamber only has 0.2 mm width of the guard ring (which has been a problem for Markus chamber), and the improved version of Markus chamber now has 2 mm width of the guard ring.

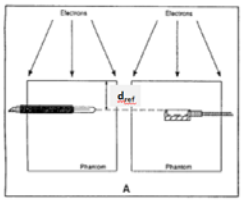


Schematic cross section through a plane parallel ionization chamber.

- It shown an image of a Farmer and Parallel plate chamber side by side with build cap showing. Explain where they work best and why? Drawing of a Cylindrical chamber and a Parallel plate chamber at depth. Discuss cross calibration. Which energy do you use for calibration?

Why does TG51 suggest high e energy for cross calibration used in the e dosimetry?

- Due to the larger correction of the $P_{repl} = P_{fl}P_{gr}$ is shown in low e- energy beam, high e- is a better choice for the cross calibration procedure.
- d_{ref} is to the center of the CC and front face of the PP.



$$(N^{^{60}Co}_{D,w}\, k_{ecal})^{PP} = \frac{(D^{Q}_{w})^{PP}_{test}}{(k'_{R_{50}}M)^{PP}_{test}} = \frac{(D^{Q}_{w})^{cyl}_{test}}{(k'_{R_{50}}M)^{PP}_{test}} = \frac{(N^{^{60}Co}_{D,w}\, P^{Q}_{gr} k'_{R_{50}} k_{ecal} M)^{cyl}_{test}}{(k'_{R_{50}}M)^{PP}_{test}}$$

*The physics of radiotherapy X-rays and electrons, Sec. 8.2.5, Metcalf *et al.* (2007)

What do you use Farmer chamber for?

- Absolute dose measurement
- Why: Farmer chamber has very simple and well-understood design, almost foolproof. Calibration parameters for this chamber is well known and available. Known stuff + simplicity = safer and less error.

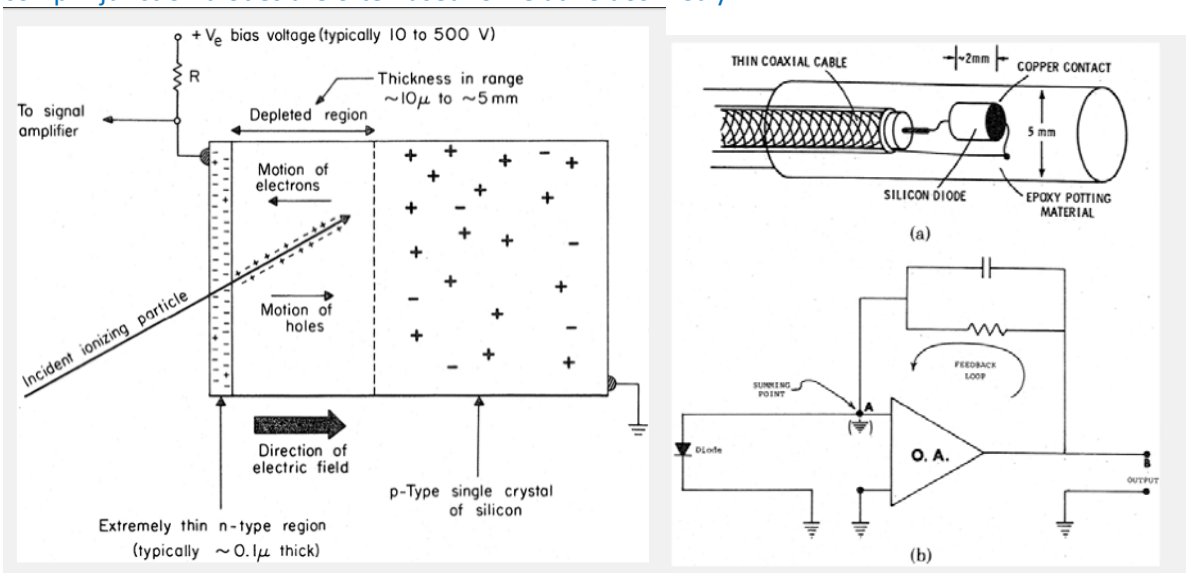
- Routine output check
- Why: Although there are a lot of other devices you can use for routine output check, simple Farmer chamber in solid water is relatively inexpensive and very reliable (if you don't break it!)

PP(good for electron dosimetry, no Pgr correction work for sharp gradient region, buildup region)

- Farmer chamber and parallel plate chamber. What are they? Dimensions? Details about construction/material... Do they require shift? How much?
  PP no shift requirements
  Farmer chamber: 0.6r for photon and 0.5r for electron

(Diode)

- (2006) Identify various regions/parts, describe usefulness
- A diagram of p-type diode from Khan.
  What is it? Describe operation. Direction of current flow. Diagram of a diode.
- What are the advantages and disadvantages?
- Shown a diagram of a diode. Various parts labeled. What is this? Arrows pointing in different directions, what happens here? How does it work? Is it dependent on temp., energy, voltage? Why do you use it?
  (Kahn p148-150)
  Silicon p-n junction diodes are often used for relative dosimetry.



A diode consists of a silicon crystal which is doped with impurities (boron or phosphorus) to make p- or n-type silicon, respectively.

The p-type silicon is doped w boron → (e deficient) electron receptor.
The n-type silicon is doped w phosphorus → (e excessive) electron donor.

The p or n type diode is determined by the dope on the diode substrate. The above the case is a p-type diode.

A p-n junction diode is designed with one part of a p-silicon disc doped with an n-type material (Fig. 8.15).

At the interface between p- and n-type materials, a small region called the depletion zone (collecting or sensitive volume, 0.2 – 0.3 mm^3 at a depth of 0.5 mm from the front surface of the detector, unless buildup is provided) is created because of initial diffusion of electrons from the n-region and holes from the p-region across the junction, until equilibrium is established. The depletion zone develops an electric field which opposes further diffusion of majority carriers once equilibrium has been achieved.

When **a diode is irradiated electron-hole pairs are produced within the depletion zone**. They are immediately separated and swept out by the existing electric field in the depletion zone. This gives rise to a radiation-induced current. The current is further augmented by the diffusion of electrons and holes produced outside the depletion zone within a diffusion length.

The direction of **electronic current flow** is from the n- (e donor) to the p-region (e receptor) (which is opposite to the direction of conventional current).

Advantage:

(1). higher sensitivity

{Diodes are far more sensitive than ion chambers. Since the energy required to produce an **electron-hole pair in Si is 3.5 eV** compared to 34eV required to produce an ion-pair in air and because the density of Si is **1,800 times that of air**, the current produced per unit volume is about **18,000** times larger in a diode than in an ion chamber. Thus, a diode, even with a small collecting volume, can provide an adequate signal}

(2). instantaneous response,
(3). small size and ruggedness
(4). Particular good for e beam
(5). Output constancy checks
(6). In vivo pt. dose monitoring

{Diodes are becoming increasingly popular with regard to their use in patient dose monitoring. Since diodes do not require high voltage bias, they can be taped directly onto the patient at suitable points to measure dose. The diodes are carefully calibrated to provide a check of patient dose at a reference point (e.g., dose at d_{max}).}

offer special advantages over ionization chambers.

Disadvantage:

(1). energy dependence in photon beams,

- What (or why) makes diode better for electrons and not photon? When would you use a diode for beam measurements? Why?

{Because of the relatively **high atomic number of silicon (Z = 14) compared to that of water or air**, diodes exhibit severe energy dependence in photon beams of non-uniform quality. Therefore, their use in x-ray beams is limited to relative dosimetry in situations where spectral quality of the beam is not changed significantly, for example, profile measurements in small fields, dose constancy checks.
In electron beams, however**, the diodes do not show energy dependence as the stopping power ratio of silicon to water does not vary significantly with electron energy or depth.** Thus diodes are qualitatively similar to films so far as their energy dependence is concerned.}.

Diode is good for electron dosimetry. Because the stopping power ratio between the Si and water does not vary significantly and its small size, it is good for **PDD (no shift needed) and profile** measurement.

(TG62) The radiation-induced charge per MU in diodes designed for in vivo dosimetry often depends on beam energy. Although the mass absorption coefficient and the stopping power of the silicon die contributes to the energy dependence for photon and electron beams respectively, most of this energy dependence is due to the materials around the die, such as the electrode attachment, protective housing, and buildup. Some diodes use foundry products that may already have a high Z electrode attached to the die, while other detectors are manufactured from the bare die with wire bonding techniques that minimize the electrode materials. Scattered electrons from these high Z materials in close proximity to the die contribute to the ionization in the die in amounts that depend on construction details of the diode model. (The high z material contributes more PE effect so for large depth and the location at the field edge the diode shows over-response)

(2). directional dependence,

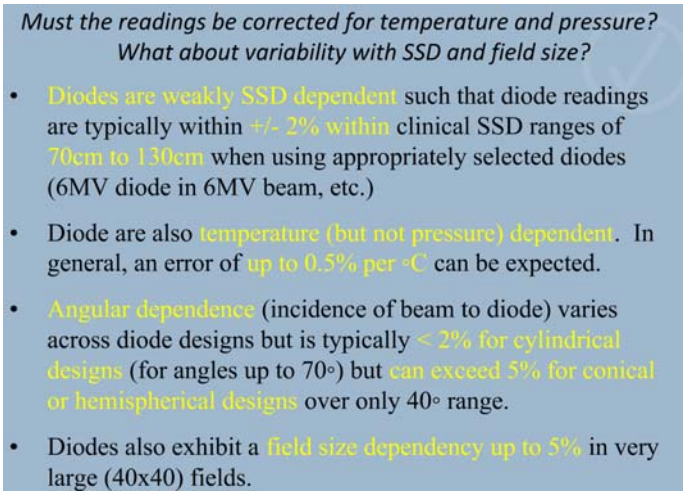
(3). thermal effects, &

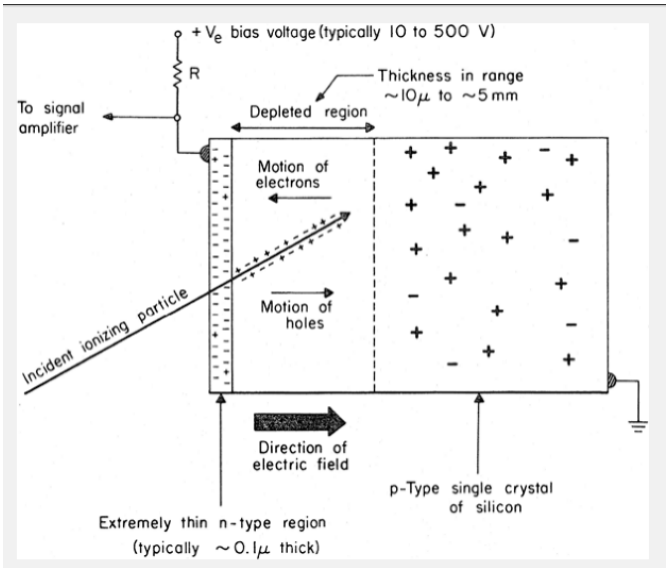
Diodes show a small temperature dependence (0.1 – 0.5%/c)that may be ignored. The temperature dependence of diodes is smaller than that of an ion chamber. Moreover, their response is independent of pressure and humidity.

(4). radiation-induced damage.

A diode can suffer permanent damage when irradiated by ultrahigh doses of ionizing radiation. Because of the possibility of radiation damage, diode sensitivity should be checked routinely to assure stability and accuracy of calibration. Sensitivity variation with accumulated dose(SVWAD) reported between 0.7%/1000Gy in 4, 6, 8MV beam to 0.2-3.4% /100 Gy for 18 MV beam (TG62) sensitivity check should be part of periodic QA.

(5). Dose rate dependence: Change in SSD, instantaneous linac dose rate or the presence of beam modifiers (wedges and blocks) alter instantaneous dose rate **→ *alter sensitivity of diode*(TG62)**





- Why is there bias voltage in the picture? How much bias voltage applied? (Kahn's figure as well as in Attix p458)
- Do you apply a bias? **(No)** What happens if you apply a bias?

The diode diagram shown in Kahn is actually a **"reverse-biased" p-n junction detector**, NOT an unbiased diode (Attix p458)

(Reverse-biased diode) When a positive potential (10 – 1000V) is applied to the n-terminal, electrons and holes are pulled out of the depletion zone, and current cannot flow across the junction. When we apply radiation, we can detect the radiation-induced current.

(Diodes without bias) Although the sensitivity is greater & the response time is less for Si diode with reverse bias applied, for DC operation there is an advantage in operating without any external bias: As the bias voltage is reduced to 0, the DC leakage current decreases more rapidly than the radiation-induced current. Since this leakage current is strongly temperature-dependent, minimizing its magnitude is advantageous.

If bias voltage is applied for an unbiased diode, there will be current starting to flow within the depletion zone, and we will have leakage current (DABR P260).

Due to low impedance of diodes (~100 MΩ, compared with IC's ~1TΩ), electrometers with moderate offset voltage (across diode) can cause significant leakage current in the diode (TG62).

- - The schematic from the AAPM report of a diode (it's in Khan as well). Why is the different orientations?

The different detector orientation design is to reduce the directional dependence (TG62).

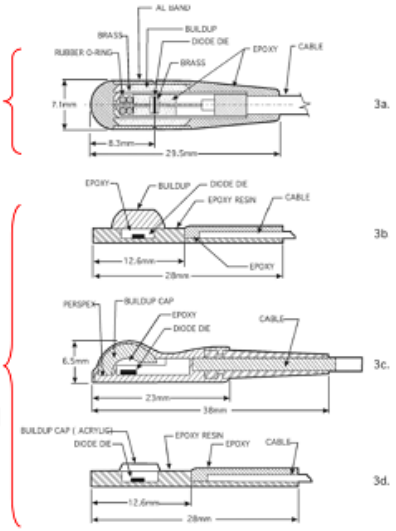
Diode shape and directional dependence

Cylindrical: relatively small directional dependence (<2% for θ< ± 70°)

cylinder should be placed against the patient

Conical (hemispherical): relatively strong dependence (~5% for θ< ± 40°)

detector placed with flat side on the patient, central axis parallel to normal of plane of diode die

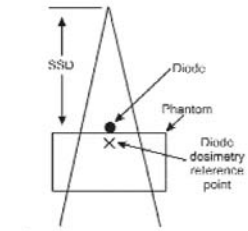


Entrance calibration factor, $F_{cal,en}$

Suitable phantom conditions: on 25x25 cm^2 area, 10 cm thick solid water.

DDRP: on central axis at d_{max} for moderate field sizes (10x10 to 15x15) in water equivalent material.

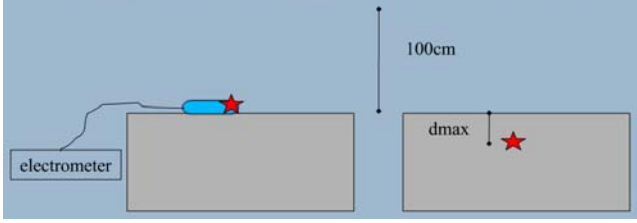
Diode *usually* has inherent buildup of d_{max} thickness equivalence in its stated energy range to ensure e^- equilibrium of measurement.



a. Setup for measuring entrance dose calibration factor.

How is it calibrated?

- Calibration relates the diode readings under reference conditions of field size and SSD to dose at selected point in water phantom.
- A commonly selected point is 100cm + dmax therefore diode reading is correlated with cGy if linac is calibrated to give 1cGy per MU at 100cm + dmax in standard field size.



What do you do if your patient dose verification diode reading is 6% off from expected?

It depends.....

- The goal of diode program is to identify large errors.
- An action level of 7% is sufficient to identify wedge, beam energy, SAD/SSD and daily dose errors (Lee et.al. 1994).
- Many clinics adopt a tiered approach of actions:
  - >10% triggers immediate physics staff review of calculations, calibration, setup. The measurement is typically repeated by physics at next treatment.
  - 5-10% results in 2nd therapist review of setup, notification of physics and remeasurement at the next treatment (need for physics support depend upon outcome of setup review)
  - <5% often considered acceptable validation and the measurement is forwarded to physics for review with no follow-up action.

Table 28-1. Package Specification of the Different Diode Detectors

Diode Type	Shape	Buildup Material, Total buildup thickness (g/cm^2)	Energy Range	Manufacturi period
Nuclear Associates Veridose Yellow	Flat	1.2 mm Copper, 1.36	5–11 MV	1998–
Nuclear Associates Veridose Green	Flat	1.7 mm Tungsten, 3.57	18–25 MV	1998–
Scanditronix EDP 2^{3G}	Flat	Epoxy (0.50 mm), 0.20	Electrons	2001–
Scanditronix EDP 10^{3G}	Flat	0.75 mm Stainless Steel + epoxy, 1.0	4–8 MV	2001–
Scanditronix EDP 20^{3G}	Flat	2.2 mm Stainless Steel + epoxy, 2.0	10–20 MV	2001–
Scanditronix PFD	Flat	Epoxy (0.5mm), 0.20	Photon Scanning	2001–
Scanditronix EDP10	Flat	0.75 mm stainless cap + epoxy, 1.0	6–12 MV	1990–2001
Sun Nuclear Isorad Red (n-type)	Cylinder	1.1 mm Tungsten, 2.8	15–25 MV	1993–1998
Sun Nuclear Isorad Electron	Cylinder	0.25 mm PMMA, 0.030	Electrons	1993–1998
Sun Nuclear Isorad-3 Gold #1	Cylinder	1.1 mm Molybdenum, 1.6	6–12 MV	2003–
Sun Nuclear Isorad-3 Gold #2	Cylinder	1.1 mm Molybdenum, 1.6	6–12 MV	2003–
Sun Nuclear QED Gold (n-type)	Flat	2.1 mm Brass, 1.9	6–12 MV	2003–
Sun Nuclear QED Red (n-type)	Flat	3.4 mm Brass, 3.0	15–25 MV	2003–
Sun Nuclear QED Blue (p-type)	Flat	3.4 mm Aluminum, 1.0	1–4 MV	1997–2002
Sun Nuclear QED Red (p-type)	Flat	3.4 mm Brass, 3.0	15–25 MV	1997–2002
Sun Nuclear QED Electron (p-type)	Flat	0.25 mm PMMA, 0.030	Electrons	1997–2002

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(TLD)

- TLD question: reference Kahn p145. TLD Diagram from Khan's Book (see Khan new edition Fig.8.11). Explain the diagram? How does TLD work? What is the material (Which TLDs are most common)? Dose range? Accuracy?

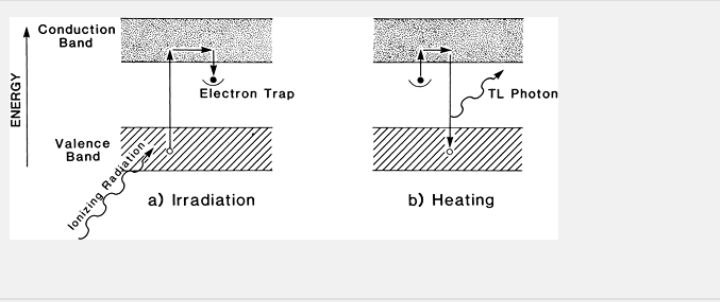


FIG. 8.11. A simplified energy-level diagram to illustrate thermoluminescence process.

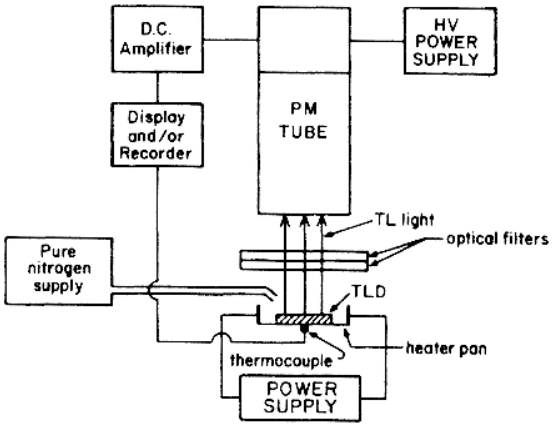
(Kahn p146) In a crystal lattice, on the other hand, electronic energy levels are perturbed by mutual interactions between atoms and give rise to energy bands: the "allowed" energy bands and the forbidden energy bands. In addition, the presence of impurities in the crystal creates energy traps in the forbidden region, providing metastable states for the electrons. When the material is irradiated, some of the electrons in the valence band (ground state) receive sufficient energy to be raised to the conduction band. The vacancy thus created in the valence band is called a positive hole. The electron and the hole move independently through their respective bands until they recombine (electron returning to the ground state) or until they fall into a trap (metastable state). If there is instantaneous emission of light owing to these transitions, the phenomenon is called fluorescence. If an electron in the trap requires energy to get out of the trap and fall to the valence band, the emission of light in this case is called phosphorescence. The phosphorescence at room temperature is very slow, but can be speeded up significantly with a moderate amount of heating (~300 degree), the phenomenon is called thermoluminescence (TL).

As e drop back down to the ground state they release light photons in proportion to the energy initially absorbed. The calibrated application of heat cycles in the post-irradiation processing of the TLD accelerates this process & allows for a correlation between PMT signal & dose absorbed by the TLD.

The gap between the conduction and valance band is about 10 eV which is 3 fold less than the work function required in the air used in ion chamber so TLD is much sensitivity compared ion chamber.

(Kahn p145) (LiF Lithium fluoride) Among TL phosphors, LiF is most extensively studied and most frequently used for clinical dosimetry. LiF in its purest form exhibits relatively little thermoluminescence. But the presence of a trace amount of impurities (e.g., magnesium) provides the radiation-induced TL. These impurities give rise to imperfections in the lattice structure of **LiF** and appear to be necessary for the appearance of the TL phenomenon.

- The dimension is about 3 mm Area x 1 mm thick (Attix p403)
- The useful dose range is about $5x10^{-5}$ – 10^{3} Gy range, approximately order of **7** difference.
- What's typical accuracy achievable with TLD? 3% (Kahn)
- The emission wavelength is 350 – 600 nm and max at 400 nm (Attix p404)



- The TLD diagram from Attix (on right). What's this? (TLD reader, readout process) how does it work? What's the purpose of nitrogen gas? Know the use of optical filter, function of PMT. What is the wavelength? Any filters – which one and why? How is the signal amplified in PMT? Explain the electronics in a PMT. Why is HV needed at the top? What does the D.C. amplifier do**?**

  A TLD reader is the machine used to measure the amount of energy stored in a sample crystal & correlate that energy into absorbed dose. A basic TLD reader needs 1. Planchet, 2. PMT, 3. Electrometer

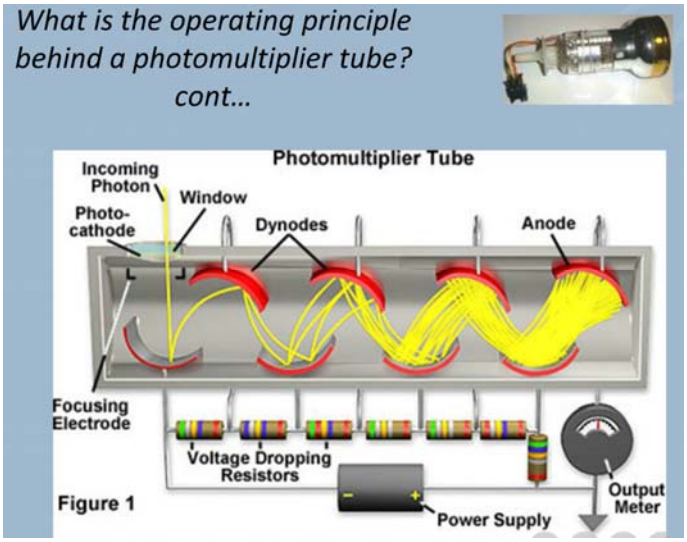
  The arrangement for measuring the TL output is shown schematically in above figure. The irradiated material is placed in a heater cup or planchet, where it is heated for a reproducible heating cycle. The emitted light is measured by a photomultiplier tube (PMT) which converts light into an electrical current. The current is then amplified and measured by a recorder or a counter.

  (wiki) A **planchet** is a round metal disk that is ready to be struck as a coin.

  Because the emission wavelength of LiF is 350 – 600 nm and max at 400 nm (Attix p404), to maintain a constant light sensitivity readout not affected by other non-dose related light such as heat(Infrared) signal from phosphor & the heating tray during heating process , we need the optical filter can filter the thermoluminescence and pass the light to PMT. Normally, the bandpass filter 400 – 500 nm are used (Attix p400).

  The N_2 (nitrogen gas) is to reduce the spurious (偽) TL signal (background signal) from phosphor surface and the surrounding gas, especially we have small doses to be measured (Attix p400).

  PMT:



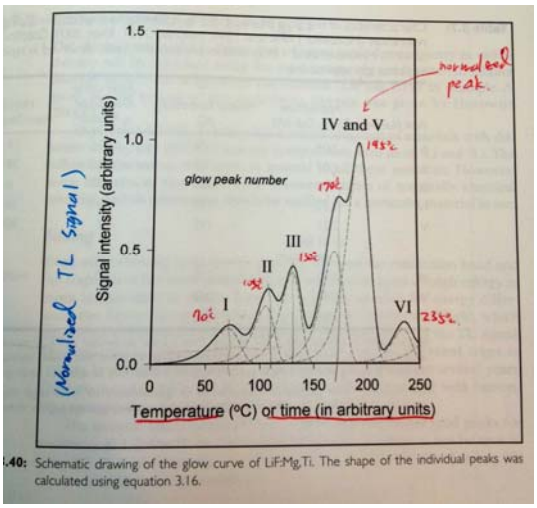
- A photon interacts w a scintillating crystal to produce a burst of light proportional to the energy of the initiating photon.
- The light ejects a number of electrons from the photocathode, and the number of electrons is proportional to the incoming light.
- The photoelectrons are accelerated through a series of dynodes (倍增電極), each at a higher potential, resulting in an amplification of the number of photoelectrons.
- The photoelectrons are ultimately collected at the end of anode, where the accumulation of charge results in a sharp current pulse indicating the arrival of a photon at the photocathode (wiki). Then the current was amplified by the DC. amplifier and the electrometer read the charge which is proportional to the incoming photon numbers.

Photon → photonelectrons → amplification through dynode → collected at the anode → produce current and amplified.

As described in above, the HV power supply is to provide the higher potential for dynodes used in PMT to amplify the **number of photoelectrons**, and the DC amplifier is to increase the PMT output voltage signal.

- How do you use TLDs in clinic? Glow curve? Draw a glow curve.

We don't use TLD in penn, but due to its small size, TLD can be used as *in* vivo dosimeter and personal dosimeter. (LiF has an effective atomic number of 8.2 compared with 7.4 for soft tissue. This makes this material very suitable for clinical dosimetry.)TLD's main advantage is in measuring doses in regions where ion chamber cannot be used. For example, TLD is extremely useful for patient dosimetry by direct insertion into tissues body cavities. Since TLD material is available in many forms and sizes, it can be used for special dosimetry situations such as for measuring dose distribution in the build-up region, around brachytherapy sources, and for personnel dose monitoring.



.40: Schematic drawing of the glow curve of LiF:Mg,Ti. The shape of the individual peaks was calculated using equation 3.16.

(MetCalf Fig. 3.40)

A plot of thermoluminescence signal vs. temperature (or incubation time) is called a glow curve. In most TL materials, there is more than 1 trap type. These traps have different energy gaps to the conduction band and will therefore empty at different temperatures. As the temperature of the TL material exposed to radiation is increased, the probability of releasing trapped electrons increases. The light emitted (TL) first increases, reaches a maximum value, and falls again to zero. Because most phosphors contain a number of traps at various energy levels in the forbidden band, the glow curve may consist of a number of glow peaks as shown in above. The different peaks correspond to different "trapped" energy levels.

- What are annealing and its purpose? Know heating temperature, How do you do it in your clinic? Would reading a TLD 1 hr or 1 day from irradiation make any difference? (Yes) How can you improve this (preheat) what does preheating actually do? How would you avoid those little bumps? What you need to do pre-radiation and post-radiation?

Because the response of the TLD materials is affected by their previous radiation history and thermal history, the material must be suitably annealed to remove residual effects.
The standard **preirradiation annealing procedure** for LiF is 1 hour of heating at 400C and then 24 h at 80C.

- The heating to 400C (the degree corresponding to the max wavelength in light) is to release any remaining charges from deeper traps (Attix p401).

- The slow heating, namely 24 hours at 80C, removes peaks 1 and 2 of the glow curve (Fig. 8.12) by decreasing the "trapping efficiency".

Peaks 1 and 2 can also be eliminated by **postirradiation annealing** for 10 minutes at 100C.

