ARDENT

Advanced Radiation Dosimetry European Network Training

Gas Detectors for Neutron Dosimetry and Monitoring

4th Annual ARDENT Workshop

Prague, June 22-26, 2015

Anthony Waker

UOIT

CHALLENGE INNOVATE CONNECT

Gas Detectors - Scope

- Neutron Monitoring vs Neutron Dosimetry
- Counters and Chambers
- Counters – how and why they are used
  - Neutron detection
    - Imaging
    - Nuclear safe guards
  - Radiation Protection Dosimetry
    - through spectrometry
    - through monitoring
    - through cavity dose determination
- Chambers – how and why they are used
  - precision dosimetry for radiobiology and therapy

Neutron Monitoring vs Neutron Dosimetry

- Monitoring

Detection of neutrons, usually thermal neutrons, using instrument response functions to convert a count-rate to a dosimetric quantity such as *ambient dose equivalent.*

Calibration is an essential part of the measurement process

- Dosimetry

Measurement of absorbed dose directly through the measurement of an ionization current generated in a gas cavity of known dimensions. Precision relies on :

  - Full charge collection
  - Ionization to energy conversion (W-value)
  - Properties of materials (stopping powers)
  - Mass of gas in chamber

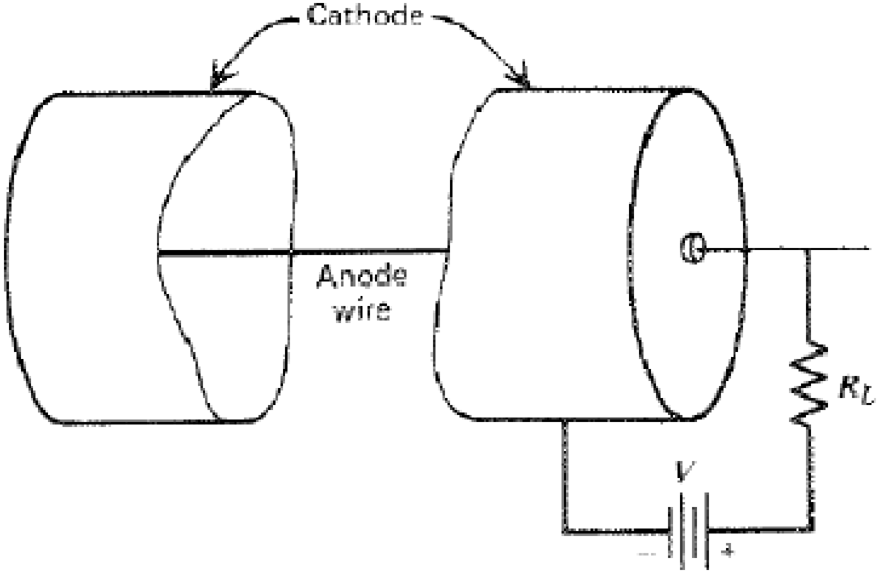
Counters

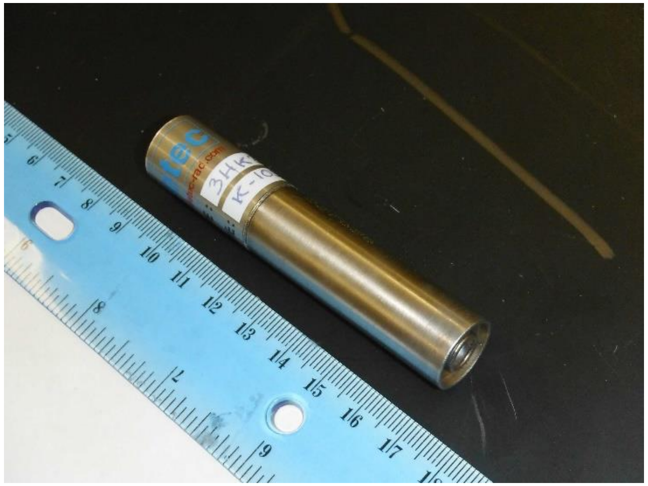
- Proportional Counters (different gas fillings)
  - ^{3}He
  - BF_3
  - Ar-$C0_2$
  - Tissue Equivalent

- Geiger-Muller Counters

Proportional Counters

A proportional counter is a gas-ionization device consisting of a cathode, thin anode wire and fill-gas. Ionization in the fill gas is multiplied providing an amplified signal proportional to the original amount of ionization.

