# 臨床常用劑量計介紹

**嘉義基督教醫院**
**放射腫瘤科**
**傅筱如**

時間 ： 97年11月11日

講師 ： 傅筱如

課程名稱 ：臨床常用劑量計介紹

教學內容計畫 ：

主要對於臨床常用劑量計作一個簡單的介紹，包含基本的原理及應用。

教學目的 ：

瞭解目前放射治療所使用的劑量測量系統與測量原理，並熟悉臨床上常用之劑量修正因子。

## The methods of measuring absorbed dose

- Calorimeter
- Fricke ferrous Sulfate dosimeter
- Ionization chamber

External beams:

- cylindrical: photons, high-energy electrons (>10 MeV)
- parallel plate (plane parallel): low energy electrons (<10 MeV)

Brachy source:

- well-type chamber

- Film, radiochromic film, digital radiography.
- Thermo luminescent dosimeters, TLDs
- Diodes

## Calorimeter

- Calorimetry is based on the principle that the energy absorbed in a medium from radiation eventually appears as heat energy, resulting in a small rise in temperature, which can be measured with a thermistor.
- The temperature increase in water produced by 1Gy is $2.39\times10^{-4}$℃.

$$D = \frac{dE_h}{dm} + \frac{dE_s}{dm}$$ ← Heat defect

- $1\ cGy = 10^{-2}\ Gy = 10^{-2}\ J/kg = 10^{-2} \times \underline{1/4.18}\ cal\ kg^{-1}$
  $= 0.00239\ cal\ kg^{-1}$

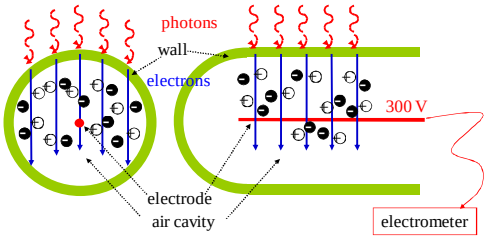
- $S_{water} = 1\ cal/g\ ^oC\ (=10^3\ cal/kg\ ^oC)$
  $\Delta T = 0.00239 cal\ kg^{-1} / 10^3\ cal\ kg^{-1}\ ^oC^1$
  $= 2.39\times10^{-6}\ ^oC$

## Fricke ferrous Sulfate dosimeter

- Chemical dosimetry is based on the principle that energy absorbed from radiation may cause chemical change. Most developed system is the *ferrous sulfate* (Fricke dosimetry). The absorbed dose *D*, can be determined by the measured chemical change $\Delta M$, and the *G-value* (# of molecules produced per 100 eV of absorbed dose) of the chemical.
- $FeSO_4$ (UV with the wavelength of 224 nm and 304 nm)
  $Fe^{3+}$ (0xidation reaction)

## Ionization Chamber ¡ External Beams

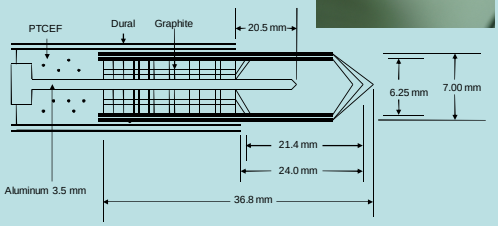
An ion chamber is a volume of air (cavity), usually surrounded by a layer of material (chamber wall) just thick enough to provide electron equilibrium. The electrons generated in the wall enter the cavity, causing ionization. The ions produced in the air cavity are collected and read out through an electrometer.



