Facility Survey

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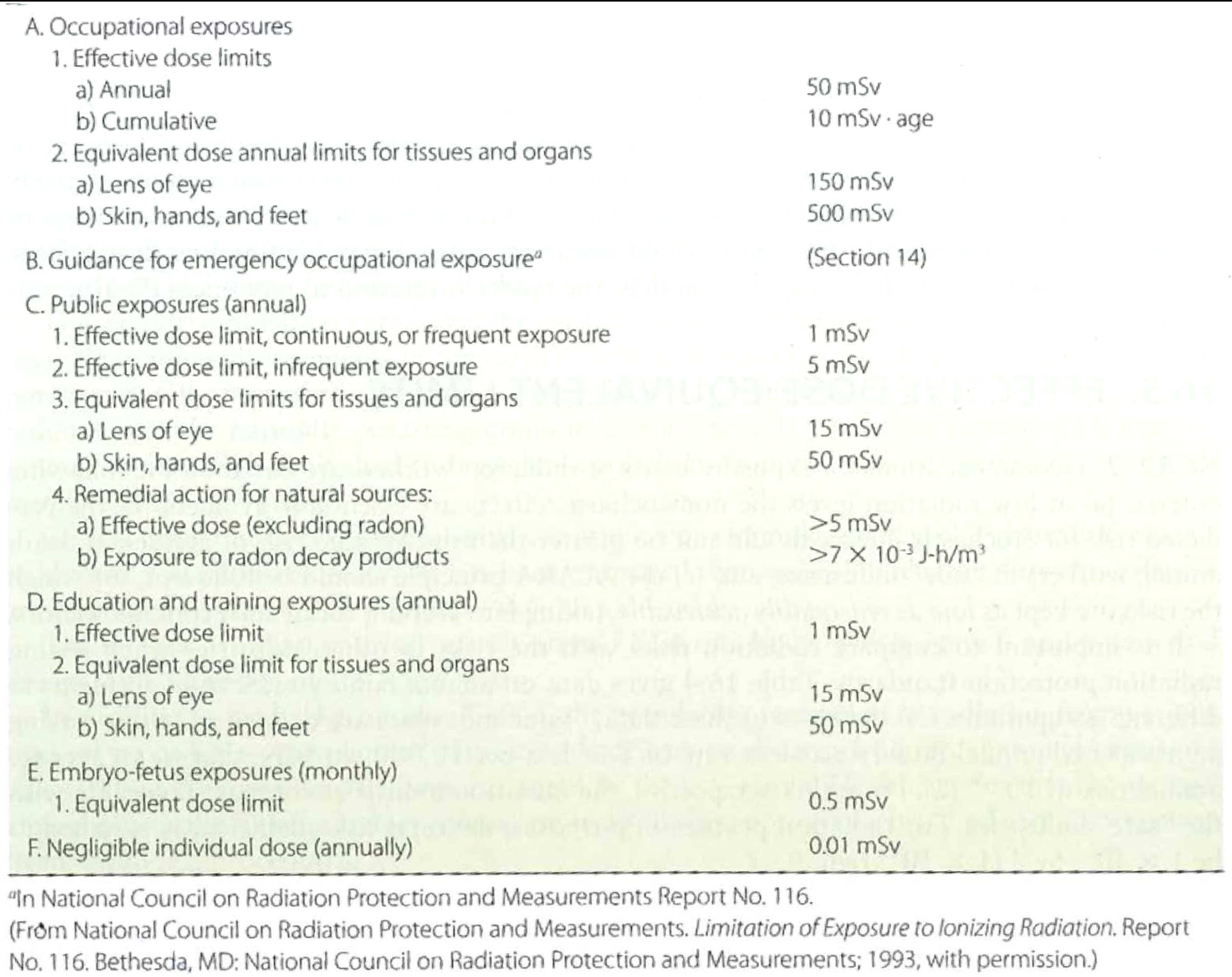
Radiation Survey

- Radiation Survey required for:
  - New Facilities
  - Old installation that have been modified
  - New procedures
- Preliminary survey immediately after accelerator is operational (before acceptance and commissioning)
- Complete survey once accelerator is completely operational
- NCRP 151 provides guidelines for surveys

Effective Dose Equivalent Limits



A. Occupational exposures	
1. Effective dose limits	
a) Annual	50 mSv
b) Cumulative	10 mSv · age
2. Equivalent dose annual limits for tissues and organs	
a) Lens of eye	150 mSv
b) Skin, hands, and feet	500 mSv
B. Guidance for emergency occupational exposure[a]	(Section 14)
C. Public exposures (annual)	
1. Effective dose limit, continuous, or frequent exposure	1 mSv
2. Effective dose limit, infrequent exposure	5 mSv
3. Equivalent dose limits for tissues and organs	
a) Lens of eye	15 mSv
b) Skin, hands, and feet	50 mSv
4. Remedial action for natural sources:	
a) Effective dose (excluding radon)	>5 mSv
b) Exposure to radon decay products	$>7 \times 10^{-3}$ J-h/m^3
D. Education and training exposures (annual)	
1. Effective dose limit	1 mSv
2. Equivalent dose limit for tissues and organs	
a) Lens of eye	15 mSv
b) Skin, hands, and feet	50 mSv
E. Embryo-fetus exposures (monthly)	
1. Equivalent dose limit	0.5 mSv
F. Negligible individual dose (annually)	0.01 mSv

[a] In National Council on Radiation Protection and Measurements Report No. 116.

(From National Council on Radiation Protection and Measurements. *Limitation of Exposure to Ionizing Radiation*. Report No. 116. Bethesda, MD: National Council on Radiation Protection and Measurements; 1993, with permission.)

NCRP 116

NCRP 151 Shielding Recommendations

The purpose of radiation shielding is to reduce the effective equivalent dose from a linear accelerator to a point outside the room to a level that is determined by individual states.

NCRP recommendation for **Controlled** Areas:
Shielding design goal (*P*) (in dose equivalent):
0.1 mSv/week (5 mSv/y)

NCRP recommendations for **Uncontrolled** Areas:
Shielding design goal (*P*) (in dose equivalent):
0.02 mSv/week (1 mSv/y)

Shielding design goals are expressed most often as weekly values since the workload for a radiotherapy source has traditionally utilized a weekly format.

Radiation Surveys for Shielding Evaluation

1. Record name of individual performing surveys
2. Record facility name and linac information
3. Record survey instrument manufacturer, model no., and date of calibration.
4. Set machine to desired energy
5. Use maximum field size
6. Set machine to highest dose rate
7. Remove phantom (if one present)
8. Record linac parameters

Radiation Surveys for Shielding Evaluation

9. Set gantry angle at 0°
10. Perform photon and neutron measurements at 30 cm from (outside) the primary barrier
11. Record readings on plans and sections
12. Repeat with gantry angles at 90, 180 and 270 degrees and oblique angles as necessary (wall floor intersections, etc.)
13. Repeat all the above measurements for secondary barriers with phantom in beam

Impact of Pulsed Operation on Linac Monitoring

- Repetition rate vary from ~100 to 400 pulses/sec
- Pulse widths range from ~1 to 10 μs
- Fraction of linac operating time is called Duty Factor (DF)
  - DF = pulse width x rep rate
  - For e.g. DF=100 pulses/s x 1×10^{-6} s = 1×10^{-4}
- Very small DF imposes severe restrictions on instruments
- Peak intensity = Average intensity/DF
  - E.g.: Peak intensity = 10,000 * Average intensity

Impact of Pulsed Operation on Linac Monitoring

- This intense photon pulse will overwhelm any active detector that detects particle electronically
- Instruments with long dead times (GM tubes and proportional counters) saturate
- Scintillation survey meters may become non-linear at high dose rates because PM tubes cannot handle the high dose rate
- Ionization chambers are less influenced but must be operated with adequate voltage to overcome recombination losses

Photon Monitoring Outside Vault

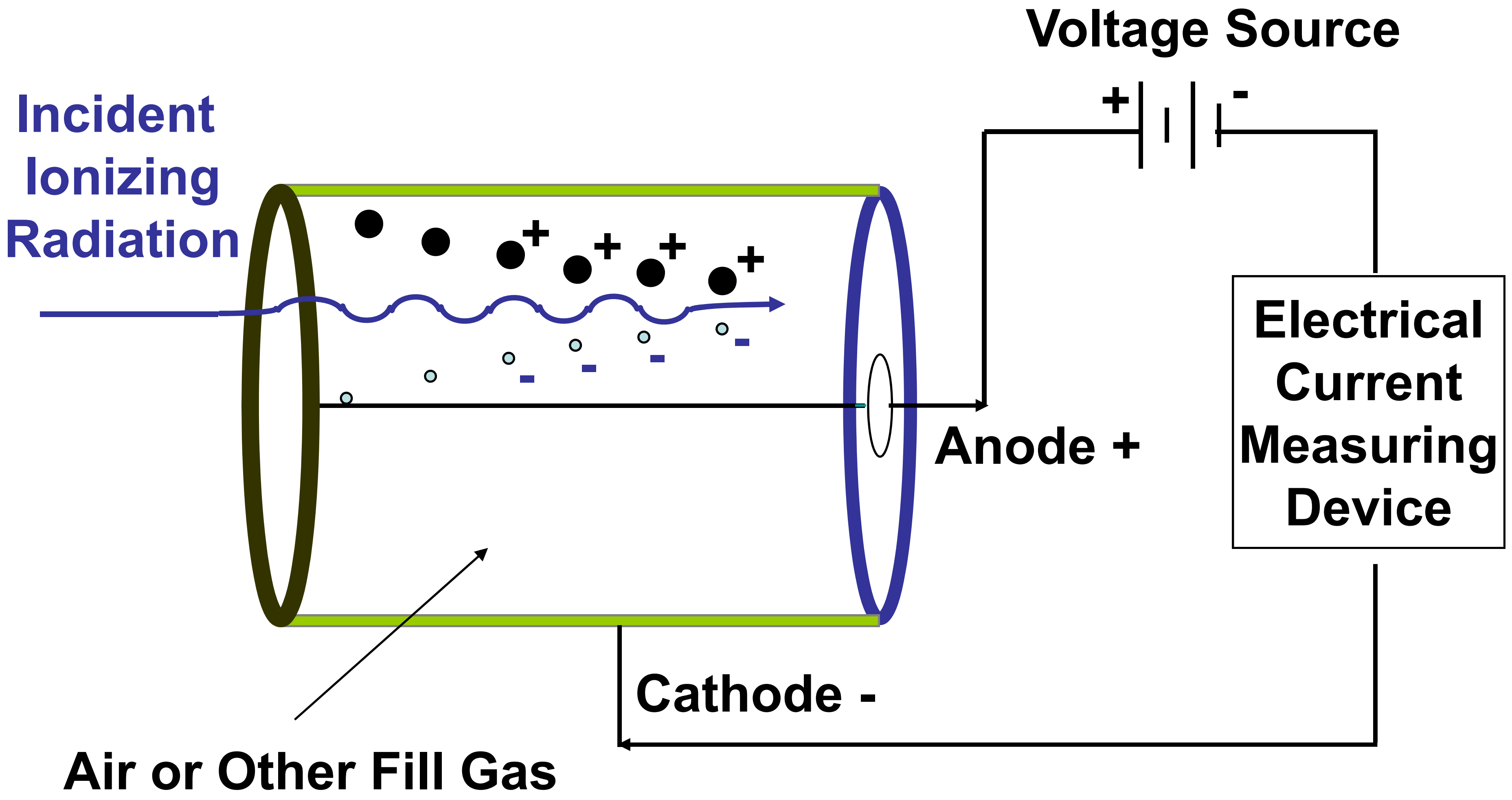
- Since low levels of radiation are measured, the instrument must be sensitive
- The best instrument to use outside the vault is an ionization chamber with rate and integrate modes
- Integrate mode is handy for measurements outside maze where low dose rates exist.
- Range up to 50 mGy/h
- Several commercial instruments available