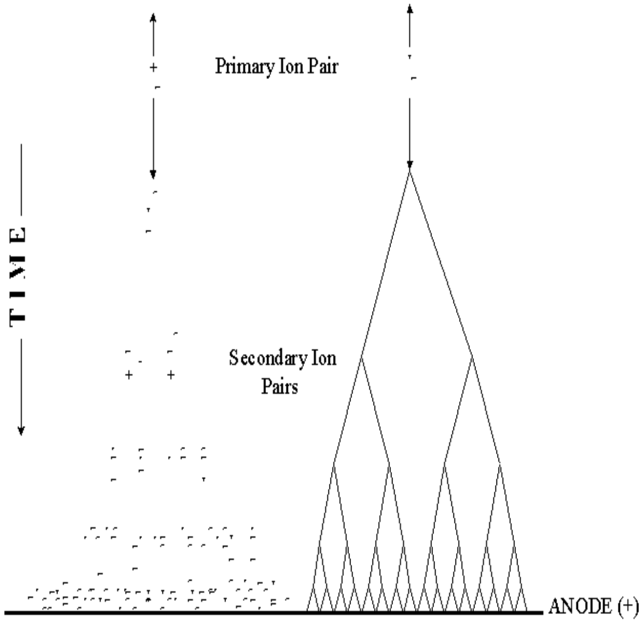




Proportional Counter Gas Gain

The gas-gain achievable in a proportional counter is determined by the first Townsend coefficient α for the counter fill gas used

α itself depends on the reduced electric field in the counter, which is determined by the applied voltage and counter geometry

