	Ion-chamber	TLD	Semiconductor (TG-62)	Radiograph film (TG-69)	Radio-chromic film (TG-55)	Gel Dosimetric
Basic theory	Cavity theorem: $D_{med} = D_{air}\left(\frac{L}{\rho}\right)_{air}^{med} P_{wall}P_{fl}P_{gr}P_{cel}K_h$	Two energy bands: valance & conductive bands Impurities: traps and recombination centers	Crystal mixed or doped with impurities Boron -> p-type (holes) Phosphor-> n-type (e-) Depletion zone (equilibrium and intrinsic E field)	film base coated with emulsion (crystals of silver bromide) Radiation -> chemical change-> latent image	a single or double layer of radiation sensitive organic microcrystal monomers on a thin polyester base	Rad. produce chemical changes: Fricke (ferrous -> Ferric ions), then measured by spectrophotometry or MRI
Energy dependency	Z_{eff} – water = 7.42 Z_{eff} - air = 7. 67 $(L/\rho)^w_{air}$ small from 100keV to 1MeV (±4% from 200keV to Co-60); $(L/\rho)^w_{air}$ ~~becomes large~~ reduce significantly after 1MeV -- K_Q up to 6% (typical 6MV (66.5%)- 0.992; 15MV (77.3%) – 0.972 The window or wall is very important for energy response	Z_{eff} – LiF = 8.2 (ρ=2.6g/cc) Z_{eff} – LiB = 7.4 Z_{eff} – CaSO4=16.3 Over-response (20-30%) for low E compared with Co-60; under response 5% for linac energy range compared with Co-60	Z-Si = 14 (ρ=2.3g/cc) High Z build-up used cause large E depend (limit to relative measurement in photon beam) $(L/\rho)^w_{si}$ changes in MeV range, but smaller than Water to gas (good for e- beam because $(L/\rho)^w_{si}$ not change with E and depth) Buildup thickness ↑, E depend ↑; E ↑=> E depend ↑	Z-silver = 45 Low kV -> photoelectric -> scattering Strong E depend for photon beams, but their response is relative small in MV e- beams	Garfchromic Z=6.0-6.5 Nearly tissue equivalent (little stopping power ratio change) XR radiochromic film loaded with high Z (strong E depend)	Nearly tissue equivalent
Sensitivity	33eV per ion pairs; 0.6cc -> 20nC/Gy p.p.1 0.05cc -> 2nC/Gy ↑ ×10 well -> 8.7nA/Ci	Sensitivity and supralinearity affected by impurities (parts per millions ppm) Energy band gap = 10eV	1.1-3.5eV per ion pairs Current per volume is 18,000 times higher than ion-chamber Intrinsic bias = 1V, the depletion layer = 10μm => electric field of 1000V/cm	Slope = $(D_2-D_1)/\log(E_2/E_1)$ Speed = 1/(R for OD=1)	Intrinsic 1eV to polymerize the diacetylene molecules	G value (# of molecules per 100eV) : 15.7/100eV
Linearity	Very good linearity	Linear up to 10Gy; supralinear 10Gy-1kGy Damage after 1kGy		Latitude (contrast) – range of Log exp in linear region	Large dynamic range: EBT: 0.01-100Gy Also depend on scanner	Max to 400Gy
Dose rate dependency	Pion basically is dose rate dependent (ion recombination) To achieve 99% collection: DR < 0.1cGy per pulse		Strong DR (dose per pulse) depend: p-type is less dependent on DR. (if DR changed by # of pulses,	Relatively independent	No significant DR depend	No obvious DR effect

	(0.04MU per pulse for Varian @500MU/min)		not change in diode response.			
Dose and Time dependency	N/A	Fading effect (a few % per yr) Per Attix: <5% in 12 wks; some have larger fading 10% in first months) Depends on the unstable traps which fade-off quickly at normal temperature.	Strong dose dependency (pre-irradiated to a few kGy). Radiation damage -> Recalibration	Fog (unirradiated background)	Read at least 24hrs after exp. Signal ↑ slowly with time	Post-irradiation diffusion of ions -> blurred dose distribution
Environment: T, P Background	Need T, P correct Leakage < 10fA		T ↑, more charges collected (0.3% per degree)	Processing Temp/Time affect OD; Fog effect	At Temp>70, dye de-activated Avoid UV light	
Directional	Not significant for MeV beams		About 4% change. Cylindrical less directional depend, but large E depend due to complex structure.	Perpendicular/ parallel has different OD (pall > pend)		
Spatial resolution	Relative large size	High spatial resolu. 1mm TLD power	High spatial resolu. Depletion layer 5-10 μm Diffusion layer 50-100μm	2D superior spatial resolu. Large area	2D superior spatial resolu. Large area	Unique 3D ; Anatomic shape; Integration measurement
Read-out	Quick readout	Be consistent in readout: Heating temp and rate and cooling rate are important Susceptible to surface contamination (Nitrogen hot gas) Structure damage PMT sensitivity and dark current	Quick response time (μsec compared with msec of ion chamber) In TG106: the detector response is typically μsec whereas electrometers are msec.	Densitometer/Scanner artifacts	Reader system is very important; Calibration, linearity is instrument dependent!	
Others:	Stem effect: E and field size and guard dependent; For well guarded <0.1%; for guarded <0.3%, for unguarded 0.6% Guard ring: define volume	Li2B4O2:Mn the best water equiv., min E depend, but supra-linearity starting at 1Gy	e- diode should only be used for e- beam and photon diode should only used for photon beam measurement	Sensitive to air-gas and alignment with phantom. Variation in batches	Turn blue after exp. No processing is needed. Also sensitive to air gap (e- stream	

	(uniform E field; min fluence perturbation); reduce leakage				loss)	
Accuracy/ reproduce		2% for EBRT, 3% for brachy; 10% in health physics	For invivo dosimetry, calibration plus correction factors	3% for measurement isodose curves; Only for relative measurement	Possible to achieve 3% precision	Relative 2-3% Absolute: 3-5%
Advantages:	Absolute dose measurement and primary standard Perform as Brag-Gray cavity in MV photon and e- beams Precious and small uncertainty	Relatively small energy dependency Small size Wide linear range Reusable	High sensitivity; Quick response readout No external bias needed Good mechanical stability Small size/ reusable Small energy dependency of stopping power ratio -> Good for e- beam , but not the absorption coefficient ratio (f-factor)			
Disadvantage		Instability in sensitivity => need to be consistent Susceptible to surface contamination Structure damage affect readout Slow readout	Dependency on temperature, dose rate, dose Energy dependency, especially for low E photon (kV photons) Radiation damage			

Other radiation measurement detectors:

Calorimetry: 1Gy->2.4x10^{-4} degree Temp increase (graphite is an ideal material); the most fundamental method of realizing primary standard for absorbed dose
Alanine: (chemical based) Tissue equivalent; typically used for high dose (10Gy or more) dosimetry; very little fading for months; the response depends on environmental conditions during irradiation (temp) and storage (humidity) potential use for dose comparison between hospital
Plastic scintillate system: Radiation include light in scintillator and is carried away by optical fiber to a PMT located outside of irradiation room Linear response in the therapeutic dose range Almost tissue water equivalent in term of electron density and atomic composition Can be very small (1mm) with adequate sensitivity

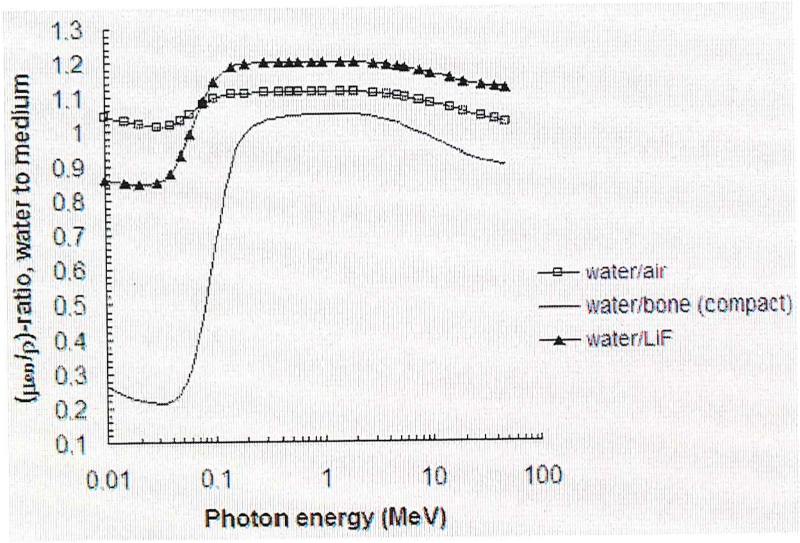
Good reproducibility; no dose damage ; independent of DR up to 10Gy/min. No significant direction dependency; No P/T correction
Diamond dosimeter: Essentially a solid state semiconductor detector Diamond change resistance upon radiation exposure. When applied a bias voltage, the resulting current is proportional to dose Good for measure relative dose distribution in high E photon an e- beams Small sensitive volume (a few mm3) ; good for small field dosimetry and profile measurment Almost tissue-equivalent Little directional effect Has to be irradiated prior to remove polarization effects No radiation damage, little Temp effect Small dependency on dose rate Difficult to manufacture and Expensive
Metal-oxide-silicon-semiconductor field effect transistor (MOSFET): Similar to conventional dosimeters in reproducibility, linearity, energy and angular response Short life span (total dose) compared with diode Not suitable for commission, but good for point dose verification

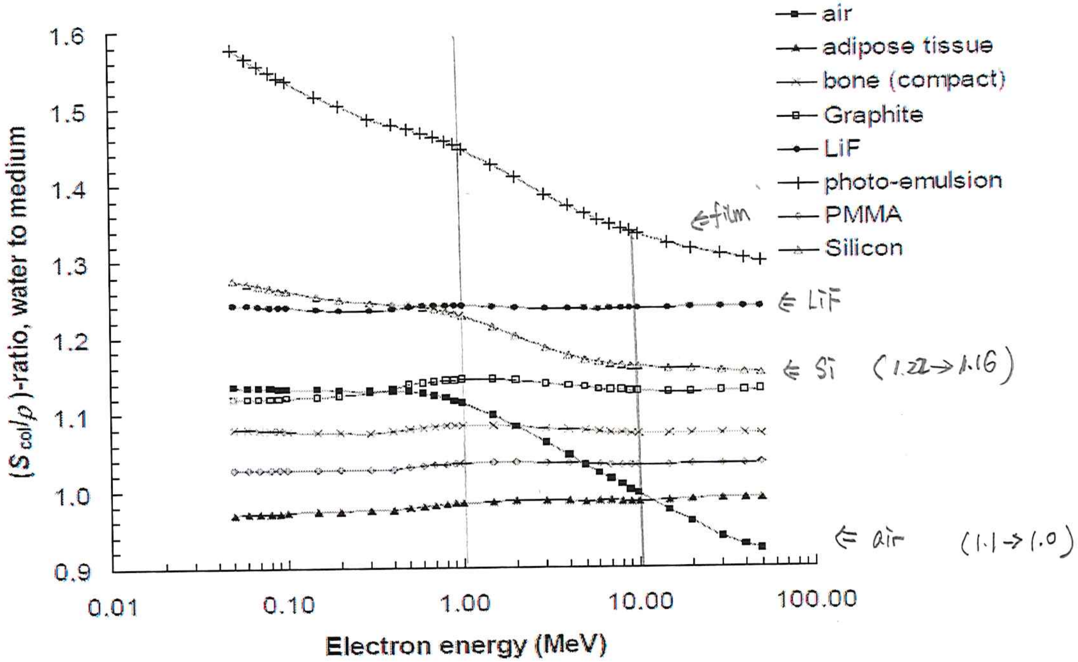
1) Overall (Burlin general cavity theorem)

$$\frac{\overline{D_{\text{det}}}}{D_{\text{med}}} = d\left(\frac{\overline{L_\Delta}}{\rho}\right)_{\text{med}}^{\text{det}} + (1-d)\left(\frac{\overline{\mu_{en}}}{\rho}\right)_{\text{med}}^{\text{det}}$$