The need for **eliminating peaks 1 and 2** arises from the fact that the magnitude of these peaks **decreases relatively fast with time** after irradiation. By removing these peaks by annealing, the **glow curve becomes more stable and therefore predictable.**

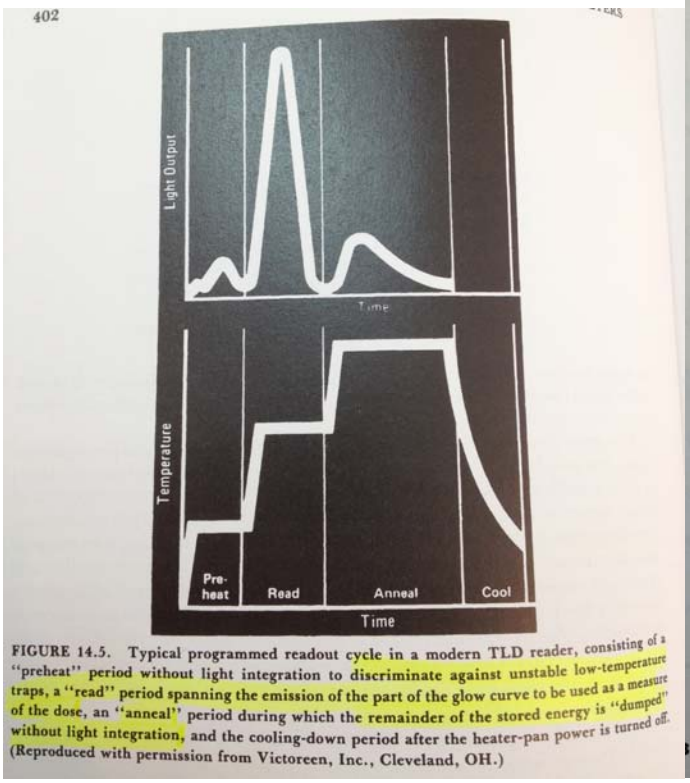
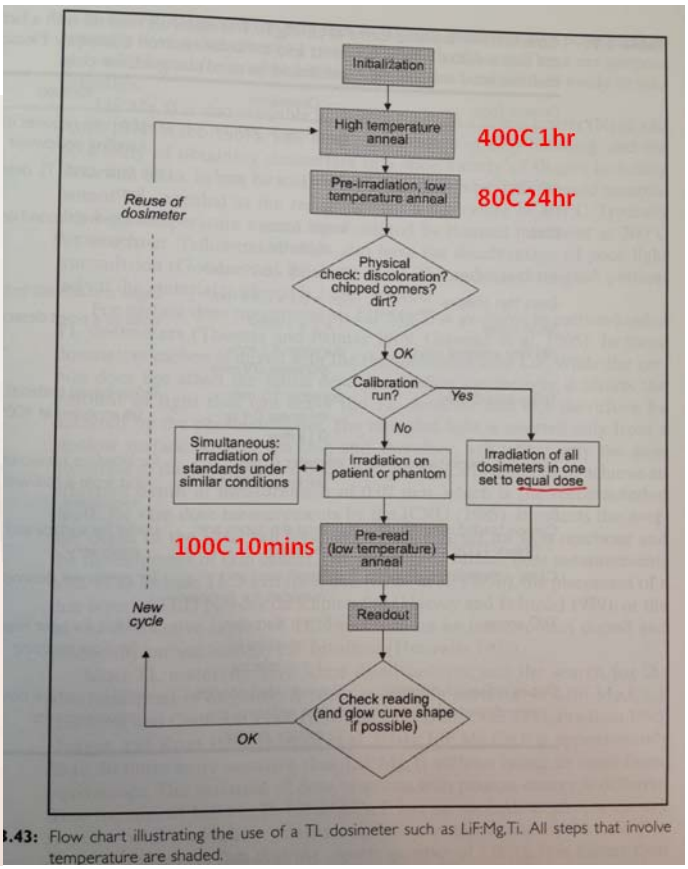


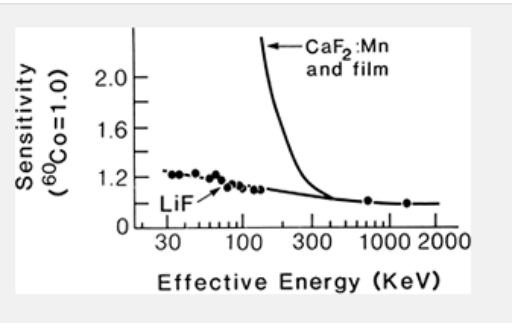
FIGURE 14.5. Typical programmed readout cycle in a modern TLD reader, consisting of a "preheat" period without light integration to discriminate against unstable low-temperature traps, a "read" period spanning the emission of the part of the glow curve to be used as a measure of the dose, an "anneal" period during which the remainder of the stored energy is "dumped" without light integration, and the cooling-down period after the heater-pan power is turned off. (Reproduced with permission from Victoreen, Inc., Cleveland, OH.)



.43: Flow chart illustrating the use of a TL dosimeter such as LiF:Mg,Ti. All steps that involve temperature are shaded.

- Is TLD energy dependent?

The TLD response is defined as TL output per unit absorbed dose in the phosphor. Figure 8.14 gives the energy response curve for LiF (TLD-100) for photon energies below megavoltage range. 20% over response at low E (30keV), and 5% under-response for linac energy range, normalized to Co60. (So very small energy sensitivity in our linac energy range)



- Why are TLD so great?

  Advantage:

- Small size: 3 mm Area x 1 mm thick (Attix p403)
- Wide useful dose range is about 5×10^{-5} – 10^{3} Gy range, approximately order of **7** difference.
- What's typical accuracy achievable with TLD? 3% (Kahn)
- Dose-rate independence (0-10^{11} cGy/s)
- Reusability so reduce the cost
- Economy
- Accuracy 3%

  Disadvantage:

- Fading: Irradiated dosimeters do not permanently retain 100% of their trapped charge carriers, LiF fades ~1% per month.
- Results are not instantly available
- Labor intensive (annealing, calibration, reading)
- Memory of radiation & thermal history
- Light sensitivity: TLDs all show some sensitivity to light. This can cause accelerated fading or leakage of filled traps.

- What is the advantage of TLD over diode?
  Less energy dependence compared to diode
  No angular dependence
  No dose rate dependence

- Neutron detection for TLD's
  TLD (LiF) with a variety of forms (Li has 2 isotopes, ^{6}Li & ^{7}Li) & with 3 levels of ^{6}Li/Li ratio: 0, 7, 96% for TLD-700, TLD-100, ,TLD-600, respectively. ^{6}Li {3 neutron 3 photon} has a high (n, α) capture cross section for thermal neutrons, while ^{7}Li = Li {4 neutron 3 photon} is low with this respect.

  Thus, TLD-700 primarily measure gamma-ray dose, while TLD-600 responds to any thermal neutrons present as well which is used as neutron detector.

- What do you actually read from TLDs and what are typical numbers?

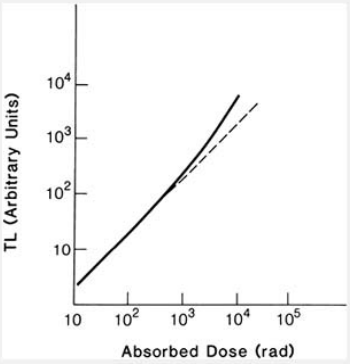
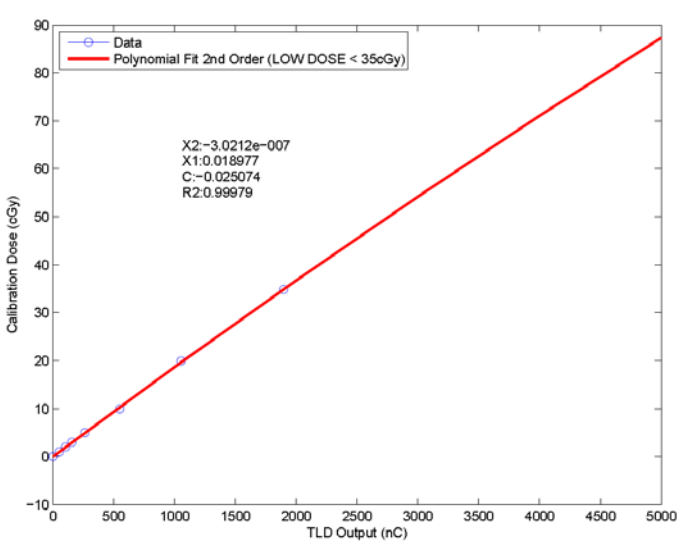
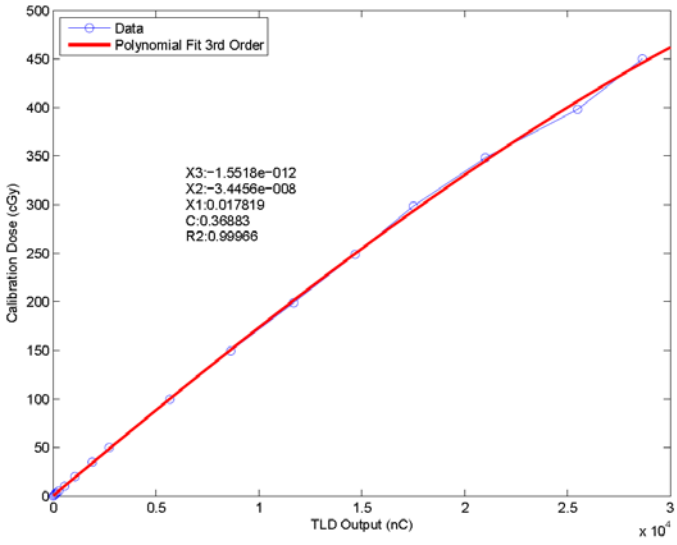


FIG. 8.13. An example of TL versus absorbed dose curve for TLD-100 powder (schematic).





(YY)Calibration curve is approximately 1Gy = 5000 nC readout.

- How do you perform TLD measurements in your department? Calibration of TLDs. Dose range. Would you calibrate your TLD at 100cGy if the measurement will be around 300? (No, due to supralinearity, we should calibrate at 300 range)?

The dose response curve for TLD-100 is shown in Fig. 8.13. The curve is generally linear up to 10^3 cGy but beyond this it becomes **supralinear**. The response curve, however, depends on many conditions that have to be standardized to achieve reasonable accuracy with TLD. The calibration should be done with the same TLD reader, in approximately the same quality beam and to approximately the same absorbed dose level.

Describe the method for calibration of TLD's.

- Prior to exposure for measurement purposes, TLDs must be annealed (baked and cooled according to protocol) to bring the electrons to ground state.
- TLD samples are irradiated to various known doses and the relative light output graphed to produce a dose curve which is used to determine the dose from unknown sources.

C4-B (Calibration)

TG51

- How do you setup for electron TG-51 calibration? Can you use a different SSD if more convenient for you? What kinds of chambers are recommended?

  The chamber should be set to at depth of $d_{ref} = 0.6R_{50} - 1$ for each electron energy and SSD distance to water surface is 100 cm. The cone >= 10 x 10 cm should be used, and >= 20 x 20 cm^2 should be used for R_{50} > 8.5 cm (Roughly for electron energy > 20 MeV). Yes, different SSD 90 – 110 cm is allowed. But when we determine the beam quality R_{50}, we must use SSD = 100 cm, and field size 10 x 10. Parallel plate chamber is recommended for the electron beam <= 10 MeV and it is a must for energy <= 6MeV

- TG 51 dose equation and explain each term and how you use it

  Photon: $D^Q_W = Mk_Q N^{60\text{-}Co}_{D,W} = M_{raw}P_{TP}P_{ion}P_{pol}P_{elec}k_Q N^{60\text{-}Co}_{D,W}$

  Electron: $D^Q_W = Mk_{R50}P^Q_{gr}N^{60\text{-}Co}_{D,W} = Mk_{ecal}k'_{R50}P^Q_{gr}N^{60\text{-}Co}_{D,W} = M_{raw}P_{TP}P_{ion}P_{pol}P_{elec}k_{ecal}k'_{R50}P^Q_{gr}N^{60\text{-}Co}_{D,W}$

$$P_{TP} = \frac{273.2+T}{295.2}\frac{760}{P},\ P_{pol} = \frac{\left|M^+_{raw} - M^-_{raw}\right|}{2M_{raw}},\ P_{ion} = \frac{1 - V_H/V_L}{M_H/M_L - V_H/V_L},\ P_{gr} = \frac{M(d+0.5r)}{M(d)}$$

  V_H = 300 V , V_L = 150 V.

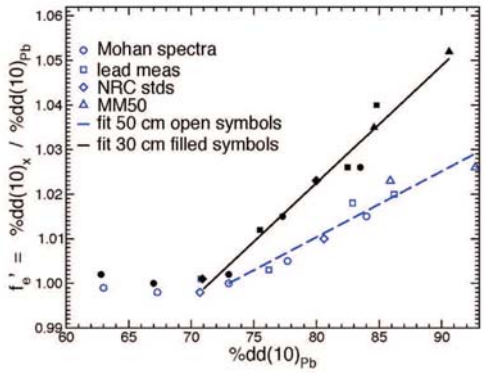
- TG51. Why do you need the lead foil? What correction factors do you need?

  To correct the e contamination from linac head. Because the photon beam specifier, %dd(10)x depends on the d_{max} , the %dd(10) will be reduced due to e contamination at d_{max}.

  If E > 10 MV $\Rightarrow$ get $\%dd(10)_x$ from $\%dd(10)_{Pb}$

30 ± 1 cm from phantom surface:
$\%dd(10)_x = [0.8116 + 0.00264\%dd(10)_{Pb}]\%dd(10)_{Pb}$
$(\%dd(10)_x = \%dd(10)_{Pb}$ if $\%dd(10)_{Pb} < 71\%)$

50 ± 5 cm from phantom surface:
$\%dd(10)_x = [0.8905 + 0.00150\%dd(10)_{Pb}]\%dd(10)_{Pb}$
$(\%dd(10)_x = \%dd(10)_{Pb}$ if $\%dd(10)_{Pb} < 73\%)$



- Shown the TG-51 equation: Dw = $MkqN_{DW}^{60}$ What is kq? How do you get it for electrons and photons? What is kq for Co-60?

K_Q is the beam quality factor, transferring N_{DW} Q Co60, to N_{DW} Q.
Photon: $D^Q_W = Mk_QN^{60\text{-}Co}_{D,W} = M_{raw}P_{TP}P_{ion}P_{pol}P_{elec}k_QN^{60\text{-}Co}_{D,W}$
Electron: $D^Q_W = Mk_{R50}P^Q_{gr}N^{60\text{-}Co}_{D,W} = Mk'_{R50}P^Q_{gr}N^{60\text{-}Co}_{D,W} = M_{raw}P_{TP}P_{ion}P_{pol}P_{elec}k_QN^{60\text{-}Co}_{D,W}$
K_Q = 1 for 60Co

- Know about Kq (what it is, how is it determined, what are the Kq values for Co-60, 6 MV, 18 MV)

SSD = 100
kQ
Co = 1
6x (67%): 0.99 (msk: 0.667; 0.773)
15x (77%): 0.98 (msk: 0.771; 0.869)
18x(80%): 0.97

- Shown the Fig.1 graph in TG-51. Explain the graph? How do you convert depth ionization to depth dose? For e- and for photon beams? What are the correction factors involved?
- If Given Figure 1 from TG-51 (just the e- curve). Know what it is. Know about finding beam quality of electron field and R50. How do you measure it?

- Depth ionization curves for electron and photons is shown (with and without shifts overlaid) what are these plots, which one is electron and which one is photon (how did you identify) (electron curve is with sharp gradient)(Pointing to electron curve) is this a PDD curve? Why is PDI and PDD different for electrons? What do you need to use to convert it to PDD? Have you actually done that and how?

% depth ionization graph vs depth for photon and electron.
We will need to shift the depth ionization curve upstream, 0.6r for photon and 0.5r for electrons to correct the gradient effect.
For photon, the variation of stopping power ratio passing d_{max} is < 0.1% so the PDI can be taken as the PDD.

For electron, because the stopping power ratio is depth dependent which is different than the photon beam. So, the PDI needs to be corrected by the stopping power ratio at different depth along with the P_{repl} correction. For the well-guard chamber, the $P_{repl} = P_{fl}$.

TABLE IV. Ratios of average, restricted stopping powers for photon spectra, $\Delta = 10$ keV (Ref. 25).

Nominal accelerating potential (MV)	$(\bar{L}/\rho)^{med}_{air}$ Water	Polystyrene	Acrylic	Graphite	A-150	C-552	Bakelite	Nylon
2	1.135	1.114	1.104	1.015	1.154	1.003	1.084	1.146
^{60}Co	1.134	1.113	1.103	1.012	1.151	1.000	1.081	1.142
4	1.131	1.108	1.099	1.007	1.146	0.996	1.075	1.136
6	1.127	1.103	1.093	1.002	1.141	0.992	1.070	1.129
8	1.121	1.097	1.088	0.995	1.135	0.987	1.063	1.120
10	1.117	1.094	1.085	0.992	1.130	0.983	1.060	1.114
15	1.106	1.083	1.074	0.982	1.119	0.972	1.051	1.097
20	1.096	1.074	1.065	0.977	1.109	0.963	1.042	1.087
25	1.093	1.071	1.062	0.968	1.106	0.960	1.038	1.084
35	1.084	1.062	1.053	0.958	1.098	0.952	1.027	1.074
45	1.071	1.048	1.041	0.939	1.087	0.942	1.006	1.061

For electron, we can use TG70 formula with use the stopping power ratio and electron fluence correction to transfer the % depth ionization curve to % depth-dose curve.

$$\%dd_w(d) = \%di_w(d) \times \frac{(\bar{L}/\rho)^w_{air}(R_{50}, d) \cdot P_{fl}(E_d)}{(\bar{L}/\rho)^w_{air}(R_{50}, d_{max}) \cdot P_{fl}(E_{d_{max}})}.$$

$$\left(\frac{\bar{L}}{\rho}\right)^w_{air}(R_{50}, d) = \frac{A + B(\ln R_{50}) + C(\ln R_{50})^2 + D(d/R_{50})}{1 + E(\ln R_{50}) + F(\ln R_{50})^2 + G(\ln R_{50})^3 + H(d/R_{50})}$$

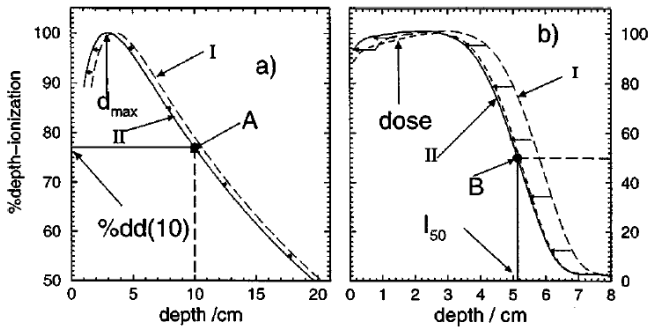
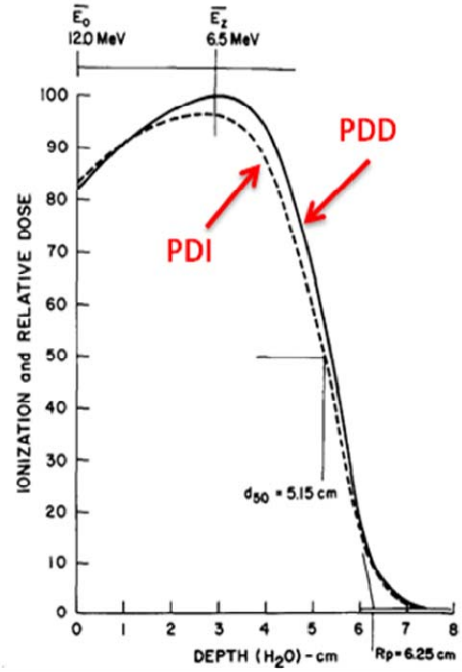


FIG. 1. Effect of shifting depth-ionization data measured with cylindrical chambers upstream by 0.6 r_{cav} for photon beams [panel (a)] and 0.5 r_{cav} for electron beams [panel (b)] (with r_{cav} = 1.0 cm). The raw data are shown by curve I (long dashes) in both cases and the shifted data, which are taken as the depth-ionization curve, are shown by curve II (solid line). The value of the % ionization at point A (10 cm depth) in the photon beam gives $\%dd(10)$ and the depth at point B (solid curve, 50% ionization) in the electron beam gives I_{50} from which R_{50} can be determined (see Sec. VIII C). For the photon beams, curve II is effectively the percentage depth-dose curve. For the electron beams, curve II must be further corrected (see Sec. X D) to obtain the percentage depth-dose curve shown (short dashes—but this is not needed for application of the protocol).



- Picture of electron PDD from TG-51? Why do we need to know kr50? Why do we shift the curve. What direction do we shift the curve? He then had me draw a 6 MeV electron PDD.

A: the k_{R50} is the beam quality factor for electron beam multiplying with the gradient correction P_{gr} equal to kQ which transfer the Nd,w for Co60 to Nd,w Q for our user beam.

Shift the curve is to correct the gradient effect

Upstream

6 MeV d_{max} is about 1.5 cm, and R50 = 6/2.3 = 2.6 cm, Rp = E0/2 = 3 cm (TG70 eq: Rp = 1.271R50 – 0.23 → 3.04 cm for 6 MeV), and the surface dose is around 70.8%, and the bremstralung contamination is around 0.5%, so we can plot the curve according this info.

TABLE VI. Percentage depth dose at the surface and superficial regions of high-energy electron beams for a Varian 2300 C/D for a 10×10 cm^2 cone at 100 cm SSD. Also shown are the depths at which D_{max} and D_{90} occur.

	Electron percentage depth dose[a] (%)					
Depth	6 MeV	9 MeV	12 MeV	15 MeV	18 MeV	22 MeV
Surface[b]	70.8	76.5	82.0	86.6	88.4	89.1
0.5 cm	82.5	84.7	89.5	93.7	96.0	97.0
1.0 cm	94.0	90.0	92.6	96.4	98.7	98.9
D_{max} depth (cm)	1.4	2.2	2.9	2.9	2.9	2.2
D_{90} depth (cm)	1.8	2.8	3.9	4.8	5.4	5.8

[a]Measurements given in this table were taken with an Attix chamber whose front electrode is 0.025 mm thick, 4.8 mg/cm^2 Kapton (Ref. 130).
[b]Defined as 0.5 mm depth on the central axis.

(MSK) X-ray contamination for Electron: 6MeV (0.2%), 9 (0.7%), 12 (1.2%), 16 (2.5%), 20 (3.6%)

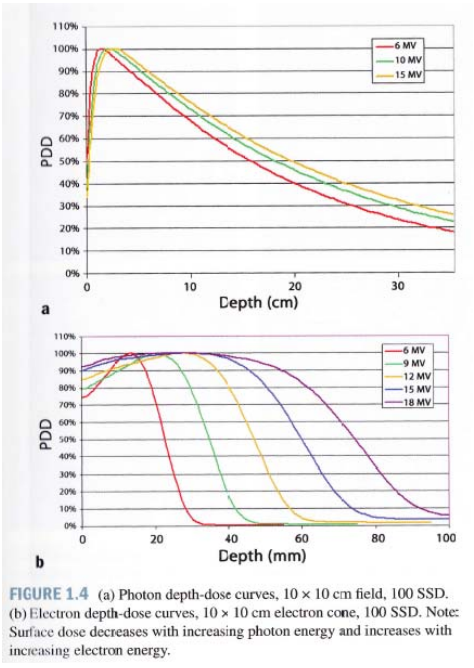


FIGURE 1.4 (a) Photon depth-dose curves, 10 × 10 cm field, 100 SSD. (b) Electron depth-dose curves, 10 × 10 cm electron cone, 100 SSD. Note: Surface dose decreases with increasing photon energy and increases with increasing electron energy.

TABLE 1.2 Selected Beam Characteristics

Photons	Electrons
^{60}Co: D_{max} = 0.5 cm, attenuation ~5%/cm	MeV/5 = D_{max} (cm)
4 MV: D_{max} = 1.0 cm	MeV/4 = 90% IDL
6 MV: D_{max} = 1.5 cm, attenuation ~4%/cm	MeV/3 = 80% IDL
10 MV: D_{max} = 2.5 cm	MeV/2.33 = 50% IDL
18 MV: D_{max} = 3.5 cm, attenuation ~3%/cm	MeV/2 = R_p

Abbreviations: ^{60}Co, Cobalt 60; IDL, isodole line; R_p, practical range.

- TG51 Electron beam calibration equation

$$D_w^Q = M P_{gr}^Q \, k'_{R_{50}} k_{ecal} \, N_{D,w}^{^{60}Co}$$

- What is this equation?
- Define k'$_{R50}$

k'R50 is one of the component of K_{R50} which translates the calibration factor of the beam quality Q_{ecal} to the user electron beam quality Q.

- What is the depth correction

The gradient correction is to correct the fact of the chamber signal obtained at the center of the chamber is different than the signal supposed to be obtained in an undisturbed medium.

- How do you obtain it?

For the reference dose measurement, the P_{gr} is obtain by applying the correction factor $P_{gr} = \frac{M(d+0.5r)}{M(d)}$

For the measurement of getting I_{50} & then further getting the k'R50 using cylindrical chamber, we should shift the ionization curve upstream by 0.5r for electron.

- The follow up question was about why do we use CO-60 beam for calibration? Why not a linac.
  Know that we cannot use a linac because the linac output is not constant and needs to be calibrated too. The CO-60 beam has two constant energies (1.2 and 1.3 MV, so ave = 1.25 MV), but mainly because the exposure rate constant (13.07 (R cm^2)/(mCi h)) is a constant value and dose not change with activity. Therefore, it is highly reproducible.

- TG-51 Electron curve for I50, R50, how to get Ep, E0. Effective point. How to get R50 from I50
  $E_0 = 2.33R_{50}$;
  Ez = E0(1 – z/Rp)
  Ep(Z) = Ep0(1 – Z/Rp)
  $Ep0 = C_1 + C_2R_p + C_3R_p^2$ (Kahn 14.2)
  $C_1 = 0.22$, $C_2 = 1.98$, $C_3 = 0.0025$

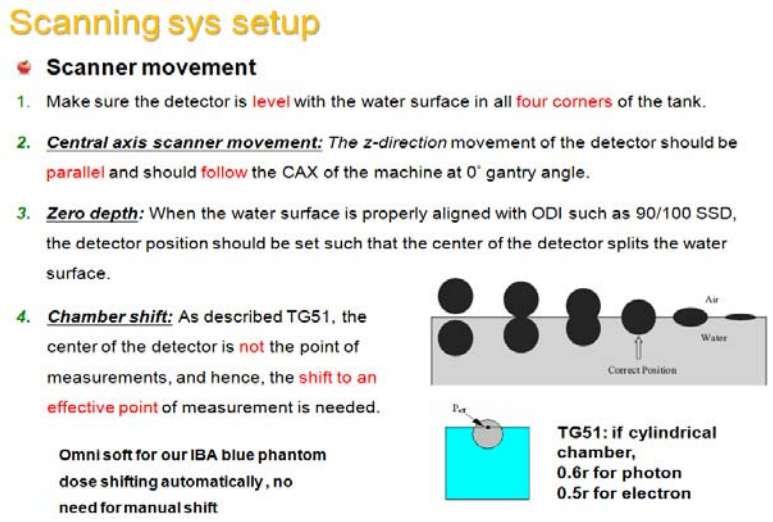
  TG51 provided 2 equations for 2 <= I50 <= 10 cm, and I50 > 10 cm

  $$R_{50} = 1.029I_{50} - 0.06 \quad (\text{cm}) \quad (\text{for } 2 \leq I_{50} \leq 10 \text{ cm}) \qquad (16)$$

  or

  $$R_{50} = 1.059I_{50} - 0.37 \quad (\text{cm}) \quad (\text{for } I_{50} > 10 \text{ cm}). \qquad (17)$$

  Effective point of measurement is 0.5r upstream for cylindrical chamber, so we can move the chamber down 0.5r when we first setup the chamber or shift the depth ionization curve later.



  For PP, the effective point of measurement is the inner surface of the entrance window.

- TG-51 Electron Kq factor. Why is it important? How do you get it; K'(r50), K(ecal), P_gradient.