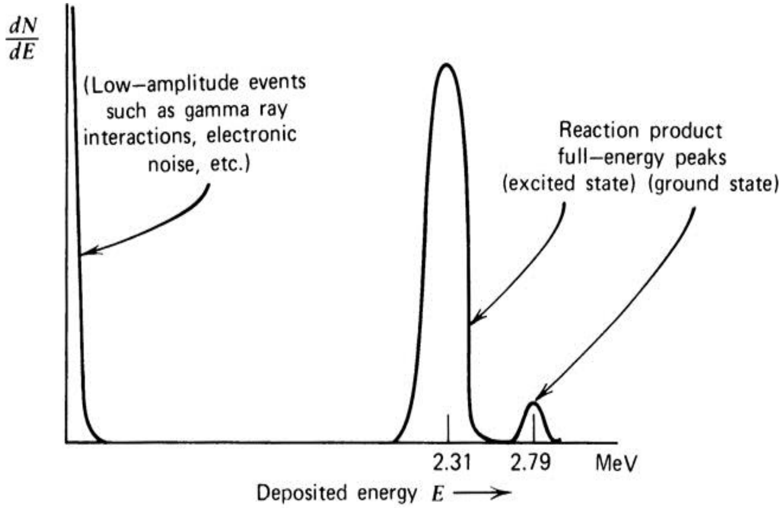


$$\ln(G) = \alpha * d$$

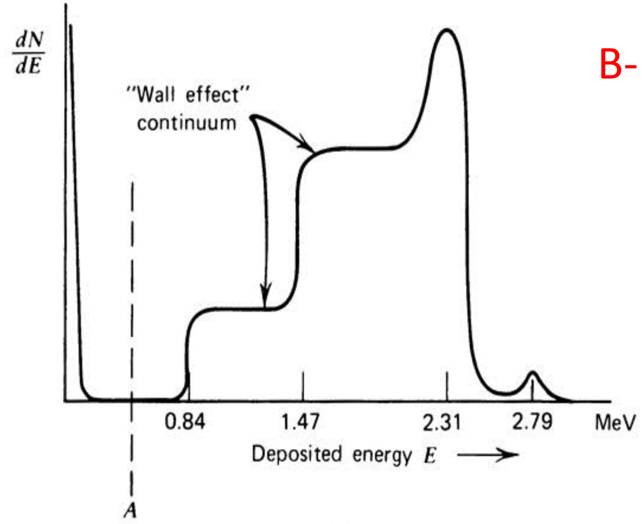
Proportional Counters for Neutron Detection and Monitoring

- Thermal neutron capture reactions
  - $^{10}B(n,\alpha)^7Li$ Q = 2.31 MeV (1.47 MeV; 0.84 MeV)
  - $^{3}He(n,p)^3H$ Q = 764 keV (0.573 MeV; 0.191 MeV)

Proportional Counters for Neutron Monitoring

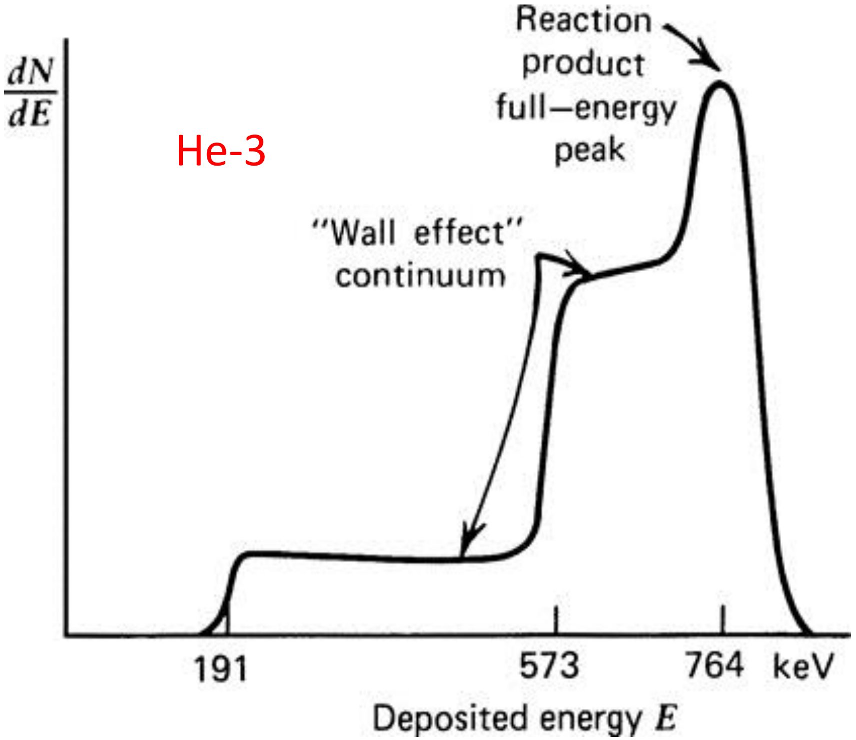


(a)