Inovision 451B, Fluke Medical

Gas-filled detectors

- A gas-filled detector consists of a volume of gas between two electrodes, with an electrical potential difference (voltage) applied between the electrodes
- Ionizing radiation produces ion pairs in the gas
- Positive ions (cations) attracted to negative electrode (cathode); electrons or anions attracted to positive electrode (anode)
- A small current proportional to the radiation dose rate is generated
- In most detectors, cathode is the wall of the container that holds the gas and anode is a wire inside the container

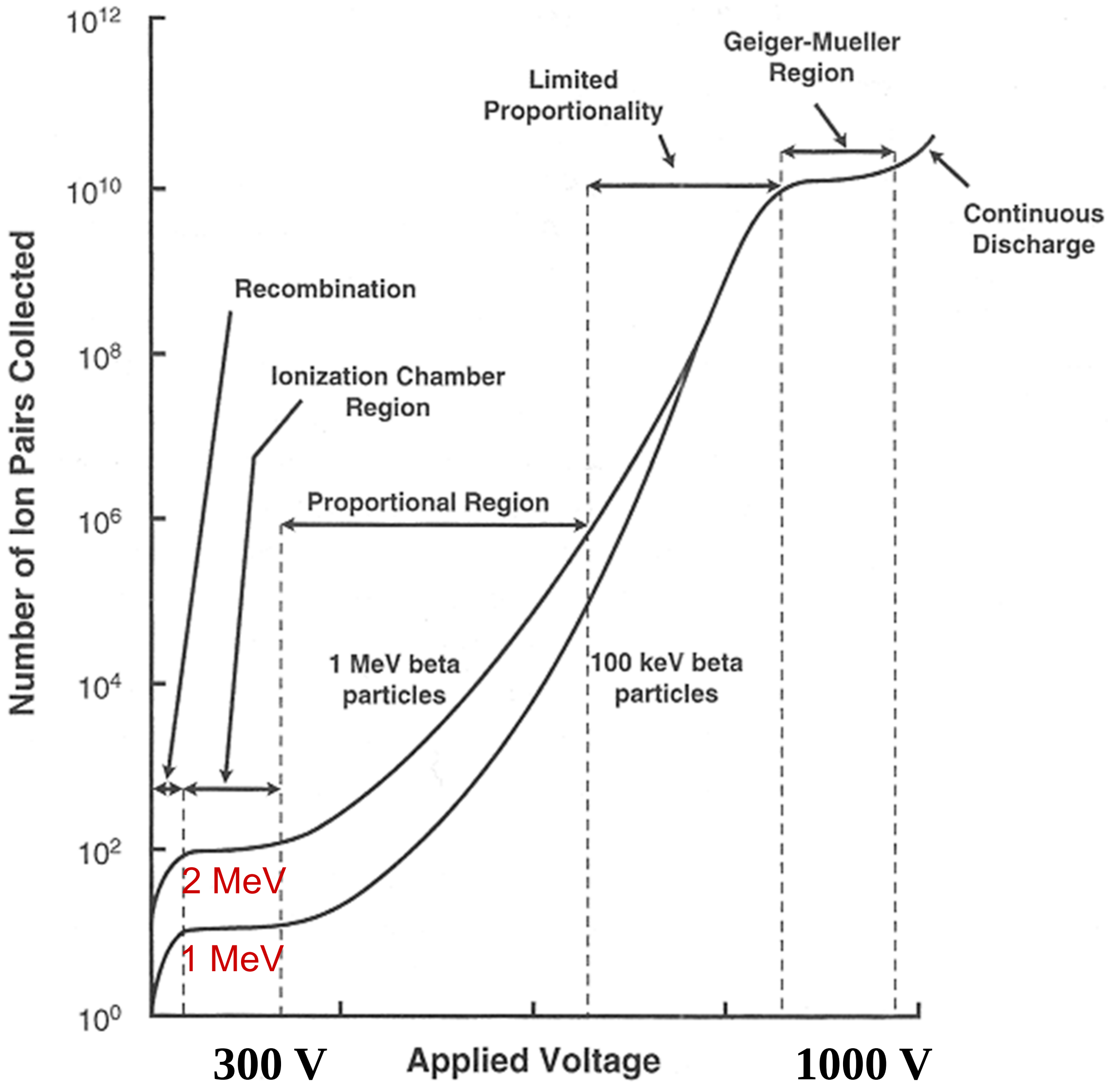
Gas-Filled Detectors



Types of gas-filled detectors

- Three types of gas-filled detectors in common use:
  - Ionization chambers
  - Proportional counters
  - Geiger-Mueller (GM) counters
- Type determined primarily by the voltage applied between the two electrodes
- Ionization chambers have wider range of physical shape (parallel plates, concentric cylinders, etc.)
- Proportional counters and GM counters must have thin wire anode

Regions of operation for gas-filled detectors



- First plateau region is the "ion chamber" mode
- Typically 300 volts applied voltage
- Pulse size is independent of LET
- No secondary ionizations - which would amplify the pulse height
- Pulse size distinction is a disadvantage

Ion Chamber Survey Instruments

- Example of Ion Chamber
- Large collection volume
  - 6 cc; 180 cc volumes
- Readout unit is separate from the detector

Cutie pie exposure rate meter

- Not as sensitive as G-M devices and not affected by pulsed beams such as occur with linacs
- Because of the above, this is the preferred device around high energy radiotherapy accelerators

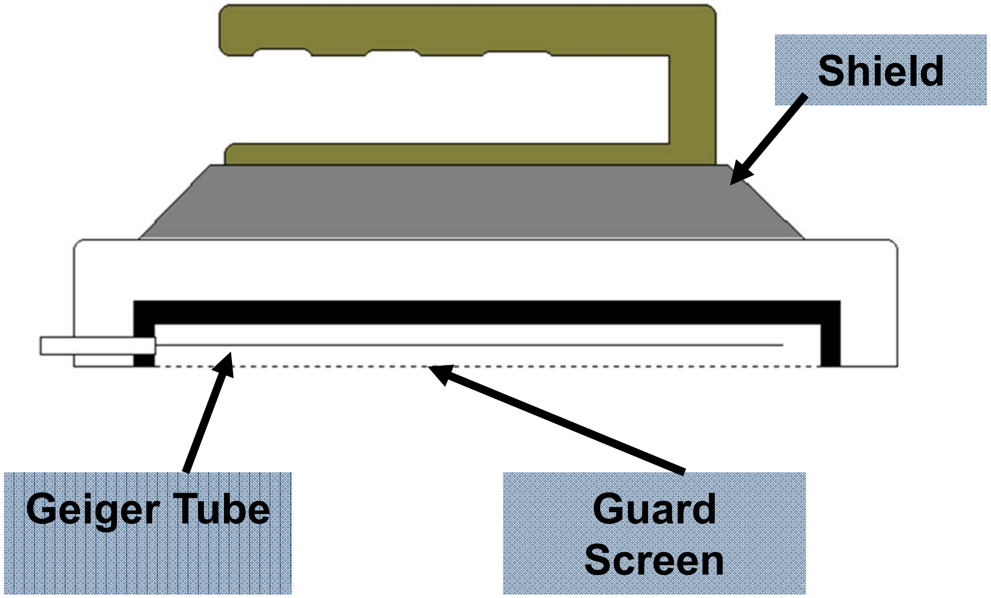
Ionization chamber applications

- Useful for radiation monitoring work especially photons detection
- They have good energy dependence characteristics, and hence desirable for general radiation safety survey's. Results in units of air kerma rate or equivalent dose rate
- Low sensitivity, high accuracy
- Though less sensitive than GM counters, they can be used in high counting rate situations where they give precise results
- To measure only higher energy photons (>40keV) most chambers can be fitted with a cap or sleeve
- They are used in conjunction with a precision electrometer to calibrate x-ray producing equipment

The Geiger Counter

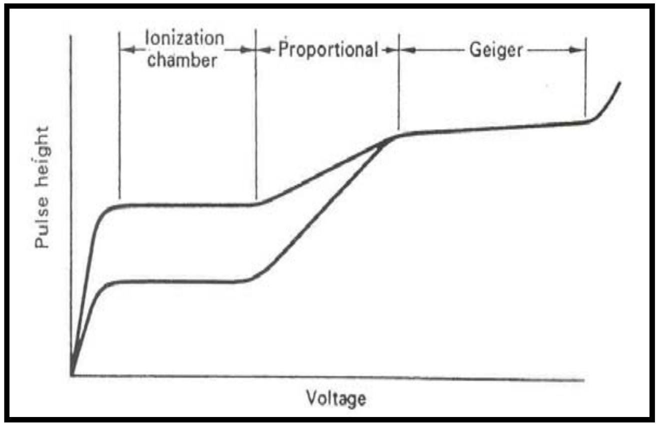
- The oldest type of gas ionization detector -1928
- Widely used in brachytherapy
- Sensitive to low levels of radiation
- Simple electronics