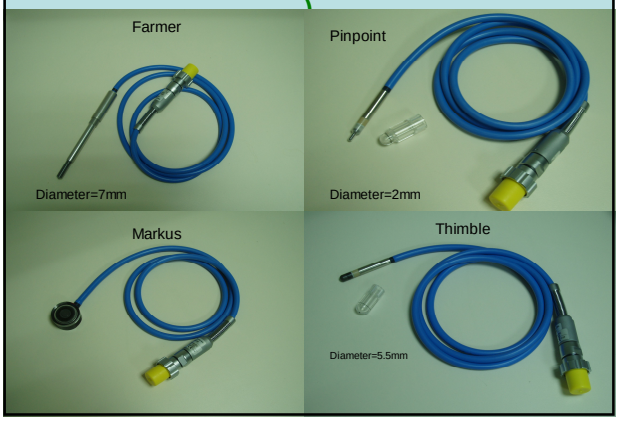

## Configuration of Farmer chamber

¡ Cylindrical chamber

¡ Collecting volume=0.6 c.c

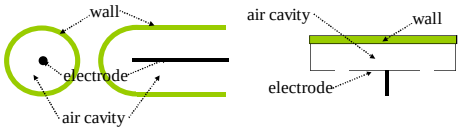



## Ion chamber(电离腔)

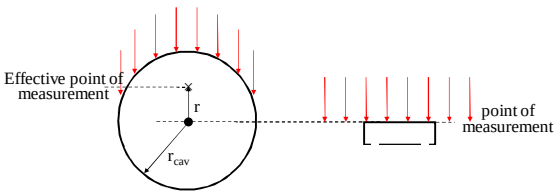



## Ionization Chamber ¡ External Beams

An ion chamber may be sealed (used in machines as monitor chamber) or unsealed (used for routine calibrations).
There are 2 major designs of unsealed ion chambers, cylindrical and parallel-plate.




## Point of Measurement and Effective Point of Measurement




cylindrical parallel plate

Photon: r = 0.6 $r_{cav}$
electron: r = 0.5 $r_{cav}$
Theory: r = 0.85 $r_{cav}$

## Electrometer

The electrometer is connected to the chamber during the entire time of exposure and readout.

It can be used to measure the charge (integration mode, *nC*), current (rate mode, *nA*), or direct exposure-reading (direct reading dosimeter mode).

## Corrections to Chamber Reading

Reading for an unsealed chamber generally needs to be corrected for temperature, pressure, polarity effect, and ion-recombination (collection efficiency).

$$M_{corrected} = \left(\frac{T(^{\circ}C)+273}{295}\right)\left(\frac{760}{P}\right)\left(\frac{M^{+}+M^{-}}{2}\right)P_{ion}$$

## Farmer chamber

¡ The calibration factor of Farmer chamber was provided for standard environmental of temperature $T_0$= 22℃ and pressure $P_0$= 760 mm Hg or 101.33 kPa (1 atmosphere).

$$C_{T,P} = \left(\frac{1013}{P}\right)\times\left(\frac{273.2+T}{273.2+22}\right)$$

## Chamber Polarity Effects

The charge collected by an ion chamber changes in magnitude when the polarity of the collecting voltage is reversed.

This effect can be minimized by taking the average of the 2 readings with reversed polarity.

$$\left(\frac{M^{+}+M^{-}}{2}\right)$$

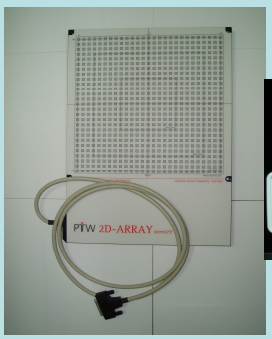
The polarity effect is more severe for electron beams than for photon beams.

## Farmer chamber

¡ PDD,TPR,TMR,FSF¡.

¡ 2D array- symmetry and flatness

## 2D array




Detector


Electrometer

## 袖珍劑量筆(pocket dosimeter)

- £小型游離腔
- £ 使用前先歸零
- £ 適用能量：30 keV～1.25 MeV
- £ 量中子：B-10、H-1
- £ 避免撞擊、受潮、激烈振動
- £ 方向依持較大
- £ 中子能量依持較大
- £ 適合作輔助性劑量計
- £ 顯示深部等效劑量

圖 2 袖珍劑量筆

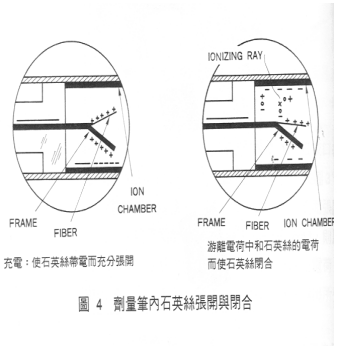



圖 4 劑量筆內石英絲張開與閉合

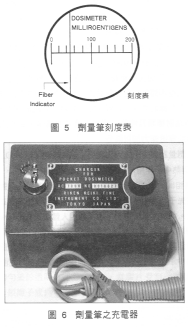



圖 5 劑量筆刻度表

圖 6 劑量筆之充電器

## Film

When the film is exposed to ionizing radiation, chemical change takes place in the crystals to form the *latent image*. When the film is developed, the affected crystals reduced to small grains of metallic silver, and the film is *fixed*. The unaffected granules are removed by the fixing solution. The metallic silver remains on the film, causing darkness. The degree of blackening depends on the dose.