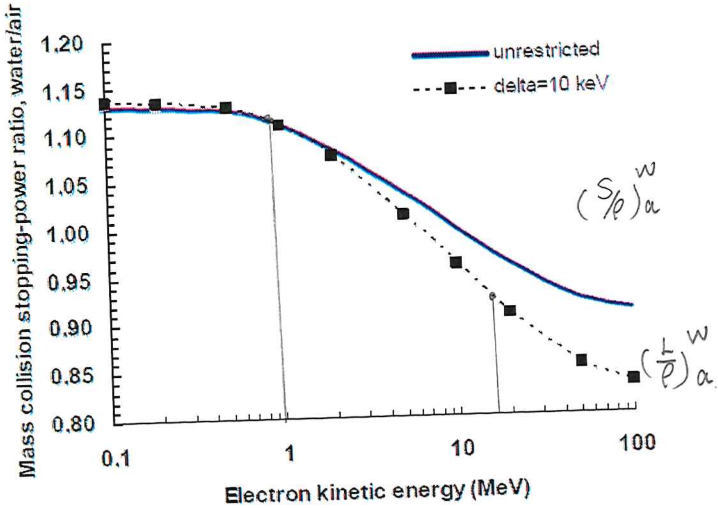
where d is the fraction of the dose in the cavity due to electrons from the medium (Bragg-Gray part),

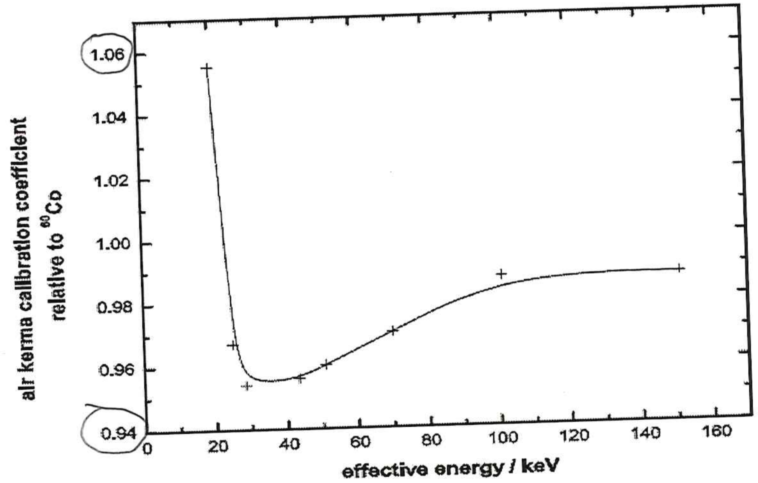
and $(1 - d)$ is the fraction of the dose from photon interactions in the cavity ("large cavity"/photon detector part)

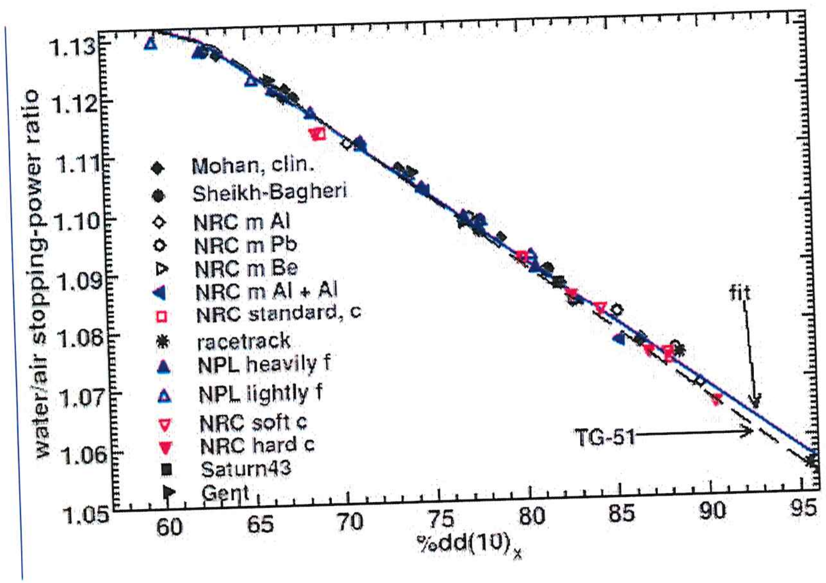


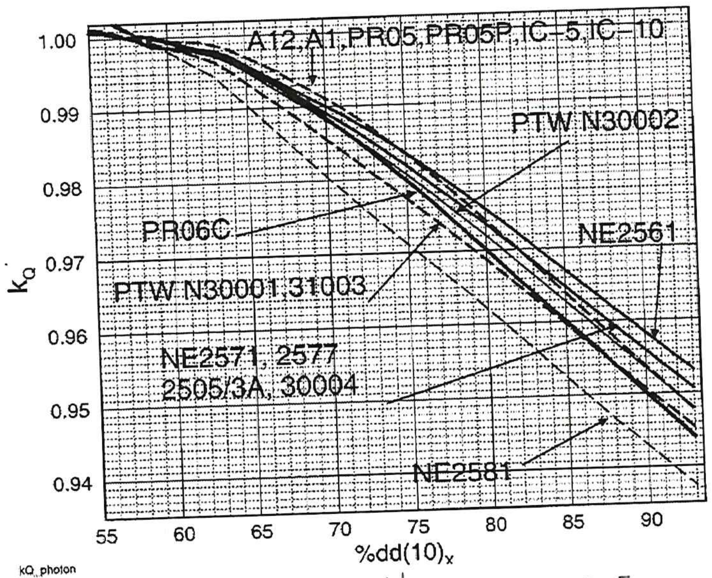


2) Ion-chamber (water to gas):









$$k_Q = \frac{[(L/\rho)^w_a \cdot P_w \cdot P_{fl} \cdot P_{gr} \cdot P_{cel}]_Q}{[(L/\rho)^w_a\ P_w \cdot P_{fl} \cdot P_{gr} \cdot P_{cel}]_{Co\text{-}60}}$$

3) TLD: (water to LiF, water to CaF2, water to CaSO4)

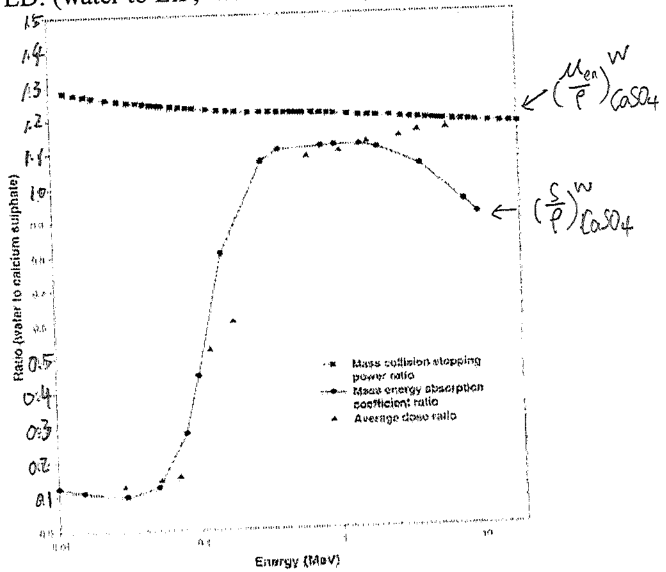
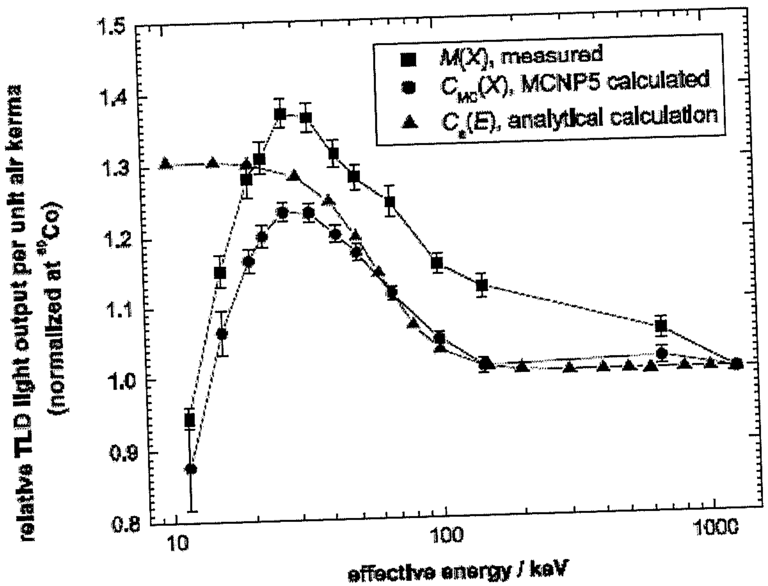


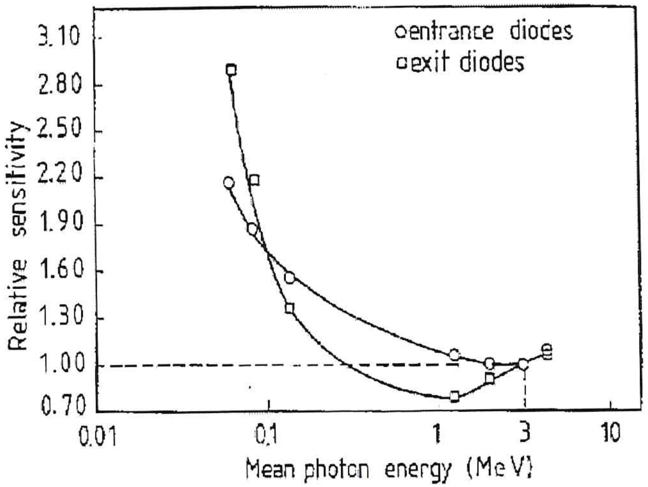
Figure 2. Calcium sulphate TLD discs, 0.9 mm thick, in MV and kV x-ray beams: comparison of the Monte Carlo derived average dose ratio, water to $CaSO_4$, with the mass collision stopping-power and mass energy-absorption coefficient ratios, as a function of the mean photon energy.