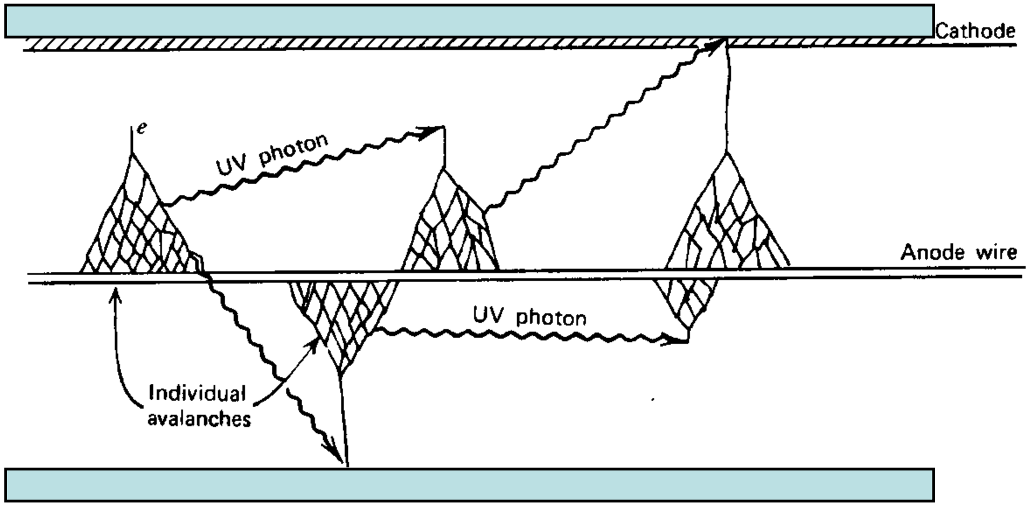
A Pancake Probe



The Geiger Counter

- Operates in the “Geiger Counter” region.
- Voltage is sufficiently high that both ions of the initiating ion pair are accelerated.
- Accelerated ions cause additional ionizations (avalanche).
- Accelerated +ve ions strike cathode (tube shell), cause excitations of cathode molecules, yielding UV production.
- UV is additional source of gas ionization/excitation.
- When intense ionization occurs in the tube the E-Field along the anode wire drops to zero. This causes dead time.





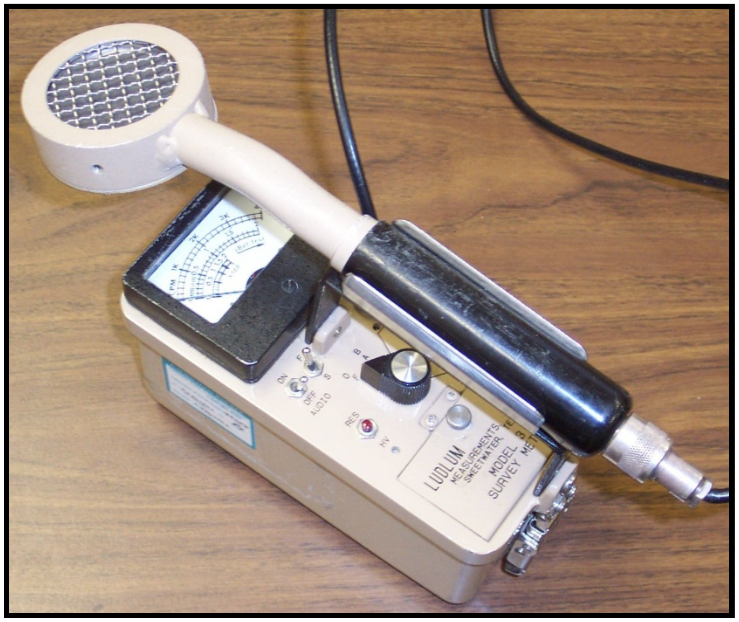
The Geiger Counter

- GM tube can go into continuous discharge when avalanche occurs. Halogen or Alcohol is added to gas to quench the discharge and to absorb the UV produced when accelerated +ve ions strike the shell. Halogen or Alcohol molecules dissociate in this process.
- GM tube is easy to build, simple electronics, cheap
- Choose operating voltage for G-M region at 1/3 to 1/2 way up the plateau.
- Lifetime of the tube is limited by the quenching gas - total lifetime is 10^8 - 10^9 ionizations.
- If voltage is raised above the Geiger region, the avalanche spreads and continuous discharge occurs. Gas tube cannot operate as a detector above the Geiger region.

The Geiger Counter

- Output pulses occur independent of size of initiating ionization - no discrimination with LET of the radiation
- GM detectors suffer from extremely long dead times – seldom used when accurate measurements are required of count rates greater than a few hundred counts per second
- Portable GM survey meter may become paralyzed in a very high radiation field – should always use ionization chamber instruments for measuring such fields
- In general, GM survey meters are inefficient detectors of x-rays and gamma rays
- Over-response to low energy x-rays – partially corrected by placing a thin layer of higher atomic number material around the detector

Geiger Müller-tube



- Useful for area monitoring, room monitoring, personnel monitoring
- Useful for brachtherapy procedures such as to find lost radioactive seeds survey incoming packages, etc.
- Care required in regions of high dose rate or pulsed beams as reading may be inaccurate

Sample Survey Table

15 MV

	Locations	TrueBeam 4					Maximum Observed (mSv/hr)	W (Gy/wk)	TADR (Gy/hr)	T Occupancy	Corrected (mSv/wk)
		Primary - Observed exposure rate (mSv/hr)									
		0	90	180	270						
Blue Basement	Wall near maze				0.004275	controlled	0.004275	50	360	0.1	0.000059
	Mechanical Room		0.005750			uncontrolled	0.005750	50	360	1	0.000799
	BB.5001				0.001800	controlled	0.001800	50	360	1	0.000250
		Secondary - Observed exposure rate (mSv/hr)									
		0	90	180	270						
	Mechanical Room	0.000200	0.000000	0.000000	0.000000	uncontrolled	0.000200	50	360	1	0.000028
	Storage Room	0.000600	0.000200	0.000300	0.000400	controlled	0.000600	50	360	0.1	0.000008
	BB.5052a	0.008100	0.006200	0.007200	0.006700	controlled	0.008100	50	360	0.1	0.000113
	BB.5052	0.000100	0.000200	0.000100	0.000100	controlled	0.000200	50	360	1	0.000028
	Door	0.008000	0.006700	0.007100	0.009200	controlled	0.009200	50	360	0.1	0.000128
	BB.5049a	0.012100	0.010400	0.009200	0.017200	controlled	0.017200	50	360	0.1	0.000239
	BB.5001a	0.004300	0.003000	0.002200	0.004000	controlled	0.004300	50	360	1	0.000597
	Console	0.004300	0.003000	0.002200	0.004000	controlled	0.004300	50	360	1	0.000597
	BB.5001	0.005300	0.004000	0.005100	0.022000	controlled	0.022000	50	360	1	0.003056
	Neutrons (door)	0.007000	0.005000	0.006000	0.006000	controlled	0.007000	250	360	1	0.004861
Ground Floor		Primary - Observed exposure rate (mSv/hr)									
		0	90	180	270						
	5179			0.000050		uncontrolled	0.000050	50	360	1	0.000007
	5182			0.000500		uncontrolled	0.000500	50	360	1	0.000069
	5183			0.000050		uncontrolled	0.000050	50	360	1	0.000007
	5186			0.000225		uncontrolled	0.000225	50	360	1	0.000031
	5187			0.000050		uncontrolled	0.000050	50	360	1	0.000007
	Hallway			0.000350		uncontrolled	0.000350	50	360	0.2	0.000010
		Secondary - Observed exposure rate (mSv/hr)									
		0	90	180	270						
	5179	0.000100	0.000200	0.000100	0.000200	uncontrolled	0.000200	50	360	1	0.000028
	5182	0.000300	0.000200	0.000600	0.000200	uncontrolled	0.000600	50	360	1	0.000083
	5183	0.000200	0.000200	0.000100	0.000200	uncontrolled	0.000200	50	360	1	0.000028
	5186	0.000100	0.000300	0.000300	0.000100	uncontrolled	0.000300	50	360	1	0.000042
	5187	0.000200	0.000100	0.000100	0.000200	uncontrolled	0.000200	50	360	1	0.000028
	Hallway	0.000200	0.000200	0.000900	0.000200	uncontrolled	0.000900	50	360	0.2	0.000025

TADR	Time averaged dose-rate equivalent

Limits		
Controlled	0.1	mSv/wk
Uncontrolled	0.02	mSv/wk

Example of what can go wrong!!!

Outside Consultant to Architect - Design criteria for uncontrolled regions 100 mR/yr (~1 mSv/yr)

No comprehensive final report

No independent peer review

Example of what can go wrong!!!

- 400 MU/min with no phantom, measured exposure rates on the floor above:

Vault 1	7 mR/h
Vault 2	7 mR/h
Vault 3	18 mR/h
Vault 4	95 mR/h

Example of what can go wrong!!!

- Assuming 1 hour of beam on time per week towards the ceiling, 50% attenuation by the patient, 8 mR/hr x 0.5 x 50 weeks/yr results in a total annual exposure of approximately 200 mR/yr.
- Thus the design criteria was not met.
- 1 hour of beam time is conservative (more like 4 to 5 hours per week).

Example of what can go wrong!!! Recommendations

- For vaults 1, 2, and 3, install one tenth value layer (TVL) of additional shielding.
- The second floor was finished.
- The carpet was removed. The cement floor was jack hammered. Additional layer of lead bricks were added.