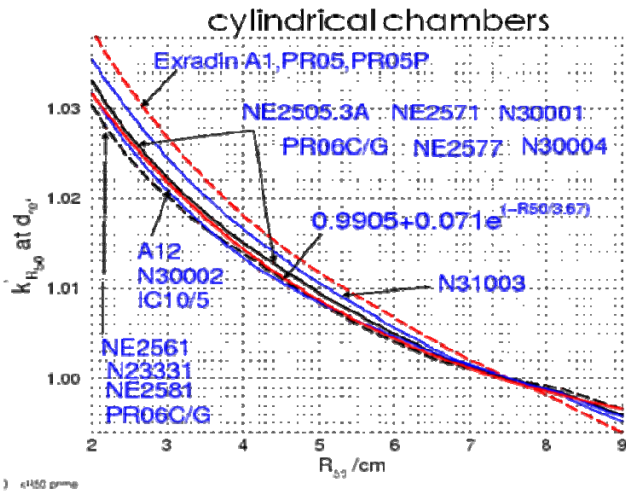
  For electron $K_Q = P_{gr}\ K'_{R50} \times K_{ecal}$
  K_{ecal} table look up for a specific chamber type
  For our Exradin A12, the k_{ecal} is 0.906, and inner radius is 0.305 cm, wall thickness is 0.9 mm

K'R50 can also obtained from the graph provided by TG51.
Pgr is corrected by the eq.

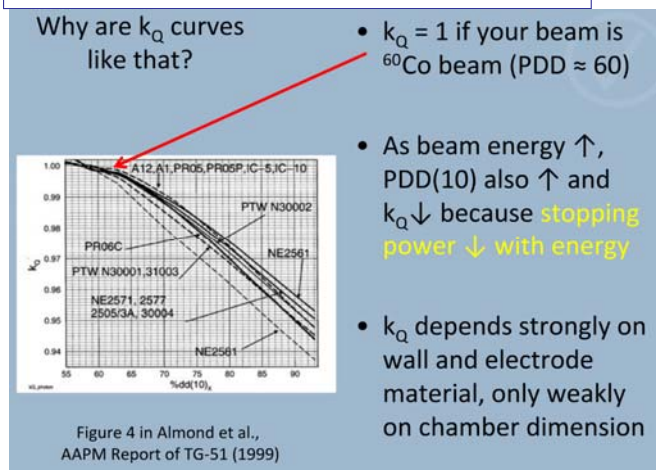
TABLE III. Values of the photon-electron conversion factor, k_{ecal}, for commercial cylindrical chambers, calculated as described in Ref. 52 and adopting a beam quality Q_{ecal} of R_{50}=7.5 cm.

Chamber	k_{ecal}	Wall Material	Wall Thickness g/cm²	Cavity radius r_{cav} (cm)	Al electrode diameter (mm)
Farmer-like					
Exradin A12	0.906	C-552	0.088	0.305	
NE2505/3,3A	0.903	Graphite	0.065	0.315	1.0
NE2561[a]	0.904	Graphite	0.090	0.370[e]	1.0
NE2571	0.903	Graphite	0.065	0.315	1.0
NE2577	0.903	Graphite	0.065	0.315	1.0
NE2581	0.885	A-150	0.041	0.315	
Capintec PR-06C/G	0.900	C-552	0.050	0.320	
PTW N23331	0.896	Graphite	0.012	0.395[e]	1.0
		PMMA	0.048		
PTW N30001[b]	0.897	Graphite	0.012	0.305	1.0
		PMMA	0.033		
PTW N30002	0.900	Graphite	0.079	0.305	
PTW N30004	0.905	Graphite	0.079	0.305	1.0
PTW N31003[c]	0.898	Graphite	0.012	0.275	1.0[f]
		PMMA	0.066		
Other cylindrical					
Exradin A1[d]	0.915	C-552	0.176	0.200	
Capintec PR-05/PR-05P	0.916	C-552	0.210	0.200	
Wellhofer IC-10/IC-5	0.904	C-552	0.070	0.300	

[a]The NE2611 has replaced the equivalent NE2561.
[b]PTW N30001 is equivalent to the PTW N23333 it replaced.
[c]PTW N31003 is equivalent to the PTW N233641 it replaced.
[d]The cavity radius of the A1 here is 2 mm although in the past Exradin has designated chambers with another radius as A1.
[e]In electron beams there is only data for cavity radii up to 0.35 cm and so 0.35 cm is used rather than the real cavity radius shown here.
[f]Electrode diameter is actually 1.5 mm, but only data for 1.0 mm is available.

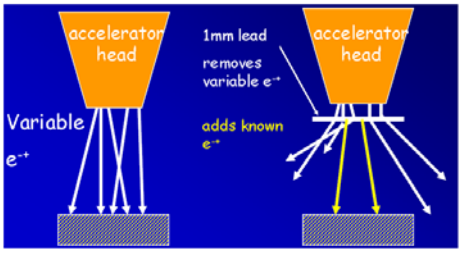


$$k'_{R_{50}}(\text{cyl}) = 0.9905 + 0.0710e^{(-R_{50}\ 3.67)}$$



- TG-51 lead foil. Details about location, size, thickness. Two reasons for using it? What if you did not use it? How much error do you expect? At what energy do you need it?
  30 cm+/- 1cm and 50 cm +/- 5 cm from the water surface, 1 mm +/- 20% thickness large enough to cover the collimator opening, **k_Q ~ 0.4% (=calibration error),** > 10 MV

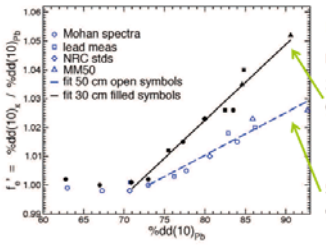
E contamination for %dd(10)$_x$



1 mm lead foil placed from 30 or 50 cm from phantom surface

- The e contamination can contribute the dose at d_{max} so any measured %dd(10) can be potentially reduced, Photon > 10 MV, we need to consider the e contamination
- 1 mm lead placed below linac head, the lead scatters the electrons so broadly that the contribution to the dose at d_{max} in the phantom is negligible.
- The lead also leads its own e contamination & slightly bean harden but it can be accurately calculated by MC.

E contamination for %dd(10)$_x$



1 mm lead foil placed from 30 or 50 cm from phantom surface

If E > 10 MV ⇒ get %dd(10)$_x$ from %dd(10)$_{Pb}$

30 ± 1 cm from phantom surface:

%dd(10)$_x$ = [0.8116 + 0.00264%dd(10)$_{Pb}$]%dd(10)$_{Pb}$

(%dd(10)$_x$ = %dd(10)$_{Pb}$ if %dd(10)$_{Pb}$ < 71%)

50 ± 5 cm from phantom surface:

%dd(10)$_x$ = [0.8905 + 0.00150%dd(10)$_{Pb}$]%dd(10)$_{Pb}$

(%dd(10)$_x$ = %dd(10)$_{Pb}$ if %dd(10)$_{Pb}$ < 73%)

- Say f'_e wrong by 1% near %dd(10)$_x$ = 80 % ~ 18 MV beam
  → %dd(10)$_x$ is 80.8% not 80% → error in k_Q is 0.17%
  → Ignore correction → 0.35% error in k_Q
- TG-51 is not sensitive to accounting accurately for e- contamination.

Why did TG-51 complicate things by allowing you to use either 50 cm or 30 cm distance for the lead foil? Why can't they just pick one distance?

- This is mostly for historical reasons
- The original idea for the Pb foil was to replace the machine-dependent electron contamination with relatively known contamination from a Pb foil with a given thickness
- Early researchers on this idea (early 90's) picked a distance of 50 cm, which worked out for machines at that time
- Then MLC became popular and for some machines with tertiary MLC you can no longer fit a 50 cm distance so they came up with 30 cm distance to accommodate it
- Now we are stuck with both

DWO Rogers, Correcting for electron contamination at dmax in photon beams, Med. Phys. 16, 133 (1992)

3 Do you really have to use the lead foil for higher energy photon beams? (1)

- TG-51 wants you to use the Pb foil
- But it also gives you a formula that you can use if you do NOT use the Pb foil
- TG-51 claims that this may lead to error in %dd(10)$_x$ of up to 2% and calibration error of up to 0.4%

%dd(10)$_x$ = %dd(10). For higher-energy beams the following applies up to %dd(10) = 89%:

$$\%dd(10)_x = 1.267\%dd(10) - 20.0 \quad [\text{for } 75\% < \%dd(10) \leq 89\%], \qquad (15)$$

where %dd(10) is measured as described above for an open beam. This formula is based on a global fit[45] to data in Fig. 7

4 Do you really have to use the lead foil for higher energy photon beams?

- In practice, calibration varies by no more than 0.2% if you use the no-Pb-foil formula (RPC data)
- If the lead foil is encased with a thin layer of plastic, no measurable difference will be seen in k_Q
- RPC's policy is to use lead foil until there are peer-reviewed data that demonstrate that it is not necessary

TABLE I. Error in k_Q if lead sheet is not used.

	Nominal MV	%dd(10)$_{Pb}$@30	%dd(10)$\|_0^{Pb@30}$	%dd(10)$_x\|_0^{Pb@30}$	$k_Q\|_0^{Pb}$
Varian machines	23	80.0	1.010	1.018	1.002
	18	79.7	1.008	1.015	1.002
	10	73.4	1.004	1.009	1.001

TG-51 experience from 150 institutions (RPC)

- - A quesiton about TG-51. Very specifically how do you cross-calibrate a plane plate chamber.

Should you use the parallel plate ADCL calibration for TG-51 electron dosimetry or cross-calibrate with a farmer chamber?

- TG-51 recommends cross-calibration of the parallel plate chamber with a cylindrical chamber in a high energy electron field (also recommended in TG-21 and TG-39).
- "^{60}Co calibration factors of at least some plane-parallel chambers appear to be very sensitive to small features of their construction" – TG-51 sec. 10
- Differences in excess of 2% have been measured between PP chamber models.

Can you use a cylindrical chamber for absolute dosimetry of low energy electrons beams?

- TG-51 requires the use of a PP chamber for electron beams with incident energies <= 6MeV
- TG-51 suggests the use of a PP chamber for electron beams with incident energies <= 10MeV
- The Radiological Physics Center (RPC) compared the use of PP and cylindrical chambers for the absolute calibration of electron beams.
  - No measureable difference between PP and cylindrical chamber from 5 MeV to 20 MeV.
  - PP chamber models can differ by >2% so cross-calibration with cylindrical chambers is critical.

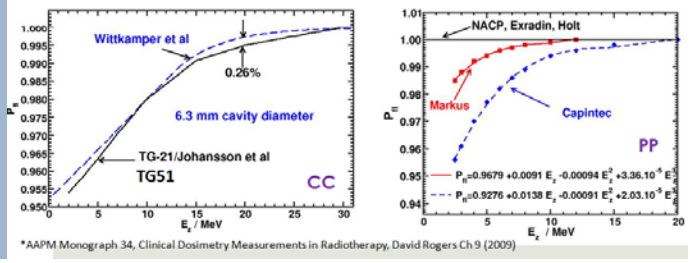
So RPC shows no difference between 5 – 20 MeV, so Penn still use CC for absolute dosimetry for 6 MeV beam

What are the steps to cross-calibrate a parallel plate chamber with a farmer chamber?

- Per TG-51, Worksheet C
  - Perform absolute calibration of high energy (>= 16 MeV) electron beam with cylindrical chamber at d_{ref}
  - Perform absolute calibration of same beam with PP chamber at d_{ref}
  - Determine k'_{R50} for PP from Fig. 6 or 8
    - Note that there is no P^{Q}_{gr} for PP chamber
  - Equate cylindrical and PP calibrations and solve for $(k_{ecal}\, N_{D,w}{}^{60Co})^{PP}$
  - This is your cross calibration factor!

Fluence correction factor, P_{fl}

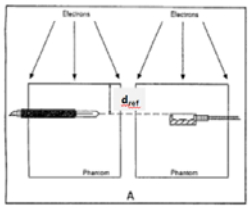
- The significant departure from unity of P_{fl} for commonly used CC makes this chamber unsuitable in low energy e beams
- Well guard PP chamber P_{fl} is taken as 1, except the Markus and Capintec PP
  - TG51 recommends using well-guard PP for E < = 10 MeV, R50 <= 4.3 cm .
  - TG51 requests using well-guard PP for E < = 6 MeV, R50 <= 2.6 cm .



*AAPM Monograph 34, Clinical Dosimetry Measurements in Radiotherapy, David Rogers Ch 9 (2009)

Why does TG51 suggest high e energy for cross calibration used in the e dosimetry?

- Due to the larger correction of the $P_{repl} = P_{fl}P_{gr}$ is shown in low e- energy beam, high e- is a better choice for the cross calibration procedure.
- d_{ref} is to the center of the CC and front face of the PP.



$$(N^{^{60}Co}_{D,w}\, k_{ecal})^{PP} = \frac{(D^{Q}_{w})^{PP}_{test}}{(k'_{R_{50}} M)^{PP}_{test}} = \frac{(D^{Q}_{w})^{cyl}_{test}}{(k'_{R_{50}} M)^{PP}_{test}} = \frac{(N^{^{60}Co}_{D,w}\, P^{Q}_{gr} k'_{R_{50}} k_{ecal} M)^{cyl}_{test}}{(k'_{R_{50}} M)^{PP}_{test}}$$

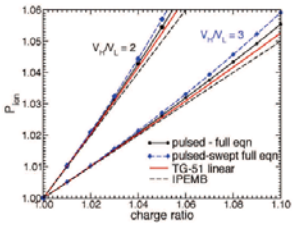
*The physics of radiotherapy X-rays and electrons, Sec. 8.2.5, Metcalf *et al.* (2007)

- (2006) Pion question ?

Recombination correction factor, P_{ion}

- In an IC cavity, some electrons and positive ions recombine before being collected. Therefore, P_{ion} is required to correct for this lack of 100% charge collection.
  - Dose rate dependent.
  - Determined from

$$P_{ion}(V_H) = \frac{1-(V_H/V_L)^n}{M^H_{raw}/M^L_{raw}-(V_H/V_L)^n}$$



  - Pulsed beams (like linac): n = 1
  - Continuous beam (Co^{60}): n = 2
  - If we use, $V_H/V_L = 2$, the accuracy can be within 0.2%
  - If $P_{ion} > 1.05$, we should use other chamber.

Describe, step by step, how you determine P_{ion} in TG-51. What are acceptable values?

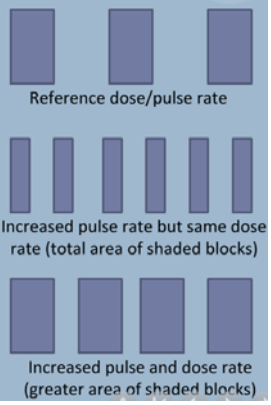
- Take a measurement (M^H_{raw}) at your normal operating voltage (V_H) and document your electrometer reading.
- Change the operating voltage on the electrometer to ½ of your V_H.
- Wait for several minutes after changing electrometer voltage for the chamber readings to come to equilibrium (electrometer to stabilize).
- Take another measurement (M^L_{raw}) at this new voltage (V_L).
- Plug your four terms above into the proper equation (pulsed or continuous source) to determine P_{ion}.
- The uncertainty in the correction factor becomes unacceptably large at P_{ion} greater than 1.05, necessitating the use of an alternative ion chamber.

Do you need to measure P_{ion} at each dose rate you employ in the clinic?

- *According to TG-51, YES!*
  - *"It must be emphasized that P_{ion} is a function of dose per pulse in accelerator beams and thus will change if either the pulse rate for a fixed dose rate, or the dose rate is changed. The correction must be measured in each set of experimental conditions for which clinical reference dosimetry is being performed."* **– TG-51**
- It seems reasonable to determine the range of P_{ion} for the various dose rates used at your clinic but practically speaking it is unlikely you'll change calibration factors (cGy/MU) from one patient to the next based upon minor changes in dose rate.

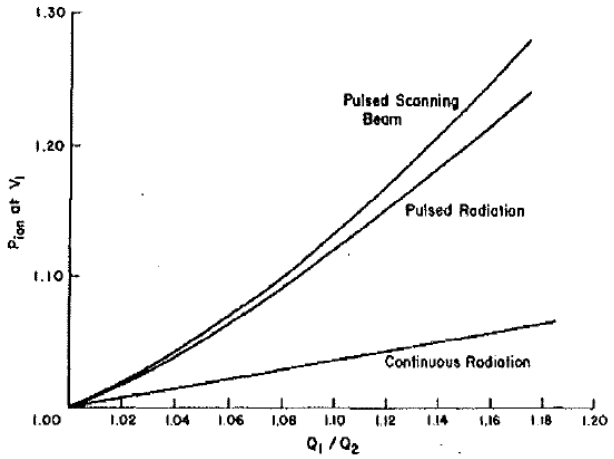
Why does dose rate or pulse rate matter for P_{ion} determination?

- The likelihood of recombination is dependent upon the number of ions available for collection at any given instant (ion density). As the dose rate or pulse rate changes, so does this ratio which in turn affects the likelihood of collection prior to ion recombination.



- (2006) TG21 scanned beam, continuous beam, pulsed beam
- If Given Figure 4 form TG-21 (Pion). Have to tell which curve was for pulsed scanning, pulsed, and continuous radiation. Why are they like that?

What does the "P_{ion} as a function of charge" graph look like for scanned, pulsed, and continuous radiation beams?



The ratio of the charges collected by 2 voltage (ex: 300 & 150 voltage) can be related P_{ion}. The pulsed radiation has large ion recombination than the continuous radiation.

Ion recombination can happen 2 ways,

1, intra (initial) electron track recombination
2. inter (volume) electron track recombination

For given beam energy #1 is the same for both pulsed and continuous beams.

For #2 in order to achieve the same dose rates (dose/min), the number of electron tracks per unit area in the chamber volume will be larger for pulsed beams wrt. continuous beams because there is a break where no radiation is present in the pulsed beam followed by radiation on. In the other word, the pulsed used less time to deliver more dose than the continuous beam.

Therefore at a certain time point, for the pulsed beam the electrons tracks are closer together wrt. to continuous beam so the recombination probability between the electron tracks is larger. This effect leads to higher recombination correction for pulsed beams wrt. continuous beams

From Ar

- What is the polarity factor of an ion chamber? What causes it? How does it change with energy? Is it different between cylindrical and plane parallel chambers?
  Is P_{pol} energy dependent? Why? For electron beams, for which beam P_{pol} is higher? Why?

IC polarity effects refer to the difference observed when negative charge (using positive bias v.) vs. positive charge (using negative bias v.) is collected. If the e field pattern is parallel to the direction of the radiation, the secondary charged particles of different polarities (positive or negative charge) will gain different energies and speeds (I think its due to the mass difference of the positive or negative ion) on their way to the collecting electrodes, which will induce different reading when we change our bias voltage to positive/negative. {The polarity effect actually can be corrected by taking average reading of both charged reading}. (Metcalf p144)

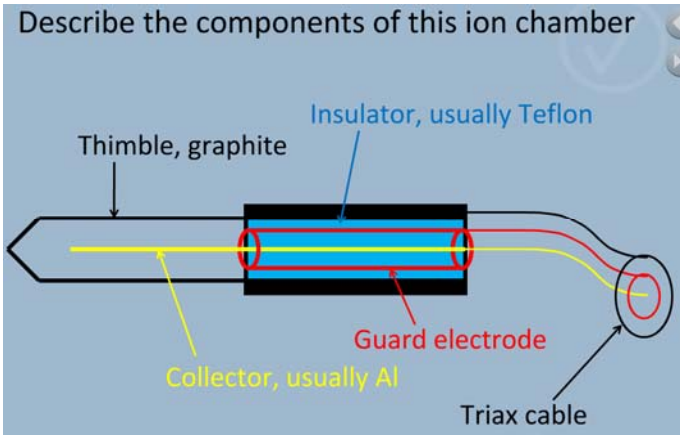
Kim et al. (2005) have associated polarity effects with electric field distortions due to potential differences between the guard electrode and the collecting electrode. In general, this effect is larger for parallel-plate chambers than for thimble chambers, and it depends on the type of irradiation (i.e., photon beam or electron beam) and the depth of measurement (Gerbi and Khan 1987).

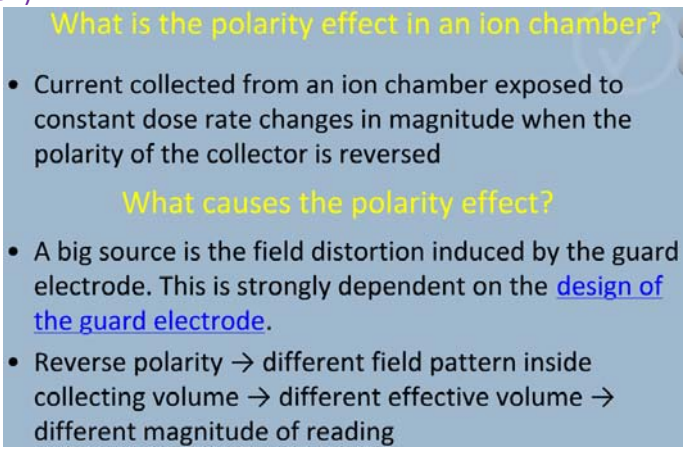
The polarity effect is also especially large in the **build-up region where no CPE** is established. Therefore, it is even more significant for **electron**, which there is no CPE established at all. (Australas. Phys. Eng. Sci. Med. 26, 85-87)

Polarity effect is larger for low energy beam (Med. Phys. **82**, 239,1981), particular for **low energy electron beam**, because the lower e beam is easier affected by the e field of the IC than the high e beam (my opinion).

(TG51) Typical polarity corrections should be between 0.997 and 1.003 (i.e., **within ±0.3%),** and is generally assumed to be unity for the ^{60}Co calibration beam. In the unlikely event that the polarity correction is more than 0.3% different from unity in a photon beam of 6 MV or lower energy, then one must establish what the value of Ppol is in the calibration laboratory's beam. This can be requested from the calibration laboratory or established by the clinical physicist using a ^{60}Co source. Since calibration laboratories traditionally report the calibration factor for one polarity, if there is a significant polarity correction in the calibration beam, the user must use $N^{60}Co/P^{60}Co$ everywhere in this protocol instead of N60Co

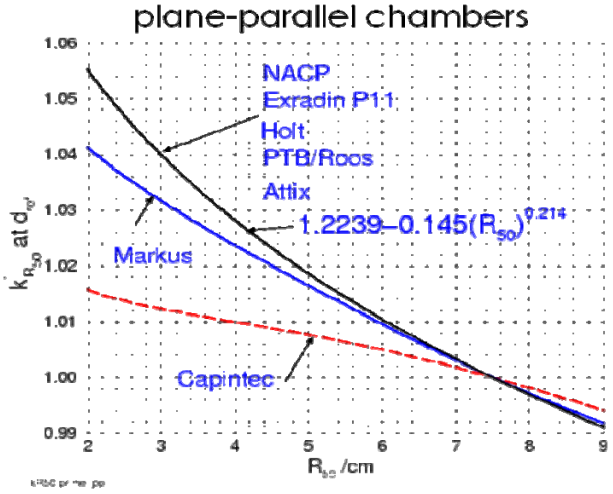
(AAPM summer school Clinical dosimetry, Ch 6 P201, and TG51)





(1). One source of polarity differences can occur when radiation interactions in the collecting electrode of the ion chamber can add or subtract from the measured signal. This effect is known as Compton current. **(2).** Current arising from ionizations outside the defined collecting volume, known as extracameral current, can also lead to polarity effects. A correction for this effect is determined by performing measurements with positive and negative equal voltages. The correction is then determined using the equation from the TG-51 protocol.

- (2006) Picture of K'R50 vs Energy graph from TG51 showing different parallel plate chambers. What's k'R50? What's going on in this graph? TG-51 term k'R50, define. Given PP graph from TG-51, why are 3 chambers the same?

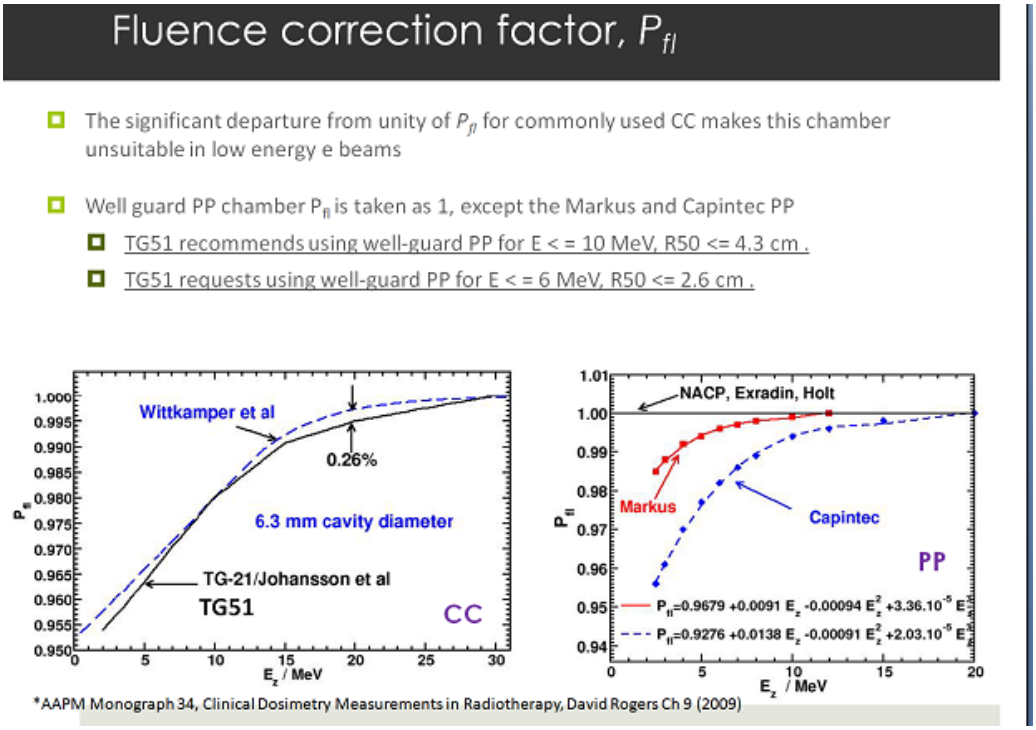


$$k'_{R_{50}}(\text{pp}) = 1.2239 - 0.145(R_{50})^{0.214}$$

$$k'_{R_{50}} = \frac{\left[(\bar{L}/\rho)^{w}_{air} P_{wall} P_{fl} P_{cel}\right]_{Q}}{\left[(\bar{L}/\rho)^{w}_{air} P_{wall} P_{fl} P_{cel}\right]_{Q_{ecal}}}$$

The k'R50 decreases from low energy to high energy and the value is > 1 to < 1 after passing R50 = 7.5 cm because the stopping power ratio is larger in the low energy and the smaller in the high energy and we normalized to the R50 = 7.5 cm so the k'R50 = 1. Except the markus and capintec chamber, we can use a curve to fit the k'R50 trend, so we need to be careful when we use the equation because it doesn't fit for all the chamber. The difference we see for the Markus and Capintec chamber is due to the lower $P_{fl} < 1$ for this 2 pp chamber seen in the lower energy range. Moreover from the kR50' equation, for a well-guard chamber, Pfl = 1, for PP, Pwall = 1, so for a well guard chamber,

$k'_{R_{50}} = \frac{\left[\left(\frac{L}{\rho}\right)^{water}_{air} P_{cel}\right]_Q}{\left[\left(\frac{L}{\rho}\right)^{water}_{air} P_{cel}\right]_{Qecal}}$, and for electron field, Pcel ~ 1, $k'_{R_{50}} = \frac{\left[\left(\frac{L}{\rho}\right)^{water}_{air}\right]_Q}{\left[\left(\frac{L}{\rho}\right)^{water}_{air}\right]_{Qecal}}$ that's the reason why we have these wellguard chamber all behave the same.



- If given PDD curves with depth correction for chamber radius. Lead to discussion of TG-51 including measurement of %dd(10) – why, how is it done, effects of Pb filter. What are sources of electron contamination?

Electron contamination is due to the high energy photon interacting with the high z material of the linac head.

- 2 Photon PDDs in same graph one is shifted for effective point of measurement. Why is it shifted? Explain underlying phenomena. Can you just start with shifted ion chamber and make no corrections?

To correct the gradient effect

Yes

(Effective point of measurement)

- Know cylindrical / pp chamber point of measurement questions, point where the fluence entering the chamber is counted at and know if it is it the photon or electron fluence that counts?
- Definition of "point of measurement" vs "effective point of measurement." Why the cylindrical and PP chamber differ? Math description for the effective point. How this was used during the calibration. Do you use the PP chamber for in-water measurement? What situation requires PP chamber.
- Showing a pic of effective point of measurement for ion-chamber and PP chamber. Discuss. (Kahn 116-118)

Electron fluence

Pp front surface

CC upstream from the center of the chamber

PP: Because the front plane of the PP is flat, and the electron is forward scattering, the PP senses the electron fluence mostly coming at the front surface window, so for PP the point of measurement = effective point of measurement
CC: the point of measurement is at the chamber center, however, due to the cylindrical geometry of the air cavity, the electron fluence passing through the air cavity sensing different attenuation if they pass the air cavity at different locations. Therefore, the effective measurement location to correct some of the electron fluence facing less attenuation in the air cavity is upstream of the point of measurement.

$$X_{eff} = \frac{\int_0^{\frac{\pi}{2}} x \cdot (2x \cdot \Phi \cos\theta ds)}{\int_0^{\frac{\pi}{2}} (2x \cdot \Phi \cos\theta ds)}$$

If we look at the above talk slide, we can see due to the P_{fl}, the CC is not suitable for the low energy electron beam, PP is good choice for low energy electron beam especially for energy less than 6MeV.