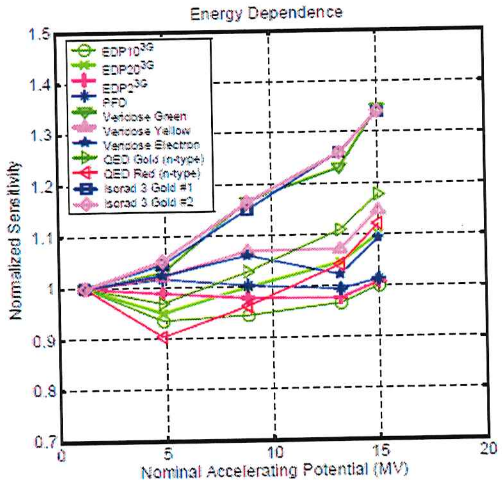


⇓

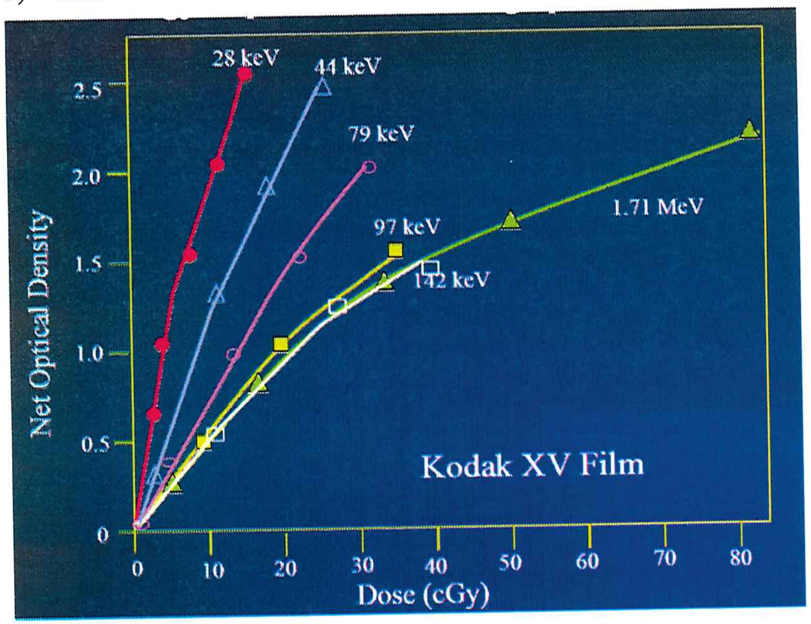
over-response 20% ~ 30% for low E compare with Co-60.

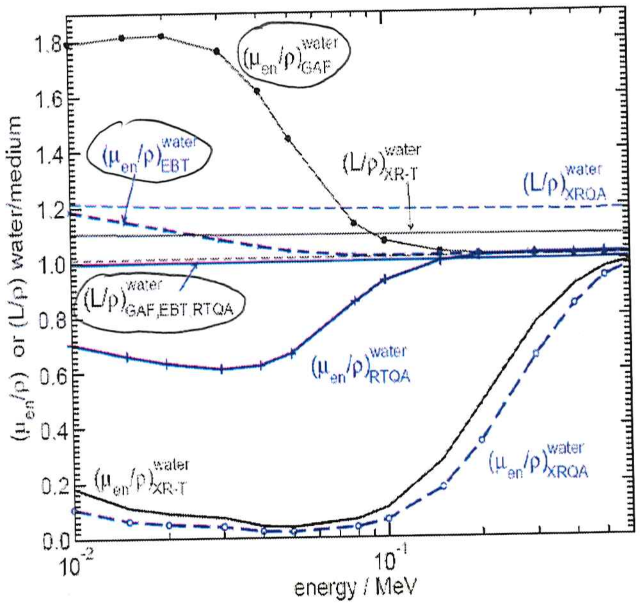
4) Diode (water to Silicon; effective Z)

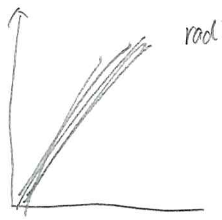




5) Film






radichromic

Radiation Survey system:

	Gas –filled			Solid State
	Ion-chamber	**Proportional counter**	**G-M counter**	**Scintillator**
Region of Operation	Ionization Saturation	Proportional region	G-M	Radiation energy absorbed and converted to light (Photoelectric effect)
Voltage	100-400V	500-800V	800~1000V	
Charges collected	Only primary charges	Gas amplification (charge multiplication) ; Primary ion cause further ionization (secondary ions)	Avalanche (a max number of secondary ions)	30 light photons (3eV) produced per 1keV radiation energy; 30% of light photons will reach PMT
Mode	Integration (current or mean level) (mR/hr or mrem/hr)	Pulse (cpm or can be calibrated to mR/hr)	Pulse (cpm or can be calibrated to mR/hr)	
Particles	x-, γ rays	α, β, neutron in very low radiation level (lab)	α, β, γ rays	Low energy gamma α, β
Energy	Measured signal (current, charge) proportional to total energy absorbed. But can not differentiate types of radiation with mixed energy and particles (No energy selection; measurement is a total contribution)	Discriminate type of radiation by pulse height The pulse height is proportional to the total energy absorbed and voltage applied. By look at each individual pulse-> energy selection	No energy differentiation. Pulse height is independent of the energy of incident radiation and applied voltage. No energy selection.	Superior to GM because # of light photons is proportional to energy. In scintillator: Rad Photon -> light photon In PMT: light photon -> e- by photo-cathode Dynode: amplify e- (secondary e-), eventually get to milivolt range Signal is portioned to energy deposited
Dead time	Suitable for high dose rate radiation area;		10-1000μsec; Paralyzed in high radiation area (< a few thousand dps) Not good for pulsed field	0.25μsec ??? (<2MGq or 50μCi)
Efficiency		Efficiency is less than LSC	Good for x, γ and high energy β Less sensitive to α or low energy β Low E β: (C-14, S-35) -> 2-10% eff; Med E β (P-32, Ca-45)-> pan cake GM 15-40% eff; Low E γ (I-125): pan cake or thin window 1-10% Med-high γ (I-131, Cs-137): moderate eff 25%	(In general is more sensitive than GM for γ rays because of higher γ and dynode amplifier) NaI -> low energy γ (I-125, Cr-51) and medium β; can **not** detect α or very low β LSC is ideal for α or β contamination

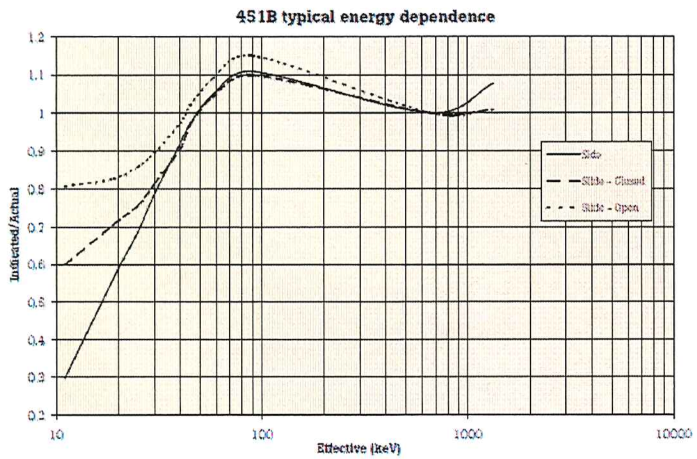
Types	Some has sliding window for α, β detection		Compensated or Thin-window (pan cake or end-window) : pan cake is more sensitive	
Example Specifications	Victoreen 470A			
particles	Alpha > 8 MeV, Beta > 120 keV, and Gamma > 10 keV			
range	0-10mSv/hr 50R/hr (1000mR/hr)			
response	Response time is longer for low DR. (8sec for 3mR/hr)			
Energy response	Energy corrected from 8keV to 2MeV		Good for E>300keV β, γ Over-response for low E (70-200keV) Strong E dependency for E < 80keV Needs special calibration for low E γ-rays	
Accuracy	Within 10% Calibrated at Cs-137			
Volume	275cc			
Wall:	17mg/cm2 wall Cycolac equilibrium sleeve and buildup cap (500mg/cm2)			

General operation of Survey meters:

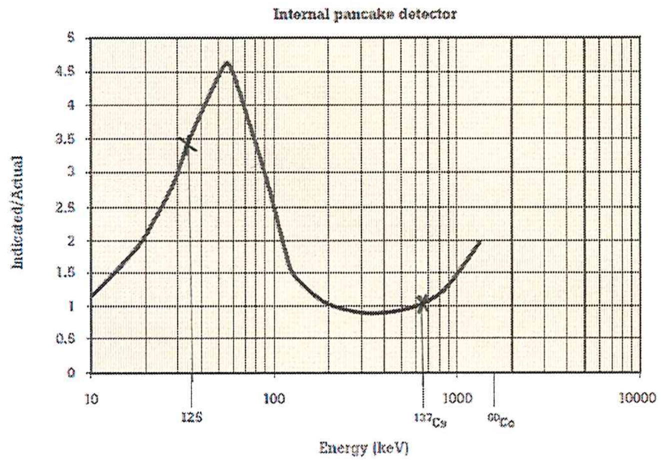
1. Check for physical damage and verify calibration certification
2. Check battery
3. Check source verification (+/-20%)
4. Detect background reading
5. Made survey measurement

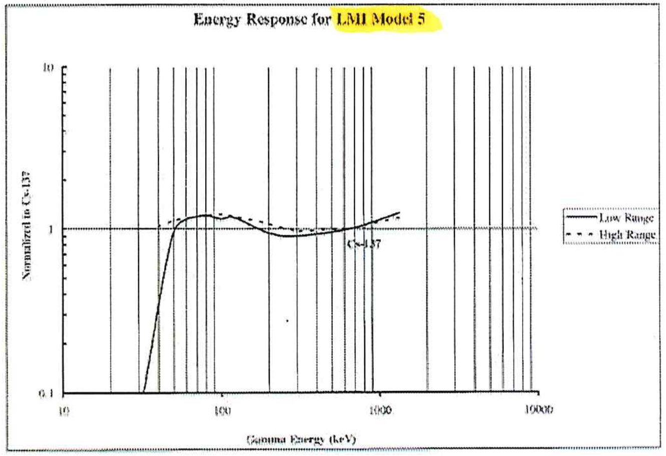
NRC requires for minimal detection of 100cpm or 0.1mR/hr (0.2mR/hr per TG-45 citing NRC) for survey meter. Calibration should be annually using a point source (5% accuracy tractable to NIST standard) and calibration each scale for two points (20%, 80%) up to 1000mR/hr.