¡ $Ag^+ (AgBr) + e^- \Rightarrow Ag$

¡ Radiation dose α the degree of blacking

$$D = \log_{10}\left(\frac{B_0}{B}\right)$$

## Film Emulsions ¡ latent image

Several light photons must be absorbed to sensitize each grain.

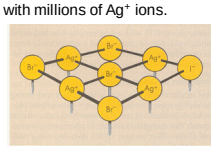
A grain may be sensitized by a single x-ray photon.

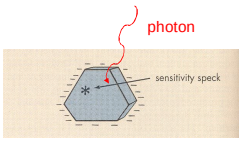
Absorbed photons liberate electrons in the grain, which combine with positively charged silver ion ($Ag^+$), forming a latent image of silver

$Br^- + photon \rightarrow Br + e^-$

$e^- + Ag^+ \rightarrow Ag$

After exposure, grains have a few neutral silver atoms in the speck along with millions of $Ag^+$ ions.






## Film development ¡

converts invisible latent image to permanent visible image

¡ Film speed, contrast, and base and fog levels are affected by developer chemistry and temperature.

¡ Increasing the developer temperature or time increases the film contrast, density, and fog.

¡ The development process is one of the most important aspects in producing good quality images.

## Film Processors

Development: converts latent image (invisible) to a manifest image (visible)

Fixing: makes the image stable, prevents further development and effects of light.

Washing: removes all chemicals and followed by drying.

The total processing time is ~90 seconds.

Developer temperature 31° to 35°C.

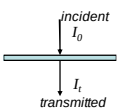
Film processor quality control is essential in maintaining film image quality.

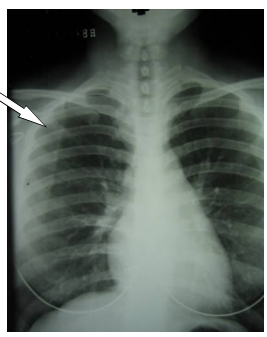

## Film Density

Film blackening is directly related to the # of photons reaching the film, and is measured using optical density (OD):

$$OD = \log_{10}\left(\frac{I_0}{I_t}\right)$$

$$\text{transmittance} = \frac{I_t}{I_0}$$



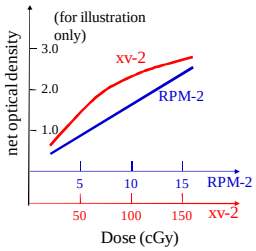
Useful range of OD is from 0.3 to 2, corresponding to transmittance of 50% to 1%.

The OD of superimposed films is additive.
Ex: If $OD_1$=$OD_2$=1 (10% transmittance),
then $OD_{(1+2)}$= $OD_1$+$OD_2$=2 (1% transmittance).

## Radiographic Film

In dosimetry, the background fog (OD of unexposed processed film) should be subtracted to obtain the *net optical density*, whose relationship with dose is called H-D curve, or sensitometric curve.

Each box of films may have different characteristics, prior to use, H-D curve should be obtained for samples from the box.




## Radiographic Film

¡ Advantages:

High spatial resolution ( < 1 mm)

Ideal for 1D or 2D relative dose distribution measurement. (beam profiles, isodose distributions), accurate to within ~ ± 3%.

Inexpensive for personnel dosimetry (film badge, accurate to within ±10%)

¡ Disadvantages:

Requires careful calibration prior to use.

Over responds to low energy photons (due to increased photo-electric events in silver bromide), not suitable for absolute dose measurement.

## Radiochromic film

¡ large dynamic range ($10^{-2}$-$10^{6}$ Gy): suitable for brachy source dose distribution measurement.

¡ no dark room processing required: the radiochromic film is insensitive to visible light, the emulsion changes color when exposed to radiation without any processing.

¡ tissue equivalent ($z_{eff}$ 6.0 to 6.5)

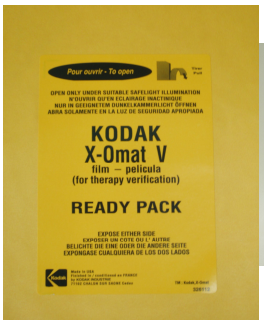
¡ less energy dependency compared to conventional film

¡ film response dependent on room temperature. Acceptable range of room temperatures 20-30¢ªC.