(Pressure & humidity)

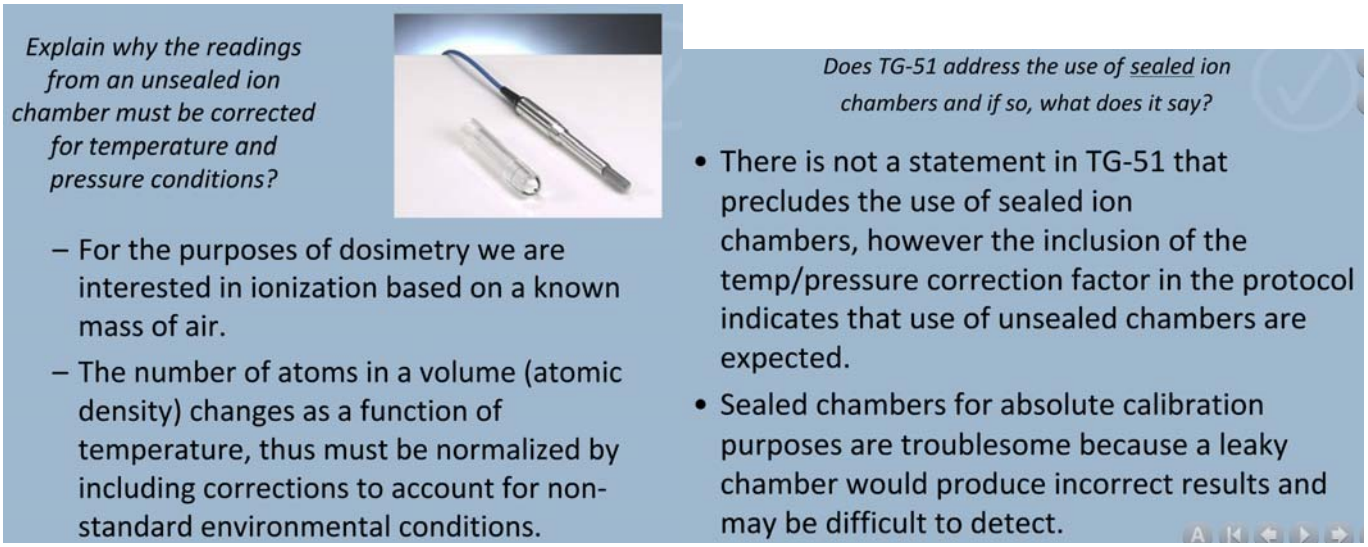
- Discuss Humidity effect, pressure effect. Airport pressure reading issue, why don't we have sealed chambers? What is the name of PV=nRT equation (ideal gas equation)?

(TG51) The humidity is virtually constant at 20 – 80%. In this range, the error introduced by ignoring this correction is +/-0.15%. Humid air can cause condensation inside the IC & this can effect chamber response, especially for nylon-wall chamber which therefore should not be used.

Check (DABR P114-116)

10% temp 1% output change
10% pressure 10% output change (5 mm Hg change, 0.6%)

The pressure we get from website is taken at the **sea level**, therefore, if the hospital is in a mountain, the pressure taken from the airport (at sea level) will need to be corrected.
7%/1000 m
http://www.altitude.nu/: Our place is at the same level as the airport (only 5 – 10 m above sea level),10 m is only 0.07% change in pressure.



If we have a sealed IC and send it to ADCL for absolute the calibration, we don't need to do the temperature and pressure correction. However, if there is a leakage, we may not be aware off.

Why are the ion chambers in most commercially available medical linear accelerators sealed?

- If unsealed chambers were used in medical linear accelerators one would need to update the temp/pressure correction factor daily and perhaps throughout the day as the linac head is heated with use and cooled between patients. This is the case with many Cyberknife units.

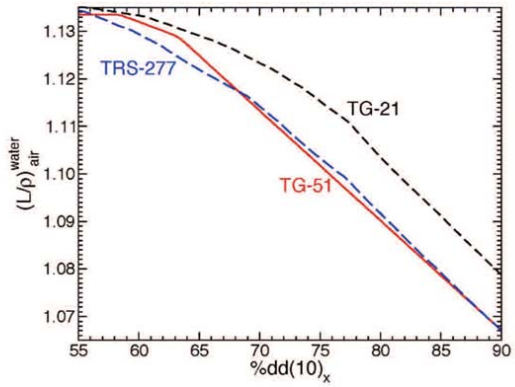
- TG-51 photon use with lead foil→ lots of questions on this. Also, how do you measure the e^- energy.

We can using the R50 to get the E_0

- TG 51 v.s. TG 21 – what's changed, why TG 51 is better.

Electron stopping power ratio; photon as a case, TG51 used newer data set ICRU37 than TG21 using ICRU35. TG51 photon is 1% higher than TG21. Electron beam TG51 is 2 – 3% higher.

$(\bar{L}/\rho)^{w}_{air}$ for Photon beam in TG51 and 21



The biggest difference between TG51 and 21

- %dd(10)x. TG-51, TRS-277, and TRS-398 values are based on ICRU 37 stopping powers and TG-21 values are based on ICRU 35 stopping powers.

C4- Calibration, Quality Control and Quality Assurance

Characteristics and use of calibration equipment; measurements of radiation quantity and quality; calibration and evaluation of ionizing and nonionizing radiation sources and installations; calibration and evaluation of measuring, recording and imaging devices; acceptance testing, commissioning, quality control and quality assurance; and related subjects.

Machine QA: Annual & monthly QA procedure
Acceptance & commissioning: TG106 talk slide, resident commissioning slide
IMRT QA
HDR: daily procedure, source exchange procedure
LDR: LDR note
C4-C (Machine QA)

- What tests do you do for annual QA on Linac, explain in detail setup & parameters.

List some of the major annual QA tests performed on your linear accelerator.

- Safety – emergency off buttons, interlocks, warning lights, area rad. detector, video/audio
- Mechanicals – mech. isocenter and readout accuracy
- Visual – ODI, lasers, light field
- Film – spoke shots, rad. vs. light (jaws and MLC)
- Scanner – PDD, flatness, symmetry
- Chamber – output, wedge/tray factors, linearity with MU, dose rate, gantry angle, absolute dosimetry calibration

In what order would you perform the tests mentioned, and why?

- Safety – patient/staff safety is paramount
- Mechanicals – if mechanicals are off, most other measurements are effected
- Visual (laser, ODI) – these tools are often used to setup up subsequent measurement tests
- Film – similar rationale as for mechanicals
- Scanner – deficiencies in this area may require beam steering or energy, which may affect chamber measurements
- Chamber – has least affect on other tests

With the increased implementation of image-guided radiation therapy, why might testing of the treatment couch be more critical?

- Remote movement of the treatment couch is a frequent occurrence with IGRT
- Many centers do not acquire a verification image following a minor couch movement, creating reliance upon accurate couch movement.
- Detailed annual measurements provide a baseline of table movement accuracy but should be augmented by a daily phantom test including couch motions and a verification image.
- Remote table movements that are on the same order as the table accuracy should be verified prior to patient treatment delivery.

TG40

Daily	Dosimetry	
	X-ray output constancy	3%
	Electron output constancy[b]	3%
	Mechanical	
	Localizing lasers	2 mm
	Distance indicator (ODI)	2 mm
	Safety	
	Door interlock	Functional
	Audiovisual monitor	Functional
Monthly	Dosimetry	
	x-ray output constancy[c]	2%
	Electron output constancy[c]	2%
	Backup monitor constancy	2%
	x-ray central axis dosimetry parameter (PDD, TAR) constancy	2%
	Electron central axis dosimetry parameter constancy (PDD)	2 mm @ therapeutic depth
	x-ray beam flatness constancy	2%
	Electron beam flatness constancy	3%
	x-ray and electron symmetry	3%
	Safety Interlocks	
	Emergency off switches	Functional
	Wedge, electron cone interlocks	Functional
	Mechanical Checks	
	Light/radiation field coincidence	2 mm or 1% on a side[d]
	Gantry/collimator angle indicators	1 deg
	Wedge position	2 mm (or 2% change in transmission factor)
	Tray position	2 mm
	Applicator position	2 mm
	Field size indicators	2 mm
	Cross-hair centering	2 mm diameter
	Treatment couch position indicators	2 mm/1 deg
	Latching of wedges, blocking tray	Functional
	Jaw symmetry[e]	2 mm
	Field light intensity	Functional
Annual	Dosimetry	
	x-ray/electron output calibration constancy	2%
	Field size dependence of x-ray output constancy	2%
	Output factor constancy for electron applicators	2%
	Central axis parameter constancy (PDD, TAR)	2%
	Off-axis factor constancy	2%
	Transmission factor constancy for all treatment accessories	2%
	Wedge transmission factor constancy[f]	2%
	Monitor chamber linearity	1%
	x-ray output constancy vs gantry angle	2%
	Electron output constancy vs gantry angle	2%
	Off-axis factor constancy vs gantry angle	2%
	Arc mode	Mfrs. specs.
	Safety Interlocks	
	Follow manufacturers test procedures	Functional
	Mechanical Checks	
	Collimator rotation isocenter	2 mm diameter
	Gantry rotation isocenter	2 mm diameter
	Couch rotation isocenter	2 mm diameter
	Coincidence of collimetry, gantry, couch axes with isocenter	2 mm diameter
	Coincidence of radiation and mechanical isocenter	2 mm diameter
	Table top sag	2 mm
	Vertical travel of table	2 mm

For the mechanical part,
The collimator, gantry, and couch rotation isocenter is important. We

Verify Calibration of Frontpointer vs Collimator

Specification for radius of runout -.25 mm

The machine Frontpointer was mounted. The main 100-105 cm Frontpointer was mounted and it was rotated on its long axis to verify its linearity. Graph paper was placed beneath the front pointer at 100 cm SSD and the crosshairs aligned to the frontpointer. The collimator was rotated from 90 to 270 and the run out was verified to be less that .25 mm.

Collimator Physical Isocenter – Frontpointer

TG40 < 2 mm diameter
The location of the central axis of the collimator was verified with the front pointer. The check of the front pointer verified a run out less than the specification

Gantry Physical Isocenter

Specification AAPM TG-40 – Maximum diameter of circle formed when rotating gantry through full range of motions no more than 2 mm

The physical isocenter was checked by observing the maximum drift from isocenter of the Frontpointer while rotating the gantry from 180 to 180E. The gantry front pointer was inserted and placed at 100.0 cm length. Another Frontpointer was placed on the end of the table and was aligned to meet the isocenter pointer with the gantry at zero. The gantry was then rotated through its entire rotation.

Couch Physical Isocenter

AAPM TG-40 Specification – Maximum diameter of circle formed when rotating table through full range of motions is no more than 2 mm

The Frontpointer indicating the physical center of the machine was in place and aligned to graph paper. With the tabletop aligned at 100 cm SSD, the turntable was rotated through its full range of motion. The maximum radius of deviation was noted

Coincidence of Gantry, Table and Collimator Isocenter

AAPM TG-40 Specification – Maximum diameter of circle formed when rotating collimator, gantry and table through full range of motions no more than 2 mm

Displacement of the front pointer from the pointer aligned at the original isocenter never deviated by more than 2 mm through movement of the table, gantry, and collimator.

Table Top Sag

AAPM TG-40 Specification – Maximum movement of 2 mm

Tabletop sag was measured by aligning the table to 100 cm SSD. A 30 cm stack of solid water was then placed on the gantry end of the table. The change in SSD is recorded below

Vertical travel of table (as we do in monthly QA)

Safety interlocks (Varian has 6 of them):

Absolute Primary Dose Calibration
TG51

Field Size Dependent Photon Output Factors

AAPM TG-40 Specifications – Measured values within +/-2% of stated values

Field size dependent output factors were measured at 100 cm SSD at a depth of 10 cm in the Blue Phantom for both photon energies. The depth of measurement was 10 cm for both 6x and 15x. All values are normalized to 1.000 for a field size of 10 x 10 cm^2. The field factors listed were measured with the Wellhofer CC-13 chamber. The measured data were compared to the data measured during acceptance and commissioning with the same setup. Factors were measured for field sizes of square 5, 10, 15, 20, 25 and 30 cm.

Cone factors

AAPM TG-40 Specifications – Measured values within +/- 2% of stated values

Cone factors were measured for each cone and energy combination in water at the depth of the 10 x 10 cone D_{max} for each energy and normalized to the reading at 10 x 10 at D_{max}. These values were compared to the values measured during acceptance and commissioning.

OAR Constancy vs. Gantry Angle

AAPM- TG-40 Specification – symmetry within +/-2% of normalized value

The Startrak device was used to measure the flatness/OAR at the three gantry angles (90, 0, 270) for two photon energy and one electron energy. These readings reflect the consistency of the off axis ratios with gantry angles. The differences in OAR for each angle were compared to the mean reading of the three. No value differed from the mean by more than the 2% specification

3. RADIATION ALIGNMENT TESTS

Collimator Radiation Star

Specification AAPM TG-40 – maximum diameter of isocenter shape- 2 mm

Films were exposed to radiation with a very irregular field of one large jaw setting and one small jaw setting. The films were irradiated for multiple collimator settings (270, 45, 0, 315). The intersection of the center of these fields was measured to evaluate the collimator radiation isocenter.

MLC Collimator Radiation Star

Specification AAPM TG-40 – maximum diameter of isocenter shape- 2 mm

A film was exposed to radiation with a open jaws and a fully closed bank of MLC leaves. The film was irradiated for MLC settings (90, 45, 0, 315). The intersection of the center of these fields was measured to evaluate the radiation isocenter of the MLC leaves.

Gantry Radiation Star

Specification AAPM TG-40 – maximum diameter of isocenter shape- 2 mm

Films were exposed to radiation with a very irregular field of one large jaw setting and one small jaw setting. The films were irradiated for multiple gantry settings (90, 0, 275, 185). The intersection of the center of these fields was measured to evaluate the gantry radiation isocenter.

Coincidence of Mechanical and Radiation Isocenter

AAPM TG-40 Specification – Maximum deviation from one isocenter to the other is no more than 2 mm in its maximum diameter

Evaluation of the gantry radiation isocenter was performed to verify the location of the two within 2 mm of each other. The gantry star shot was performed and the film was marked so that the physical isocenter could be located as well when developed.

Accessory Factors

AAPM TG-40 Specifications – Measured values within +/- 2% of stated values

Note: In commissioning we put SSD 90, and d = 10 cm.
The tray factor was measured and compared to the factor measured at acceptance and commissioning. The tray factor was measured as a ratio of the open to the tray blocked field at the depth of dose max for both photon energies.

TG106 suggest both d_{max} or 10 cm for measurement.

Wedge Centering

Note: In commissioning we put SSD 90, and d = 10 cm.

AAPM TG-45 Specification – All values within +/-1% of opposed reading

Results - Pass

EDW wedge factor readings were taken with both the in and out orientation for multiple energies and multiple wedges to verify the accurate delivery of the wedge independent of virtual orientation. The variance of each reading from the mean for the given setup was evaluated to verify wedge centering.

Dose per Monitor Unit Linearity

AAPM TG-40 Specification – All Values within +/-1%

Doses were delivered to a depth of d_{max} for 6 MV photons over a wide range of monitor unit settings and the dose per monitor unit linearity was evaluated. The evaluation shows the MU point at which MU linearity no longer falls within to specifications with the calibration value for MU(100). The evaluation also shows deviation from the mean for all values measured. Beams of 5 MU and less are no longer within the 1% specification.

Dose Rate Linearity

AAPM TG-40 Specification – All Values within +/-1%

Using the 6 MV set-up above, 100 monitor units were delivered for six different dose rates to measure any possible effects on output that the dose rate might have. The dose rate errors are evaluated against the calibration and standard treatment dose rate of 600 MU/min. This range is within specifications of TG-40. If evaluated against the mean of all dose rate readings, the specification is also met.

X-ray & Electron: Output Constancy vs. Gantry Angle

Note: This test is basically to exam the sagging effect

AAPM TG-40 Specification – All values within +/-2% of normalized value

Output versus gantry angle was measured for 6 MV photons and 12 MeV electrons using the CC-13 wellhofer chamber mounted in air at the machine isocenter as the measurement device and delivering 100 MU for a photon field size of 5 and an electron cone of 6 cm. The evaluations were performed both with the normalization to the calibration geometry (gantry=0) and with normalization to the mean of all gantry readings. The test passes for comparison to the mean of all gantry angle outputs for both photons and electrons

- Picture of Linac head shown with parts – waveguide, bending magnet, flattening filter, scattering foil, monitor chambers, jaws & MLCs. What annual test checks the proper functioning of each of these parts?

Waveguide: PDD, energy verification, flatness and symmetry, dose calibration
Bending magnet: PDD, energy verification, flatness and symmetry, dose calibration
Flattening filter: PDD, flatness and symmetry, dose calibration
Scattering foil: PDD, flatness and symmetry, dose calibration
Monitor chambers: dose/MU linearity, dose rate linearity, dose calibration, profile
Jaws: light-to-rad test, independent jaw calibration (position) test …
MLCs: MLC collimator radiation star, picket fence test, leaf position check with light field, leaf position reproducibility…

Machine	Component	NAP	% DD	Profiles	Dose calibration
In-line	magnetron	X		X	X
	Ion chamber			X	X
	Tgt/gun/guide	X	X	X	X
With magnet	Klystron/magnetron	X			X
	Gun	X			X
	Ion chamber			X	X
	Foil/flat. Filter		X	X	X
	Guide	X	X	X	X
	Bending magnet	X	X	X	X

(what need to be checked when we change these components)

(Mechanical Iso & Star)

- What is your favorite test from the annual calibration & explain how do you do it & what are the limits? (Star Pattern Shot Test) How do you check mechanical and radiation isocenter? Mechanical and radiation separately? How do you verify they match? Tolerances of rad. and mechanical iso. Led to differences in tolerances for radiosurgery.

- (2011) Shown picture of gantry star shot image. but it was basically how do you find linac mechanical iso. He asked a series of follow-ups on tolerances, what do you do if it's out of tolerance?

- Picture of front pointer and pointer affixed to table. What is this for? (check gantry mechanical iso) Several questions about mechanical and radiation isocenter. How do you find it? Spec? For table? For Gantry? For Collimator? What about the congruence of each to the other? Radiation iso of collimator vs. radiation isocenter of gantry?
  (DABR 137-138 has good procedures + Varian acceptance test p22 gantry star shot)
  We can open one of the jaw as 0.5 cm, and another one is wide open as 40 cm. With 0.5 cm build up placed on the film, film is at 100 SSD on the couch (for collimator & couch radiation star), delivering about 80 MU to achieve OD as 1. All lines should intersect 2 mm diameter circle.

  Radiation isocenter, 2 mm as shown above, 1mm for the radiosurgery (TG142)

  I discussed with Arthur about the radiation star ISO. In the correct way, we need to find the longest intersection of the star shot, and software is supposed to find a circle starting from that longest section and cover all the intersection of the exposure from different angle. In this case, we will have a circle, and this circle needs to cover the mechanical iso within 1 mm radius to fulfill the TG40 requirement. Basically, the software based on the radiation star shot to find the radiation iso.

  I think this makes much sense because it is consistent with the Varian acceptance suggestion.

  How do you place film? Which on is this (gantry, collimator, table)? How can you tell? What is the pass/fail criteria?

DABR(138 – 139), All lines should intersect 2 mm diameter circle.

For gantry rotation:

- *The film is sandwiched vertically between two 5 cm phantom slabs.*
- *The axis of rotation will now be a horizontal line.*
- *The perpendicularly incident entrance dose causes more darkening on one side of the film than the exit dose on the other side of the film.*
- *The majority of the film sandwiched between the slabs will feature more darkening due to scatter than the naked film edges.*
- *For these reasons, a simple glance is enough to distinguish a gantry star shot from a collimator or couch shot.*
- **Chosen angles (clockwise): -60°, -30°, 0°, 90°.*

For collimator rotation:

- *The gantry is set at 180°.*
- *The film is placed flat on the table with a 0.5 cm build up slab.*
- *The upper jaws are opened wide and the lower jaws are narrowed shut.*
- *The axis of rotation will be a vertical line.*
- *The process is repeated with swapped jaw settings.*
- **Chosen angles (clockwise): -30°, 0°, 60°, 90°.*

For couch rotation:

- *The film is placed flat on the table with a 0.5 cm build up slab.*
- *The axis of rotation will also be a vertical line.*
- *The angular range of couch motion is not 360°, but rather 90° to 270°. This is obviously due to the presence of the gantry body.*
- **Chosen angles (clockwise): -45°, 0°, 45°, 90°. (perfect star)*

- Do you ever adjust your machine output after monthly? Why? How do you justify it? If output is different by 1.7%, what would you do?

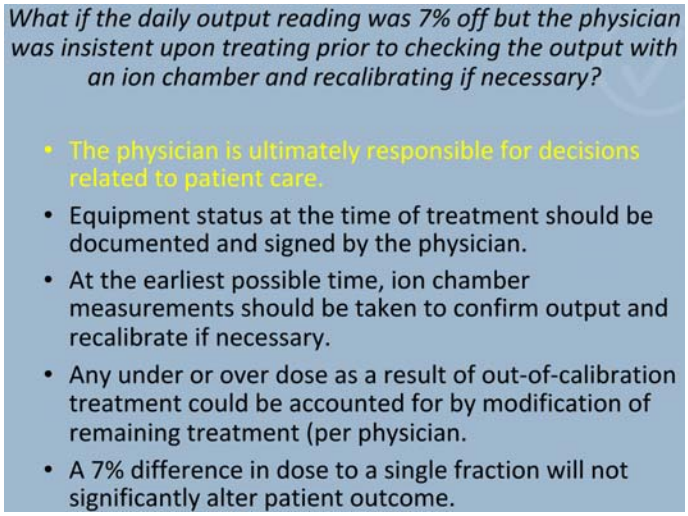
  It is based on the tolerance. As recommended by TG40, it is 2%. Because this 2% included the setup and measurement uncertainty, if the output is larger than 2% uncertainty, we will adjust it. If the output is different by 1.7%, however, it is consistent on that 1.7% repeatedly for several months, we can adjust it. (TG40 p590 sec. C)

Describe some of the dose output checks performed on the linacs at your facility.

- Annual TG-51 with ADCL calibrated ion chamber and electrometer in liquid water
- Annual TLD measurement
- Monthly constancy check with ion chamber in solid water (@ 2 depths for energy check)
- Daily constancy check with beam checker (simultaneously checks output, energy, flatness and symmetry)

What actions would be taken at your institution if the daily constancy check was off by 4% from the benchmark value?

- Our therapists perform the daily constancy check and are required to notify the physicist of deviations between 3% and 5% but may treat . Deviations >5% require Physics investigation prior to reinitiating treatment.
- If the deviation persisted, I'd perform the measurement myself paying particular attention to setup and procedure.
- I would utilize an independent (and more robust) measurement to confirm any deviation noted by the daily check device prior to contemplating any modification to output.



- Excel spread sheet of daily outputs for 3 electrons and 2 photons (5 value vs date curves). Why the mean values of the curves are different? What daily QA you need to do? Tolerance and Action level? What if the deviation is 3.2% or 4.8%? What do you check if the output is truly off by 7%? how do you setup Monthly, Daily QA, etc.

  The stability of each beam modality can be different, as time goes by. Therefore, the output variation can be different for each beam, so we can see the mean value are different. For daily QA, we check the machine output, laser coincidence with isocenter, ODI indicator, door interlock and audiovisual monitor (TG40). The daily output tolerance is 3%. If the daily output is 3 – 5%, physicist will be notified and check the output, mostly using monthly setup. More than 5% the treatment should be discontinued until the physicist identify the problem (TG40).

  I will pay attention to the measurement setup and make sure the measurement are done correctly, especially SSD, 2cm off SSD can contribute 4% error, field size, and if the correct energy is used. I will also do monthly setup to check if the 7% off due to daily QA device or truly from linac output.

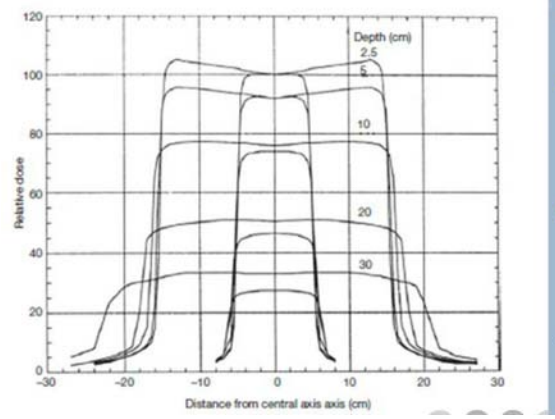
  The daily QA we use StarTrack 100 SSD to the device + manufacturer provided build up
  Monthly QA, we set 105 cm to a pp chamber, with 5 cm backscatter piece, and 5 cm buildup for x-ray and 1.5 cm buildup for electron.

- A graph of dose profiles. These were taken at near surface, 10 cm, and greater than 10 cm. Discuss shape of each. Discuss limits for flat/sym. Detail the equation and methodology for determining flat/sym. How to measure?

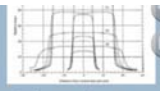
  Discuss Flatness and symmetry definition. What are Acceptance values. How often do you check flatness and symmetry? Where are flatness and symmetry measure at? How does flatness and symmetry differ with depth? Why does flatness and symmetry differ with depth?

  The flattening filter is designed to make flat profile at 10 cm depth. The horn effect we saw in the shallow depth is due to the necessary compromising the flattening filter design. At the deeper depth, due to the flattening filter, we have hardening photon at the central part of the beam, and soft photon close to the field edge entering the water. At the deeper depth, the soft photon is largely absorbed by water, so we can see the flatten profile at the deeper depth. (MetCalf Fig. 4.22)

Define flatness and symmetry.



Define flatness and symmetry?

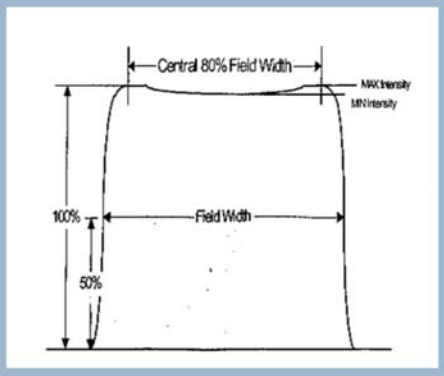


- Flatness is a measure of the max and min deviations from the mean intensity over the central 80% of the beam profile.
- Symmetry is a measure of the max difference between two points that are the same distance from the central axis (generally within the central 80% of the field size).
- Flatness and symmetry are most often measured at a depth of 10cm for photon beams and at or near dmax for electron beams.

The limits x-ray flatness consistency 2%
E flatness consistency 3%

x-ray and E symmetry consistency 3% (TG40)

Is there only one single definition of flatness and symmetry or are there multiple definitions? What definition do you use?



- Flatness relates the max intensity vs min intensity.
- Symmetry relates max on one side of profile vs other side.

Photon Flatness and Symmetry

Varian definition:

	Field Width	Penumbra	Flatness	Symmetry	Devi-ation	Flattened Area
Varian	50%	80% , 20%	Variation over Mean (80%)	Point Difference		a)

Field Width

The curve width at a user defined percentage value (default=50 %) of the Central Axis Dose (DCAX)

Offset

The distance from the central axis to the field width's middle point.

Penumbra

Consists of 2 values, at left and right side, calculated as distance between two user defined percentage values (usually 20% and 80%) on each side.

Flatness

5. Variation over Mean (80%):

   Flatness = 100*|Dmax-Dmin| / (Dmax+Dmin)

   within flattened area, defined as a) below.