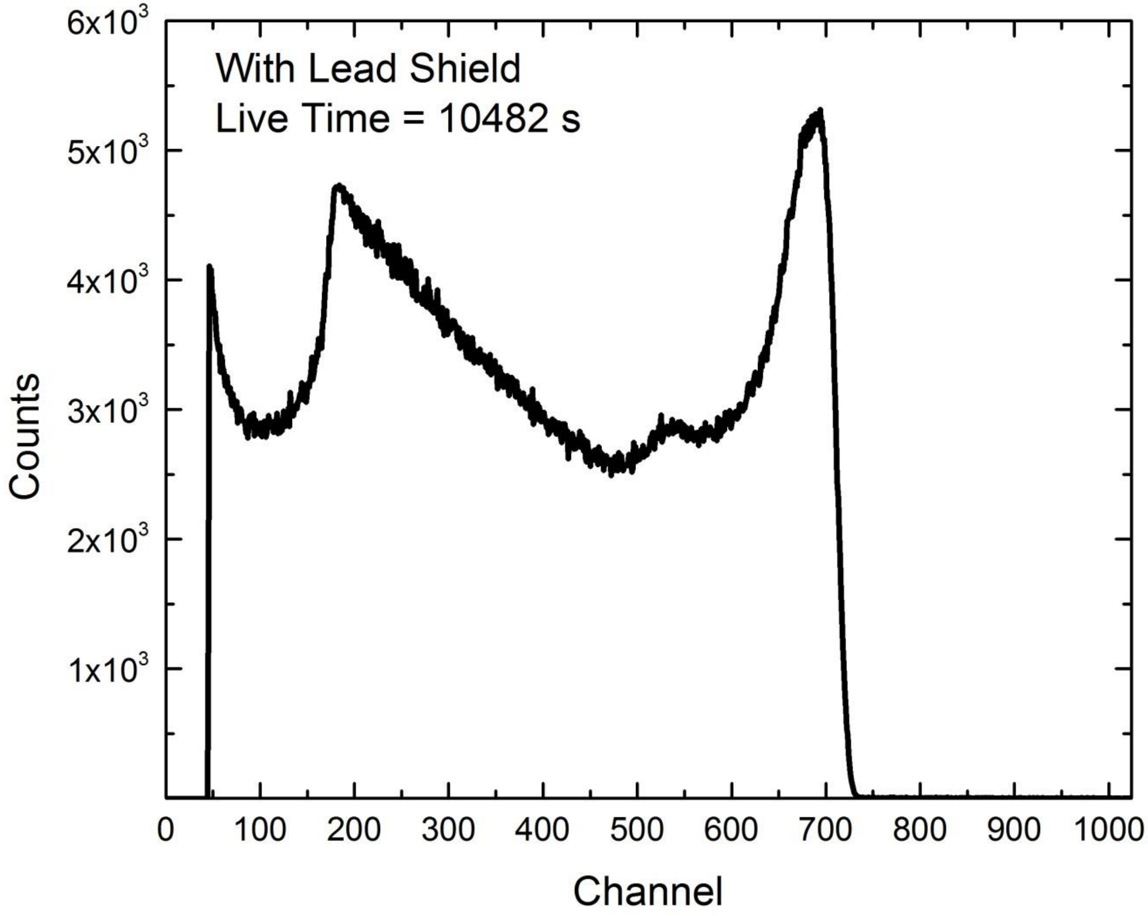
(b)