¡ sensitive to ultraviolet light (do not expose to fluorescent light)

¡ more expensive, requires special densitometer (laser scanner at specific wavelength 610-670 nm)

## Films for QA



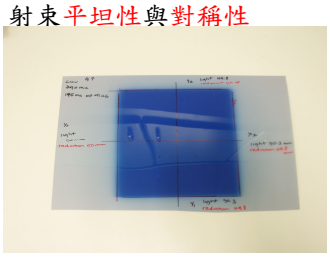


## Monthly QA

¡ 光照野與輻射照野一致性

¡ 容許值¡2mm或¡1%照野

¡ 射束平坦性與對稱性



## H-D curve

¡ Toe: underexposure

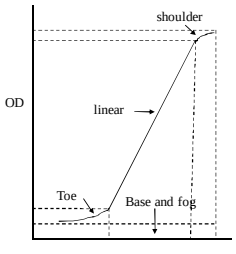
¡ Linear :useful area

¡ Shoulder: overexposure

¡ Calibration curve

X= net optical density

Y= absorbed dose (cGy)

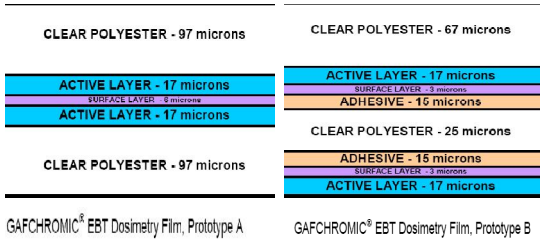


# Gafchromic film$^{R}$ EBT

Self-developing film for radiotherapy dosimetry
ISP (International Specialty Products)

- Dose range 1 cGy- 800 cGy
- Energy independence from KeV into MeV range(<5%)
- Uniformity better than 1.5%
- Large 8¡×10¡ size
- Faster and lower post-exposure density growth
- Will withstand temperature up to 70° C

# Configuration and structure

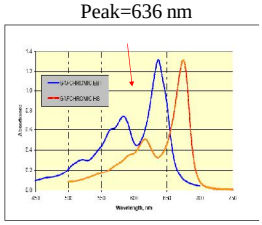



***Polyester特點是薄而耐用；有較大的介質強度；又能抗受較高的溫度；也有化學物、溶劑及水份抵禦力**

# Measurement

- Densitometers, film scanners or spectrophotometers
- When the active layer exposure to radiation ,it reach blue colored polymer with absorption maxima at about 636 to 585 nm.
- The response will be enhanced by measurement with red

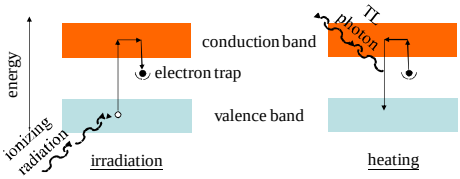
Peak=636 nm



*HeNe laser scanner (Lumisys) provide the highest response with EBT because the laser has a wavelength of about 633 nm

# Solid State Methods (TLD)

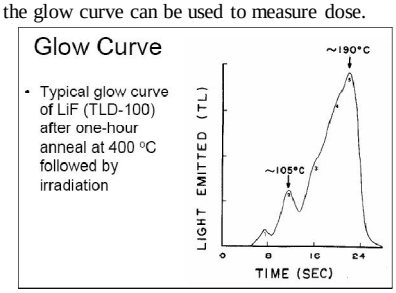
When certain crystal is irradiated, a small fraction of the absorbed energy is stored in the crystal. Some of this energy can be recovered later as visible light when the crystal is heated. This phenomenon is called thermoluminescence (TL).




The emitted light is amplified by the *photomultiplier tube.*

# Solid State Methods (TLD)

When a previously exposed sample of TLD is heated, the light output as a function of time is called a ¡glow curve¡. The area under the glow curve can be used to measure dose.