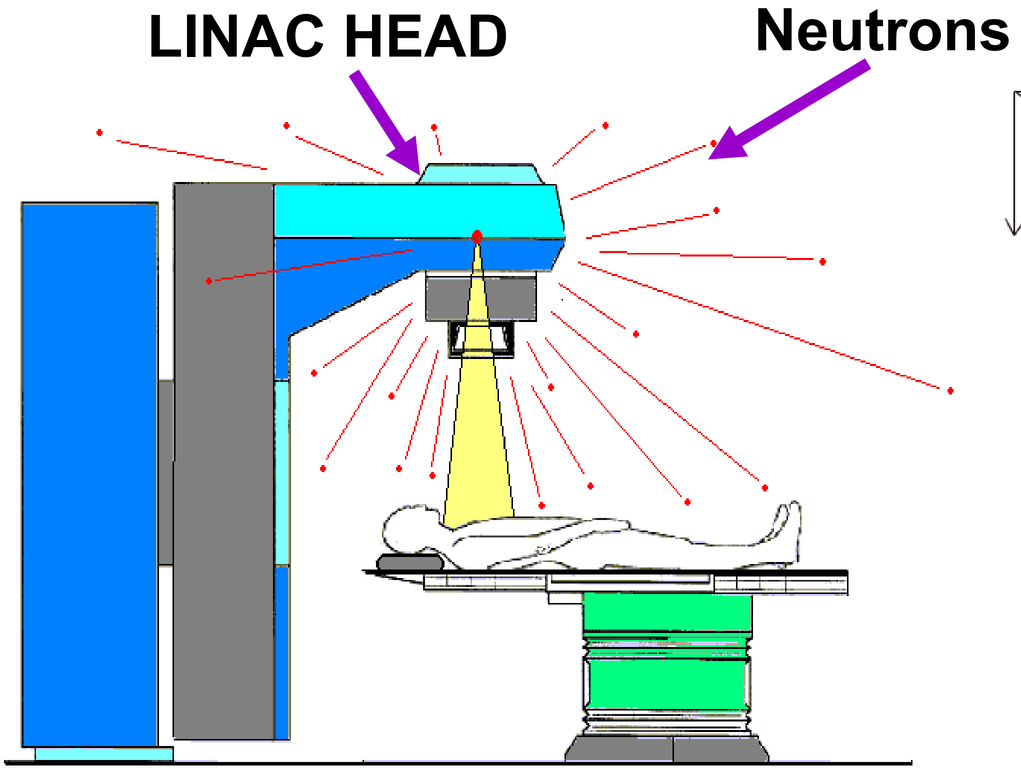
Example of what can go wrong!!! Recommendations

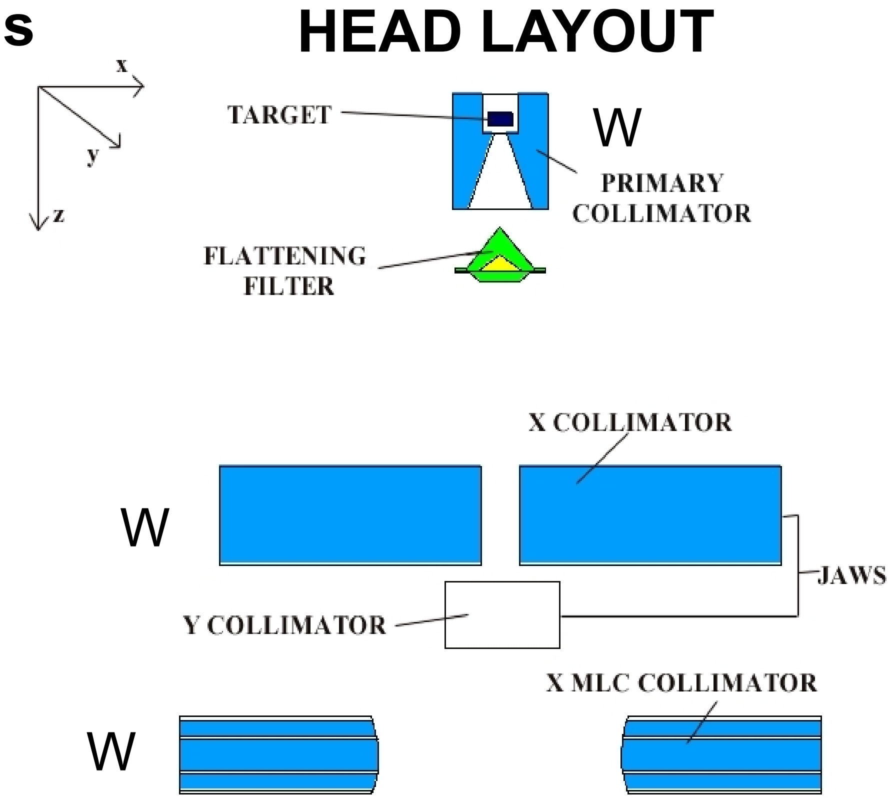
- For vault 4, the second floor and the vaults were already completed.
- Lead bricks were added to a specially designed in-room support structure in order to provide the additional shielding. 3 feet wide, 6 inches (> 2TVL) of lead was added across entire length of room.

Photoneutron Production in Accelerator Head

- Photoneutrons produced by interaction of photon beam with accelerator components
- Produced mainly in the target, primary collimator, flattening filter and jaws/collimators, etc.
- Typical materials used in linac head are copper, iron, gold, lead and tungsten
- Neutron production in electron mode is lower than in photon mode
    - Direct production of neutrons by electrons is at least 2 orders of magnitude lower due to lower electron currents

Photoneutron Production in Linacs





Neutrons are produced by Giant Dipole Resonance (G.D.R.) reaction

Threshold Energy G.D.R.

W: 7.42 MeV

Fe: 10.9 MeV

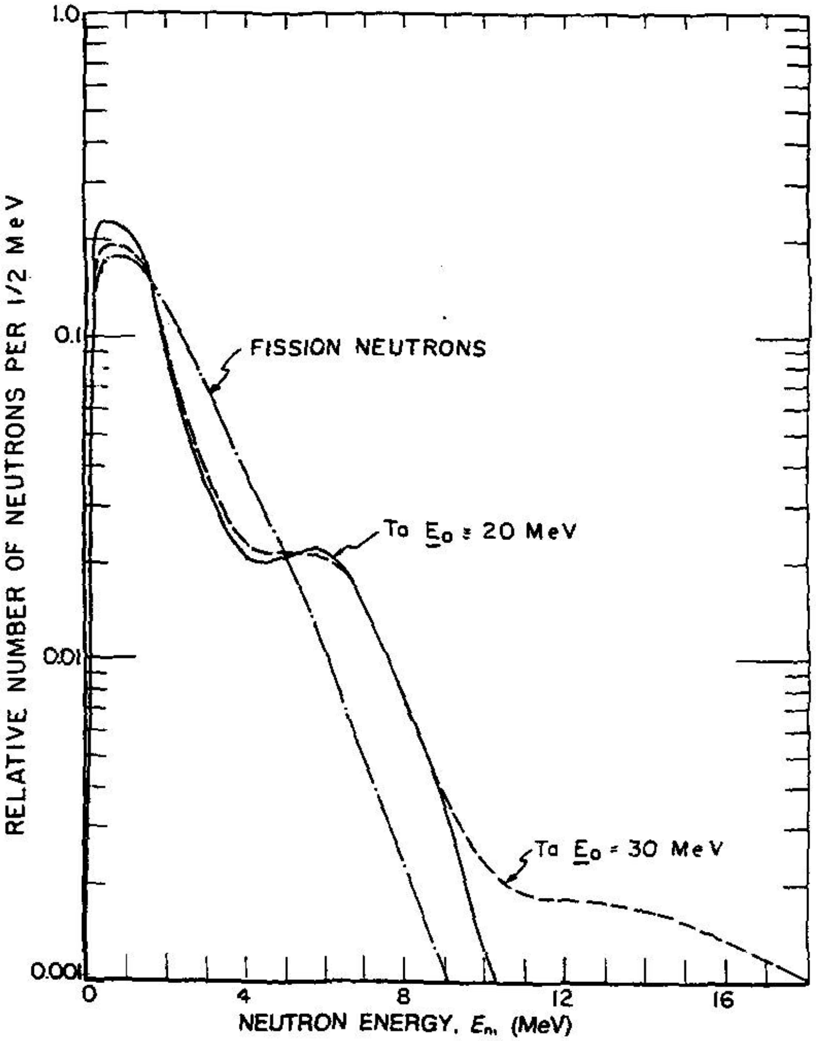
Cu: 9 MeV

Pb: 7.41 MeV

Photoneutron Production

- Photoneutrons consists of direct emission and evaporation neutrons
- Direct Emission
  - Average energy is ~few MeV
  - Forward directed
  - Contributes about 10-20% of neutron yield for Bremsstrahlung energies between 15 MV to 30 MV
- Evaporation neutrons
  - Dominant process in heavy nuclei
  - Emitted isotropically
  - Spectral distribution is independent of photon energy for energies that are a few MeV above neutron production threshold
  - Average energy is 1-2 MeV
  - Closely resembles fission spectra