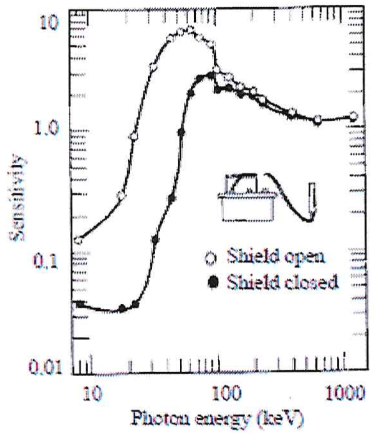
Ion-chamber:

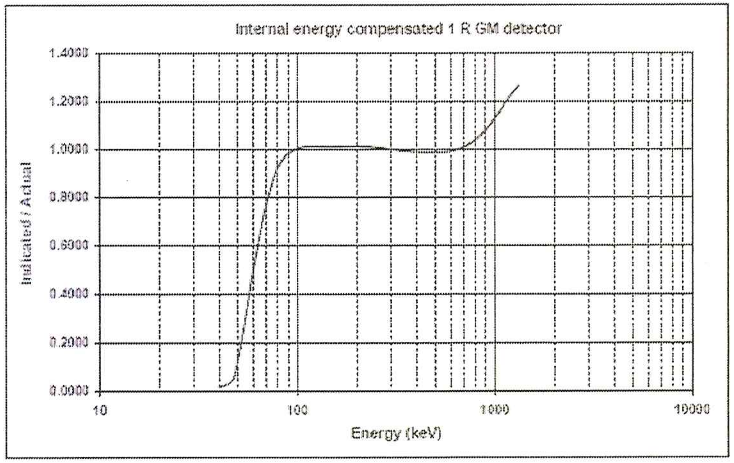


G-M counter:



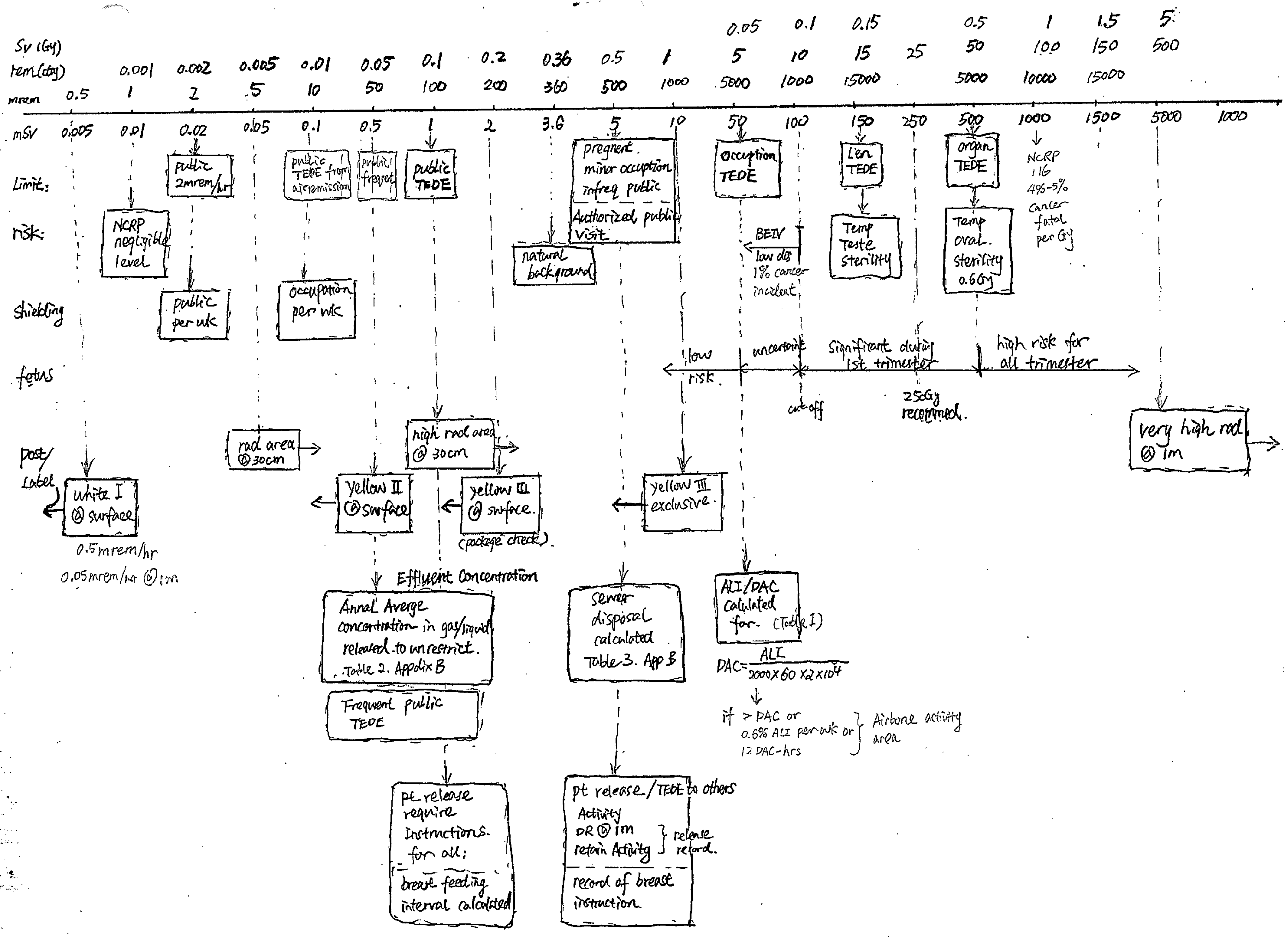






Radiation Personal Monitoring (10-20% uncertainty)

	Film	TLD	OSL	Pocket
Type of radiation	x-, γ rays high energy β (>400keV) neutron	x-, γ, β rays neutron	x-, γ, β rays neutron	A condensed ion-chamber or EPD (G-M counter; radio-sensitive diode)
Energy	extremely energy dependency (+/-20%)	Less energy dependency	Flat response (5keV-40MeV)	(photon energy > 20keV - 1.3MeV +/-20%
filters	open – β + low γ + high γ alumina - low γ + high γ copper - high γ Fast n -> proton recoil tracks on film to be counted Cadmium - absorb n-thermal; only cause by n_fast Tin – both n_thermal + n_fast Other filter to flatten the energy response	For neutron detection: TLD 600: Li-6 (n_thermal, alfa) H-3, γ, β rays TLD 700: only γ, β rays (cadmium filter can be used to different fast and thermal neutron) Mylar window – β rays Plastic filters with different equiv. thickness (1cm, 3mm, 0.7mm)		
range	10mrem – 10Gy	10mrem – 10Gy	1mrem – 10Gy	Pocket: 5 mrem - 200 mSv EPD: 0.1mrem – 10Gy
Calibration:		γ – Cs-137 β- Sr-90/Y-90 0.5MeV n – Cf-252		
Pron/Con	Permanent record Fogging; Not tissue equivalent Sensitive to environment / fading	Reusable Can only read once Tissue equivalent Fading problem; less sensitive than film	Repeatable reading ; More sensitive	Instantaneous reading



Sv (Gy)
rem (cGy)
mrem
mSv
Limit:
risk:
shielding
fetus
post/Label
0.001 0.002 0.005 0.01 0.05 0.1 0.2 0.36 0.5 1 5 10 15 25 50 100 150 500
0.05 0.1 0.15 0.5 1 1.5 5
0.5 1 2 5 10 50 100 200 360 500 1000 5000 1000 15000 5000 10000 15000
0.005 0.01 0.02 0.05 0.1 0.5 1 2 3.6 5 10 50 100 150 250 500 1000 1500 5000 1000
public 2mrem/hr
public TEDE from airemission
public frequent
public TEDE
pregnent. minor occuption infreq public
Authorized public visit
Occuption TEDE
Len TEDE
organ TEDE
NCRP 116 4%-5% Cancer fatal per Gy
NCRP negligible level
natural background
BEIV low dos 1% cancer incident
Temp Teste sterility
Temp oval. sterility 0.6Gy
public per wk
occupation per wk
low risk
uncertain
Significant during 1st trimester
high risk for all trimester
cut off
25cGy recommed.
rad area @ 30cm
high rad area @ 30cm
very high rad @ 1m
white I @ surface
0.5mrem/hr
0.05mrem/hr @ 1m
yellow II @ surface
yellow III @ surface. (package check)
yellow III exclusive.
Effluent Concentration
Annal Averge concentration in gas/liquid released to unrestrict. Table 2. Appdix B
Frequent public TEDE
sewer disposal calculated Table 3. App B
ALI/DAC Calulated for. (Table 1)
DAC = ALI / 2000 X 60 X 2 X 10^4
if > DAC or 0.6% ALI per wk or 12 DAC-hrs
Airbone activity area
pt release require instructions. for all:
breast feeding interval calculated
pt release / TEDE to others
Activity DR @ 1m retain Activity
release record.
record of breast instruction

Calibration of survey meter
- first use / annual / repair
- all scales up to 1000mR/hr 1R/hr
- two readings per scale/decade
- < 20% compared with real exp. rate
- document (date, check source activity, calib scales)

Possession of sealed source
- leak test every 6 months
  (< 5nCi)
  except: $T_{1/2} < 30d$
  I-192 ribbon
  source not used.
  β, γ source < 100uCi
- inventory check every 6 months
  (auto radiograph; inventory log;
  identity/code/color of source
  decay update to 1%)

manual brachytherapy:
- survey before/after implant
- source accountability (log)
- safty instructions initially/annually
- safty precaution
  No room share
  post room/visitor line
  emerg equipment.
- calibration output/source position accuracy within applicator
  or by manufacture value. before 1st use
  or ADCL calibration
- mathematically decay at 1% interval.
- TPS acceptance tests
  source specific inputs
  dose/dwell time/tx time @ representive points
  isodose plots/graphic display
  source position determination from image.

Teletherapy
FC:
- annually/source change/SC indicate >5%
- ±3% output
  coincidence of Rad/Light field. ⇒ SC
  uniformity of field.
  Time accuracy/Linearity ⇒ SC.
  on-off error.
  distance measurement.