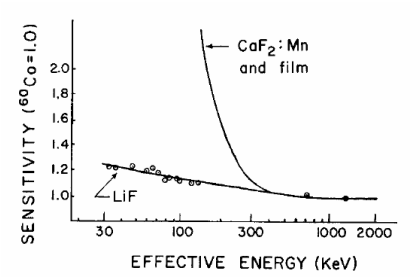

# Solid State Methods (TLD)

The most commonly used TLD material is lithium fluoride (LiF). Prior to use, the LiF is annealed for 1 hour at 400¢C, followed by 24 hours at 80¢C (pre-irradiation annealing).

In radiation therapy, TLD is primarily used for *in vivo* measurement (if placed on skin, proper build-up is needed, e.g. bolus). TLD is available in different forms (powder, chips, rods) and sizes.

For megavoltage dosimetry, TLD can provide accuracy of ¡ 3%.

## TLD Energy Response




## Solid State Methods (Silicon Diodes)

Diode is a solid state semi-conductor device which generates a current when exposed to radiation.

Small size, instantaneous response, ruggedness, and high sensitivity, but is energy, directional, and temperature dependent, also suffers from radiation damage.

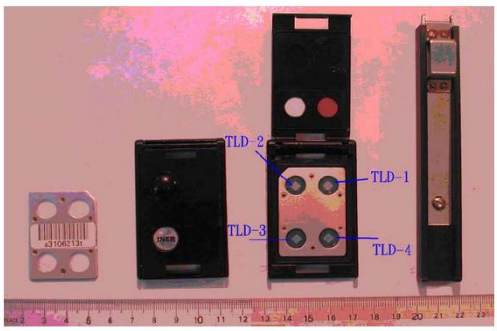
Primarily used for relative dose measurement (dose distribution)

It can also be used for in-vivo dosimetry (does not require 300 V high voltage).

Absolute dose measurement (machine output calibration) is done with a chamber.

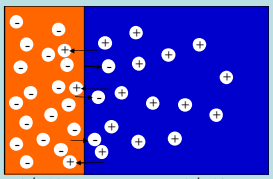

圖 3.2 Harshaw 3500 型熱發光劑量計讀儀

## 熱發光劑量計




## Silicon Diodes (theory)

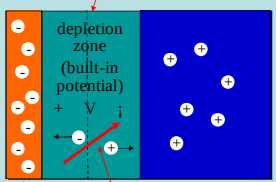
A silicon doped with impurities to make p-type (electron receptor) and n-type (electron donor).



n-type (donor) e.g. $_{15}$P — Silicon diode $_{14}$Si — p-type (receptor) e.g. $_{5}$B

Carriers near the interface diffuse across the boundary and recombine with the opposite carrier, forming a depletion zone

At equilibrium, a built-in potential is established in the depletion zone.




n-type (donor) — Silicon diode — p-type (receptor)

The ion pairs produced along the electron track are attracted towards to +/- sides of the depletion zone, generating a current that can be measured.

## Silicon Diodes

¡ no bias voltage applied.

¡ diodes are more sensitive than ion chambers ¡

¡ $(W/e)_{Si}$ ~ 3.5 eV [In contrast, $(W/e)_{air}$ ~ 34 eV ]

¡ $\rho_{Si}$ ~ 1800 $\rho_{air}$

¡ energy dependency for photons (due to $Z$=14 for $Si$), but not for electrons (therefore can be used for electron relative depth-dose measurement).

¡ angular dependency.

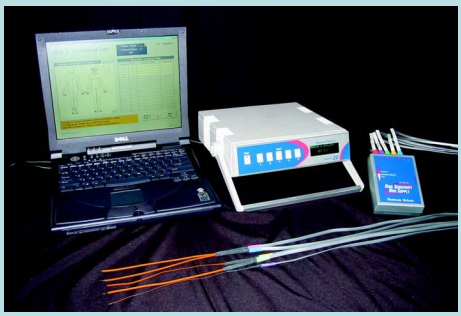
¡ temperature dependency, but independent of pressure.

¡ radiation damage ¡ needs periodic calibration.

¡ used for patient dose monitoring and when small detector size is needed.

## MOSFET
## (Metal Oxide-silicon Semiconductor Field Effect Transistor)

- TLDs and diodes are most used for TBI,
  but TLDs do not allow an immediate response and their use is time consuming；diodes necessitates the use of cable to measure the signal.
- Advantages of MOSFET:
  small size, portability,
  permanent storage of dose, instant readout,
  dose rate independence,
  requirement of low power,
  immediate reuse, ability to conduct multiple point dose measurement negligible attenuation of the radiation.