Photoneutron spectrum for Tantalum with peak Bremsstrahlung energy 20 and 30 MeV

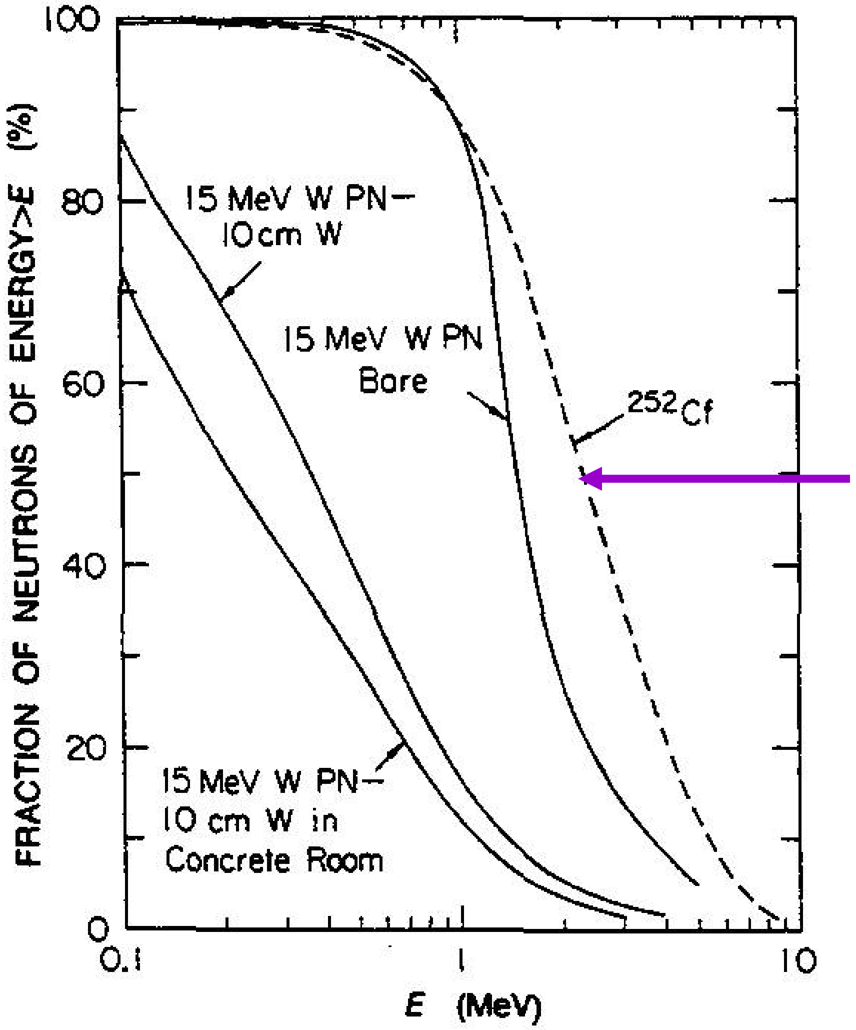


NCRP 79, Fig 24 (1984)

Photoneutron Spectrum

- Photoneutron spectrum from accelerator head resembles a fission spectrum
- Spectrum changes after penetration through head shielding
- Since linac is in concrete vault, room scattered neutrons will further soften the spectrum
- Spectrum outside the concrete shielding resembles that of a heavily shielding fission spectrum
  - Average energy is significantly less than inside room
  - Most neutrons are <0.5 MeV in energy

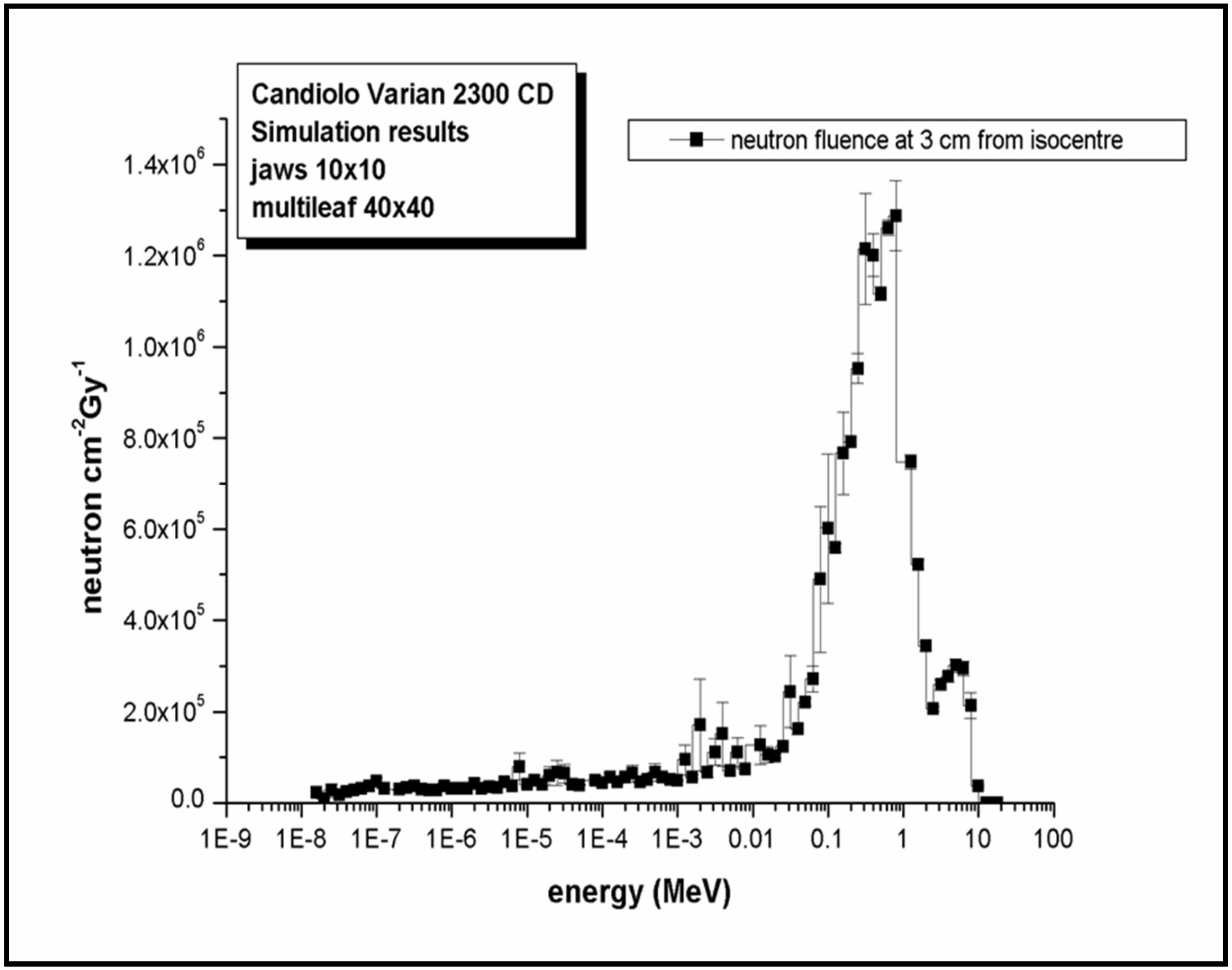
Integral Photoneutron Spectra for 15 MeV Electrons Striking a Tungsten Target



Fission Spectrum (for comparison)

NCRP 79, Fig 25 (1984)

Neutron Spectra at the Patient Plane
Field 10 x 10 cm^2 - SSD 100 cm
(Varian 2300 CD 18 MV)



(A. Zanini et al. PMB. 45 L55-L61, 2000)

Neutron Energy Classification

- Thermal: $E_n = 0.025$ eV at 20ºC

  Typically: $E_n \leq 0.5$ eV (Cd resonance)
- Intermediate: 0.5 eV $< E_n \leq 10$ keV
- Fast: $E_n > 10$ keV
- Epithermal: $E_n > 0.5$ eV

For linacs, neutron spectrum can be divided roughly into two energy regions:

- Thermal (0-0.5 eV)
- Epithermal (>0.5 eV)

Neutron Detection

- Neutron detection is always based on some interaction of the neutron with the nucleus in a target material.
- Since these cross sections are very energy dependent one can distinguish detection of slow (<0.5 eV) and fast (>0.5 eV) neutrons.
- The issue usually is distinguishing the neutrons from the, often much more numerous, gamma rays

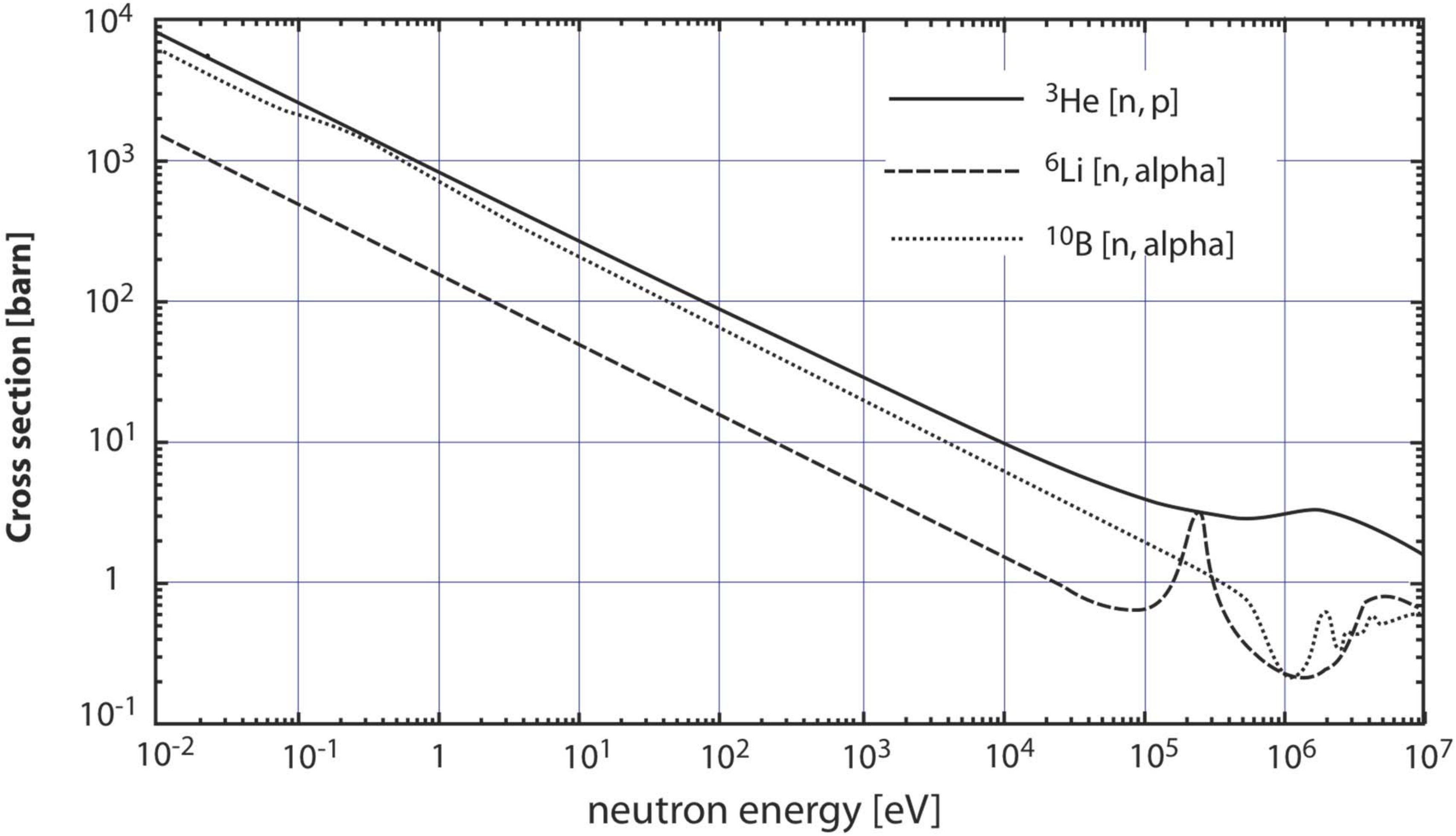
Neutron Detection

Some materials have a very large cross section for slow neutrons

1) Boron	${}^{10}_{5}B + n \rightarrow {}^{7}_{3}Li + \alpha$ ${}^{10}_{5}B + n \rightarrow {}^{7}_{3}Li^{*} + \alpha$	Q=2.79 MeV Q=2.31 MeV
2) Lithium	${}^{6}_{3}Li + n \rightarrow {}^{3}_{1}H + \alpha$	Q=4.78 MeV
3) ${}^{3}He$ reaction	${}^{3}_{2}He + n \rightarrow {}^{3}_{1}H + p$	Q=764 keV