SC:
- monthly

SRS.
FC.
- annually/source change/ >5% SC
- ±3% output
  rel helmet factor
  ISO coincidence
  time accuracy/linearity
  on-off error
  trunion centricity
  table retraction
  emergency timing circuits
  SRS frame and localization

Written directive:
- before or oral befor and written within 48hrs
- HDR: radionuclide, site, # of fx, fx dose, total dose
  others: befor: radionuclide. site, total dose
  after: # of sources, total strength / tx time

Present @ TX:
- MDR/PDR
  AMP + AU or SAU physically present at initiation
  AMP + AU or SAU immediately aviable during continuation
- HDR
  AMP + AU physically present at initiation
  AMP + AU or SAU physically present during
- Gama knife (SRS)
  AMP + AU throughout TX physically present.

RAU:
- survey after tx, before release pt
- safty precautions
  No dual operation
  secured RAU.
  written procedure posted
  control access with interlock.
  CCTV/AV except LDR RAU

- TPS:
  soure input parameters
  dose/time at points
  isodose/graph
  localization of seeds
  electronic transfer to RAU console.

- calibration
  except for LDR (↓ manufactor). 2yrs NIST/ADCL calibration
  FC before 1st use. / every source exchange / annual for LDR.
  5%/1mm.
  tube length/functions
  source retraction
  time accuracy/linearity
  LDR ⇒ quaterly autoradiograph
  SC before 1st TX (LDR), 1st use daily (others)
  AMP can review others (<15d)
  interlocks, lights/indicators, AV, emergency equip, source po
  timer, clocks/date. decay, survey meter ....

'osting (trefoil – megental, purple, black on yellow bckground)

rad area	>0.05mSv/hr @ 30cm	(5mrem/hr)
high rad area	>1mSv/hr @ 30cm	(100mrem/hr)
...ery high rad area	> 5Gy/hr @ 1m.	
...e radioactivity area / airborne	> 1 DAC > 0.6% ALI in a wk.	
radiactive material	>10 x quantity of Appd C.	
container label	> quantity of Appd. C.	

hipping:

① packing according to vendor (loose seeds in pig and label)

② dose rate / contamination measurement

	@ surface		TI (mrem @ 1m from surface)	
white-I	≤0.005mSv/hr	(0.5mrem/hr)	0	< 0.05mrem
yellow-II	≤0.5mSv/hr	(50mrem/hr)	0 < TI ≤ 1	< 1mrem
yellow-III	≤2mSv/hr	(200mrem/hr)	1 < TI ≤ 10	< 10mrem

③ Labeling: radionuclide, Activity (Bq), TI value if yellow label.
UN label.

Fedex shipping form: special handeling declaration

Reciving & openning

receiving:
- perform monitoring < 3hrs during normal working hours
- perform . . . < 3hrs the beginning of next working day [memo to security guar... to take the package to locked area in dept. Inform RSO/deliver if package appears damag...
- special arrangement (exceptional) if A > type A quantity

openning:

① visal inspection ⇒ monitor contamination / Rad level if appeared damage.

② if visal inspection ok, and if labeled pack.
- contamination wipe test (>300cm²) ⇒ { β, γ < 220 dpm/cm² ; α < 22 dpm/cm² } NaI scintillator fo... / LSC for β α
- if > Type A, ext. surf radiation level ⇒ { < 2mSv/hr @ surface & TI < 10. ; exclusive use ship: < 10mSv/hr @ sur... , < 2mSv/hr @ vehic... surf... }

③ immediately inform carrier/NRC if ② fails

④ open package, verify content agrees with ordered

⑤ wipe test of source if suspect contamination.

⑥ survey packing materials / empty packs for contamination before discard

⑦ record / log of receive. (radionuclide, activity, # of seeds, model, serial #, survey results ....)

⑧ leak test of source < 5nCi using a standard source

$$\text{Eff} = \frac{\text{cpm}_{std} - \text{cpm}_{bck}}{\text{A of std}} \quad (\text{cpm/nCi}) \qquad \text{leak} = \frac{\text{cpm}_{wipe} - \text{cpm}_{bck}}{\text{eff (cpm/nCi)}}$$

⇒ immediate withdraw the use
file report to NRC < 5d.

atient release

$$D(t) = \frac{A \cdot T_S \cdot 1.44 \times 24 \times T_{1/2} \times \left(1 - e^{-\frac{\ln 2}{T_{1/2}} t}\right) \cdot \overset{0.25}{T_{ocp}}}{r^2}$$

	Basis (<5mSv)	release record	I-125 (<5mSv)	I-125 instruction (>1mSv)	P-103 <5mSv	P-103 Instru (>1mSv)	I-131 <5mSv	I-131 Instru (>1mSv)	Tc-99m <5mSv	Tc-99m Instru (>1mSv)
...u ...atients	Adm A.	N	9mCi	2mCi	40mCi	7mCi	33mCi	8mCi	760mCi	150mCi
	retained A	Y	9mCi	2mCi					58mR/hr	12mR/hr
	measured DR	Y	1mR/hr	0.2mR/hr	3mR/hr	0.6mR/hr	7mR/hr	12mR/hr		
	Pt specific calculation	Y								
							(>1mSv) Instru	(>5mSv) record	(>1mSv) Instru	(>5mSv) record that instru provided.
...ast ...eding	All above. Add. Instru if equv A > 1mSv	if >5mSv or equ.A					0.0004 mCi	0.002 mCi. complete cessation	10mCi	50mCi 6 hrs for 20mCi

Personal Monitoring

require personal monitoring if

		annual limit	
Adult → 10% of	TEDE (1cm)	50mSv	⇝ 5mSv
	SDE (0.07mm)	500mSv	⇝ 50mSv
	LDE (3mm)	150mSv	⇝ 15mSv
minor →	20% of TEDE	5mSv	⇝ 1mSv
	10% of SDE	50mSv	⇝ 5mSv
	10% of LDE	15mSv	⇝ 1.5mSv

pregnant woment → 20% of limit (5mSv) ⇝ 1mSv

To demonstrate Not necessary for monitoring:
- prior experience.
- area survey combined with Toccup and calculation
- reasonable calculation

To estimate missing dosimeter
- recent dose history
- doses of co-workers

Investigation level
- level I (10% of annual Limit) ⇒ invest/review action; record results.
- level II (30% of annual limit) ⇒ investigate/action to reduce; report of action reviewed by management. re-establish new level with justification

Records:
- NRC Form 5: current exposure (annually)
- NRC Form 4: exposure history

Waste Disposal:
- return/transfer to authorized recipient (10CFR71. DOT regulations)
- treatment or disposal by incineration (CFR 20)
- release in effluents (Sanitary sewerage) < Concentration in Appd B
- decay in storage.
  - $T_{1/2} \le 120d$
  - shield container with label info.
  - wait for enough time
  - remove shield. survey/monitor at contact. DR ≈ background.
  - remove rad labels. discard as in-house waste.
  - document date. survey meter, background rate/measured rate

Apply for license:
- NRC form 313
- NRC form 313A – qualification/training
- procedures: softy procedure/precaution. peoridic spotcheck calibration/dose measurment instrument/equipment. Floor/facility design

RSO
RSSC
ALARA
QMP.

Report to NRC

	level	telephone	written report	
e/ plosions	Exp > regulatory limit	⇒ Immediate < 4hr	30d.	
	RAM > 5×ALI	⇒ < 24hr		
/theft	>1000× Appd C.	⇒ Immediate	30d.	⇒ Cs-137 ⇒ 10uCi × 10 = 0.1mCi; × 1000 = 10mCi
	>10 × Apped C.	⇒ 30d		I-125 ⇒ 1uCi × 10 = 10uCi; × 1000 = 1mCi; Ir-192 ⇒ 1uCi × 10 = 10uCi; × 1000 = 1mCi
els of or entration	Exp > regulatory limit	⇒ Immediate	30d.	
	unplanned contamination	⇒ 24hr	30d	
	RAM > specified.	⇒ N/A		
ipment ilure	if failure ⇒ Exp > regulatory limit	⇒ 24hr	30d.	
taminated ckage	if > 22dpm/cm^2; DR > 2mSv/hr; TI > 10	⇒ Immediate		
k source	>5nCi	⇒ Immediate withdraw (not report)	5d.	
osure	>5× Annual Limit	⇒ Immediate	30d.	
	>1× Annual limit	⇒ 24hr		
e to us	>5mSv to fetus; >50mSv to nursing child	⇒ < next calendar day	15d.	(also referral physician/parent
edical ord.	>1 annal limit of EDE. SDE. DE to organs and {TD−PD ≥20%; f×D ≥50%	< next calendar day	15d.	(also referal physician/patient)
	>1 annal limit of SDE, DE to organs and wrong person/RAM/mode/route/leaking			
	>1 annal Limit of SDE/DE to organs			

Teletherapy: (medical event)
- wrong pt/energy/site/type of TX
- fx>3, TD > 20%
  fx<3, TD > 10%
  wkly TD > 30%

H&N patient.

212 cGy x 33 = 6996 cGy
180 cGy x 33 = 5940 cGy
[illegible] cGy x 33 = 5445 cGy

or

212 cGy x 30 = 6360
200 cGy x 30 = 6000
180 cGy x 30 = 5400

Spinal cord 45Gy. 1cc < 50Gy — $TD_{5/5}$ - 5cm = 50Gy
Brain stem 54 Gy — $TD_{5/5}$ - 3/3 = 50Gy — $TD_{5/5}$ - 1/3 = 60Gy
optical chiasm 50Gy — $TD_{5/5}$ = 50 Gy
optical nerves 50 Gy — $TD_{5/5}$ = 50 Gy
lens 6.5 Gy — $TD_{5/5}$ = 10 Gy
branchial Plexus 1% < 60Gy — $TD_{5/5}$-3/3 = 60 Gy
esophagus 50 Gy — $TD_{5/5}$-3/3 = 55Gy
larynx : 20% > 30 Gy <45Gy — $TD_{5/5}$ = 45Gy
parotid : mean < 26 Gy
pituitary : 50 Gy
mandible : 1cc < 70 Gy — $TD_{5/5}$ - 3/3 = 60Gy

Prostate:
phase 1: 180x30 = 54Gy (prostate + SV)
phase 2: 180x12 = 21.6 Gy (prostate)
180 x 42 = 75.6 Gy

bladder: 50% < 60 Gy — $TD_{5/5}$ 3/3 = 60 Gy — $TD_{5/5}$ - 1/3 = 80 Gy
25% < 70 Gy
rectum: 50% < 60 Gy — $TD_{5/5}$ = 60Gy
25% < 70 Gy
Femoral: 30% < 36 Gy — $TD_{5/5}$ = 52Gy
max < 45Gy

Breast:
180x28 = 5040cGy Tang
180x28 = 5040cGy SCLV.
200x5 = 1000 cGy E^- boost.