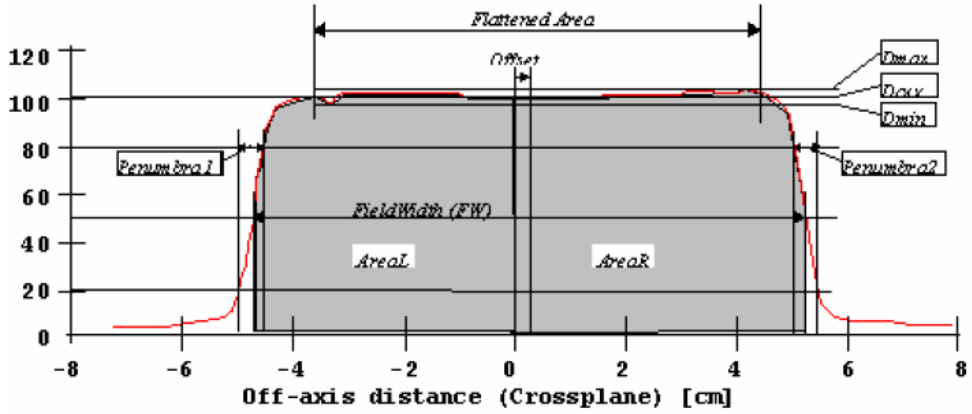
   a) 80% means 80% of the FW ex: FW 10 cm, 80%FW means 8 cm (same as TG45)

Symmetry

3. Point Difference:

   Max difference in dose between points on equal distance from central axis within flattened area, defined as a) below.

   Symmetry = 100*Max(|PointL-PointR|) / DCAX



X-ray:
AAPM TG-40 Specification – Flatness constancy - 2%
Symmetry – 3%

For flatness and symmetry checks, scans were done at depth of 10 cm, in the transverse and radial directions, with field sizes of 40 x 40 cm^2 and 10 x 10 cm^2 with the water surface set to 100 cm SSD (linac1 is 90 cm) for both photon energies. The Varian protocol as stored in the Wellhofer software was used to quantify the flatness and symmetry according the Varian acceptance test specifications. The absolute symmetry of the beam meets both TG-40 and Varian specifications following adjustment.

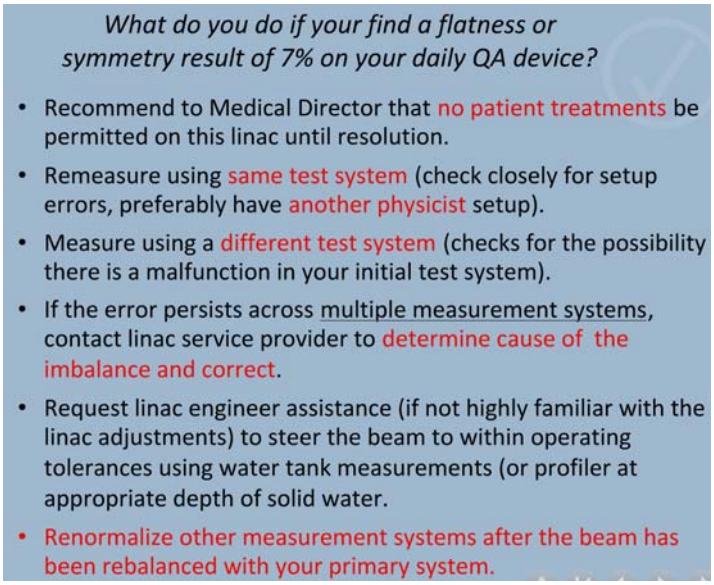
Electron Flatness and Symmetry

AAPM TG-40 Specification – Flatness constancy – 3%
Symmetry – 3%

Scans were taken at 100 cm with the Wellhofer water phantom using the wellhofer electron scanning diode chamber. Flatness and symmetry scans done at 100 cm SSD at Varian defined depths for acceptance testing which are depths generally just shallower than the ionization max. Scans were done for both the 10x10 and 25x25 cone. The Varian

protocol as stored in the Wellhofer software was used to quantify the flatness and symmetry according the Varian acceptance test specifications.

- flatness/symmetry: How often? What to do if it is beyond tolerance?
  Monthly (TG40); But we do daily check, because we have to check output daily and StarTrack can check flatness/symmetry/energy in one measurement. Tolerance is 3% for S/F(electron) and 2% for F of photon (TG40). The tolerance of flatness (flatness consistency) is relative to the baseline (generally commissioning data). If it is > beyond tolerance, physicist (in house engineer performed our daily QA) will redo the measurement to make sure the setup and measurement result are correct. If daily QA check on flatness and symmetry are really off, we will also investigate the case to see if there is a trend of the deviation in the daily base, but not a one time event. I will setup monthly QA output check, and measure a couple of points symmetrically from center of the field (shift couch) for the largest field size to confirm that off is not due to malfunction of the daily QA device. If the monthly QA setup is off as well, I will setup water tank and check it again. In this case, we should ask engineer adjust the beam. If adjustment is needed, I will request a new daily QA device or setup temporary QA procedure and calibrate new device when it comes.



I think the basic idea is: out of tolerance->check setup->check trend-> independent device to confirm->adjust->recalibrate device if needed.

Monthly flatness and symmetry check (MSK, yy)

x-ray: the field size we set is 30x30, shift the chamber **10 cm** in all 4 directions
Electron: use 25x25 cone, shift the chamber **8 cm** in all 4 directions

for trilogy SRS beam, use 15x15, shift the camber **5 cm** in all 4 directions

definition for symmetry: Radial → $(M_{gun} - M_{target})/((M_{gun} + M_{target})/2)$
transverse → $(M_R - M_L)/((M_R + M_L)/2)$
tolerance 3% → this is referring the result, not compare to baseline

definition for flatness: Radial → $(M_{gun} + M_{target})/2M_{center}$
transverse → $((M_R + M_L)/2M_{center}$
tolerance 2% for x-ray;

3% for electron or SRS beam comparing to baseline

Basically you can pick points within 80% iso dose line, so they decide to choose 67% of the field size... the key is this is a consistency test.

- Three rotations for LINAC, what are they (gantry, collimator, couch). How do you check it, what is the tolerance, what is the protocol?

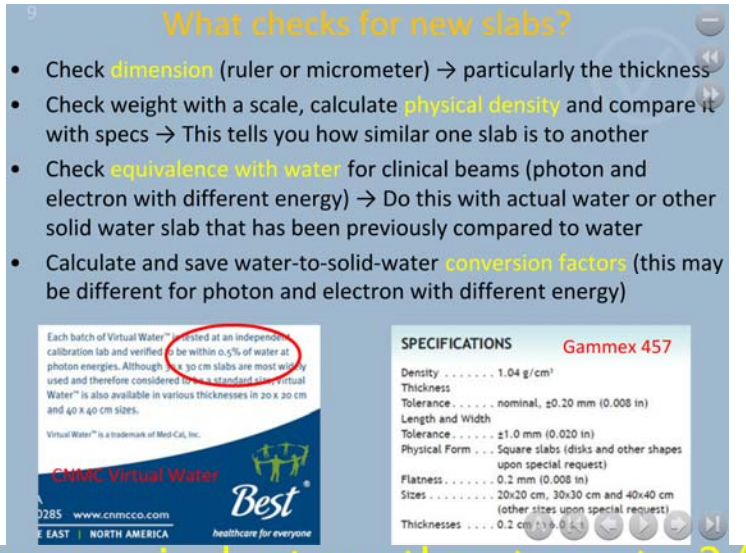
  We check the collimator, gantry and couch isocenter using the front pointer during annual, and also check the angle indicator of these 3 following the monthly QA procedure. 2 mm in diameter, and 1 degree angle TG40. The

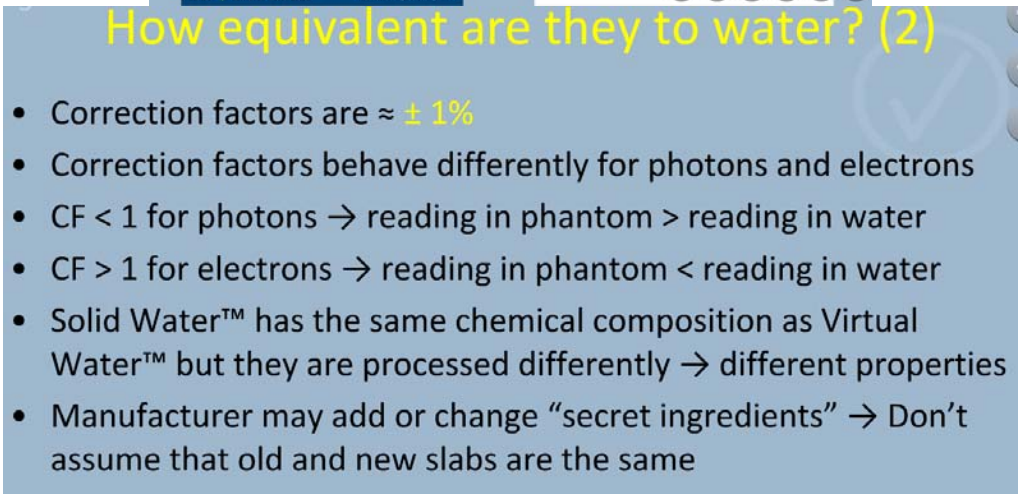
- You get a Water Equivalent Phantom - prove that its water equivalent - what goes into this process? Break down what interactions and equations define.

  (H) Just need to check the correction factor: under your calibration condition (depth in water, field size, energy, SSD...), measure in your solid water, CF=reading in water/reading in solid water. ideally, it should be 1 if it is water equivalent. Most time, it is close to 1, and depend on energy and modality (photon or electron). Generally for commercial solid water, the difference is within 1%. But be careful the products from different vendors and do not simply replace one by another. Also, constantly using the same group of solid water for the same measurements.

  For a new solid water need to check 1. dimension; 2. uniformity; 3. weight it and calculate its physical density vs vendor provided density; 4. Scan with CT and check the electron density uniformity as well as comparing the e density with vendor provided material; 5 CF

Wepassed: solid water





(Acceptance & Commissioning)

- What is acceptance testing and what is commissioning? Difference? Define clearly and explain what you would do in each case.
- New LINAC acceptance and commissioning. What are some important procedures? Orders?
- Question regarding linac acceptance testing vs. commissioning. Why? What do you do? Order you go in? ... safety, mechanical, dosimetry

(TG106)

- Acceptance test: Verification process of the machine based on manufacture's guidelines for a small subset of beam data.
- Commissioning: A process where a full set of data is acquired that will be used for patient treatment. Define routine QA baseline down the line (acceptance baseline sometimes use for QA as well).

(Study guide vol. 1, p83)
Acceptance may be divided in 3 groups: (1). Safety (2). Mechanical (3). Dosimetry Check

(Study guide vol. 1, p87, TG45 p1107)
Commissioning: (1). Define the scope of data collection based on the requirements from TPS (extra data can be taken to check commission data accuracy)
(2). Estimate the time needed to commission the machine.
(3). Choose proper detectors and set scanning system properly.
(4). Acquiring all beam data
(5). Entering the data into TPS and test its accuracy
(6). Write a concise report with all the collected data.
(7). Check on the report and collected data. Have a qualified medical physicist perform an independent audit of the collected data and the report.
(8). Developing all dosimetry, planning, & treatment procedures
(9). Verifying the accuracy of these procedures
(10). Establishing QA procedures
(11). Training all personnel

	Acceptance (Varian in order) performed by Vendor engineer & signed by engineer & physicist	**Annual (in order)** performed by physicist
Safety (Studying guide p83)	1. Interlocks, warning lights, pt. monitoring equipment Radiation survey: 1. Primary & secondary barrier 2. Collimator transmission (0.5% of CAX) 3. Head leakage (1 m from source should be 0.1% of iso)	1. Safety training for therapist 2. Review of room shielding & safety devices for any changes 3. Emergency off button function
Mechanical test (MLC acceptance procedure is in additional to linac acceptance) TG40, 142	o Mechanical iso variation w rotation (1mm) 1. Collimator physical iso (verify cal. of frontpointer vs. Coll. & Gantry <0.25 mm) 2. Gantry physical iso 3. Couch physical iso o Crosshair alignment (Run out 1 mm, x, y jaw alignment 2.5 mm) o Independent jaw pos. readout (2mm)	o Mechanical iso variation w rotation (2mm) 1. Collimator physical iso (verify cal. of frontpointer vs. Coll. <0.25 mm) 2. Gantry physical iso (verify cal. of frontpointer vs. Gantry) 3. Couch physical iso o Crosshair alignment (Run out 1 mm, x, y jaw alignment 2.5 mm) o Independent jaw pos. readout (2mm)

specification is in **green** Varian specification is in **purple** Underscore is the test not in acceptance but in annual	o **MLC** Leaf pos. accuracy check w light field (1 mm) o **MLC** Leaf pos. reproducibility (1 mm TG142) o Gantry rotation readout (0.5 deg.) o Collimator rotation readout (0.5 deg.) o Couch Mechanical motions 1. Couch rotation readout (0.5 deg.) 2. Couch longitudinal, vertical, & lateral (1mm) o ODI verification (1mm at 100SAD, 5 mm at 80 & 130 cm)	o **MLC** Leaf pos. accuracy check w light field (1 mm) o **MLC** Leaf pos. reproducibility (1 mm TG142) o Coincidence of Gantry, Table & collimator iso (2 mm) o Gantry rotation readout (1 deg.) o Collimator rotation readout (1 deg.) o Couch Mechanical motions 1. Couch rotation readout (1 deg.) 2. Couch longitudinal, vertical, & lateral (2mm) o ODI verification (2 mm at 90, 100, 110 cm) o Table Top Sag (2 mm) o Laser Alignment to Mechanical Iso (2mm)

Mechanical test: Radiation Isocenter : TG142 MLC star shot spec is 1 mm	o Gantry rotation star shot (2 mm dia.) o Winston-Lutz test (test gantry, collimator (1 mm dia.) & couch rad. iso (1.5 mm dia.)) for SRS component o Light-to-ray field 6x & 15x (25 x 25 field) (1.5 mm) o **MLC** Collimator radiation star (2mm dia.) o **MLC** Gantry radiation star (2mm dia.) o **MLC** Light-to-ray field 6x & 15x (10 x 10 & 24 x 24 field) (2 mm) o Varian MLC acceptance has several DMLC test using dynalog.	o Collimator radiation star (2 mm dia.) o Gantry radiation star (2mm) o Coincidence of Mechanical (coll. gantry) & Radiation star (2mm) o Light FS, Rad. FS, & Light-to-ray field 6x & 15x (10x10 & 20 x 20) (2 mm) o **MLC** Collimator radiation star (2mm dia.) o **MLC** Light FS, Rad. FS, & Light-to-ray field 6x & 15x (10x10 & 24 x 24) (2 mm) o **MLC** Beam delivery test: Picket fence at GA 0, 90, 270, and Synchronized segmented strips and continuous strips at 0 only o Simple Field (Half field) alignment test (1mm)
Dosimetry measurement: Beam performance	o Photon depth of ionization (100 SSD TSD, 10 x 10, 10 cm) (6x: PDI_{10}: 67% +/-1%, D_{max} : 1.6 +/- 0.15 cm 15x: PDT_{10}: 77% +/- 1%, D_{max} : 2.9 +/- 0.15 cm **BJR11 & 17**) *For SRS, it is the same criteria except +/-0.5% for PDI. o Photon flatness & symmetry (10 x 10, 40 x 40 at 10 cm depth, radial & transverse) Flatness (ACTUAL): 3% Symmetry: 2% o Electron depth of ionization(using IC)(10 x 10 , 25 x 25 cone) I90, I80, I50 < 1 mm, I30<Spec o Electron flatness & symmetry (10 x 10, 25 x 25 at D_{max}, radial & transverse) Flatness (ACTUAL): 4.5% Symmetry: 2% o Symmetry interlock	o Photon depth of ionization (90 SSD, FS: 5, 10, 20, 30 ,40, Depth: 5, 10, 20, 30 cm) (PDI & D_{max} compared to commissioning data, 2%) o Photon flatness & symmetry (90SSD, 10 x 10, 40 x 40 at 10 cm depth, radial & transverse) Flatness (constancy compared to acceptance): 2% Symmetry: 3% o Electron depth of dose (using diode) (10 x 10 , 25 x 25 cone) R100, R90, R80, R50, R30 < 2 mm o Electron flatness & symmetry (10 x 10, 25 x 25 at D_{max}, radial & transverse) Flatness (constancy compared to commissioning): 3% Symmetry: 3%

Dosimetry measurement	o Short term dose reproducibility (1%) o Dose per MU linearity (1%) o Dose Rate linearity (1%) o Output constancy vs. Gantry angle (1.5%)	o Short term dose reproducibility (1%) o Dose per MU linearity (1%) o Dose Rate linearity (1%) o Output constancy vs. Gantry angle (2%) o Wedge centering (1%)
Laserguard collision protection sys.	Protection zone area verification Protection zone tilt verification Motion stop function verification Power key switch & override function verification	
Dosimetry Calibration (Annual & Commissioning)		o Spot Check of TG51 chamber performance fac. Such as Pion & Ppol o TG51 dose calibration(2% w stated output) o Back-up Monitor constancy (2%) o Secondary chamber calibration MU2 (1%)
2nd measurement device setup & Recalibration		o Startrak Calibration for Daily QA
TPS parameter		o Scp (2%) o EDW Wedge factor (2%) o Tray factor (2%) o Cone factor (2%) o Electron effective SSD spot check (PA state reg 1 eng w 1 cone, we also check output within 2% at 10 cm gap compared to commissioning data)
		OBI Testing

*According to Varian acceptance procedure, radial scan (inplane) should always be performed prior to transverse (crossplane) scans in case any steering adjustments are required.

**Notice there is no couch radiation star in both acceptance and annual; the couch radiation star mainly used to check if the radiation iso aligns with the mechanical iso of the couch. The main reason we don't do couch radiation star could be that couch rotation does not affect the source positioning, not like gantry. If we check the coincidence of the couch, gantry and collimator physical iso are within spec and individual physical iso is also within spec as well as gantry star shot within spec, it is unlikely that couch mechanical star will be off compared to the radiation iso.

Commissioning data needed: Linac 1,2 + Eclipse manual

Eclipse photon (AAA)	Eclipse Electron (eMC)
1. Open field PDD in water (IC+ diode) 2. Open field beam profiles in water (diode) 3. Scp (CC13, 0.6 cc farmer chamber is too large for small field such as 3 x 3 or just use diode) 4. Tray, Block, MLC transmission fac in water (diode)	1. PDD & Profile for various cone (diode) 2. Open-field beam profile in air (SDD 95 cm, diode) 3. Cone factors in water at d_{max} + open field 40 x 40 (diode)

Penn Commissioning report order:

1. Data required from Eclipse
2. TG51 + building Fspot & set up energy consistency baseline
3. PennMU data
   Photon requires additional data: beam attenuation, Sc
   Electron requires additional data: PDD for circular cutout (SSD 100 – 120cm), Block factor (SSD 100 – 120 cm), Distance factor (SSD 100-120) [output variation + different cone size vs. distance]
4. Benchmark compared PennMU, Eclipse, & Measurement

5. RPC TLD checking

- **(Acceptance)** Why do we survey and check interlocks for a new LINAC first? What steps do you do for acceptance of a new LINAC? - Do you survey and then check the door? Do you check door interlock first and why?
  - What kind of survey do you conduct?
  - What other tests do you do (they are in three parts: safety, mechanical, radiation) as listed above
  - How do you check for collimator rotation (mechanically) as listed above?

  Because the safety has the highest priority than other parts, we want to make sure our shielding is enough no harm to the patient, staff and general public as well as the interlock is functional.

  Safety → Mechanical check → dosimetry measurement

  Check door interlock first and then survey, because if there is any accident, such as someone happened inside the room during radiation on, we want to make sure that we can open the door and the beam should be stopped.

- **(Acceptance)** After you've done a radiation safety test and a mechanical safety test, what are the next 5 tests you'll do on an acceptance test? What's the tolerance of the MLC leakage?

  Mechanical check (such as Mechanical iso, cross hair alignment, jaw position, couch movement, Mechanical readout ODI, MLC leaf positioning) → (Radiation iso, light-to-rad, MLC rad. iso) → dosimetry measurement (Beam performance, ion chamber accuracy)

  TG142 the tolerance of MLC transmission is +/- 0.5% from baseline value. For Varian, MLC inter and intraleaf transmission are 2 & 3%.

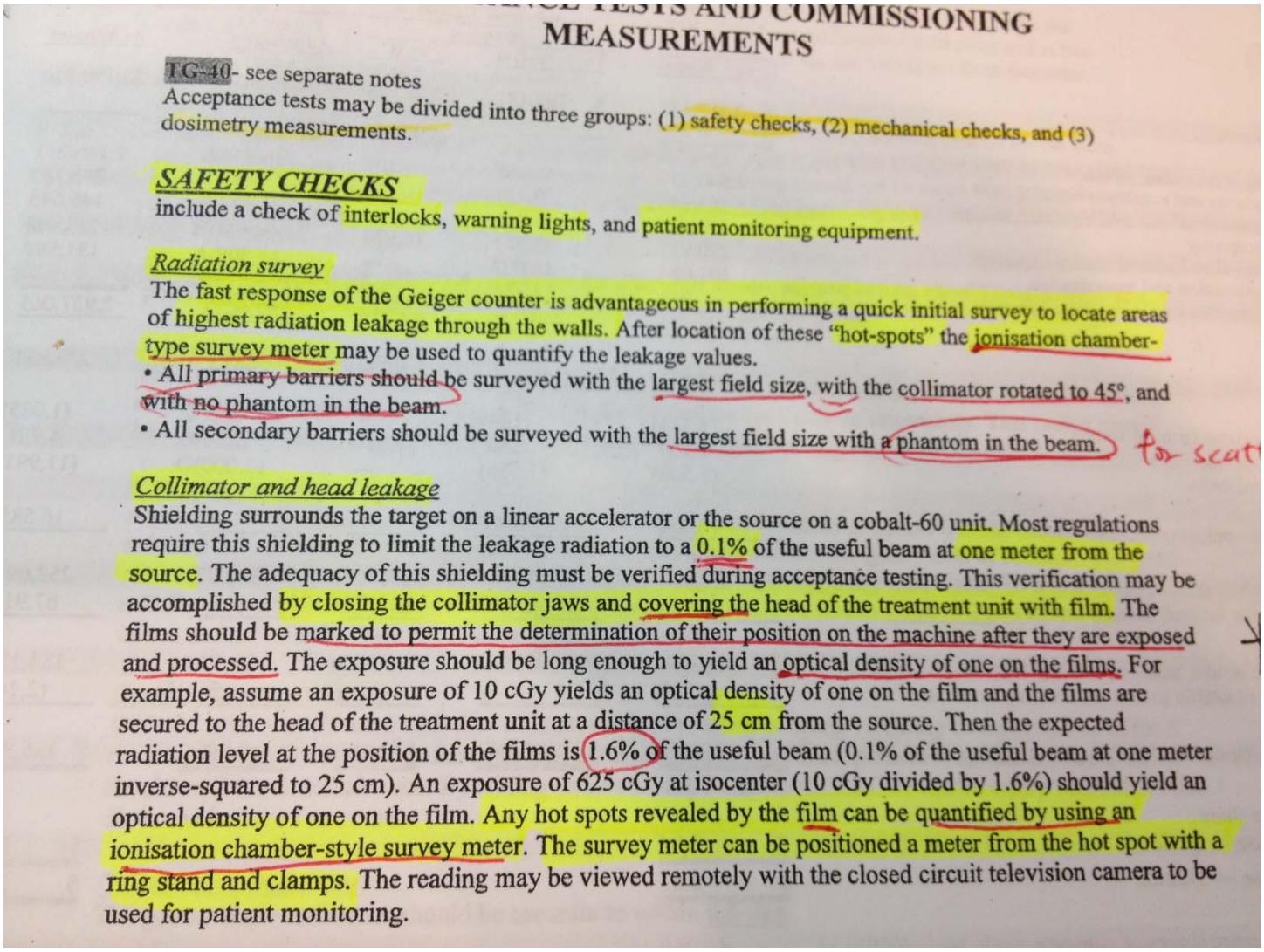
- **(Acceptance)** How to survey neutron measurements? How would you measure for scatter and leakage?

  (TG45) Neutron shielding must be considered for all machines with a maximum bremsstrahlung energy of 10 MV or greater. The principal sources of neutrons are the target, the primary collimator, the flattening filter, and the movable photon jaws (high-z material, such as lead and tungsten). The neutron energy spectrum is similar to a fission spectrum, with a most probable energy of about 1 MeV. Concrete, because of its high water content, is the most practical and least expensive shielding material for neutrons. Where concrete is not appropriate (e.g., in doors) borated polyethylene should be substituted. In general, the neutron fluence in the primary x-ray beam is approximately 2-3 times greater than the neutron fluence outside the beam in the treatment plane. If concrete barriers are designed to protect against photons, it may be that these barriers will also provide adequate protection against neutrons (although this should be verified by calculation). However, if lead or steel is used for shielding one must add either concrete or borated polyethylene to allow for proper neutron shielding. In the case of doors where photon shielding materials are limited to lead or steel one must include borated polyethylene on the inside of the door preceding the lead or steel on the outside. As noted above, this is a case where a maze near the door becomes important in the room construction.

  Neutron survey measurements should also be made of neutron leakage both inside and outside the room. In general, an activation technique (activation foil, passive detetcor) using phosphorous is recommended for measurements in the primary beam with peak bremsstrahlung energy above 20 MV. For energies below 20 MV and inside the room the phosphorous and moderated foil technique using either indium or gold can be employed. . Know that inside the room we measure the neutrons with activation foil. Outside the room we use Rem ball counter (search rem ball counter in safety note).

Thus, for a high energy accelerator one has to plan for a **maximum dose equivalent** for x rays plus neutrons.

(survey meter for scatter with phantom placed on the table and films wrapped around the head for the leakage measurement)



...TESTS AND COMMISSIONING
MEASUREMENTS

TG-40- see separate notes
Acceptance tests may be divided into three groups: (1) safety checks, (2) mechanical checks, and (3) dosimetry measurements.

SAFETY CHECKS
include a check of interlocks, warning lights, and patient monitoring equipment.

Radiation survey
The fast response of the Geiger counter is advantageous in performing a quick initial survey to locate areas of highest radiation leakage through the walls. After location of these "hot-spots" the ionisation chamber-type survey meter may be used to quantify the leakage values.
- All primary barriers should be surveyed with the largest field size, with the collimator rotated to 45°, and with no phantom in the beam.
- All secondary barriers should be surveyed with the largest field size with a phantom in the beam.

Collimator and head leakage
Shielding surrounds the target on a linear accelerator or the source on a cobalt-60 unit. Most regulations require this shielding to limit the leakage radiation to a 0.1% of the useful beam at one meter from the source. The adequacy of this shielding must be verified during acceptance testing. This verification may be accomplished by closing the collimator jaws and covering the head of the treatment unit with film. The films should be marked to permit the determination of their position on the machine after they are exposed and processed. The exposure should be long enough to yield an optical density of one on the films. For example, assume an exposure of 10 cGy yields an optical density of one on the film and the films are secured to the head of the treatment unit at a distance of 25 cm from the source. Then the expected radiation level at the position of the films is 1.6% of the useful beam (0.1% of the useful beam at one meter inverse-squared to 25 cm). An exposure of 625 cGy at isocenter (10 cGy divided by 1.6%) should yield an optical density of one on the film. Any hot spots revealed by the film can be quantified by using an ionisation chamber-style survey meter. The survey meter can be positioned a meter from the hot spot with a ring stand and clamps. The reading may be viewed remotely with the closed circuit television camera to be used for patient monitoring.

- **(Acceptance)** How to verify the beam quality (i.e. by looking at PDD_{10}, d_{max}, surf-dose etc) ? Why do you want to get a specific beam quality (BJR). How (and with what) do you measure surface dose, what's a typical value for MV beams? What energy machines you worked with? What's PDD_{10} for those energies (6, 10 and 18)?
  Varian acceptance: Photon: PDD_{10}, D_{max}, BJR 7 & 11 or BJR25
  Varian acceptance: Electron: I90, I80, I50, I30

  Comparing with the literature values is to prevent potential problem coming from the linac.

  1. Extrapolation chambers are the detectors of choice for surface dose. However, its availability is limited and its use in surface dose measurements is very time consuming. Instead, fixed-separation plane-parallel chambers are commonly used for surface dose and the dose in the buildup region. Because of their relative large separation compared with the extrapolation chamber and their small guard ring, the plane-parallel chambers show an over-response in the buildup region and especially at the surface. The inaccuracy may be reduced by using chambers with a small plate separation and wide guard ring.

2. In Penn during commissioning, we use **photon diode** to get the buildup and surface dose. (A thimble-type ionization chamber is the most popular and reliable detector for PDD but it over-estimates the dose in the buildup (steep dose gradient) region because of its relatively large volume, however CC13 can also be the choice since it)

TABLE VI. Percentage depth dose at the surface and superficial regions of high-energy electron beams for a Varian 2300 C/D for a 10×10 cm^2 cone at 100 cm SSD. Also shown are the depths at which D_{max} and D_{90} occur.