4) ${}^{235}U$ and ${}^{239}Pu$ have very large cross sections for slow neutrons, ${}^{238}U$ or ${}^{237}Np$ for neutrons with energy> 1 MeV very large Q value.

5) ${}^{157}Gd$ gamma and beta emission



Mean free path of thermal neutrons

- in ^{3}He gas ≈ 7cm
- in solid ^{10}B ≈ 70µm

Thermal Detectors

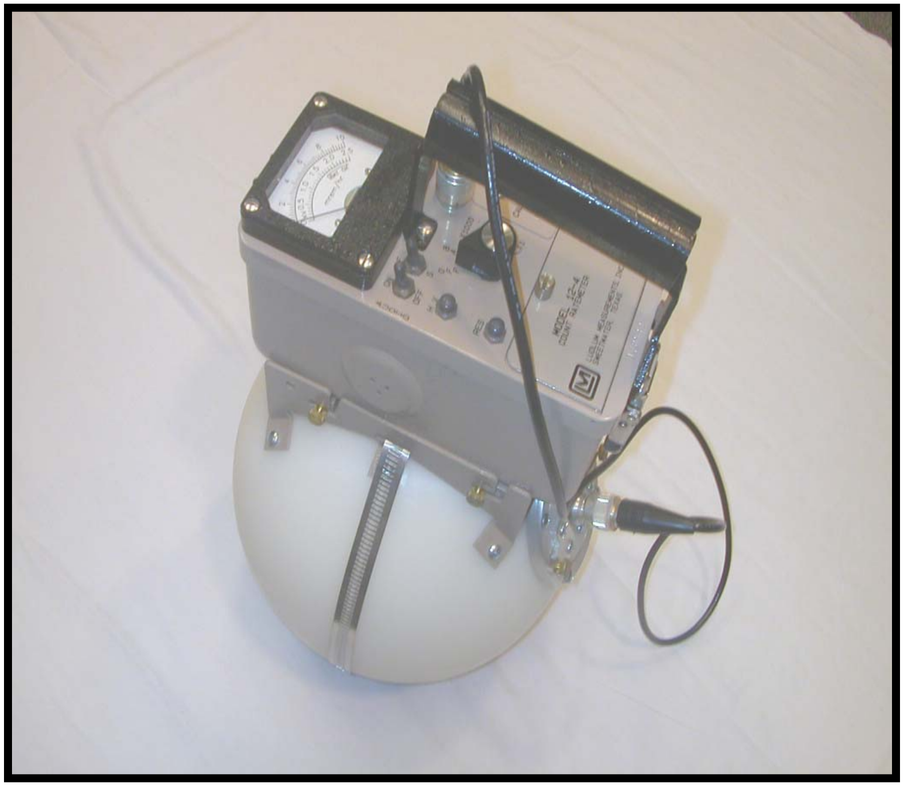
- BF_3 Proportional Counter
  - $^{10}B(n_{th},\alpha)^7Li$, $E_Q=2.31$ MeV, $\sigma=3840$ barns
  - α and recoil ^7Li nucleus produce large pulse, orders of magnitude higher than photon pulse
  - Excellent photon rejection, low cost
  - Most commonly used outside shielded therapy rooms

Thermal Detectors

- ^{3}He Proportional Counter
  - ^{3}He(n_{th},p)^{3}H, E_Q= 0.76 MeV, σ = 5330 barns
  - More sensitive, more stable, much more expensive
- LiI(Eu) Scintillator
  - ^{6}Li(n_{th},α)^{3}H, E_Q= 4.78 MeV, σ = 940 barns
  - Very high sensitivity, poor photon rejection
  - Difficult to use in mixed photon-neutron fields

Neutron Rem Meter

- A gas detection tube (BF_3) is located at the centre of a polyethylene sphere with a thin cadmium filter.
- Sphere moderates neutrons to permit detection by BF_3 tube
- Energy range 0.025 eV to 10 MeV
- Gamma radiation is rejected



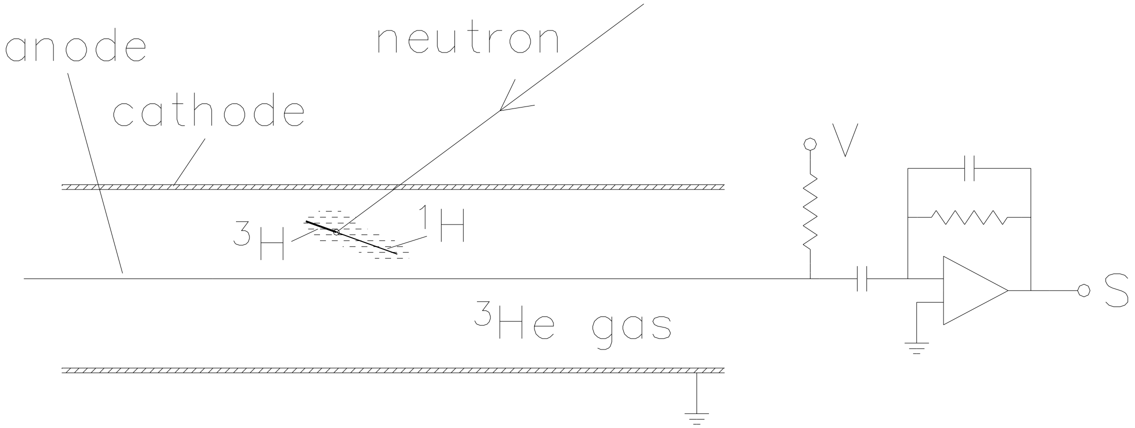
Rem-Meters

- Consist of a neutron moderator (hydrogenous like material e.g. polyethylene) surrounding a thermal detector
- Moderator slows down fast and intermediate neutrons which are then detected by the thermal detector
- Useful in radiation fields for which spectrum is not well characterized
- Important to have a rough idea of the spectrum

Rem-Meters

- Energy response is determined by size and geometry
- Response is shaped to fit an appropriate fluence to dose-equivalent conversion coefficient over a particular energy range
- Most rem-meters over respond in intermediate energy range
- <u>Provide adequate measure of dose equivalent between 100 keV and 6 MeV</u>
- Pulse pile up at high photon dose rates
- Dead time corrections at high neutron dose rates