Lung : V20 < 20%. — $TD_{5/5}$ - 3/3 = 17.5Gy — $TD_{5/5}$ - 1/3 = 45Gy
heart : < 40~50Gy — $TD_{5/5}$ - 3/3 = 40Gy — $TD_{5/5}$ - 1/3 = 60Gy

Table 1. Normal tissue tolerance to therapeutic irradiation

Organ	TD 5/5 Volume			TD 50/5 Volume			Selected endpoint
	1/3	2/3	3/3	1/3	2/3	3/3	
Kidney I (50% < 15Gy) Kidney II	5000	3000*	2300	—	4000*	2800	Clinical nephritis
Bladder (50% < 60Gy)	N/A	8000	6500	N/A	8500	8000	Symptomatic bladder contracture and volume loss
Bone: (max < 40Gy, 30% < 36Gy)							
Femoral Head I and II	—	—	5200	—	—	6500	Necrosis
T-M joint mandible (1cc < 70Gy)	6500	6000	6000	7700	7200	7200	Marked limitation of joint function
Rib cage	5000	—	—	6500	—	—	Pathologic fracture
Skin	10 cm² —	30 cm² —	100 cm² 5000	10 cm² —	30 cm² —	100 cm² 6500	Telangiectasia
	7000	6000	5500	—	—	7000	Necrosis Ulceration
Brain	6000	5000	4500	7500	6500	6000	Necrosis Infarction
Brain stem (< 54Gy, 1cc < 60Gy)	6000	5300	5000	—	—	6500	Necrosis Infarction
Optic nerve I & II < 50Gy	No partial volume		5000	—	—	6500	Blindness
Chiasma < 50Gy	No partial volume		5000	No partial volume		6500	Blindness
Spinal cord < 45Gy	5 cm 5000	10 cm 5000	20 cm 4700	5 cm 7000	10 cm 7000	20 cm —	Myelitis necrosis
Cauda equina	No volume effect		6000	No volume effect		7500	Clinically apparent nerve damage
Brachial plexus < 60Gy	6200	6100	6000	7700	7600	7500	Clinically apparent nerve damage
Eye lens I and II < 10Gy	No partial volume		1000	—	—	1800	Cataract requiring intervention
Eye retina I and II < 45Gy	No partial volume		4500	—	—	6500	Blindness
Ear mid/external	3000	3000	3000*	4000	4000	4000*	Acute serous otitis
Ear mid/external (cochlea) < 36Gy	5500	5500	5500*	6500	6500	6500*	Chronic serous otitis
Parotid* I and II (mean < 26Gy, 50% : 30Gy)	—	3200*	3200*	— (TD 100/5 is 5000)	4600*	4600*	Xerostomia
Larynx	7900*	7000*	7000*	9000*	8000*	8000*	Cartilage necrosis
Larynx < 45Gy	—	4500	4500*	—	—	8000*	Laryngeal edema
Lung I Lung II V20 < 20%	4500	3000	1750	6500	4000	2450	Pneumonitis
Heart	6000	4500	4000	7000	5500	5000	Pericarditis
Esophagus < 60Gy	6000	5800	5500	7200	7000	6800	Clinical stricture/ perforation
Stomach	6000	5500	5000	7000	6700	6500	Ulceration, perforation
Small intestine	5000		4000*	6000		5500	Obstruction perforation/fistula
Colon	5500		4500	6500		5500	Obstruction perforation/ ulceration/fistula
Rectum 50% < 60Gy	Volume 100 cm³ No volume effect		6000	Volume 100 cm³ No volume effect		8000	Severe proctitis/ necrosis/fistula, stenosis
Liver 1/2 < 20Gy 1/3 < 30Gy	5000	3500	3000	5500	4500	4000	Liver failure

*<50% of volume doesn't make a significant change.

Unsealed RAM

Source:
- Nuclear medicine: ^{99m}Tc. ^{201}Tl. ^{67}Ga. ^{111}In. ^{123}I (Diag)
  - ^{131}I. ^{90}Y (Therapeutic).
- PET (^{11}C. ^{13}N ^{15}O. ^{18}F)
- Radiation Oncology: [^{32}P. ^{125}I (unsealed brachytherapy)]
  - ^{32}P → Infusion therapy

Monitoring Package:
- contamination survey:
  - NRC: ① ALL diamond labeled ② Except gas. special form. ③. package is wet crushed ...
  - state: ≤ Exempt quantities; ≤ 10 mCi of ^{3}H ^{14}C ^{35}S ^{125}I; Gas. special form; $^{99}Mo/^{99m}Tc$ ≤ 3Ci; ½ <30d. ≤ 100mCi
- radiation levels:
  - ① ALL diamond label
  - ② Exception: Less or equal to Type A quantities
  - state: rams in excess of Type A quantities; No current radiopharmacy < Transport group III. 3Ci

Monitoring Time:
- NRC: 3. hours after receive; 3 hours of the start of the next working day
- State: 3 hours; 18 hours

Notification requirements:
- ① removable contamination > 22 dpm/cm². 10^{-5} µCi/cm² 0.4 Bq/cm² (NRC) for β. γ emitters.
- ② radiation level > 200 mrem/hr at surface; 10 mrem/hr at 1m. (NRC. IAC)

Inventory: verify total quantity < any limits

Calibration:
- Unit dosage: direct measurement. decay correction.
- Other than unit: direct measurement; combination measure. & math; combination volumetric measure math calculation.
- "May not use if" ① the dosage does not fall within the precribed range or ② differs from the precribed range by 20%

Sealed RAM.

- Nuclear Medicine:
  - Dose calibrator: ^{137}Cs. ^{57}Co. ^{60}Co. ^{133}Ba
  - γ counter standard: ^{129}I.
  - check source: ^{137}Cs.
  - Gamma camera source (^{153}Gd, ^{133}Ba)
- PET: calibration source (^{68}Ge)
- Oncology:
  - Teletherapy (^{60}Co)
  - Implant Source: ^{192}Ir, ^{137}Cs, ^{198}Au, ^{103}Pd

- contamination: NRC: same as unsealed. State: special form
- radiation levels: NRC: same. State: same. 3Ci for majority of sealed sources used in medicine except ^{90}Sr (0.050)

same.

same.

(physical Inventory performed every 6 months)

same.

Leakage Test:
- requirments: before use. unless performed within 6 months; at least every 6 months. detect at least 0.005 µCi. report in 5 days.
- Examptions: ① ½ life < 30 day; ② gas. ③ β. γ < 100µCi; α < 10µCi; ④ seeds of ^{192}Ir in nylon ribbon. ⑤ sources in storage
- Method:
  - efficiency = net cpm of standard / dpm of standard
  - MDA(dpm) = $(4.65\sqrt{Bkg} + 3)$ / efficiency
  - MDA(µCi) = MDA(dpm) / 2.22×10^{6}
  - sample (dpm) = Net cpm / efficiency
  - sample (µCi) = sample (dpm) / 2.2×10^{6}.

Photon monitor unit calculation Summary

General definitions:

SCD = source to calibration distance = distance at which calibration equals 1.0 cGy/MU

CSF = collimator scatter factor – always use the collimator jaw setting (if table requires equivalent square, use BJR Equivalent squares of rectangular fields table)

K = calibration = 1.0 cGy/MU at the SCD

Modifying factors = product of any necessary tray factors, wedge factors, off-axis factors, etc.

SSD calculations:

$$\boxed{\#MU = \frac{TD \cdot 100}{K \cdot SSDfactor \cdot CSF \cdot PSF \cdot PDD \cdot MayF \cdot ModFactors}}$$

TD = tumor dose

SSDfactor = inverse square correction for calibration = $\dfrac{(SCD)^2}{(ptSSD + d_{max})^2}$

PSF = phantom scatter factor – use the blocked equivalent square at the patient's surface

PDD = percent depth dose – use blocked equivalent square at patient's surface and depth of calculation

MayF = Mayneord F factor – modifies PDD value if patient SSD is not the same as the PDD table SSD. MayF = $\left(\dfrac{SSD_2 + d_m}{SSD_1 + d_m}\right)^2 \cdot \left(\dfrac{SSD_1 + d}{SSD_2 + d}\right)^2$ where SSD_1 = PDD table SSD and SSD_2 = patient SSD

SAD calculations:

$$\boxed{\#MU = \frac{TD}{K \cdot SADfactor \cdot CSF \cdot PSF \cdot TMR \cdot ModFactors}}$$

SADfactor = inverse square correction for calibration = $\dfrac{(SCD)^2}{(ptSSD + d)^2} = \dfrac{(SCD)^2}{(SAD)^2}$

PSF = phantom scatter factor – use the blocked equivalent square at the isocenter of the patient's treatment

TMR = tissue-maximum ratio – use blocked equivalent square at patient's isocenter and depth

AAPM	ICRU
TG-21: Air-kerma based calibration TG-25: e- dosimetry TG-70 TG-29: TBI TG-30: TSET TG-36: Fetal dose TG-39: PP chamber calibration TG-35: Linac Safety TG-40: QA TG-45: Code of linac TG-42: SRS TG-43: TG-43U Brachy dosimetry TG-50: MLC TG-51: MV calibration TG-61: KV calibration TG-53: TPS QA TG-56: Code of Brachy TG-59: HDR TG-64: Prostate Implant TG-55: Radiochromic film TG-58: EPID TG-62: Diode TG-66: CT TG-69: Radiographic film TG-65: Inhomogeneity TG-74: Sc measurement TG-72: Respiration Motion TG-75: Imaging Dose TG-104: IGRT TG-105: MC TG-106: TPS Commission TG-111: CT dose TG-119: IMRT comissiong TG-128: Ultrasound TG-137: Prostate Prescription TG-142: QA	ICRU-35: e- dosimetry ICRU-37: (L/p) ratio for e- ICRU-38: Intracavity GYN ICRU-50: Prescription ICRU-62: Prescription (update) ICRU-49 : (L/p) for proton ICRU-58 : interstitiel brachy **NCRP :** NCRP-38 : neutron protection NCRP-79 : neutron from linac NCRP-49: Shielding NCRP-51: Rad protection design guidelines for facilities NCRP-147: kV shielding NCRP-151: MV shielding NCRP-116: limitation of exposure NCRP-136: LNT model **NRC:** Part 19 – notices, report, instruction Part 20 - standards for protection Part 35 – medical use of by product Part 71 – packing and transportation NUREG 1556: Guideline about material licensees RG.8.13 - Instruction Concerning Prenatal Radiation Exposure **Others:** BJR Supp. 25: PDD/ Beam data

Secondary barr

① PS:

$$B_{ps} = \frac{P \cdot d_{sca}^2\, d_{sec}^2 \cdot 400}{\alpha \cdot W \cdot T \cdot F}$$

scatter fraction

$a(\theta, E) \downarrow$ with $\theta \uparrow$. = 10°: 1~2%, 90°: 0.01~0.04%

TVL ~ (E, θ)

90° MV	concrete	lead
6X	17cm	1~1.5cm
18X	19cm.	1.5 for 10MV

E (MeV) mean energy

	40°	90°	20°
6X	0.7	0.2	1.2
18X	0.9	0.3	2.1

② Leakage.

$$B_L = \frac{1000 \cdot P \cdot d_L^2}{W T}$$

→ 0.001 always with W

③ scatter from wall

E = 6X or 18X.