B-10

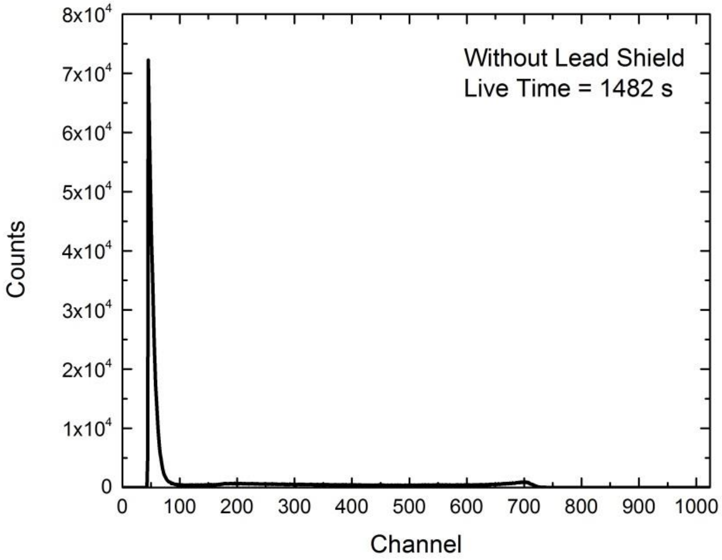


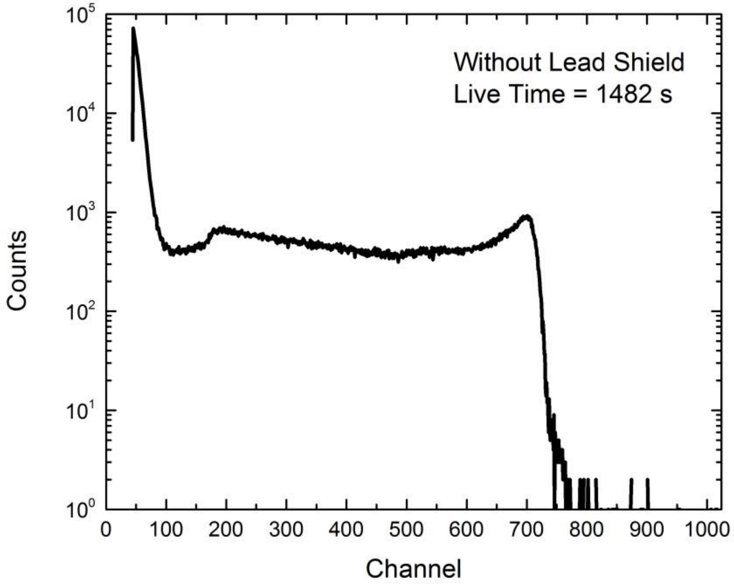
He-3

Proportional Counters for Neutron Monitoring



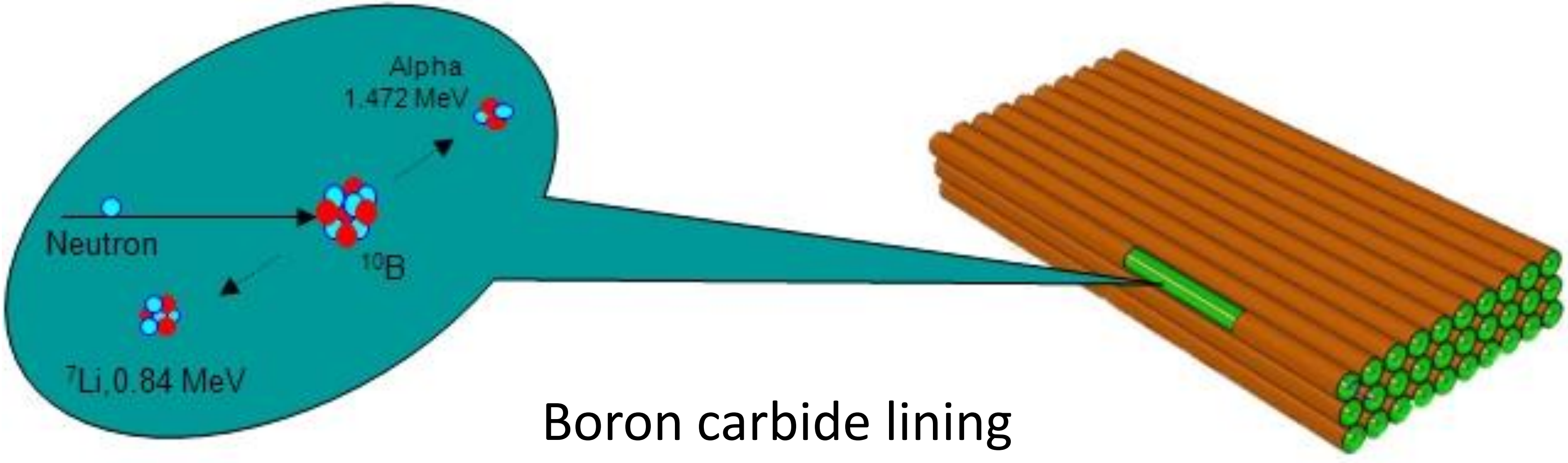
Proportional Counters for Neutron Monitoring