^{3}He Proportional Counter

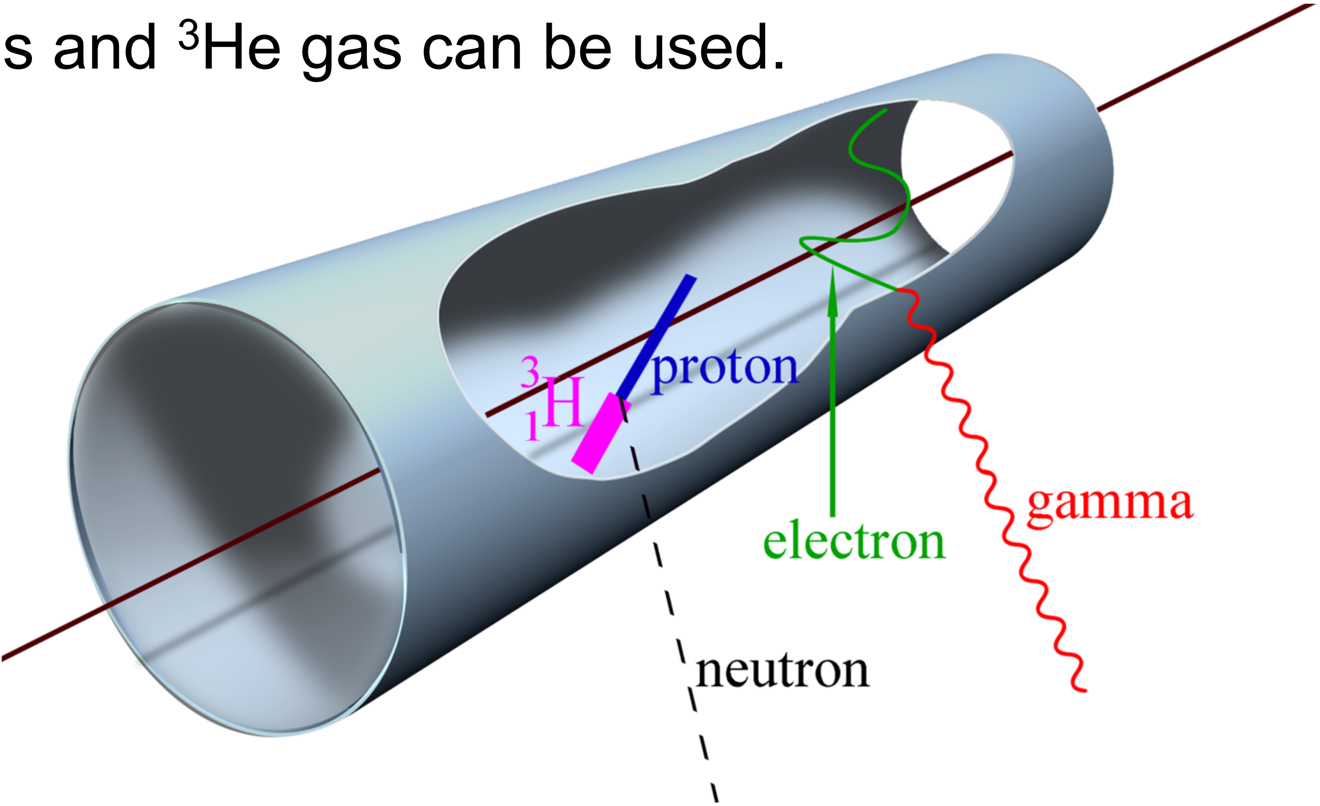


$$n + {}^3He \rightarrow {}^3H + {}^1H + 0.76 MeV$$

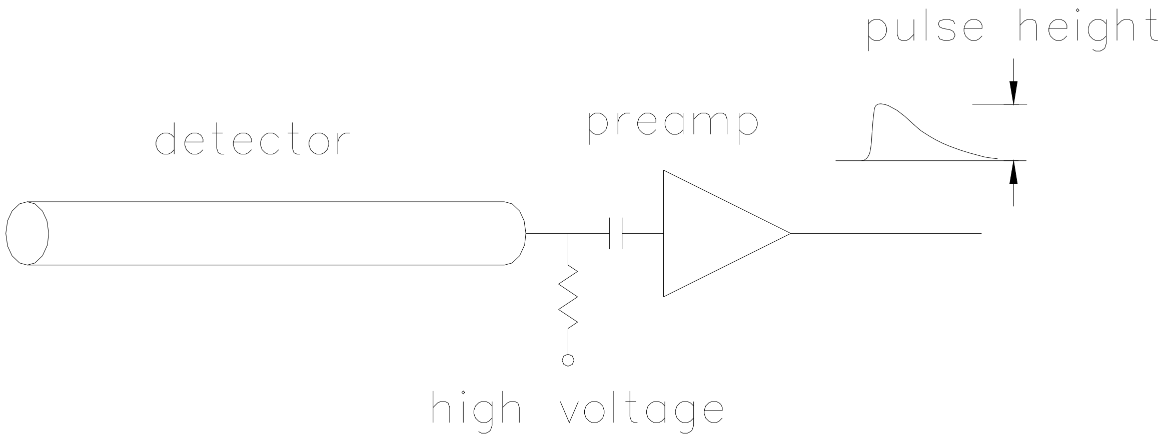
~25,000 ions and electrons produced per neutron (~4×10^{-15} coulomb)

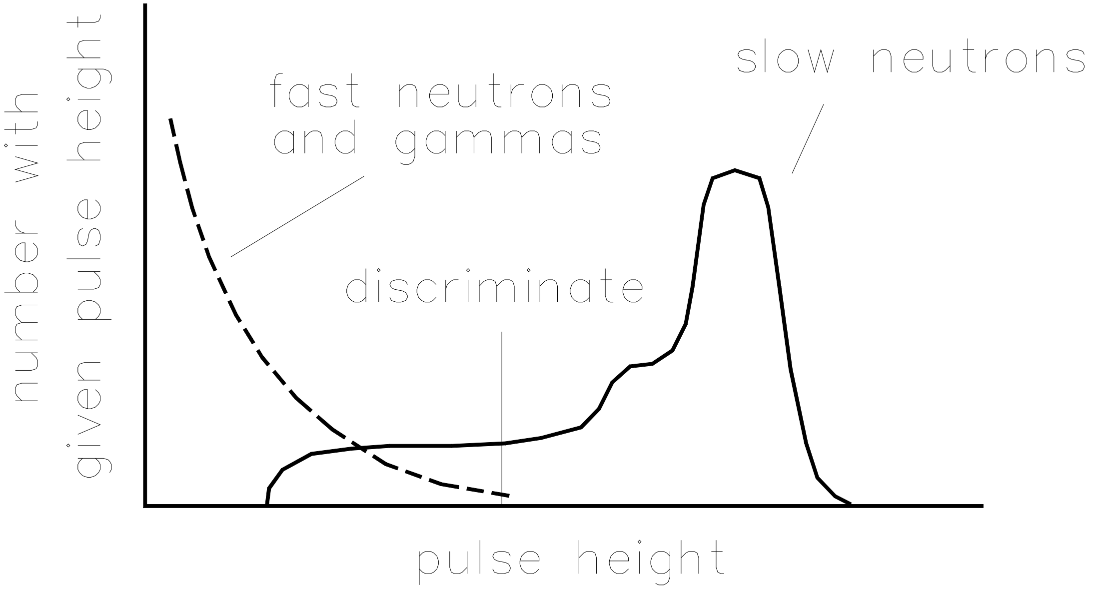
Proportional tubes have very good gamma discrimination. Gamma rays can interact in the walls and produce electrons in the gas, but the energy loss of electrons is small(≈ 2keV/cm), so that these pulses are much smaller that neutron pulses, a suitable pulse amplitude threshold will eliminate most gamma interactions.

BF_3 gas and ^3He gas can be used.



Pulse Height Discrimination





Neutron Monitoring

- Neutron Monitoring inside treatment room may be performed to determine
  - Neutron leakage from accelerator head
  - Neutron dose equivalent in patient plane, inside and outside primary beam
- Prudent to perform spot checks outside treatment room with hydrogenous barriers
- Laminated barriers shall be monitored for neutrons
- Neutrons shall be monitored at door, maze entrance and any opening through shielding

Neutron Monitoring Techniques

- Active Detectors
  - Relies on slowing down or moderating fast neutrons until they reach thermal energies
  - Thermal detector used to detect thermal neutrons
  - Instrument is designed to measure dose equivalent (rem-meters) or fluence (fluence-meters)
  - Can be used for measurements outside the room
- Passive Detectors
  - Relies on direct interaction
  - Method of choice for measurements inside room

Active Detectors

- Can use outside room, outside maze entrance, NOT inside room
  - Rem-meters
  - Moderated BF_3 detectors

Neutron Detector Calibration

- Calibration Sources
  - PuBe (E_{avg} = 4.2 MeV); AmBe (E_{avg} = 4.5 MeV)
  - ^{252}Cf (E_{avg} = 2.2 MeV); PuLi (E_{avg} = 0.5 MeV)
- Use of PuBe and AmBe can lead to systematic uncertainties because of their higher energies
- Spectrum of fission neutrons from ^{252}Cf is similar to a photoneutron spectrum
- Detector calibrated with ^{252}Cf may be adequate for neutrons in primary beam
- Spectrum outside primary beam and outside room shielding represents a heavily shielded photoneutron spectrum
- Thus assumption of fission spectrum may lead to errors in the above case

Neutron Monitoring
Determination of Neutron Dose Equivalent (H)

- Radiation protection quantities defined in human body
- Not amenable to direct measurement
- ICRU developed operational quantitites (ambient, directional, personal dose equivalent)
- Numerical value determined
  - Measuring a physical quantity, fluence ($\Phi(E)$ n/cm^2) which characterizes field
  - Converting to dose equivalent using conversion coefficients ($h_\Phi(E)$)
  - $H = \int h_\Phi(E)\, \Phi(E)\, dE$

McDonald et al. Rad Prot Dos. 78 147-148, 1998

Difficulties With Neutron Monitoring Inside Treatment Room

- Photon interference from primary and leakage photons
- Photon fluence inside beam is 1000 – 4000 x higher than neutron fluence
- Photon fluence outside beam is 10 – 100 x higher than neutron fluence
- Intense photon pulse overwhelms active detector
- Photon pulse pile up
- Photon induced responses in passive detectors from primary beam

Difficulties With Neutron Monitoring Inside Treatment Room

- For moderated detectors measured neutron readings are higher than the repetition rate because
  - Scattered radiation in a room
  - Neutron moderation time allows an event to be detected after pulse has ended
- Neutron detection spread over decades of energy (0.025 eV – several MeV)
  - No single detector can accurately measure fluence or dose equivalent over entire range
- Only passive detectors can be used, except at the outer maze area

Difficulties With Neutron Monitoring Outside Treatment Room

- Neutron pulse spread over several 100 μs because of moderation
- Neutron spectrum resembles heavily shielded fission source-many low energy neutrons (100's of keV and less)
- Most neutrons have energies less than 0.5 MeV outside a well shielded room
- Average neutron energy at outer maze area ~ 100 keV
- Active and passive detectors can be used

Passive Detectors

- Activation detectors (inside room, and in primary beam)
- Bubble detectors (inside and outside room, not in primary beam)
- Solid state track detectors (inside room, not in primary beam)

Activation Detectors

- Stable and reproducible
- Photon interference must be considered
- Thermal neutron detectors
  - Gold (thermal)
  - Indium (thermal)
- Threshold detectors
  - Phosphorous (thermal and fast)