MV	concrete	lead
6	34(29)	4.5
18	36(34)	4.7

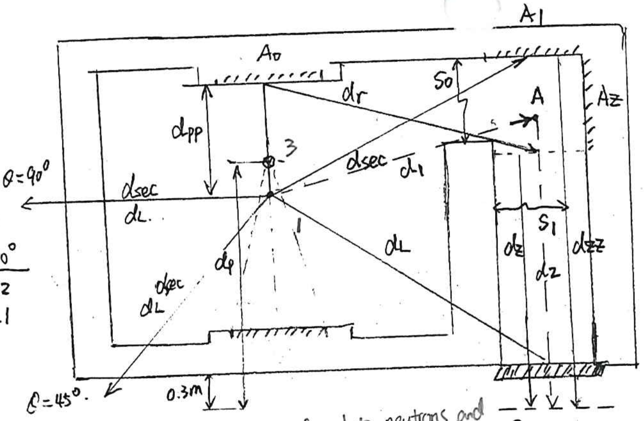
④. n, γ_{cg}

only for door. HVAC when >10MV.

$$B_n = \frac{P d^2}{W \cdot Y \cdot U \cdot T}$$

1mSv/Gy

TVL_n = 25cm concrete.



Primary

① concrete. ⇒ enough for photo-neutrons and neutron capture gamma rays

$$B_{pri} = \frac{P\, d_p^2}{W U T}$$

T = 1/8 only 1 hr per day

@ door

MV	concrete	lead	earth
6	37(33)	5.7	57
18	45(43)	5.7	

first → equilibrium

② Laminated wall.

$P_{lead} \approx 5 P_{concrete}$

$t_1\ t_m\ t_2$

$B = B_c \cdot B_L \cdot B_{steel}$

$n = n_c + n_L$

$T = n_c \cdot TVL_c + n_L \cdot TVL_L$

if >10MV:

$$H_n = \frac{D_0 \cdot R \cdot F_{max}}{(\frac{t_m}{2} + t_2 + 0.3)^2} \times 10^{-\frac{t_1}{TVL_x}} \times 10^{-\frac{t_2}{TVL_n}}$$

only for maze

$2 < \frac{d_{zz}}{\sqrt{W \times H}} < 6$

$1 < \frac{L}{W} < 2$

only consider for primary barrier

TVL_x = 45(43) 18X.

TVL_n = 25 cm. ⟷ fast neutron

$H_{TOT} = H_n + 2.7 H_{tr}$ ⇒ { γ_{tr}, $\gamma_{n,g}$

$$\left(\frac{WUT \cdot B_1 B_m B_2}{d^2}\right)$$

⇓

typically 0.91m concrete/BPE added in addition to lead

Comments:

1). use two source rules to determine thickness btw leakage and PS. (>1TVL, use the larger; <1TVL, add 1HVL)

2) leakage dominate @ high E.

3) leakage dominate @ 90° scatter, especially IMRT

weekly TADR:

$R_W = H_{mu} \cdot W(MU) \cdot U$ (Integrated)

$R_W = H_{MU\,L} \cdot W_{L(MU)} + H_{MU\,PS} \cdot W_{PS} \cdot U_{PS}$

(Instantaneous)

$$R_W = \frac{IDR \cdot W_{pri} \cdot U_{pri}}{D_0} \quad \text{or} \quad R_W = \frac{0.001 W_L \cdot B_L}{d^2} + \frac{a \cdot \frac{F}{400} \cdot W_{pri} \cdot U \cdot B_{sec}}{d_{sca}^2\, d_{sec}^2}$$

or $R_W = IDR_L \cdot \frac{W_L}{D_0} + IDR_{PS} \cdot \frac{W_{PS}}{D_0}$.

($IDR_{PS} = IDR_{total} - IDR_L$)

$R_W \cdot T < P = \{ 0.1mSv/wk;\ 0.02mSv/wk.$

⇓

adequate.

$$R_h = M \cdot \frac{R_W}{40} = \left(\frac{N_{max}}{N_{Avg}}\right) \cdot \frac{R_W}{40} < 0.02mSv\ (20\mu Sv)$$

⇒ only to public area! And only in certain regulation

<10MV { thick maze wall ⇒ 0.2~0.3 MeV (scatter); thin maze wall ⇒ HL or no maze

>10MV ⇒ n. γ_{cg} dominate

At maze/door.

photons:

① primary scatter

$$H_S = \frac{W U \cdot (\alpha_0 A_0) \cdot (\alpha_z A_z)}{(d_{pp}+1)^2 \cdot d_r^2 \cdot d_z^2}$$

α_0 (θ=75°, E=6X/18X) reflection coefficient

α_1 (θ=75°, E = 0.5MeV)

Two tables with incident angles (0°, 45°)

② patient scatter

$$H_{ps} = \frac{W \cdot U \cdot a \cdot (\frac{F}{400}) \cdot (\alpha_1 A_1)}{d_{sca}^2 \cdot d_{sec}^2 \cdot d_{zz}^2}$$

α_1 (θ=0°, E=0.5MeV)

a (θ=45°, E=6X/18X)

③ Leakage scatter

$$H_{LS} = \frac{0.001 \cdot W \cdot U \cdot (\alpha_1 A_1)}{d_{sec}^2 \cdot d_{zz}^2}$$

α_1 (θ=0°, E = 1.4MeV/6X, 1.5MeV/10X)

④ direct leakage

$$H_L = \frac{0.001\ W \cdot U \cdot B_t}{d_L^2}$$

B_t: TVL use leakage TVL table

$H_G = f \cdot H_S + H_{ps} + H_{LS} + H_L$

⇒ H_{Tot} = 2.64 HG

	MV	lead	concrete	BPE
Hs, Hps	0.2	0.5	13	32
HLS	0.3	0.8	16	40
HL	6X	4.5	34(29)	
	18X	4.7	36(34)	

0.2~0.3 MeV (scatter)

Door design

1) if 6MV with maze ⇒ 1/4'' lead door

2) if 18MV with maze ⇒ Door

measure @ direct door

{ 40x40 phantom: $H_L + H_{ps} + H_{ws} + H_{cg}$

40x40 No phantom: $H_L + H_{ws} + H_{cg}$

0x0: $H_L + H_{cg}$

w/o maze ⇒ calculate with $d_z = 0$ and $H = H_L + H_{nrg}$

n & γ_{cg} (>6 technically / >10MV practically)

①. n fluence.

at point A

$$\varphi_A = \frac{\beta Q_n}{4\pi d_1^2} + \frac{5.4 \beta Q_n}{2\pi S_r} + \frac{1.3 Q_n}{2\pi S_r}$$

direct, scatter, thermal.

Q_n = 2×10^{10} ~ 1×10^{12} # of n/Gy

n @ head { direct emission (forward, >2MeV, 10~20%); evaporation (isotropic, 1~2MeV) } ⇒ scatter n @ maze (100keV) outside room <0.5MeV

② $\gamma_{c,g}$

$$h_\varphi = K \cdot \varphi_A \cdot 10^{-\frac{d_z}{TVD}}$$

$H_{cg} = W_L \cdot h_\varphi$

for photon ⇐ TVD = 5.4m (18X), 3.9m (15X)

	MV	Lead.	Concrete	BPE	
BPE →	0.478				
polytheren →	2.2				
concrete {	3.6 (Avg)	6.1	33(33)	82	$d_z > 5$
	7	6.1	39(35)	96(86)	$2.5 < d_z <$
	10	6.1	46(37)	102(92)	$d_z < 2$

up to.

max when jaw closed gantry in 3-1 direction (gantry head close to point A)

Kersey's method. ③ n

1.41m

H_0: 0.04~1.8mSv/Gy (mSv/Gy)

$$h_{n,0} = H_0 \cdot \left(\frac{S_0}{S_1}\right) \left(\frac{d_0}{d_1}\right)^2 \cdot 10^{-\frac{d_z}{5}}$$ ← TVD

or $h_{n,D} = 2.4\times10^{-15} \varphi_A \left(\frac{S_0}{S_1}\right)^{\frac12} \cdot [1.64 \times 10^{-\frac{d_z}{1.9}} + 10^{-\frac{d_z}{TVD}}]$

tenth-value distance for neutron ⇐ TVD = $2.06\sqrt{S_1}$ or 5m.

$H_n = W_L \cdot h_{n,D}$

→ transparent when n_E < 0.5MeV

	MeV	lead	concrete	BPE (Borated polyethylene)
at maze	thermal	∞		1.2cm
	↳ 0.1	∞	16cm	4.5cm
head (fast)	→ 1		25cm	9.6cm

more effective for thermal neutrons

⇒ $H_\gamma = H_{Tot} + H_{cg}$ and H_n.

>10MV H_{tot} ignored. short maze, consider H_{LT}

ways to reduce n. { So↓; Add a leg of maze; place BPE door at inside maze entrance (A) }

reduce energy of neutrons

effective for thermal neutron

d_z > 8m: 1/2'' (0.6~1.2cm) lead + 1~2'' (2~4cm) BPE + 0.25'' steel

other: 1/4'' steel + 1'' lead + 3'' BPE + 0.25'' steel ⇒ 15cm

1/4'' steel + 3'' lead + 10~11'' BPE + 3'' lead + 1/4'' steel ⇒ 50c

- overlap > 10 × gap (6~10'' overlap)
- gap asap. (<1/2'')
- 3.8cm × 25cm lead & BPE cover inside (1.5'') (10'')
- high density concrete block at door stop (15.2cm)

Workload:

$W_{pri} = (\#\ \text{of pt/day}) \times 5 \times (\text{Avg Dose/pt})$ — Avg Dose/pt ↓ 2.5Gy/pt.

IMRT:

$W_{pri} = W_{pri} \quad W_{pt} = W_{pt}$

$W_L = \alpha \cdot C_I \cdot W_{pri} + (1-\alpha) W_{pri}$

$C_I = 2 \sim 10$: α – fraction of IMRT tx.
$1-\alpha$ – fraction of conv tx.

TBI: (730Gy/wk reg, D_{TBI} = 24Gy/wk. $d = 4^2$

$W_{pri} = W \cdot U + W_{TBI}$
$= 730 \times 0.2 + 24 \times 4^2 \times 1$
$= 146 + 384 = 530$ Gy/wk.

$W_{pt\text{-}ISO} = W_{pri} \cdot U$
$= 146$ Gy/wk.

$W_{TBI \cdot pt} = W_{WS\text{-}TBI} = W_{prim}$
$= 530$ Gy/wk.

$W_L = W + W_{TBI} = 730 + 384 = 1114$ Gy/wk.