	Electron percentage depth dose[a] (%)					
Depth	6 MeV	9 MeV	12 MeV	15 MeV	18 MeV	22 MeV
Surface[b]	70.8	76.5	82.0	86.6	88.4	89.1
0.5 cm	82.5	84.7	89.5	93.7	96.0	97.0
1.0 cm	94.0	90.0	92.6	96.4	98.7	98.9
D_{max} depth (cm)	1.4	2.2	2.9	2.9	2.9	2.2
D_{90} depth (cm)	1.8	2.8	3.9	4.8	5.4	5.8

[a]Measurements given in this table were taken with an Attix chamber whose front electrode is 0.025 mm thick, 4.8 mg/cm^2 Kapton (Ref. 130).
[b]Defined as 0.5 mm depth on the central axis.

(TG70)

Surface dose (linac1 commissioning & blue study note):

6X: 50%,
10X: 38%
15X:35%
18X: 30%

Photon Depth of Ionization (Enter NA in any boxes that do not apply)					
Energy BJR11	Energy BJR17	Dmax Spec	Actual Dmax	10 cm Spec	Actual 10 cm %
4 MV	4 MV	1.2 cm ±0.2 cm	N/A	63.0% ±1%	N/A
6 MV	6 MV	1.6 cm ±0.15 cm	1.46	67.0% ±1%	66.9
SRS6	SRS6	1.6 cm ±0.15 cm	N/A	67.0% ±1%	N/A
8 MV	8 MV	2.0 cm ±0.15 cm	N/A	71.0% ±1%	N/A
10 MV	10 MV	2.4 cm ±0.15 cm	N/A	74.0% ±1%	N/A
15 MV	16 MV	2.9 cm ±0.15 cm	2.84	77.0% ±1%	77.3
18 MV	23 MV	3.3 cm ±0.15 cm	N/A	80.0% ±1%	N/A
20 MV	25 MV	3.5 cm ±0.15 cm	N/A	81.5% ±1%	N/A
SRS6 Beam Matching					
Energy	**Dmax Spec**	**√ = Pass**		**10cm % Spec**	**√ = Pass**
SRS6	6 MV Std ±0.15 cm	N/A		6 MV Std ±0.5%	N/A
Initial	MK	*Date*			4/9/08

Varian acceptance test

- **(Acceptance)** What do you do after you're happy with the machine specs? Who should sign the ATP document?
  Double check the key point flatness symmetry, PDD.
  (Vendor representative & Physicist in charge)
  The normal procedure is
  (1). Submitting application to state for Linac license, so vendor can sell us Linac.
  (2). Vendor performs acceptance procedure. Physicist should check the QA or even repeat the QA
  (3). Physicist performs the commissioning

(4). Physicist submit the acceptance(radiation safety + QA) + commissioning to state for license

- **(Commissioning)** Why do you do commissioning? Can you just get information from vendor? Steps of commissioning. Answer this question in depth and gave all the steps and necessary answers to the sub questions.
- How do you check the accuracy of the mechanical pointer (if it fell down, etc)? How do you get TMR tables calculated/measured and input them in TPS? How are S_{cp} factors measured? S_c? How would you measure S_p? How do you check the isocenter rotation?

  - Commissioning: A process where a full set of data is acquired that will be used for patient treatment.

No, Do not rely on the manufacturer supplied beam data. Always verify the accuracy since beam data can vary from machine to machine of the same model from the same vendor. (TG106)

Review my TG106 talk! (For Sc, Scp measurement as well as TG106)

TMR/TPR

- TMR/TPR data are often difficult and time consuming to measure, because water level needs to be changed at each depth.
- **PDD to TMR**

$$TMR(d, r_d) = \frac{PDD(d, r, SSD)}{100} \cdot \frac{(SSD + d)^2}{(SSD + d_{\max})^2} \cdot \frac{S_p(r_{d_{\max}})}{S_p(r_d)}$$

$$r_d = r\left(\frac{f + d}{f}\right), r_{d_{\max}} = r\left(\frac{f + d_{\max}}{f}\right)$$

TMR data are often difficult and time consuming to measure.
There are water phantom systems that collect TMR/TPR data by pumping a known amount of water for measurements at each depth. Such measurements are time consuming and the accuracy needs to be verified by independent point measurements. **The simplest approach is creating TMR/TPR from depth dose measurements.**

How do you check the accuracy of the mechanical pointer (if it fell down, etc)?

1. We can put it on the table and rotate it to see if it tilt and we also can put it on the front pointer holder hooked on the gantry and manually rotate to see if it wobble around (tip on a graph paper)
2. We can use a micrometer to measure the length of the pointer to see if the tip was shorten by hitting on the floor.

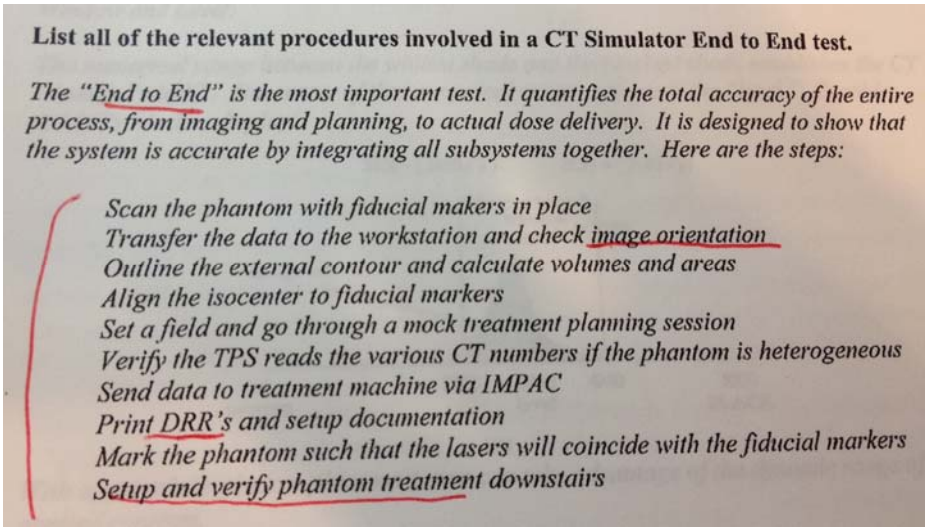
- **(TPS acceptance)** Discuss new treatment planning computer acceptance procedures, what protocols are used? Dicom RT transfer verification?

  From CT to TPS:
  Catphantom QA (Checked in TPS rather than CT console):
  Spatial integrity (contour related issue is checked here)
  Slice thickness (contour related issue is checked here)
  HU uniformity
  HU accuracy
  Low and high contrast Resolution

Image orientation

From TPS to Treatment console:
MU
DRR
Beam setup, wedge orientation, MLC Shape, Jaw positioning
ISO center positioning

From CT to treatment console:
End-2-end test check all the possible steps:



List all of the relevant procedures involved in a CT Simulator End to End test.

The "End to End" is the most important test. It quantifies the total accuracy of the entire process, from imaging and planning, to actual dose delivery. It is designed to show that the system is accurate by integrating all subsystems together. Here are the steps:

Scan the phantom with fiducial makers in place
Transfer the data to the workstation and check image orientation
Outline the external contour and calculate volumes and areas
Align the isocenter to fiducial markers
Set a field and go through a mock treatment planning session
Verify the TPS reads the various CT numbers if the phantom is heterogeneous
Send data to treatment machine via IMPAC
Print DRR's and setup documentation
Mark the phantom such that the lasers will coincide with the fiducial markers
Setup and verify phantom treatment downstairs

(TG53): An acceptance test is performed to confirm that the RTP system performs according to its specifications.

Specifications must be reasonable constraints that are quantifiable and testable or measurable. For example, it is meaningless to write a specification requiring 2% accuracy in dose calculations. This is much too broad a statement. Specifications should be written with particular tests already in mind.

Items suitable for specification can be divided into 3 broad categories:

- Computer hardware (performed by user)
- Software features and function (by user)
- Benchmark tests: Performance on benchmark tests indicates the accuracy of the dose calculation algorithm under very specific circumstances with specific beam data. Calculation times can also be measured. (by user or vendor)

The acceptance testing should be carried out on the system after it has been installed in the clinic but before it is used clinically.

Tests of the hardware and the software features should be performed by the user. Significant time may be required to perform detailed benchmark testing of dose calculation or other algorithm accuracy, so it should be determined at the time of the definition of the acceptance test procedure whether these tests are to be performed by the user or the vendor. If these benchmark tests are performed by the vendor, the user may want to repeat some or all of the tests to verify the results.

TABLE 2-2. Acceptance Test Features

Topic	Tests
CT input	Create an anatomical description based on a standard set of CT scans provided by the vendor, in the format which will be employed by the user.
Anatomical description	Create a patient model based on the standard CT data discussed above. Contour the external surface, internal anatomy, etc. Create 3-D objects and display.
Beam description	Verify that all beam technique functions work, using a standard beam description provided by the vendor.
Photon beam dose calculations	Perform dose calculations for a standard photon beam dataset. Tests should include various open fields, different SSDs, blocked fields, MLC-shaped fields, inhomogeneity test cases, multi-beam plans, asymmetric jaw fields, wedged fields, and others.
Electron beam dose calculations	Perform a set of dose calculations for a standard electron beam dataset. Include open fields, different SSDs, shaped fields, inhomogeneity test cases, surface irregularity test cases, and others.
Brachytherapy dose calculations	Perform dose calculations for single sources of each type, as well as several multi-source implant calculations, including standard implant techniques such as a GYN insertion with tandem and ovoids, two-plane breast implant, etc.
Dose display, dose volume histograms	Display dose calculation results. Use a standard dose distribution provided by the vendor to verify that the DVH code works as described. User-created dose distributions may also be used for additional tests.
Hardcopy output	Print out all hardcopy documentation for a given series of plans, and confirm that all textual and graphical information is output correctly.

The Digital Imaging and Communications in Medicine (DICOM) standard is now widely implemented in radiology as the standard for diagnostic imaging. It has also been extended for use in various sub-specialties. One of the first extensions was applied to radiation therapy and is known as DICOM-RT. In addition to the protocol used in the DICOM standard, seven DICOM-RT objects—namely, RT Image, RT Structure Set, RT Plan, RT Dose, RT Beams Treatment Record, RT Brachy Treatment Record, and RT Treatment Summary Record—have been created, each with a well-defined data model.

(Scanner)

- (2011) Shown picture of blue phantom with linear array of detectors attached. What is it? What is it used for? What are acceptance procedures? What QA do you perform on this device? What type of detectors do you use? How many detectors? If you measure a depth dose curve of a 6 MV beam, and the results indicate an 18 MV beam, what could have caused this? (not sure what the answer to this one was – she said it was not that 18 was delivered by mistake) I think it can be the water surface wasn't setup right. The water surface was set as 1.5 cm, so the 6MV PDD looks like shifted 1.5 cm downstream and make it look like 18 MV.
- Discuss the Water Phantom Scanner. What is this? What kind of care do you need on the setup?

Water Tank	
Exterior water tank dimensions (LxWxH):	675 mm x 645 mm x 560 mm
Scanning volume (LxWxH):	480 mm x 480 mm x 410 mm
Position resolution:	0.1 mm
Position accuracy:	± 0.1 mm
Position reproducibility:	± 0.1 mm
Speed:	Positioning Speed: max. 50 mm/s; Scanning Speed: max. 25 mm/s
Approximate volume:	200 l
Wall thickness / material:	15 mm / acrylic
Weight (empty):	45 kg
Common Control Unit (CCU)	
Maximum resolution:	0.5 fA at 0.4 nA full scale; 5 fA at 40 nA full scale; 0.5 pA at 4 uA full scale
Full scale range:	0.4 nA / 40 nA / 4uA
Leakage current:	typically <1 fA
Time constant:	20 ms
Bias voltage range:	± 50 through ± 500 V
Trigger interface:	RS 485 (custom specific)
Common interface:	ETHERNET (100BaseT)
Main supply:	100 – 240 V AC ± 10 %; 50/60 Hz
LDA-99SC	
Number of diodes:	99
Diode spacing:	5 mm (center-to-center)
Diode specifications	
Type of silicon:	Hi-pSi diode detectors
Chip size:	2.45 mm x 2.45 mm
Diameter of active area:	2.0 mm
Sensitivity:	35 gy/nC
Effective measurement point:	<1 mm
Positioning in phantom:	0, 45, 90 and 135 degrees
Water Reservoirs HA05 / HA06	
Pump direction:	bi-directional / uni-directional
Tank volume:	220 l
Flow control:	20 l/min
Dimensions (LxWxH):	970 mm x 660 mm x 830 mm
Weight (empty):	70 k
Lift Tables HA01 / HA03	
Operation:	manual / electric
Vertical range:	660 - 1020 mm / 660 - 1160 mm
Vertical adjustable range (tilt):	± 15 mm / 20 mm
Horizontal adjustable range:	– 15 mm in X/Y direction
Rotation in XY plane:	n.a. / ± 5°
Table size:	635 mm x 635 mm / 680 mm x 680 mm
Dimensions (LxWxH):	790 mm x 630 mm x 660 mm / 840 mm x 680 mm x 660 mm
Weight (empty):	69 kg / 116 kg
TMR Set (requires Water Reservoir HA05)	
Scan length:	30 cm
Position reproducibility:	± 0.3 mm
Filling / draining speed:	50 mm / min

- Acceptance for the detector array can be :
  1. Measure all the detector positioning are correct as it labeled on the diode
  2. Different detector can have different response to the same beam. We need to calibrate the detector, and test the detector response. One way to do it is radiate a large uniform beam, and take the profiles with detector at 0 and 180 degree orientation. Different detectors should have the same response at the same profile location.

- Acceptance for the tank can be :

QA scanning sys

1. **Basic quality assurance provided by published literature should be adopted;**

Mellenberg et al., "Acceptance testing of an automated scanning water phantom", Med. Phys., **17** p311 (1990)

TABLE I. Protocol for automated scanning dosimeter acceptance testing.

I. Detector Positioning
- A. Alignment
- B. Reproducibility
  1. (0,0,0) to (0,0,100mm) 10 times
  2. (0,0,0) to (0,100mm,0) 10 times
  3. (0,0,0) to (100mm,0,0) 10 times
  4. (0,0,0) to (200mm,200mm,200mm) 10 times
- C. Accuracy
  1. (0,0,0) to (200mm,200mm, – 400mm)
  2. (0,0,0) to (200mm, – 200mm, – 400mm)
  3. (0,0,0) to (– 200mm, – 200mm, – 400mm)
  4. (0,0,0) to (– 200mm,200mm, – 400mm)
  5. (0,0,0) to (200mm,200mm, – 200mm)
  6. (0,0,0) to (200mm, – 200mm, – 200mm)
  7. (0,0,0) to (– 200mm,200mm, – 200mm)
  8. (0,0,0) to (– 200mm, – 200mm, – 200mm)

II. Detectors and Electronics
- A. High voltage supply
  1. High voltage constance
  2. High voltage measured versus manufacturer's specification
- B. Chamber response reproducibility
- C. Chamber stem effect
- D. Chamber and cable leakage
- E. Cable and amplifier (if applicable) sensitivity to x-rays

III. Scanned dosimetry data acquisition
- A. Scanning speed effects
- B. Central axis depth dose agreement with "static" measurements
- C. Central axis depth does reproducibility of measurement
- D. Radial and transverse scan agreement with other scanned data
- E. Isodose scan consistency with other scanned data

IV. Output
- A. Data processing
  1. Scan renormalization
  2. Scan centering
  3. Scan smoothing
- B. Data analysis
  1. Symmetry calculation for electrons and photons
  2. Flatness calculation for electrons and photons
  3. Electron beam practical range calculation
  4. X-ray contamination of electron beam calculation
  5. Other (e.g., uniformity index, M&D curve normalization, TG = 21 conversion, etc.)
- C. Plots and printouts
  1. ASCII printouts
  2. Depth ionization plots
  3. Cross plane plots
  4. Isodose plots
  5. Headings and labels

1. Det. Positioning can be checked with graph paper placed on the bottom of the tank + a vertical ruler + a plumb bob

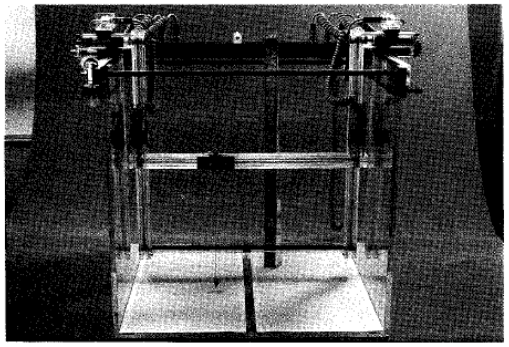


FIG. 1. Graph paper, plumb bob, and vertical ruler placed inside Wellhofer WP-600 water tank. This setup is used to verify mechanical alignment, movement precision, and software calibration.

B. Detectors and electronics

Following mechanical performance checks, radiation detector performance is evaluated. First, the ion chamber's high-voltage (HV) supply reproducibility is checked by switching the system on and off several times while observing the supplied high voltage with a digital voltmeter. Stem effect and leakage of all ionization chambers/cable combinations are checked with a high-quality integrating electrometer (e.g., Keithley 35614—Keithley Electronics, Cleveland, Ohio). Stem effect is measured using the standard technique of irradiating the chamber in a rectangular field at two collimator angles ninety degrees apart. Cable effects are measured by placing a length of cable in the radiation field with the chamber outside the radiation field.

3. Scanning data can be checked with "static" data acquisition, and also compared to secondary scanning system if it's available and works properly.
4. Data output, such as flatness & symmetry or normalization point, can be compared to the manual calculation.

Scanning step:

1. Before measurement, check the free movement of each scanning arm, and the motion in x, y, z and diagonal axis.
2. Align the light cross hair w the cross hair labeled at the bottom of the tank
3. Pour water and check the level of the scanning arm
4. Center the detector (usually starting with ion chamber) at the iso, get zero depth
5. Move the detector in and crossline direction as well as 4 corners to make sure the water surface are leveled (the water surface bisect the det. Everywhere) {If this step is done right, we can ignore the step 3 but I think it's good to check scanning arm first if there is a big tilting of the arm}
6. Move the det. to the center and dive it until the bottom of the tank to make sure the cross hair didn't drift from the chamber (this part can be skipped if we have software to align the chamber to the CAX)

- The tank mechanical accuracy is **0.1 mm**
- (TG106) When we do the diagonal profile scan for large field size at deeper depth, due to beam divergence issue, our water tank may not be big enough for the full profile scan. In this case, we can scan half beam profile and mirror it later. However, we need to make sure our open beam asymmetry is less than 0.5 %, so we can mirror it.
-

(IMRT QA)

- Shown IMRT plan calculated on a phantom. Talked about IMRT QA. How you do it at your clinic, How do you measure if good or bad QA (tolerances)? (DTA = 3 mm, DD = 3%, threshold dose = 10%, if it's gamma it will be 1) what is gamma? What is the equation for gamma?

  We use Mapcheck2 which is a diode array;

  MapCHECK 2 system contains 1,527 SunPoint™ Diode Detectors1 arranged in a grid and separated by 7.07 mm (diagonally) & 1 cm in x- & y-axis, uniformly throughout the array 26 x 32 cm. Inherent buildup between the two devices is 2 g/cm^2 water equivalent, and the physical thickness of the buildup is 1.2 cm for MapCHECK2.

  The detector active area is 0.8 x 0.8 mm n type diode.

  1. Generate QA plan in Eclipse using MapCheck phantom, (5 cm buildup and 2.75 cm backscattering thickness)
  2. We set SDD as 100 cm, and we calibrate the CAX detector under reference condition (10 x 10 100 MU) as the dose calculated from Eclipse. Beside the CAX dose calibration, the response of each detector is also set in an

array calibration file. Our IMRT QA therefore is only checking the MLC movement but not include daily output fluctuation which is taken care in our daily QA.

3. We deliver the IMRT QA plan and compared to Eclipse dose distribution, and we use DTA 3% 3 mm and 10% threshold dose (10% of the maximum dose eliminate low dose region (or the region outside ROI) because it is clinical insignificant and it has large fluctuation) used as the analysis condition, and 90% of the measured point passing this criteria we consider the plan passed.

(friend's note in the folder GraceBook)
DTA, thus, is an indicator of how good the alignment of the two distributions is, provided that the difference is zero. The percent dose difference is defined as the difference in percent, implicitly assuming that the alignment of the two distributions is perfect. In reality, as the dose difference as well as the misalignment contributes to the difference of the two clinical distributions, use of the 2 independent parameters together will be necessary.

(MapCheck2 Manual p200) DTA: If a measured point fails to agree within p% with the plan dose at that position (1st passing criteria), then the plan dose points are tested to see if there is a higher value AND a lower value within the radius "r" around the measured point (2nd passing criteria). If both a higher value and a lower value are found, then it is assumed that there is an agreement at some intermediate point within the radius, and the dose at the measured point is considered acceptable (Figure 10-4).

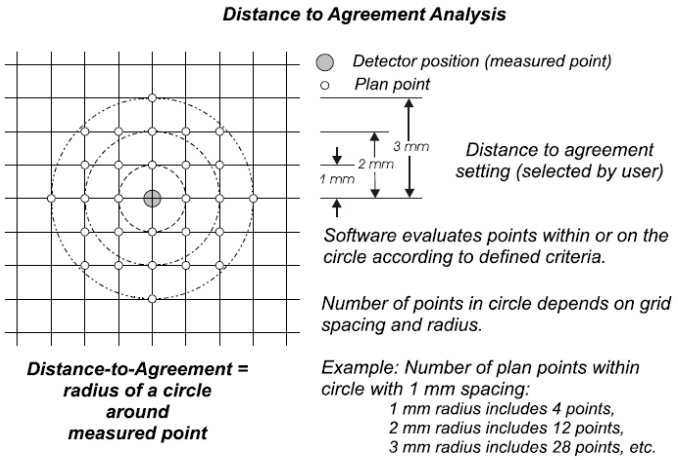


Figure 10-4. Distance to Agreement Diagram

Gamma criteria
(friend's note in the folder GraceBook)
Although the use of the two factors provides the independent evaluation of a dose difference and misalignment, the gamma offers a composite analysis with the two variables collapsed into one parameter

distance axes. The γ quantity, calculated independently for each reference point, is the minimum distance in the renormalized multidimensional space between the evaluated distribution and the reference point. The γ quantity degenerates to the dose-difference and distance-to-agreement tests in shallow and very steep dose gradient regions, respectively. Since being introduced, the γ quantity shallow means low gradient region.

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$$\Gamma(\vec{r}_e,\vec{r}_r)=\sqrt{\frac{r^2(\vec{r}_e,\vec{r}_r)}{\Delta d^2}+\frac{\delta^2(\vec{r}_e,\vec{r}_r)}{\Delta D^2}}$$

Generalized Γ function, computed for all evaluated positions $\vec{r}_e$ and reference positions $\vec{r}_r$

Part 2 ex: In a PTV point of IMRT plan the prescription dose is 240cGy, the most nearby point of closest dose is 232cGy in 2.3mm away, for a 3% dose limit, what is the Gamma factor? (A) 0.92 (B) 0.98 (C) 1.12 (D) 1.15
Assume 3%, 3mm, (240-232)/240=3.33%, gamma=sqrt((3.33% / 3%)^2+(2.3/3)^2)=1.35

(MapCheck manual 205-206, Gamma index calculation step):

For a (typical) 3%/3mm criterion, at a given detector point, if the dose difference (Δd) between the device measured and the TPS calculated values is less than or equal to ±3%, it is determined that the measured and calculated dose values match well **at the same point**, and the dose-to-agreement **(DTA) = 0.00 mm**. Then, the gamma is calculated simply as SQRT(Δd^2/3^2) = ABS(Δd)/3, which will be less than or equal to 1.00, and for that we have a passing detector point.

Else, if for the same 3%/3mm criterion and at the same given detector point, the dose difference (Δd) is found to be larger than ±3%, then the system will search for the (nearest) point on the TPS calculated dose grid, so that at this point the calculated dose value is the same as that at the given detector point. If such point is found with a DTA value less than or equal to 3 mm, the system will think that the dose difference (Δd) = 0.00% and the gamma is calculated as SQRT(DTA^2/3^2) = DTA/3, which is less than or equal to 1.00. Again, we have a passing detector point.

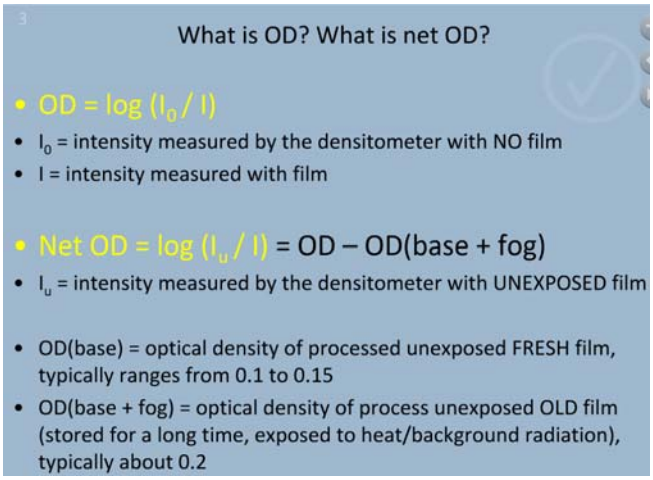
In these 2 steps, only one parameter (Δd, or DTA, not both) is used for the calculation of the gamma value. Only when both steps fail to pass the given detector point, the software tries to use a combination of Δd and DTA, and hopes to find a gamma value less than 1.00 so that the point can pass.

- IMRT QA question: ideal dosimeter, film, placement of the dosimeter etc What chamber do you use? what are the issues of fog in a H&D curve film. A 4 window view of an IMRT QA from TPS. What is it? How do you pick a point or place a chamber? Why?
- What type of film? What is the accuracy of each? Where would you put the chamber to do a point measurement (point to on plan)?

I will pick small volume chamber (maybe Exradin A16 can be a good choice which only has vol. of 0.007 cm^3 which is the chamber we used for Cyber knife QA) to avoid the volume averaging effect, and I will place my chamber in low gradient region to avoid the uncertainty of chamber placement and higher or lower dose reading at the wrong location.

I will choose EDR2 film since it has high dynamic range 0.1 – 5Gy compared to XV2 0.05 – 0.8 Gy.

Base+fog is the optical density of an unexposed film, which is related to storage for a long time, background radiation / heat.



Can you use other method with this phantom? (Had places for film.)
Some detector array came with the solid water phantom and it can have place (gap) for the film.

- Q2: Shown picture of detector arrays (matrixx, mapcheck). Series of questions – what are they? What are they for? What would you do for acceptance?

- Three different pictures of a Mapcheck, MatriXX, Profiler (or some combo of array measuring devices)-describe what each of these are and what they are used for. Tolerances in your clinic for results.

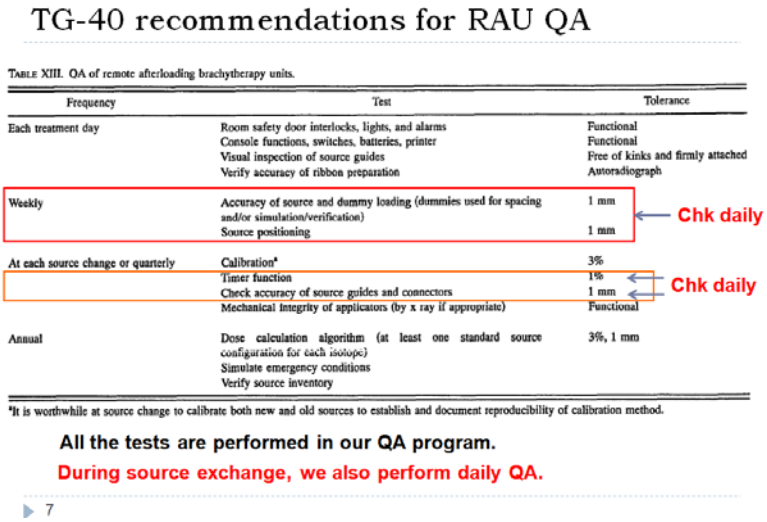
Matrixx: ion chamber array: we used it as IMRT QA as well. The beam profile measurement for Cyber knife monthly.
Mapcheck: diode array: we used for IMRT QA
IC Profiler: Parallel plate chamber array only in inline crossline and diagonal direction. to quickly measure profile
Profiler 2: diode detector array in inline and cross line direction.

1. Different detector can have different response to the same beam. We need to calibrate the detector, and test the detector response. One way to do it is radiate a large uniform beam, and take the profiles with detector at 0 and 180 degree orientation. Different detectors should have the same response at the same profile location.

C4-HDR QA

HDR daily QA.

- How to do it and what is used. Explain what you should do and at what intervals?
- Whole HDR QA, independent meter in the room (needs check source – to detect if the source is half way in.
- What do you do at morning for positioning? (source step viewer)



(Check Dept daily QA procedure!), source exchange we do every 4 months.