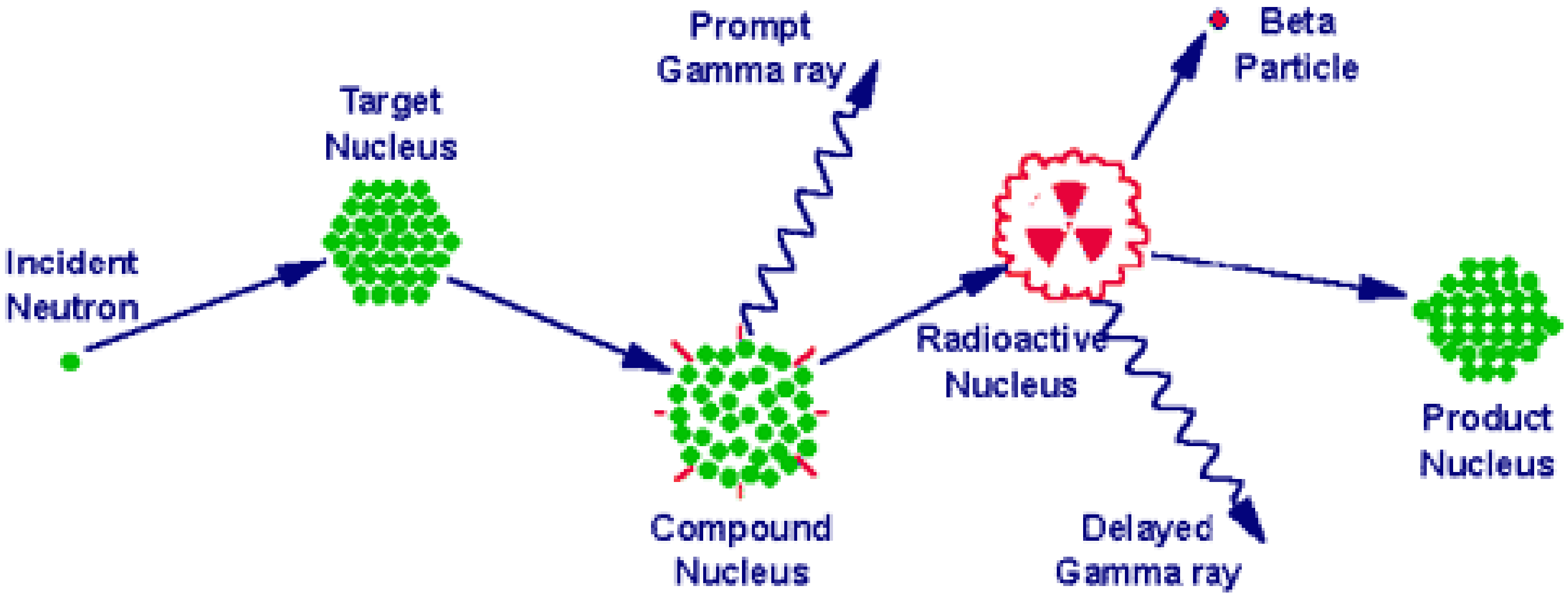
Thermal Neutron Detectors

- Bare foil and cadmium covered foil can be used to measure thermal neutron fluence
- Moderated foil for fast neutron
- Neutron absorption by foil results in production of radioactive nucleus
- Radioactivity can be correlated with incident thermal neutron fluence
- Gold and Indium foils counted with thin window GM, proportional counter, scintillation counter or GeLi detector

Moderated Activation Foils

- Moderator consists of cylinder or polyethylene, 15.2 cm diameter, 15.2 cm in height
- Covered with 0.5 mm cadmium (or with boron shield)
- Moderator provides an energy independent thermal neutron fluence, proportional to incident fast fluence
- For in beam exposures:
  - Use only at energies ≤ 20 MV because of photon induced response in cadmium and moderator lining
  - Field size wide enough to irradiate entire moderator
- Distance between moderators should be 2X diameter of the moderator

Neutron Activation Analysis



Gold Foil Activation

$$^{197}Au + n \longrightarrow {}^{198}Au \longrightarrow \beta + {}^{198}Hg + \gamma$$

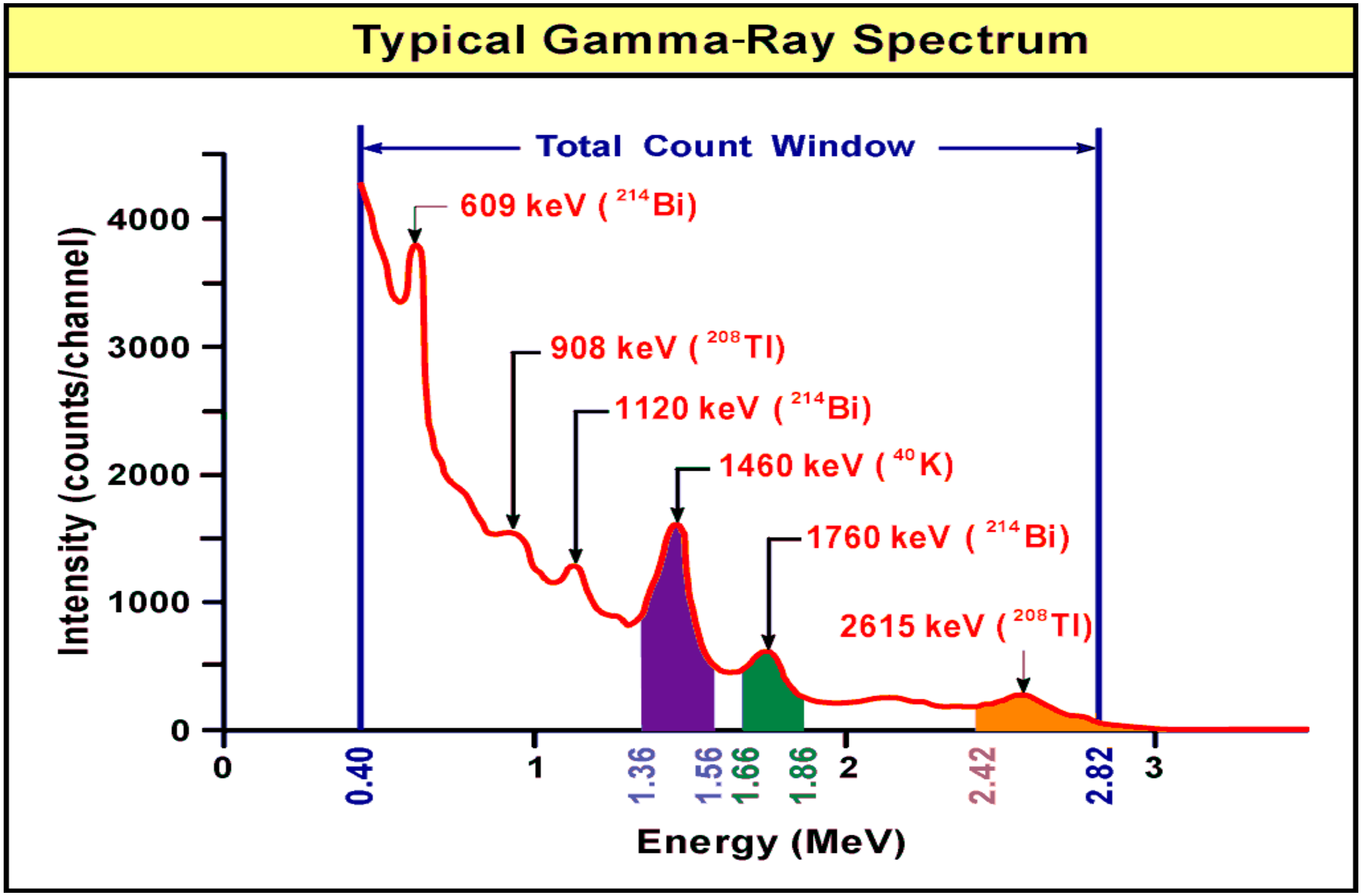
Gamma Spectrometer

γ = 411.8 keV

$$A_0 = N_{Au}\phi\sigma$$
$$A = A_0 e^{-\lambda t_d}\left(1 - e^{-\lambda t_i}\right)$$
$$\lambda = \ln 2 / T_{1/2}$$

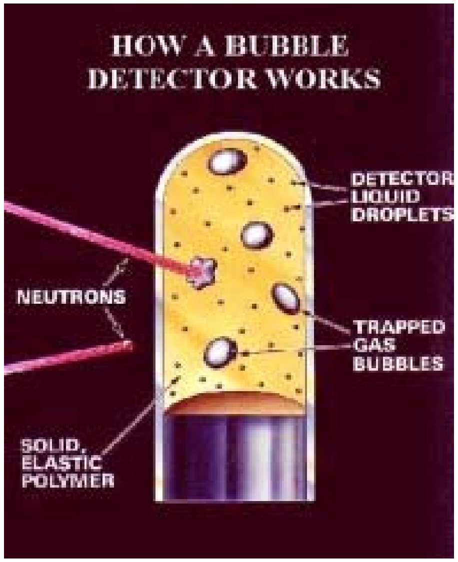
$$\boxed{\phi = \frac{A}{N_{Au}\sigma e^{-\lambda t_d}\left(1 - e^{-\lambda t_i}\right)}}$$

Spectrum Peak Analysis



Bubble Detectors
Bubble Technology Industries- BTI (Canada)

- Easy to use
- High sensitivity
- Reusable
- Integrating
- Allow instant visible detection of neutrons
- Isotropic response
- Not sensitive to gamma



Nisy E. Ipe, AAPM 2006

Bubble Detectors, BTI, Canada

- Consist of minute droplets of a superheated liquid dispersed throughout an elastic polymer
- Detector sensitized by unscrewing the cap
- Neutrons strike droplets producing secondary charged particles
- Charged particles cause droplets to vaporize, producing bubbles
- Bubbles remain fixed in polymer
- Bubbles can be counted by eye or in automatic reader
- Dose is proportional to the number of bubbles

Characteristics of Effective Survey Instruments

- Simplicity of construction -hence easy to fix, low price, etc.
- Ruggedness -Most likely to be handled by several people
- Reliability – Check source typically provided for QA purposes
- Portability -It is often necessary to use the instrument in a number of different locations. Hence should be light, compact, have battery)
- Sensitivity – It must be sensitive to type of radiation being monitored and its energy range. For instances where photons and electrons with energies between 10 and 1000 keV or alpha particles above 3 MeV, a GM detector, ionization chamber or scintillation counter is usually used. If neutrons or low energy photons or beta particles are to be detected, a proportional counter should be used

Area Radiation Monitors

Model 272 remote alarm

Model 375-10 Digital Area Monitor

Prime Alert

Area Radiation Monitors

- Capabilities
  - Measures gamma and x-ray dose rate
  - Wall mounted, 110 V
  - Internal and external alarm units
- Limitations
  - Does not detect beta, alpha, or neutrons
  - No dosimeter function
  - One hard wired remote per monitor
- Best use
  - Fixed site monitor

Accelerator Head Leakage

- Wrap film around accelerator head to identify hot spots
- Measure with ion chamber at 1 m from source [M(L)]
- Measure 10x10 cm^2 open field at isocenter with ion chamber [M(IC)]
- %Leakage = [M(L)/M(IC)]X100