Proportional Counters for Neutron Detection

Boron Coated Straw Counters



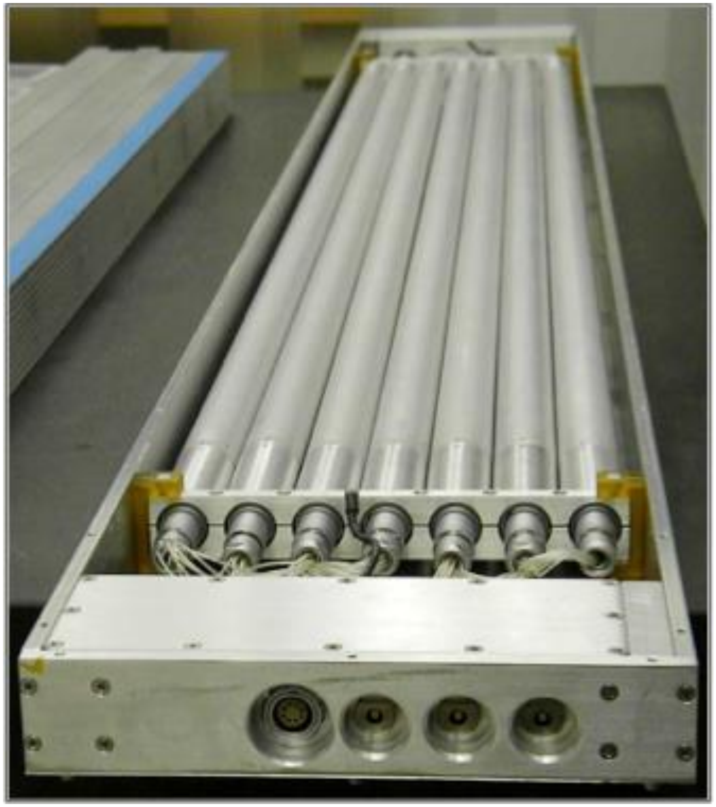
Boron carbide lining
Ar-$C0_2$ gas filling

Proportional Counters for Neutron Monitoring

Boron Coated Straw Counters

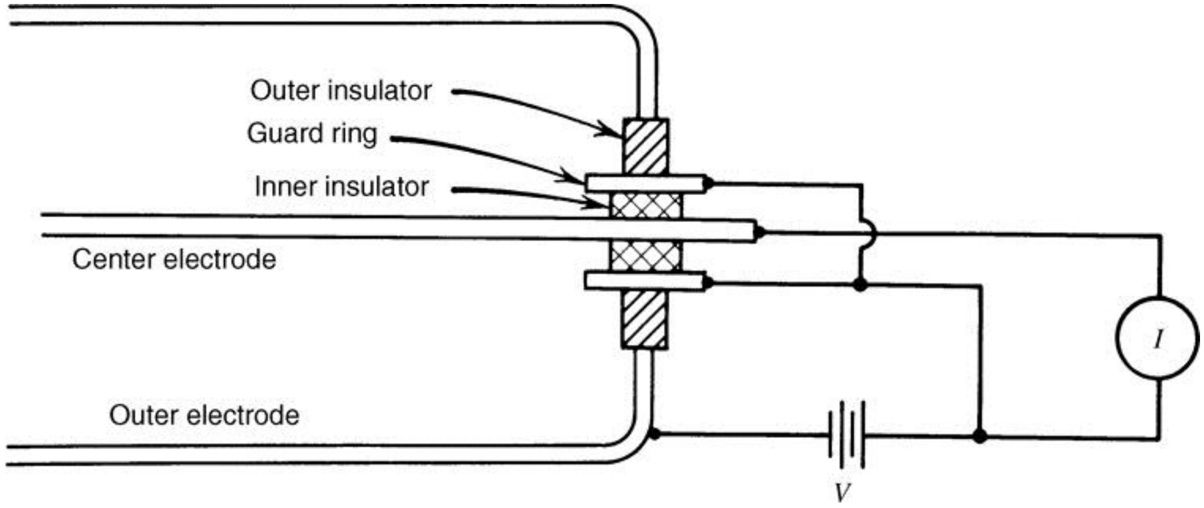
Neutron Detection:

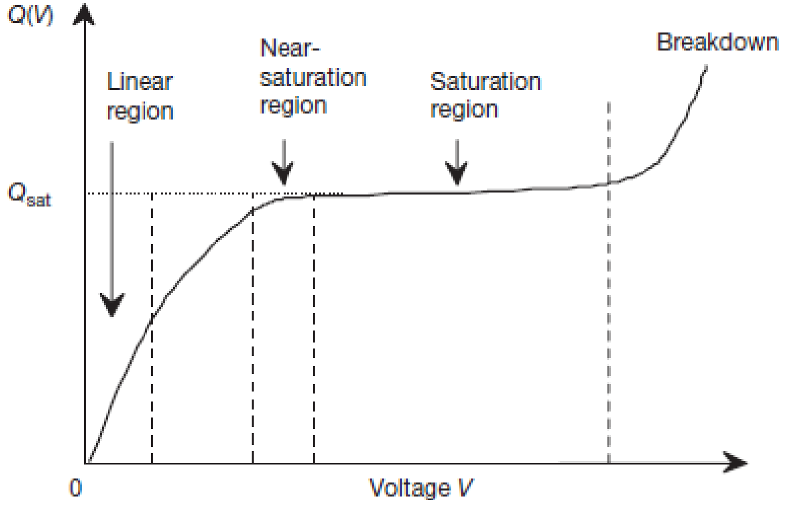
- Imaging
- Nuclear security



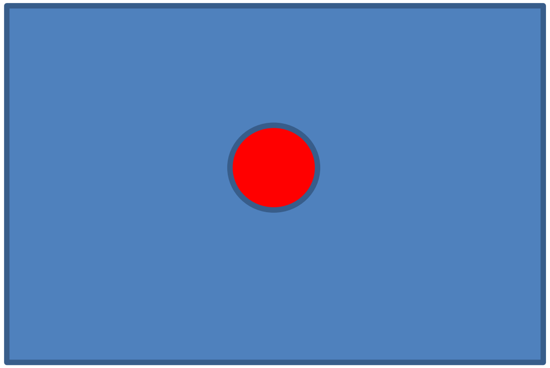
Proportional Technologies, Inc
Innovations in Nuclear Imaging

Ionization Chambers





Dosimetry with Ionization Chambers



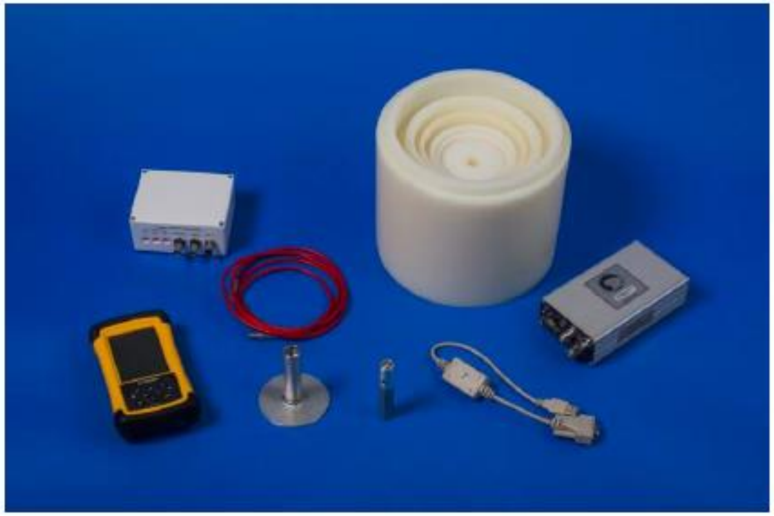
$$D_{matter} = D_{cavity} \cdot \left\{\frac{S}{\rho}\right\}_{cavity}^{matter}$$