What should be done before patient treatment (mechanical, patient specific, and radiation protection)

Patient specific radiation survey
Emergency container is in the room
Check the source guide tube, applicator, and connector are connected in correct channel and visual acceptable.
Check the curie time and source positioning in the treatment console are consistent with the TPS planned.

A question; when we do HDR patient specific survey, what is the dose limit we are looking at? or we simply just want to make sure no source outside the afterloader because if the HDR source is out, the reading will just be high.

§ 35.604 Surveys of patients and human research subjects treated with a remote afterloader unit.
(a) Before releasing a patient or a human research subject from licensee control, a licensee shall survey the patient or the human research subject and the remote afterloader unit with a portable radiation detection survey instrument to confirm that the source(s) has been removed from the patient or human research subject and returned to the safe shielded position.

(b) A licensee shall retain a record of these surveys in accordance with § 35.2404.
Retain records for 3 years,

(A):We are not surveying the patient here, we are surveying the equipment, transfer tubes, and HDR afterloader

itself to make sure that source retracted to safe position, the reading should be background except in close proximity to source holder where it will be higher but acceptable within the shielding specifications.

The background radiation is excluding radon 100 mrem/yr and including radon 330 mrem/yr => 1 mSv/yr and 3.3 mSv/yr

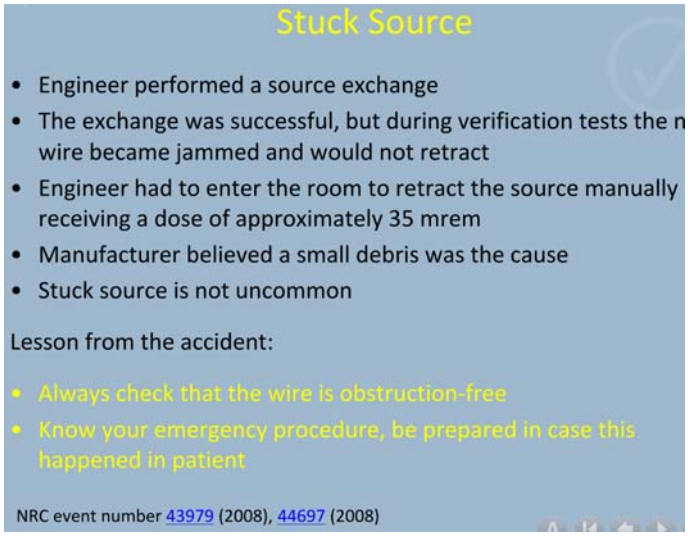
Radon is a chemical element with the z = 86, and is represented by the symbol **Rn**. It is a radioactive, colorless, odorless, tasteless noble gas, occurring naturally as the decay product of uranium or thorium, radon.

Radon is responsible for the majority of the public exposure to ionizing radiation. It is often the single largest contributor to an individual's background radiation dose, and is the most variable from location to location. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as attics and basements. It can also be found in some spring waters and hot springs.

In the old day, we have radium as the source, if there is a crack of our source container, we will have radon gas leakage.

- (HDR. Emergency procedure). How to determine source position, in pt's body or out in the room?
  Use the survey meter to determine the location.

  Kinked tube scenario; what happens during delivery if kinked, what would you do?
  Press the emergency stop button, on the console, wall, & open the door, if they all fail, entering the room, press the emergency stop button on the console. If it is still failed, we need to use the hand crank to retract the source. If it is still failed, we need to use the emergency container to put the whole transfer tube and applicator into the container.



- (Well-chamber) Describe well chambers. FU: Draw me a well chamber and discuss the components**.** How do we use well chambers?

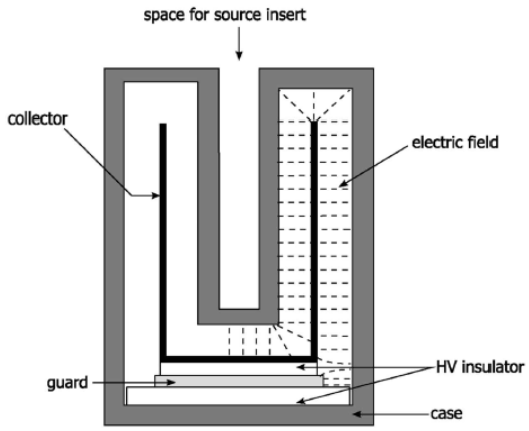
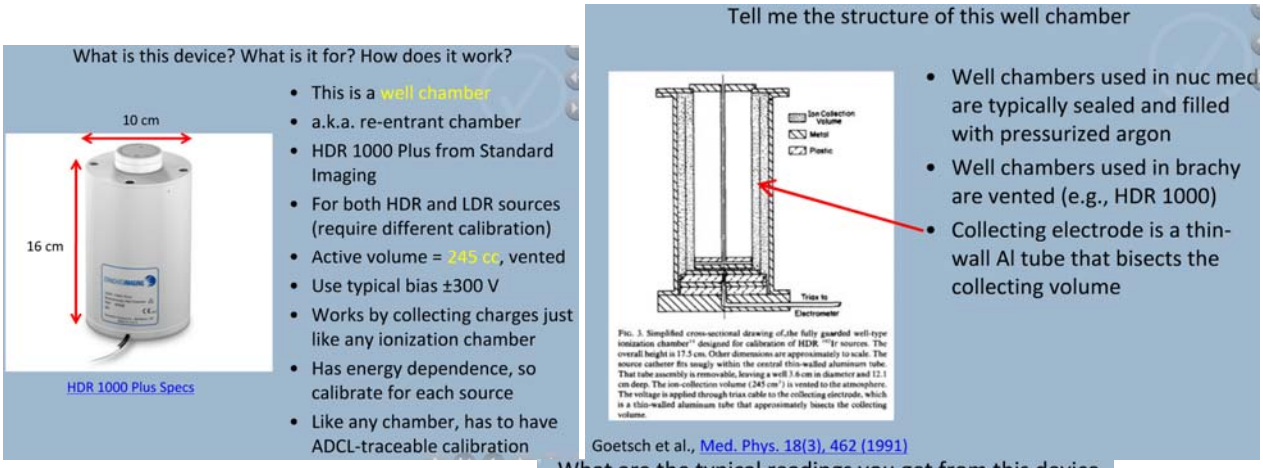
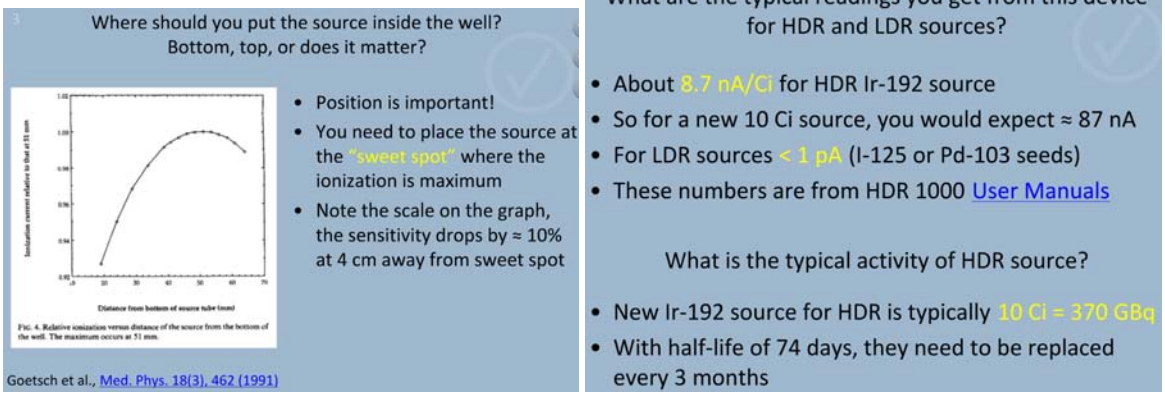


Figure 6-6. Schematic of a well chamber with field lines shown.

The well chamber is one –kind of ion chamber which provide an approximately 4pi measurement geometry (we can get the exposure spherically radiated from a source). Place the chamber above the floor and away from floor at least 20 cm to avoid the scattering affecting the chamber reading (TG41), and apply bias vol 300 V, and measure the current.





Can you estimate the well chamber current for an HDR sourc

- Air Kerma Strength (S_k) for HDR source ≈ 10^{-7} U/Bq
- For 10 Ci source → 370 GBq → S_k ≈ 37,000 U
- U = µGy.m²/h = cGy.cm²/h → S_k ≈ 10 cGy.cm²/s

- Sensitivity of 0.6 cc Farmer chamber ≈ 20 nC/Gy
- For 245 cc well chamber → sensitivity ≈ 8.5 µC/Gy

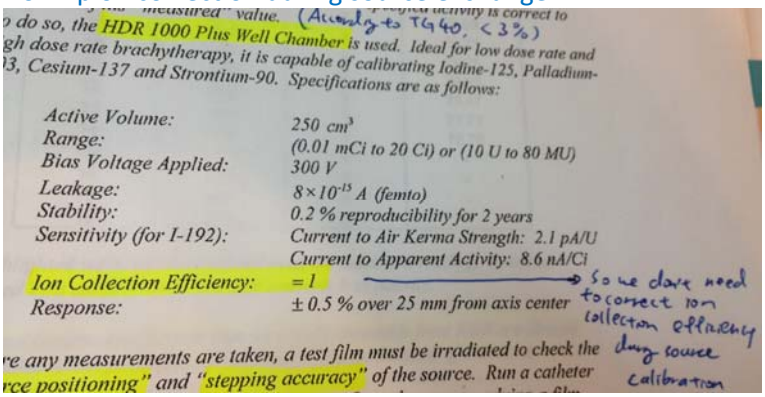
- Air Kerma Rate (AKR) = S_k / d^2
- "Effective" distance ≈ close to midway → d_{eff} ≈ 3 cm
- AKR(d_{eff}) ≈ S_k / 10 = 1 cGy/s
- Current = AKR(d_{eff}) x sensitivity ≈ 85 nA

Why is there foam in the insert of HDR 1000?

- It is solely for thermal insulation
- Some high strength seeds can generate enough heat
- The styrofoam localizes the heat and keep it from heating up the active volume of air in the chamber

- Where I work we do not correct for ionization recombination and the questioner and I got in an argument about this.

From manufacturer, the ion collection efficiency for HDR 1000+ is equal to 1, and we also measure pion which is equal to 1, so we didn't perform pion correction during source exchange.



…measured" value. (According to TG40, <3%)
…o do so, the HDR 1000 Plus Well Chamber is used. Ideal for low dose rate and
…gh dose rate brachytherapy, it is capable of calibrating Iodine-125, Palladium-
…3, Cesium-137 and Strontium-90. Specifications are as follows:

Active Volume:	*250 cm³*
Range:	*(0.01 mCi to 20 Ci) or (10 U to 80 MU)*
Bias Voltage Applied:	*300 V*
Leakage:	*8×10^{-15} A (femto)*
Stability:	*0.2 % reproducibility for 2 years*
Sensitivity (for I-192):	*Current to Air Kerma Strength: 2.1 pA/U*
	Current to Apparent Activity: 8.6 nA/Ci
Ion Collection Efficiency:	*= 1* → So we don't need to correct ion collection efficiency during source calibration
Response:	*± 0.5 % over 25 mm from axis center*

…re any measurements are taken, a test film must be irradiated to check the
…rce positioning" and "stepping accuracy" of the source. Run a catheter

- HDR Calibration. Equipments needed for it (Well chamber, source holder, electrometer); Write down the equation to get the exposure rate. What is sweet spot? (well chamber timer error / MU end effect)
  HDR calibration --- very much in detail, including explaining all the factors for the dose rate calibration equation, timer error, end effect and so on. Asked about the dwell position accuracy (1mm). How to verify, relative and absolute?

- Describe calibration procedure for a brachytherapy source? What's the frequency of calibration for RAM? What does electrometer read? What's a typical value?
  (DABR P173 has good steps) We exchange source every 4 months after the source activity is decayed about 60%.
  - Calculate the source activity at the source exchange date using exp decay.
  - Check source positioning and stepping accuracy using permadoc
  - Check source guide tube in correct length using length gauge, check connector
  - Place well-chamber on a stand away from the floor and wall
  - Measure temperature within the chamber and pressure (from airport) The reason to use the pressure from airport is our hospital not far away from the airport and we are in the same altitude. Airport pressure is supposed to be very accurate because they use pressure to determine the altitude of the airplane.
  - Set bias voltage as 300 and zero (null in PTW unidos electrometer) the electrometer to eliminate the background signal.
  - Set the electrometer in current mode in the range of **High** nA scale.
  - Send the source to the sweet spot (the location with max ionization) of the chamber, ours is 125.3 cm for GammaMedPlus 130 cm fixed source traveling range. (we measured 125.6, 125.3 & 125 3 positions to avoid any potential positioning uncertainty our source is 3.5 mm in length) . We let the source stay at the position for 15s
  - Get the current reading, and it will be approximately 86 nA (for a 10 Ci source) [we passed has the calculation]
  - Then we can calculate the source activity using air-kerma rate per activity and the chamber calibration factor, environmental correction factor.
    Our equation actually looks very cumbersome

    The activity can simply calculated as

    Source air kerma strength S_k (U) = M_{raw}(nA)x P_{tp} x P_{ion} x P_{pol} xP_{elec} x K(well chamber AKS calibration factor in U/A)/A_{ion}

    Note: Exposure rate constant in $Rcm^2/(mCi\ h)$
    Air kerma rate constant in $Rcm^2/(mCi\ h)$ x 0.876 = $cGy\ cm^2/(mCi\ h)$

  - 1U = 1 unit of air-kerma-strength = 1 $\mu Gy\ m^2\ h^{-1}$ = 1 $cGy\ cm^2\ h^{-1}$

    Exposure rate in R/h
    Air kerma rate in cGy/h

    Source activity (Ci) = S_k/(Air kerma rate constant for Ir192 in U/Ci)
    {We shouldn't use dose rate constant because the unit is in cGy/h/U defined at 1 cm in the **water,** which is not appropriate for in-air measurement}

    Our chamber calibration factor for HDR1000+ is 4.7E5 ($Gy\ m^2$)/ (hr A) = 4.7E11 ($\mu Gy\ m^2$)/ (hr A) = 4.7E11 (U/A)
    Ir192 S_k/Ci = 4.69 ($R\ cm^2$/(mCi x hr)) x 0.876(cGy/R) = 4.1 (U/mCi) = 0.0041 U/Ci

  - TG40 < 3% if more than 5%, need to notify the manufacturer and measure needs to be taken to decide if we will use manufacturer value.

Source Strength: Action level

- AAPM TG-40 recommends that if disagreement between measurements and the source certificate
  - >3% → investigate
  - >5% → report to manufacturer
- TG41 (1993) stated that single ^{192}Ir (10 Ci) have source activity to only 10% accuracy.

Apparent activity	444.12	GBq(	12.003	Ci) (1) (2)
Air kerma rate at 1 m	48.853	mGy/h	+- 5%	(3)

- The uncertainty and reproducibility of the verification measurements should be known and considered.
- Reproducibility of in air measurements can be established conveniently by measuring both the old and new source strength at the time of source change.
- In our department, we use 2 well-chamber sets to check the source activity and the reproducibility.

PTW UNIDOS Universal Dosemeter, Type 10005 - Serial # 50196

SCALES, SWITCH POSITIONS, AND CONDITIONS OF CALIBRATION:

Switch:	Setting:
Chamber and TPC factors disabled	
Voltage	0 V
HV Polarity	-

MOD (MODE)	RGE (RANGE)	CALIBRATION COEFFICIENT	PRECISION/ LINEARITY	RANGE OF READINGS
Integrate Current	Med	1.000 C/Rdg *	± 0.1 %	-200 pC to -300 nC
Current	Low	1.000 A/Rdg	± 0.1 %	+10, -20 pA to ± 200 pA
Current	High	0.999 A/Rdg	± 0.1 %	+10, -5 nA to ± 998 nA

If we look at the above electrometer calibration range, and we can see since we are supposed to get 86 nA, so we need to set our current range to High, and when we do the TG51, our chamber reading is about 20 nC, so we need to set our charge range to Med. (In fact, for this particular electrometer, we only have 1 charge measured range calibrated)

1.1.3 Measuring Ranges and Resolution

	digital resolution	*minimum*	*maximum*
measuring mode: charge (dose)			
Low	10 fC (500 nGy)	2 pC (100µGy)	220 pC (10 mGy)
High	500 fC (25 µGy)	100 pC (5 mGy)	22 nC (1 Gy)
measuring mode: current (dose rate)			
Low	1 fA (3 µGy/min)	200 fA (600 µGy/min)	200 pA (0,5 Gy/min)
Medium	50 fA (150 µGy/min)	10 pA (30 mGy/min)	10 nA (28 Gy/min)
High	5 pA (15 mGy/min)	1 nA (3 Gy/min)	1 µA (2800 Gy/min)
measuring mode: current (dose rate), display of integrated value: charge (dose)			
Low	10 fC (500 nGy)	2 pC (100 µGy)	12 µC (600 Gy)
Medium	0,5 pC (25 µGy)	100 pC (5 mGy)	600 µC (30 kGy)
High	50 pC (2,5 mGy)	10 nC (500 mGy)	65 mC (3 MGy)

Table 1: *Digital resolution and measuring ranges for current and charge measurement.*

From PTW unidos manual

Current range: 0.2pA to 1000 nA

Charge range: 2 pC to 65 mC

Leakage: 10^{-3}pA

During our source calibration, we only check timer accuracy and linearity

D. Timer Linearity and Accuracy Check:

Retrieve saved program "Timer Check' for exposure. Source position equals 1253mm. Edit Channel to adjust absolute time accordingly.

a. **Timer check**: See pre-treatment Daily QA sheet, Section D-3

b. **Timer linearity**: Set source dwell time as indicated below.

[Net Rdg = Avg. Rdg – 5s. Avg. Rdg; Net Time = Abs. Time – 5s.; Net Current = Net Rdg/Net Time]

Absolute Time (s)	Avg. Reading (nC)	Net Reading (nC)	Net Time (s)	Net Current (nA)	Ratio
5	538.2	-----	0	-----	-----
6	619.9	81.7	1	81.7	0.9990
10	947.4	409.2	5	81.84	1.0007
15	1356	817.8	10	81.78	**1.000** ← normalized to 15
35	2992	2453.8	30	81.79	1.0001
65	5445	4906.8	60	81.78	1.000
125	10350	9811.8	120	81.77	0.9998

Criterion: Ratio ≤ 1% (AAPM TG-40)

Note: this test does not test end-effect.

Accounting for Source Travel (End effect)

- Charge was measured during source transit and it should not be included.
- End effect (timer error) in seconds, a transit time of the source as a function of traveling distance d
- External timer trigger electrometer or programmable electrometer to avoid this effect / timer error
- If the RAU timer is used, corrections must be made for Q collection during source transit. The true charge collection rate can be calculated as moving source to 1 position, measuring charge at 2 different time duration, and calculate the rate;

$$\dot{M}_r = \frac{M_r(t_2) - M_r(t_1)}{t_2 - t_1}$$

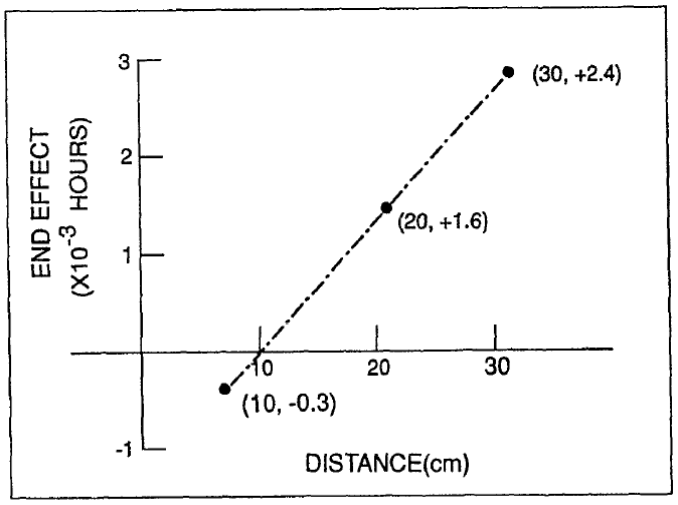


Figure 16. End effects (timer error) versus distance for a Selectron-LDR unit. Each unit will have a different timer error. (Courtesy of G. P. Glasgow, Maywood, IL).

(TG41)

The end effect can be estimated by getting the corrected charge collection rate M_r' as shown above
From our source calibration sheet, it can be calculated as (947.4(10sec) -538.2(5sec))/5 = 81.84~82 nC/s
The timer error traveling from 0 to 125.3 cm can be estimated as (947.4 – 82x10(sec)[the charge we collected during source traveling to 125.3 cm])/82(nC/s) = 1.55 sec.

Now we have timer error (end effect) = 1.55 sec at 125.3 cm which means for source traveling to 125.3 cm we should start our measurement after 1.6sec.

The same analysis can be performed at different distance, and we can have the linear relationship shown as above figure. We will have the end effect as function of traveling distance.

This end effect only affects the well chamber reading but it does not affect the dwell time at the dwell position. The dwell time won't start until the source reaching the dwell position. The source traveling time (end effect) can also be used to estimate the dose delivered to the patient while it travels.

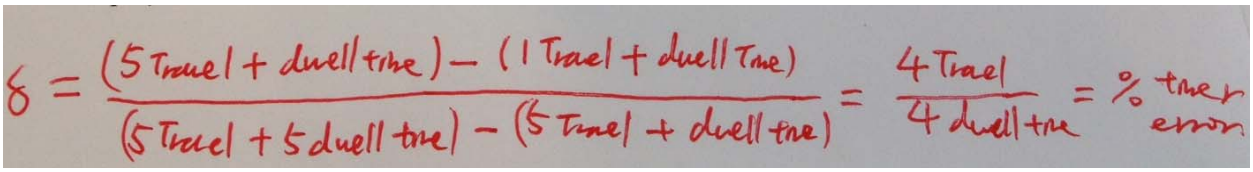
Timer error is calculated as percentage:

Timer Accuracy

In order to determine the timer accuracy, the HUP well-type ionization chamber (S/N A962484) and the HUP PTW Unidos electrometer (S/N 50164) were used to measure the fluence of the HDR source *n* times. The timer error was found from Equation 5:

$$\delta = \frac{Q_{n(T/n)} - Q_T}{nQ_T - Q_{n(T/n)}}. \qquad (5)$$

where, *n* is the total number of charge measurements with the dwell time *t*, Q_T is the charge measured for a dwell time of $T = nt$, and $Q_{n(T/n)}$ is the sum of charges collected for *n* exposures each with a dwell time *t*. The dwell time, *t,* must be greater than the time that is required for the source to travel from the safe to the center of the well chamber.



The dwell time was set to 100 seconds and 5 x 20 seconds with the source positioned at the center of the well chamber where maximum of the dose rate occurs, as determined by the HDR Source Calibration Report. Table 1, below, displays the results of the timer accuracy measurements.

Time (s)	Reading (10^{-7}C)	$Q_{n(T/n)}$ (10^{-7}C)	Q_T (10^{-7}C)	??? %
100	68.42			
20	14.18	70.94	68.42	0.93%
20	14.19			
20	14.19			
20	14.19			
20	14.19			

Table 1: Timer accuracy measurements

The accuracy of the Gammamed Plus iX HDR timer is 0.93%, which is within the criteria of less than 1.0% as reported by AAPM TG-40.

- Is there a regulation regarding calibration? (USNRC 10CFR35)

§ 35.432 Calibration measurements of brachytherapy sources.

(a) Before the first medical use of a brachytherapy source on or after October 24, 2002, a licensee shall have—
(1) Determined the source output or activity using a dosimetry system that meets the requirements of § 35.630(a);
(2) Determined source positioning accuracy within applicators; and
(3) Used published protocols currently accepted by nationally recognized bodies to meet the requirements of paragraphs (a)(1) and (a)(2) of this section.

(b) Instead of a licensee making its own measurements as required in paragraph (a) of this section, the licensee may use measurements provided by the source manufacturer or by a calibration laboratory accredited by the American Association of Physicists in Medicine that are made in accordance with paragraph (a) of this section.

(c) A licensee shall mathematically correct the outputs or activities determined in paragraph (a) of this section for physical decay at intervals consistent with 1 percent physical decay.

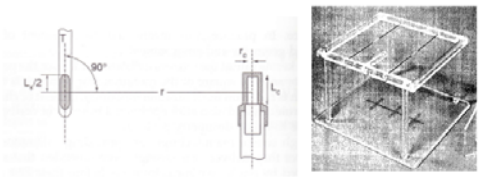
(d) A licensee shall retain a record of each calibration in accordance with § 35.2432.
(TG40)

- One subquestion was whether I could calibrate the sources with a farmer chamber. I replied that I checked the range of my farmer chamber and it is 30 kev to 30MV and if the sources are placed in a proper geometry, one can theoretically calibrate them.

1. Calibration Factor of the Chamber

- Calibration factor of the ionization chamber for LDR source can be obtained from NIST
- But no such calibration existed for Ir^{192}, such as for spherical or cylindrical chamber, at NIST or ADCL labs at time of TG-41 publishing
- However, chamber calibration is available for Co^{60}/Cs^{137}
  - TG41 and 56 suggest to interpolate the calibration factor for Ir^{192} between Cs^{137} and orthovoltage x-ray.

2. In-Air calibration set up



- The measurements are taking place at distance *r* free in-air, where *r* is defined along the transverse bisector of the source and is the distance between the center of the source & the reference point of the ion chamber
- The source is usually inserted in a tube/catheter that is normally used in brachy implants, so the measured source strength includes the effect of attenuation of radiation from wall of the tube/catheter.
- For sources used in permanent interstitial implants, the effect of this wall attenuation must be corrected.

Baltas *et al.* "The physics of modern brachytherapy for oncology", p213 -215

Chamber volume

- For HDR Ir^{192} sources, when using typical chamber for high energy photon beam, chamber volume 0.3 – 1 cm^3, and source-to-chamber distance in the range of 5 – 40 cm are appropriate.
- For LDR sources, with the low energy and low activity, the low measurement signal requires closer distance and larger volume chamber (preferable 1000 cm^3 spherical chamber), but this is only practical in ADCL not in clinical environment.

Shonka-Wyckoff

Calibration Factors: Interpolation Method (Goetsch et al.)

- The mean energy of ^{192}Ir, 370 keV, falls halfway between the energy of Cs^{137} and 250 kV x-rays.
- Obtain calibration factors N_x for Cs^{137} and 250 kV x-rays, and interpolate the factor at 370 keV for Ir^{192}

$$N_{x,Ir} = \frac{A_{w,x-ray}\,N_{x,x-ray} + A_{w,Cs}\,N_{x,Cs}}{2\,A_{w,Ir^{192}}}$$

- A_w is the wall attenuation factor (chamber wall + build-up cap) for the 3 energy. Goetsch *et al.* found if N_x for Cs^{137} and 250 kV x-ray do not differ by > 10%. We can rewrite the eq. as ..

S. J. Goetsch, F. H. Attix, D. W. Pearson, B. R. Thomadsen, *"Calibration of "Ir High Dose Rate Afterloading Systems"*. Med 24

In-Air calibration set up

- Source holders, ion chamber and supports should be made of low density plastic to minimize scatter.
- Room dimensions should be set such that the minimum distance between the chamber and the possible scattering sources is at least 1 m.
- The measurement distance *r* should be selected so that the source can be considered as a point source:
  - *r* is 3x than the active length of the source L_s
  - And 5x than the chamber vol. length L_c
- As long integrated charge collection periods may be required, leakage charge should be measured and corrected.

Baltas *et al.* "The physics of modern brachytherapy for oncology", p218

In air calibrations

- In addition to conventional chamber/electrometer charge collection efficiency corrections, additional corrections may be needed:
  - Air attenuation and multiple scattering
  - Exposure gradient across the chamber
  - Room scatter effects
  - End-effect (timer errors)

- What would your electrometer read if you drop a LDR PSI seed in a HDR chamber? Can you use any source your vendor gives you? Is there any limit on source strength? What do you do if you get a source larger than the limit?

For LDR seed, it will read close to 1pA or even less. (wepassed well chamber). 1LDR I-125 seed is about 0.1-1 mCi, and the exposure rate constant is 1.5 $Rcm^2/(mCi\ h)$, and for Ir-192 is 4.67 $Rcm^2/(mCi\ h)$. For Ir-192 10 Ci source, we have 86 nA reading. The current is proportional to the exposure rate for a given source, so 86 nA/(4.67 x 10^4mCi ir-192 /(1.5x1mCi i-125)) = 2.8 pA. Here is assumed we are in the sweet spot, and 1 mCi source. In the real case, this reading can be < 1 pA consistent with we passed answer.