## The configuration of standard MOSFET (P-type)
## (Metal Oxide-silicon Semiconductor Field Effect Transistor)

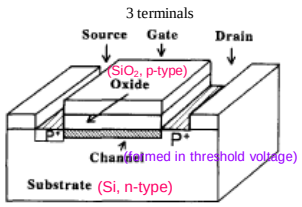



FIG. 1. Schematic cross section of a *P* channel MOSFET showing the oxide, $SiO_2$, the substrate, Si, the source, the gate, and the drain.

## The voltage shift of MOSFET

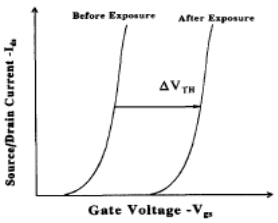
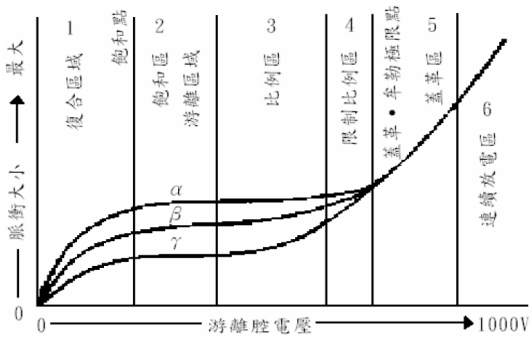



FIG. 2. Typical MOSFET source to drain current, $I_{ds}$, vs gate voltage $V_{gs}$. The difference in the gate voltages, $V_{gs}$, needed to attain a predetermined current flow $I_{ds}$, before and after radiation, is equal to the threshold voltage shift ($\Delta V_{TH}$).




游離腔偵檢器之電壓與游離電流的關係

## 光激發光玻璃劑量計
## （radiophotoluminescent glass dosimeter, RPLGD)

- 玻璃劑量計是利用銀離子活化的磷酸玻璃$AgPO_4$（silver-activated phosphate）在受到輻射曝露後，會於玻璃中形成穩定的發光中心，當以波長爲337.1 nm之紫外雷射光照射此玻璃時，穩定的發光中心便會放出波長爲600~700 nm之可見光，此過程即爲光激發光現象（radiophotoluminescent）。

## 光激發光玻璃劑量計

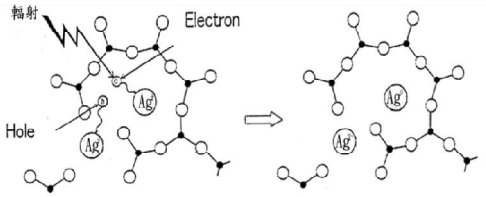



圖 1 玻璃劑量計與游離輻射作用後產生發光中心之機制

## 光激發光玻璃劑量計

- 銀離子活化的磷酸（$AgPO_4$）玻璃內含$Ag^+$及$PO_4^-$離子，當$PO_4^-$離子受到輻射照射後，$PO_4^-$會失去一個電子，形成一正電子空洞陷阱（positive trap holes, $hPO_4$），此時$PO_4^-$所失去的電子（$e^-$）與$Ag^+$結合，使$Ag^+$變成$Ag^0$；同理，由$PO_4^-$失去一個電子所形成的$hPO_4$ 與$Ag^+$結合後，$Ag^+$會增加一個電洞而成爲$Ag^{2+}$ 。$Ag^0$與$Ag^{2+}$形成穩定的發光中心。$Ag^0$爲電子陷阱（electron trap），$Ag^{2+}$則爲電洞陷阱（hole trap）。