Combine TBI. IMRT (40%)

$W_L = \alpha \cdot C_I \cdot W_{pri} + (1-\alpha) C_I \cdot W_{pri} + W_{TBI}$
$= 0.4 \times 4 \times 730 + 0.6 \times 730 + 384$
$= 2.2 \times 730 + 384$
$= 1990$ Gy/wk.

reports:
- shielding design report
- construction report.
- post-construct survey report → { title page, methods, Floor plan/view, instruments, results, conclusion.
- re-evaluation due to changes

skyshine:
- photon ⇒ $G = 180°$. h=2m, $\Omega = 11.3°$, $\Omega = 0.122$
  40x40
  measured @ 1m high. ds away ⇒ 7.5m 15m 33m: 50 ~ 157 ~ 55 uSv/hr
- neutron ⇒ $G = 0°$. h=2m. Ω defined by vault walls.
  No ds. ($ds \le 20m$ all the same value).
  ⇒ 5m 8.5m 20m: 60 ~ 209 ~ 83 uSv/hr

Groundshine:
laminated wall ⇒ at junction btw wall & floor
add lead/steel to reduce scatter under wall.

Activation: (>10MV) $\propto$ neutron dose (therapist receive 1~3mSv/yr)
- IMRT with 6x.
- min neutron production material. Avoid Al./Mn materials.
- QA after hours.

... e^- beam efficient in ozone

Special shielding (40x5cm ... stopper)

Tomo: fan beam. with be[am] stopper
high $C_I \sim 15$.
primary thickness [con + 1TVL], narrower
second leakage [con + 2TVL]

Cyberknife: $C_I \sim 15$, 6cm² FS.
All barrier potentially prim.
leakage/primary comparible.

Co-60: NRC require TADR R_H < 0.02mSv

P = 0.1mSv/wk = 10 mrem/wk
P = 0.02mSv/wk = 2mrem/wk

Simulator:
NCRP49: W = mA·min. P = 0.01R/wk
= 0.002R/wk.

K = R/(mA·min) ⇒ look for thickness on chart.

$K = \dfrac{P \cdot d^2}{W \cdot U \cdot T}$ → 60 orthovoltage

$B_L = \dfrac{P\, d_{sec}^2 \cdot 600 I}{W \cdot T}$ — HVL(125kV) = 0.28mm lead.

$K_S = \dfrac{P\, d_{sec}^2 \cdot d_{sca}^2 \cdot 400}{a \cdot W \cdot T \cdot F}$

NCRP 147
- Cardiac Angio: $B_{sec} = \dfrac{0.02\text{mGy/wk.}}{3.8\text{mGy/pt} \times 25\text{pt/wk}} = 3.4 \times 10^{-3}$
  (No primary) ⇒ 1.3mm lead ⇒ 1/16" lead.
- chest unit: $B_p = \dfrac{0.02\text{mGy/wk.}}{1.2\text{mGy/pt} \times 300\text{pts}} = 5 \times 10^{-4}$
  ⇒ 1.4mm lead ⇒ 1/16" lead.
  B_{sec} ⇒ 0.42 mm lead ⇒ 1/32" lead.
- Radiograph $B_p = \dfrac{0.02\text{mGy/wk}}{5.2\text{mGy/pt} \times 125\text{pt}} = 5.1 \times 10^{-4}$
  ⇒ $X_{barrier} + X_{pre}$ = 107mm concrete
  $X_{barrier} = 107 - 72 = 35$mm concrete.
  (72 ↓ image receptor table attenuation.)
- CT: only secondary barrier
  - $K_S = K \cdot DLI = K \cdot N_R \cdot T_b \cdot CTDI_{100}$ (DLI: dose line integral.)
  - $K_S = K \cdot DLP = K \cdot (CTDI_{vol} \cdot L)$
  - Isodose map method.
  } ⇒ 1/16" all around.
- PET (TG-108): F-18 8times bigger ⇒ 8mm lead, 11cm concrete.

HDR

	^{226}Ra	^{60}Co	^{137}Cs	^{192}Ir	^{198}Au	[illegible]	^{103}Pd
HVL-lead	1.6	1.2	0.65	0.6	0.6	0.[illegible]	0.0008
TVL-lead		4.0	2.1	2.0	1.1		
HVL-water		10.8	8.2	6.3	7.0	2.0	1.6
TVL-concrete		20.6	15.7	14.7	13.5		

HDR:
{ 4.5cGy/hr @ 1m
{ 7.5Gy/min @ 1cm

$B = \dfrac{P \cdot d^2}{W \cdot T}$ P = 0.02mSv/wk. T = 1.

the key is to estimate W.

$W = \Gamma \cdot f \cdot A \cdot t$
$= 4.68\,\text{Rcm}^2/\text{hr mCi} \cdot 0.96\,\text{cGy/R} \cdot 10^4 (\text{mCi}) \cdot t\,(\text{hr})$

$t = \dfrac{10\text{Gy/pt} \times 25\text{pt.}}{1\text{ Gy/min}} = 4.17$ hr/wk ← McGinly
6.7hr/wk ⇐ NCRP 155
2hr/wk ⇐ Glasgow.

W ≈ 0.1 ~ 0.3Gy/wk. @ 1m

⇒ 35~61cm concrete or 4~5cm lead. by McGinly
15" (38cm) concrete, 1.75" (5cm) lead door } by Glasgow

if have a maze ⇒ $H = \dfrac{10\text{Ci} \cdot T_S \cdot f \cdot \alpha \cdot \text{Area}}{d_1^2\, d_2^2}$ (α: $2 \times 10^{-2}/\text{m}^2$.)
⇒ 3mm lead door per Khan.

LDR:
χ mCi × 3.26R/hr.mCi × 0.96cGy/hr ....
⇕ (convert to)
suppose 100mg Ra. Cs-137
W = 100mg·Ra × 8.25R/hr × 0.96cGy/R × 0.8 (transmission) @ 1cm. ⇒ 1m

P = 100mrem/(24×7hr) = 0.6 mrem/hr

$B = \dfrac{Bd^2}{0.8 f \cdot \Gamma \cdot A} = \dfrac{0.6 \times 10^{-3}\,\text{Gy} \times (2)^2}{0.8 \times 8.25 \times 100 \times 0.96 \times 0.8/10000}$

⇒ 2.7cm lead or 20cm concrete

if consider 2mrem/hr

Workload:

$W_{pri} = (\#\text{ of pt}/\text{day}) \times 5 \times (\text{Avg Dose}/\text{pt})$ ↓ 2.5Gy/pt.

W at high E usualy determine the shielding requirements

IMRT:

$W_{pri} = W_{pri}$ $W_{pt} = W_{pt}$

$W_L = \alpha \cdot C_I \cdot W_{pri} + (1-\alpha) W_{pri}$

$C_I = 2\sim10$. α – fraction of IMRT tx. $1-\alpha$ – fraction of conv tx.

TBI: (730Gy/wk reg, $D_{TBI} = 24$Gy/wk. $d = 4^2$

$W_{pri} = W \cdot U + W_{TBI}$

$= 730 \times 0.2 + 24 \times 4^2 \times 1$

$= 146 + 384 = 530$ Gy/wk.

$W_{pe\text{-}Iso} = W_{pri} \cdot U = 146$ Gy/wk.

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Combine TBI. IMRT (40%)

$W_L = \alpha \cdot C_I \cdot W_{pri} + (1-\alpha) C_I W_{pri} + W_{TBI}$

$= 0.4 \times 4 \times 730 + 0.6 \times 730 + 384$

$= 2.2 \times 730 + 384$

$= 1940$ Gy/wk.

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→ title page
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photon ⇒ $G = 180°$. $h = 2m$ $\theta = 11.3°$. $\Omega = 0.122$

40x40 measured @ 1m high. ds away ⇒ 50 ~ 157 ~ 55 uSv/hr (7.5m, 15m, 33m)

neutron ⇒ $G = 0°$. h=2m. Ω defined by vault walls.

No ds. (ds ≤ 20m all the same value).

⇒ 5m 60 ~ 8.5m 209 ~ 20m 83uSv/hr

calculation underestimate measured values

Groundshine:

laminated wall ⇒ at junction btw wall & floor add lead/steel to reduce scatter under wall.

neutron activation $(n,\gamma) \rightarrow \beta^+ \beta^- \gamma$

Activation: (>10MV) ∝ neutron dose (therapist receive 1~3mSv/yr)
- IMRT with 6X.
- min neutron production material. Avoid Al./Mn materials.
- QA after hours.
- ... e⁻ beam. efficient in ozone

Special shielding (40x5c)

Tomo: fan beam with lead stopper 85cm 13cm lead
- high $C_I \sim 15.16$
- primary thickness [con + 1TVL], narrower
- second leakage [con + 2TVL]

Cyberknife: $C_I \sim 15$, 6cm² FS.
- All barrier potentially prim
- leakage/primary comparible.

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P = 0.1mSv/wk = 10mrem/wk

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Simulator: NCRP49: W = mA·min. P = 0.01R/wk = 0.002R/wk

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$K = \frac{P \cdot d^2}{W \cdot U \cdot T}$ → 60 orthovoltage HVL(125kV) = 0.28mm lead.

$B_L = \frac{P\, d_{sec}^2 \cdot 600 I}{W T}$

$K_S = \frac{P\, d_{sec}^2 \cdot d_{sca}^2 \cdot 400}{\alpha \cdot W \cdot T \cdot F}$

NCRP 147

• Cardia Angio: (No primary) $B_{sec} = \frac{0.02\text{mGy/wk}}{3.8\text{mGy/pt} \times 25\text{pt/wk}} = 3.4 \times 10^{-3}$ ⇒ 1.3mm lead ⇒ 1/16" lead.

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- Isodose map method.

⇒ 1/16" all around.

·PET (TG-108): F-18 8times bigger ⇒ 8mm lead 11cm concrete.

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HDR: 4.5cGy/hr @ 1m; 7.5Gy/min @ 1cm

the key is to estimate W.

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$= 4.68\,\text{Rcm}^2/\text{hr mCi} \cdot 0.96\,\text{cGy/R} \cdot 10^4(\text{mCi}) \cdot t(\text{hr})$

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⇒ 3mm lead door per Khan.

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suppose 100mg Ra. Cs-137 ⇕ x mCi × 3.26R/hr.mCi × 0.96cGy/hr ....

W = 100mg·Ra × 8.25R/hr × 0.96cGy/R × 0.8 (transmission) @ 1cm. ⇒ 1m (convert to)

P = 100mrem/(24×7hr) = 0.6 mrem/hr

$B = \frac{B d^2}{0.8 \cdot f \cdot \Gamma \cdot A} = \frac{0.6 \times 10^{-3}\text{Gy} \times (2)^2}{0.8 \times 8.25 \times 100 \times 0.96 \times 0.8/10000}$

⇒ 2.7cm lead or 20cm concrete

if consider 2mrem/hr