For HDR 1000+, the range is from 0.01 mCi to 20 Ci. If the activity is too high, we can use a special insert with lead inside to reduce the current from HDR sources.

Can nuclear medicine or LDR well-chambers be used to calibrate HDR sources?

- Difference between LDR and HDR:
  - The magnitude of the currents generated in chambers. HDR source can generate much larger current than LDR.
  - Current range & linearity of Well-chamber electrometer determines whether it can be used for HDR
  - Ex: RADCAL Model 4050 well chamber measures current from 4.5-fA to 22.5-nA and the maximum current of 22.5-nA only allows the measurement for 3 Ci ^{192}Ir.
  - HDR 1000 + : 0.01 mCi to 20 Ci
- Special well inserts (2 cm diameter cylinder of Pb) can be used to reduce the current from HDR sources – MSK

- How do you check well-chamber constancy?

In our clinic, we use 2 set of equipment to check the primary-chamber constancy (0.5%).

Use and QA of Well Chambers

- Constancy should be checked regularly with long-lived radionuclides (ex:Cs^{137})
  - A reproducibility better than 0.5% is desired
- Allow air temperature to stabilize then perform the measirement.
- Well chambers are sensitive to scatter radiation:
  - Use at the same location for constant geometry
  - Measure away from walls and the floor

- **(LDR Calibration)** (2006) what sources did we have calibrations for?

Well-type Brachytherapy Ionization Chambers (1U=1μGy/m²/hr) HDR Ir-192 Cs-137, Cs-131, I-125, Pd-103, LDR Ir-192	Up to 50 kU Up to 500 U Up to 100mGy/sec	2.6% 2.4% 11%	NIST calibrated Cs-137 brachytherapy sources; reference class well-type ionization chambers calibrated against NIST calibrated sources for short-lived isotopes such as Ir-192, I-125, Cs-131, and Pd-103. NIST traceable absorbed dose to water calibration at depth of 2.5 mm for NeoVista Vidion Source.
Well-type Intravascular Ionization Chambers Sr-90 Activity Sr-90 Absorbed Dose	Up to 100 mCi Up to 200 mGy/s	6.4% 15%	NIST traceable activity and absorbed dose to water source calibrations
Radioactive Brachytherapy Sources Sr-90 Ophthalmic Applicators Cs-137,Cs-131, I-125, Pd-103, LDR Ir-192	1 Gy/s Up to 500U	11% 1.9%	NIST calibrated Cs-137 and Sr-90 brachytherapy sources, reference class well-type ionization chambers calibrated against NIST calibrated sources for short-lived isotopes such as Ir-192, I-125 Cs-131, and Pd-103.
Electrometers	Charge (25 pC - 10,000 nC) Current (1pA - 1000 nA)	0.2% 0.2%	NIST traceable (A2LA accredited) capacitor calibration, voltage (through calibrated DMM), and period / time (through calibrated universal counters).

http://preview.uwmrrc.wisc.edu/index.php?option=com_content&task=view&id=27&Itemid=54

From the ADCL website, for well-chamber, we have HDR-Ir-192, LDR Ir-192 (in ribbon form). LDR: Cs-137(in tube form). LDR I-125 & Pd103 and Cs-131 in seed form.

- **(LDR Calibration)** Compare the commission difference between I-125 and Ir-192 (both are LDR). Also is there any difference in surveying? How did we calibrate sources that came in ribbons (Ir-192)? Q1: Discuss calibration techniques for I125, Ir192, and Cs137 (equipment, frequency, etc)?

(1). I125 using the single source holder with calibration factor for our well chamber **(Check our I125 calibration sheet)** Net Avg. Reading (A) *AKS Cal Coefficient (U/Amp)*Pelec*PTP = get AKS of the seed in U

70016 Single LDR Seed Sources

REF 70016

Insert an individual seed into the Teflon tube of the source holder. The source holder will place the seed at the most active area of the chamber. Take measurements following the steps outlined in ***Procedures for Well Chamber Measurements***. A seed can be removed by taking the source holder out of the HDR 1000 Plus chamber and inverting. The Teflon tube will allow the seed to easily slide out. ADCL calibrations are available for LDR iridium, iodine and palladium seeds. ADCL calibrations are not available for gold.

(2). There is a loop holder for Ir-192, but we don't use that. We calibrate ribbon by obtaining a chamber response as a function of position using HDR Ir-192 source holder but LDR Ir-192 1 cm source at 14 positions

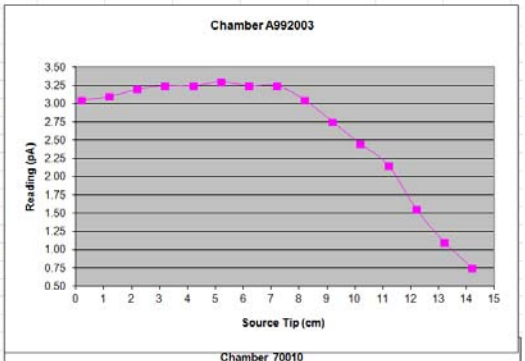
Center of Well Chamber Determination

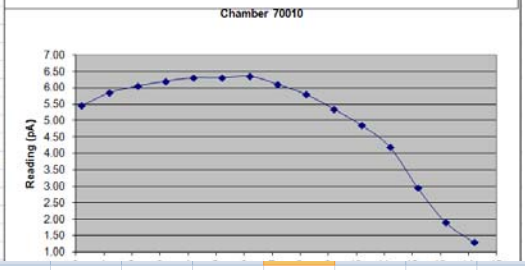
#######

Ir-192 one seed with 14 cm leader, cut 1 cm
HDR source insert chamber specific

Calibration Factors:	A962484	A992003
(Gy m^2/hr/A)	4.635 E5	4.665 E5
Calibration Dates	2010/6/7	2010/5/17

		Electrometer 50164 Chamber A962484		Electrometer 50196 Chamber A992003
Source Tip (cm)	Geometry factor	Reading (pA)	Geometry factor	Reading (pA)
14.2	0.20	1.30	0.23	0.75
13.2	0.30	1.90	0.33	1.10
12.2	0.46	2.95	0.47	1.55
11.2	0.66	4.20	0.65	2.15
10.2	0.76	4.85	0.74	2.45
9.2	0.84	5.35	0.83	2.75
8.2	0.91	5.80	0.92	3.05
7.2	0.96	6.10	0.98	3.25
6.2	**1.00**	**6.35**	0.98	3.25
5.2	0.99	6.30	**1.00**	**3.30**
4.2	0.99	6.30	0.98	3.25
3.2	0.98	6.20	0.98	3.25
2.2	0.95	6.05	0.97	3.20
1.2	0.92	5.85	0.94	3.10
0.2	0.86	5.45	0.92	3.05





Spreadsheet for calculating expected well chamber reading of Ir-192 ribbons

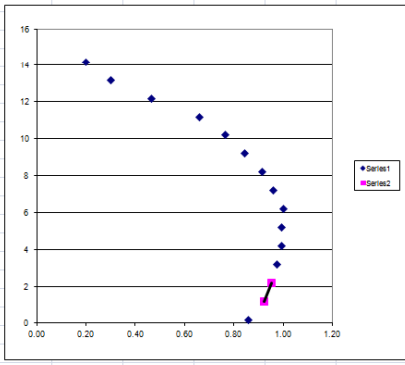
Patient Name:			Date:	2010/7/12	
Elec. factor =	0.999	Chamber fac*. =	1.1260E+02	mCi/nA	112.631
Temp =	23.4	Pressure =	762	Ctp =	1.002
		Cal. Date	2010/7/9		

Geometry factor	Seed position from tip (cm)	Calib date Strength mg Ra eq	Seed strength assay date (mg Ra eq)	Well chamber reading (nA)	**A962484**
0.86	0.2	0	0.0000	0.000000	
0.92	1.2	0	0.0000	0.000000	
0.95	2.2	0	0.0000	0.000000	
0.98	3.2	0	0.0000	0.000000	
0.99	4.2	0	0.0000	0.000000	
0.99	5.2	0	0.0000	0.000000	
1.00	6.2	0.4008	0.3897	0.006189	0.3897 (mg Ra eq) x 1 (geometry factor) x
0.96	7.2	0.4008	0.3897	0.005945	1.79 (mCi/mg-Ra Eq)/(112.6mCi/nA x Ctp x
0.91	8.2	0.4008	0.3897	0.005653	Elec fac)
0.84	9.2	0.4008	0.3897	0.005214	
0.76	10.2	0.4008	0.3897	0.004727	
0.66	11.2	0.4008	0.3897	0.004093	
0.46	12.2	0.4008	0.3897	0.002875	
0.30	13.2	0	0.0000	0.000000	
0.20	14.2	0	0.0000	0.000000	
		Expected	Total rdg (nA)	**0.03470**	
		Measured	(nA)	**0.035667**	0.0357 0.0355 0.0357 0.03545 0.03595 0.0357
			Ratio	**1.0280**	

*1μGy*m^2/hr=0.243mCi for Ir-192 chamber factor=4.635E5 Gy*m^2/hr*A

1/(4.69x0.876)

Note: Half-Life of Ir-192 = 74.3 days (based on Best Medical Industries values)
Specific gamma ray constant = 4.6 Rcm^2/mCi hr



(3). Cs-137 holder

70020 Cesium Sources

For ^{137}Cs calibrations, verify the plastic spacer inside the source holder insert is at the bottom of the source holder. Place the cesium source in the source holder for the measurement. Take measurements following the steps outlined in ***Procedures for Well Chamber Measurements***.

REF 70020

- What happens if one is off? What are the limits
- Know differences in QA program for Ir-192 vs. Cs-137 vs. I-125. Half-life of each.

TG56: The criteria is the average value is 3% for mean of batch, and individual 5% max deviation from mean.
Long live source- source calibration at initial purchase (such as Cs-137)
Short live source - source calibration at every use (such as I-125, Pd-103, Ir-192)

Every 6 months, do the inventory for all the sources, wipe test lead safe and working area, area survey

- He asked a follow-up on why you can't/shouldn't use a well chamber for Cs137?

In the nuclear med, Cs has another form in liquid form and TG41 actually mentioned it so we can't use the calibration factor for solid Cs source for liquid source

- What are your concerns to implement HDR in your facility (DABR 165-172 from TG59)
    a. Licensee application (Regulations)
    b. Radiation safety: Shielding design, emergency plan, film badgering, survey equipment, team member safety training
    c. Facility requirements: door interlock sys, AV, HDR chain locked to the unmovable structure, independent dosimetry system.
    d. Staff requirements
    e. Clinical procedure and equipment procedure establishment
    f. QA system
    g. Licensed activity should be able to keep two sources
    h. Commission system

- **(RAU)**How would you commission remote after loader? What do you check? Well chamber? Electrometer (reading unit)?

  (TG41 Acceptance):

  Safety: 1. That all console function and indicator work properly

  2. Source retraction function working properly , such as press emergency stop button, the end of treatment, loss electric power, retract when the source guide tube connect to the wrong channel, or the source guide tube is with kink (unplug source guide tube to test)
  3. The RAU works work properly under battery operation
  4. The RAU timer accuracy compared to stop watch
  5. The source decay accuracy calculated by the console computer, and the dwell time calculated by the computer is reflected by the source activity decay
  6. Source positioning check and make sure the source travel in the right channel
  7. Mechanical hand crank sys work properly
  8. Radiation detector in the RAU working properly
  9. Leakage radiation rates around the device are acceptable.

  (HDR commissioning) our HDR commissioning report:

  1. HDR source calibration
  2. HDR TPS commissioning

     (1). Hardware

     (2). Software

     1. Data verification Ir-192 g(r), and F(r,theta) distribution compared to published results

     2. Dosimetry verification (generating optimized plan and verify the CiS according to the decay table)

     (3). HDR RAU verification

     1. Timer error

     2. Timer linearity

     3. positioning accuracy using the step viewer

  3. HDR applicator commissioning

     (1) Check the applicator physical dimension and integrity, and internal shielding positioning using film consistent with the manufacturer specification

     (2) Planned Dwell pos. as compared to delivered dwell pos.

Commission BrachyVision:

1. Dose to point calculation:
   i. Point with no off axis shift

      1)Open BrachyVision

      2)Open test patient

      3)Define sources: single source; multiple sources

      4)Planning → set dwell time

      5)Add reference point:

      - Put it somewhere we know what the dose should be: for example: 1cm; 2cm; 3cm away from the middle of the source.
      - Source capsule size = 0.12 + 0.36 (source size)

      6)iCheck → independent dose calc check

   ii. check anisotropy by checking points with off axis shift
2. check DVH

   For a single source, define different structures as circles around the source → generate DVH and check.

For example, generate a circle with diameter = 2cm, then Dmin of the DVH for this circle should be close to 1cm point dose.

3. Printout Check

   Check the magnification of the printout with ruler.

4. Patient plan check

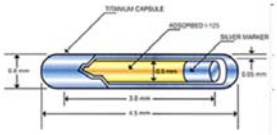
   Generate plan for an old patient: check the plan (numerical printout); check DVH; check some dosimetric indices.

5. Generate clinical protocols

- **(Prostate seed)**

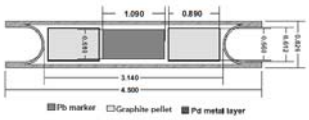
Source types

- I-125
  - Electron capture
  - $T_{1/2}$ = 59.4 days
  - E_{avg} = 27.4 keV
  - Air kerma strength between 0.4 and 1 U (0.3-0.8 mCi) per seed
  - Typical prescription = 145 Gy



Source types

- Pd-103
  - Electron capture
  - $T_{1/2}$ = 17.0 days
  - E_{avg} = 20.5 keV
  - Air kerma strength between 1.4 and 2.2 U (1.1-1.7 mCi) per seed
  - Typical prescription = 125 Gy



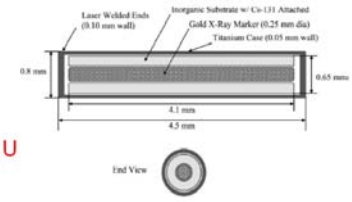
Model 200 Pd-103 Source

2012/5/5 Prostate Seed Implants

We use 0.4 mCi I-125 for 50 cc prostate
I-125 for eye plaque is 10U 85Gy (1fx) to tumor plaque, 3days in hospital

Source types

- Cs-131
  - Electron capture
  - $T_{1/2}$ = 9.7 days
  - E_{avg} = 30.4 keV
  - Air kerma strength between 0.13 and 33 U per seed
  - Typical prescription = 115 Gy

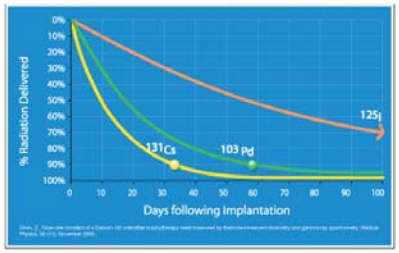


2012/5/5 Prostate Seed Implants 31

Source types

- Comparison

Isotope	Half-Life	Energy	90% Dose	Total Dose
Cs-131	9.7 days	30.4 KeV	33 days	115 Gy
Pd-103	17 days	20.8 KeV	58 days	125 Gy
I-125	60 days	28.5 KeV	204 days	145 Gy



2012/5/5 Prostate Seed Implants

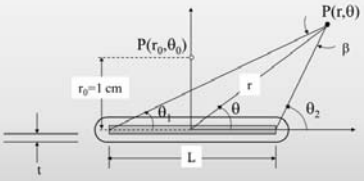
TG43

- (2011)Q4: Shown TG43 equation. Discuss each term.
  (read wepassed: TG43 protocol as well)

TG-43U1 formalism: Dose rate at point P(r,θ)

$$\dot{D}(r,\theta) = S_K \cdot \Lambda \cdot \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} \cdot g_L(r) \cdot F(r,\theta)$$

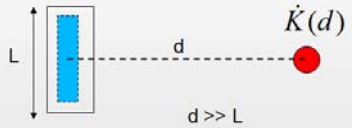
S_K: Air Kerma Strength
Λ: Dose rate constant
$G_L(r,\theta)$: Geometry factor
$g_L(r)$: Radial dose function
$F(r,\theta)$: Anisotropy function
L denotes the line source approx.



- Polar coordinate system
- The coordinate system origin is positioned on the geometric center of radionuclide distribution, with radial distances *r*. Polar angles, θ, are measured from the source long-axis.
- The reference position, $P(r_0,\theta_0)$, is located at r_0 (1 cm) and θ_0 (90°) on the transverse plane of the source, $\beta = \theta_2 - \theta_1$, and t is the capsule thickness on the transverse plane.

S_K: Air Kerma Strength

$$S_K = \dot{K}_\delta(d) \cdot d^2$$



- The product of the in-vacuum air-kerma rate dK/dt, measured along the transverse bisector of the source at distance d, and the square of this distance, d^2, where d >> L to remove distance dependence. 1 m is the reference calibration distance.
- The qualification "in vacuum" means that the measurements should be corrected for photon attenuation and scattering in air and any other medium interposed between the source and detector.
- Primarily performed at NIST/ADCLs, and to verify the accuracy of the source strength provided by vendor, user can use a well-type reentrant ion chamber that has a calibration traceable to the national standards for each type of source.

S_K: Air Kerma Strength

$$S_K = \dot{K}(d)d^2 \longrightarrow S_K = \dot{K}_\delta(d)d^2$$

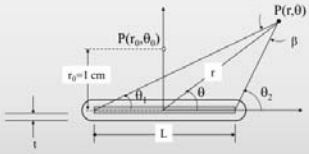
TG43 **TG43U1**

- Low energy cutoff: δ (5 keV)
- Excludes low energy photons (characteristic x-rays from outer layers of steel or titanium source cladding) that contribute to the air kerma rate, but not the dose to at distances greater than 0.1 cm in tissue.
- 1U = 1 unit of air-kerma-strength = 1 μGy m^2 h^{-1} = 1 cGy cm^2 h^{-1}

Λ: Dose Rate Constant

- Defined as dose rate to water at a distance of 1 cm on transverse axis of a source with unit air-kerma-strength in a water phantom (units: cGy h^{-1} U^{-1})

$$\Lambda = \frac{\dot{D}(r_0,\theta_0)}{S_K} = \frac{\dot{D}(1\,\text{cm},\pi/2)}{S_K}$$



- Perhaps the most crucial brachytherapy dosimetry parameter since all other parameters are relative terms. It is an absolute quantity used to transform the relative dose distribution into absolute dose rates for a given air-kerma strength of the sources.
- Depends on the S_K value traceable to NIST; in other words, if the S_K standard for a given source provided by NIST is changed in the future, the Λ value will also change.

Λ: Dose Rate Constant

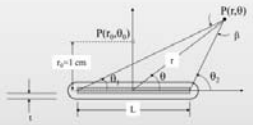
$$\Lambda = \frac{\dot{D}(1\,\text{cm},\pi/2)}{S_K}$$

- **Includes the effects of (because it's 1 cm [at reference pt.] away from the source)**
  - Source geometry
  - Spatial distribution of radioactivity within the source
  - Encapsulation and self-filtration with the source
  - Scattering in water surrounding the source

G(r,θ): Geometry factor

- G(r) neglects scattering and attenuation, and provides **an effective inverse square-law correction** by considering many infinite small point sources distributed over a linear source.

$$G(r,\theta) = \frac{\int_V \rho(r')/|r'-r|^2\,dV'}{\int_V \rho(r')dV'}$$



- G(r) only considers dose fall-off due to source geometry

$$G_P(r,\theta) = r^{-2} \quad \text{point-source approximation,}$$

$$G_L(r,\theta) = \begin{cases} \dfrac{\beta}{Lr\sin\theta} & \text{if } \theta \neq 0° \\ (r^2 - L^2/4)^{-1} & \text{if } \theta = 0° \end{cases} \quad \text{line-source approximation,}$$

G(r,θ): Geometry factor

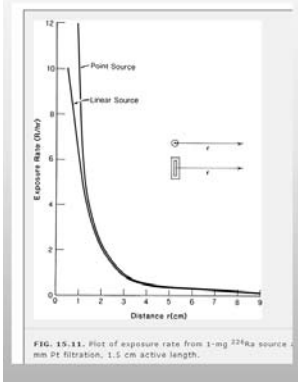


FIG. 15.11. Plot of exposure rate from 1-mg ^{226}Ra source ... mm Pt filtration, 1.5 cm active length.

At large distance, the line source is just like a point source

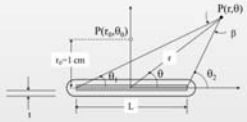
G x r^2

TABLE V. Example of the geometry factor, $G(r, \theta)$ times r^2, for a seed approximated by 3.0 mm line source as calculated with Eq. (7).

θ (deg)	r=0.5 cm	r=1.0 cm	r=2.0 cm	r=5.0 cm
0	1.099	1.023	1.006	1.001
10	1.094	1.022	1.006	1.001
20	1.081	1.019	1.005	1.001
30	1.062	1.015	1.004	1.001
40	1.039	1.010	1.002	1.001
50	1.018	1.005	1.001	1.000
60	0.9160	0.9999	1.000	1.000
90	0.9715	0.9926	0.9980	1.000

g(r): Radial dose function

$$g_X(r) = \frac{\dot{D}(r,\theta_0)\, G_X(r_0,\theta_0)}{\dot{D}(r_0,\theta_0)\, G_X(r,\theta_0)}$$



- Accounts for dose fall-off on the transverse-plane i.e.,$\theta = \theta_0 = \pi/2$ due to photon scattering and attenuation, i.e., excluding fall-off included by the geometry function.
- Equals to 1 when $r = r_0 = 1$ cm, and dimensionless
- The subscript 'X" indicates whether a point-source, "P," or line-source, "L,"

g(r): Radial dose function

Part 2 Question:
Which one has a larger value for the radial function beyond 1cm, ^{125}I or ^{103}Pd?

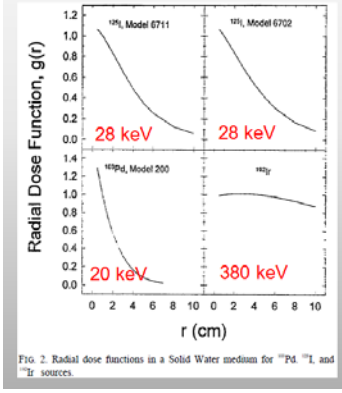


FIG. 2. Radial dose functions in a Solid Water medium for ^{103}Pd, ^{125}I, and ^{192}Ir sources.

Tissue attenuation (PE) is highly significant rather than Compton scattering for low photon energies of the order of 30 keV and below Therefore, the radial fall-off for ^{103}Pd (20 keV) is faster than ^{125}I (28keV) due to loss of scattering photon compensation.

F(r,θ): 2D Anisotropy function

- This 2D function gives the angular variation of dose rate about the source at each distance due to self filtration, oblique filtration of primary photons through the encapsulating material, and scattering of photons in the medium.

$$F(r,\theta) = \frac{\dot{D}(r,\theta)\, G_L(r,\theta_0)}{\dot{D}(r,\theta_0)\, G_L(r,\theta)}$$

- G-terms suppress the inverse-square dose variation (also due to large dose fall-off close to the source, suppressing the InvSq law to increase the accuracy of data interpolation/extrapolation to small distances < 1 cm relative to the source)
- Normalized at $\theta=\pi/2$ (transverse axis), and equals to 1 at (r, θ_0)
- Because Monte Carlo based datasets generally have superior smoothness, spatial and angular resolution, and distance range, all anisotropy functions recommended in TG43U1 are derived from MC results which have been validated by comparison to less complete experimental datasets.

F(r,θ): 2D Anisotropy function

- The anisotropy function will **decrease** when
  1. Encapsulation thickness increase (less photon penetration)
  2. Photon energy decrease (less photon penetration).
  3. Distance decrease (less scattered photon contribution to the point)
  4. Angle decrease (differential radiation path-length through capsule)

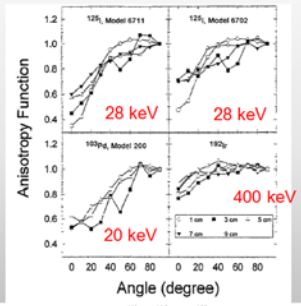
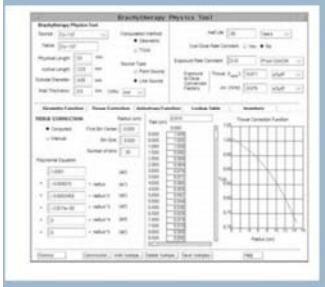


FIG. 4. Anisotropy function for ^{103}Pd, ^{125}I, and ^{192}Ir sources as a function of angle for radial distances ranging from 1–9 cm at 2-cm intervals. Angle refers to the angle between the source axis and the radial vector from source center to the point of interest.

"Clinical Dosimetry Measurements in Radiotherapy", AAPM summer school 2009, Ch13

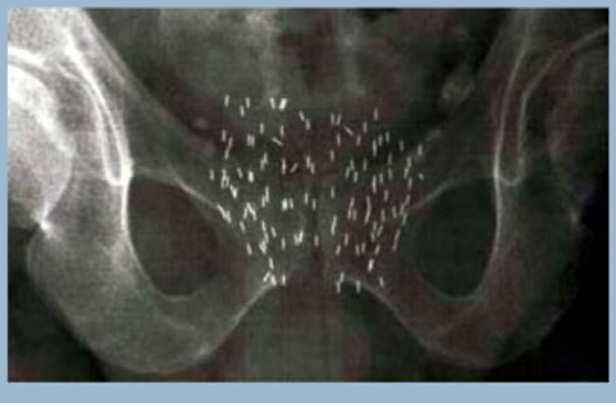
What do you do with these parameters and functions?



- Knowing TG-43 parameters and functions allows you to calculate dose rate anywhere around a seed, given its AKS.
- So these are all a brachytherapy TPS needs to calculate dose in a brachytherapy plan.
- A good part of commissioning a brachy TPS therefore involves putting these parameters and functions into the TPS.

(Nomogram)

Your radiation oncologist told you that he will do a prostate implant next week on a patient with 50 cc prostate gland. How many seeds should you order? Your TPS is down, by the way.



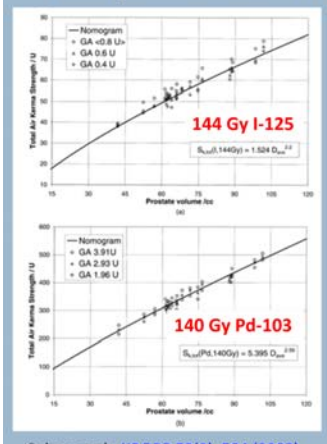
What is a nomogram?

- In permanent prostate implant, a nomogram is a graph or table that shows the relationship between the dimension of the target and the total source strength (or activity) required to deliver a given dose to it.
- Nomograms used to be utilized to guide real-time prostate implant using an alternating pattern (nomogram-guided implant, no other planning was used, no computer needed!)
- Nomogram has dependence on the loading pattern (peripheral or uniform) and properties of the seeds used

Why do we need nomogram?

- For intra-operative (real-time) treatment planning, nomogram is useful for estimating the number of seeds that need to be ordered
- Nomogram is useful as an independent check of the computer generated plans
- Nomogram provides a simple and dependable backup planning method in case the intra-op planning system fails

Example: Memorial Nomogram (from MSKCC)



Cohen et al., IJROBP 53(2), 504 (2002).

- ^{125}I with Rx dose = 144 Gy
- $S_k/U = 1.5\ (d_{ave}/cm)^{2.2}$
- ^{103}Pd with Rx dose = 140 Gy
- $S_k/U = 5.4\ (d_{ave}/cm)^{2.56}$
- For other Rx doses, scale the total strength accordingly

So how many seeds do you need for a 50 cc prostate?

- From the nomogram, if we use ^{125}I with Rx dose of 145 Gy (typical monotherapy implant dose), we need a total strength of about 44U.
- If we use typical 0.5U seeds, we will need 88 seeds.
- If we use ^{103}Pd with Rx dose of 125 Gy, then we need a total strength of about 230U.
- If we use seeds with 2U strength, we will need 115 seeds.
- If ordering for intra-op implant, order some extras! (prepare for needle-induced edema, prostate volume was measured incorrectly on ultrasound, etc.)

6

If you use 3U seeds instead of 2U, is the total required strength going to be the same?

- In the range of strength for clinical seeds, there is about 10% variation in total strength depending on the strength of the seeds used (see the nomograph shown earlier)
- Higher-activity seeds requires higher total strength
- This is because higher-activity seeds will generate more inhomogeneity in the dose distribution (and therefore more wasted dose) in the form of hot spots around the seeds and cold spots in the inter-seed space
- The most efficient distribution (theoretically) is created by continuous distribution of activity (lots of low-activity seeds), this will create a smooth distribution. Lumpier seeds means more wasted dose.