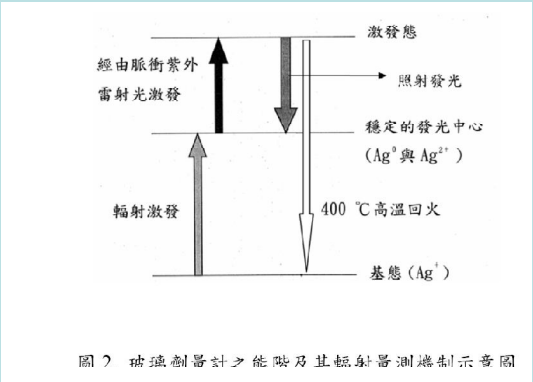



圖 2 玻璃劑量計之能階及其輻射量測機制示意圖

## 玻璃劑量計

- 銀離子活化磷酸玻璃中處於基態（ground state）的$Ag^+$，經由輻射照射後，分別與$PO_4^-$失去的電子（$e^-$）及所形成$hPO_4$ 結合成爲$Ag^0$ 及$Ag^{2+}$（發光中心）；當計讀玻璃劑量計時，此發光中心受到337.1 nm脈衝紫外雷射光共振激發後，$Ag^0$計讀和$Ag^{2+}$的電子會被激發至激發態（excited state），隨後放出600~700 nm的可見光，回到穩定的發光中心，因$Ag^0$和$Ag^{2+}$由脈衝紫外雷射光所獲得的能量不足以逃離發光中心，所以不會直接回到$Ag^+$的基態。若要使$Ag^0$及$Ag^{2+}$回到基態的$Ag^+$，則須經400℃高溫回火一小時，才能獲得足夠的能量，以回到

## 玻璃劑量計

熱發光劑量計經加熱計讀後，被電子陷阱捕獲的電子，便會回到基態，熱發光中心便消失，因此熱發光劑量計，在單次輻射照射時並不具重複計讀能力。

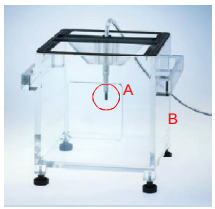
## Main Advantages and Disadvantages of Four Commonly Used Dosimetric Systems

| Dosimeter | Advantages | Disadvantages |
|---|---|---|
| *Ionisation chamber* | Accurate and precise<br>Recommended for beam calibration<br>Necessary corrections well understood<br>Instant readout | Connecting cables required<br>High voltage supply required<br>Many corrections required for high energy dosimetry |
| **Film** | 2D spatial resolution<br>Very thin - does not perturb the beam | Dark room, processing facilities required<br>Processing difficult to control<br>Variation between films and batches<br>Needs proper calibration against ion chamber measurements<br>Energy dependence problems<br>Cannot be used for beam calibration |

## Main Advantages and Disadvantages of Four Commonly Used Dosimetric Systems

| Dosimeter | Advantages | Disadvantages |
|---|---|---|
| *TLD* | Small in size - point dose measurements possible<br>Many TLDs can be exposed in single exposure<br>Available in various forms<br>Some are reasonably tissue equivalent<br>Not expensive | Signal erased during readout<br>Easy to lose reading<br>No instant readout<br>Accurate results require care<br>Readout and calibration time consuming<br>Not recommended for beam calibration |
| **Diode** | Small size<br>High sensitivity<br>Instant readout<br>No external bias voltage<br>Simple instrumentation | Requires connecting cables<br>Variability of calibration with temperature<br>Change in sensitivity with accumulated dose<br>Special care needed to ensure constancy of response<br>Cannot be used for beam calibration |

## Water Phantom




Dose measurement in a water phantom:

A. Moving probe (central axis depth dose, beam profile)
B. Fixed reference probe (position fixed, located in field)
C. Relative dose = A/B

TABLE X. Physical properties of water, acrylic, and polystyrene plastics, and muscle.

| | Water | Acrylic | Polystyrene | ICRU muscle |
|---|---|---|---|---|
| Composition | $H_2O$ | $C_5H_8O_2$ | $C_8H_8$ | |
| Density (g/cm$^3$) | 1.00 | 1.17[a] | 1.04[a] | 1.00 |
| Average atomic number $\bar{Z}$[b] | 7.22 | 6.24 | 5.62 | 7.10 |
| $\bar{Z}$ relative to water | 1.000 | 0.86 | 0.78 | 0.98 |
| Electron density (e$^-$/g) | $3.346\times10^{23}$ | $3.253\times10^{23}$ | $3.243\times10^{23}$ | $3.32\times10^{23}$ |
| Electron concentration (e$^-$/cm$^3$) | $3.346\times10^{23}$ | $3.806\times10^{23}$ | $3.373\times10^{23}$ | $3.32\times10^{23}$ |
| Electron concentration relative to water | 1.000 | 1.137[a] | 1.008[a] | 0.992 |

[a] Nominal values; the mass density of each dosimetry phantom should be individually determined.
[b] The average atomic number $\bar{Z}$ is calculated by weighting the component atomic numbers by parts by weight.

Thanks for your attention!!
Any problems ?