$$D_{matter} = Q\left(\frac{W}{e}\right) \cdot \left\{\frac{S}{\rho}\right\}_{cavity}^{matter}$$

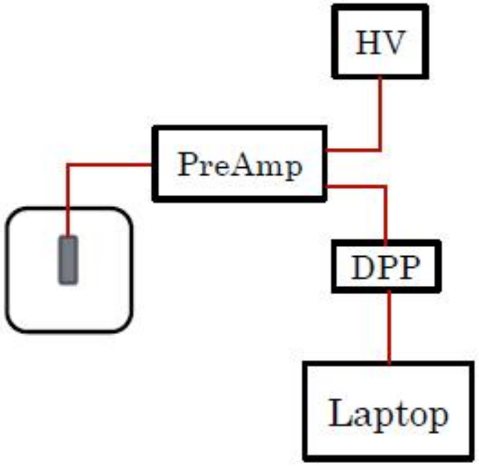
Both the wall material and the gas filling are important in accurate ionization chamber dosimetry as are the charged particles produced by neutron interaction

Radiation Protection Dosimetry Through Neutron Spectrometry

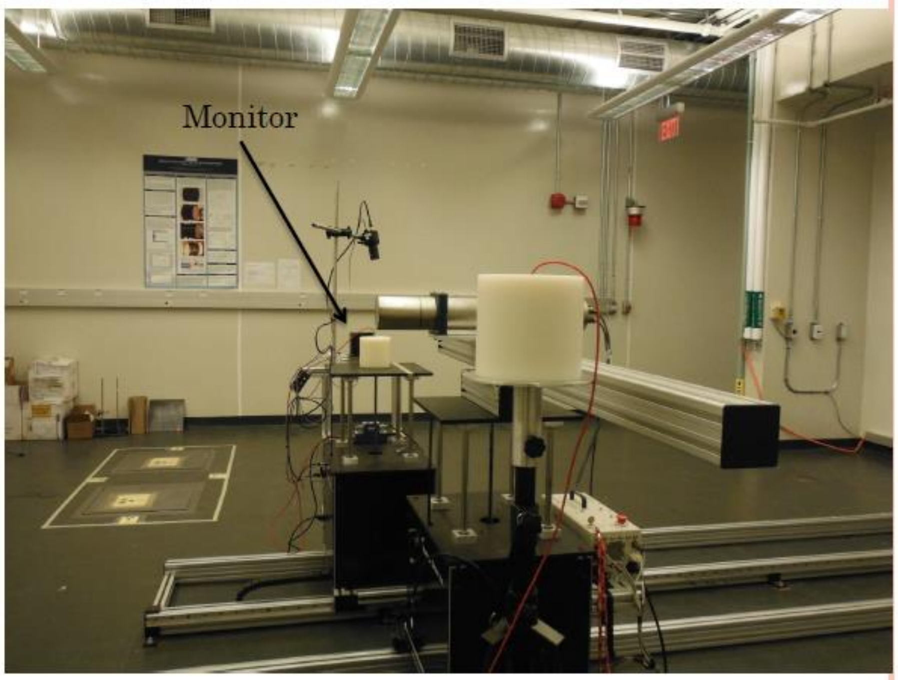
- Equipment



http://detecsciences.com/en/nested-neutron-spectrometer.html



Radiation Protection Dosimetry Through Neutron Spectrometry



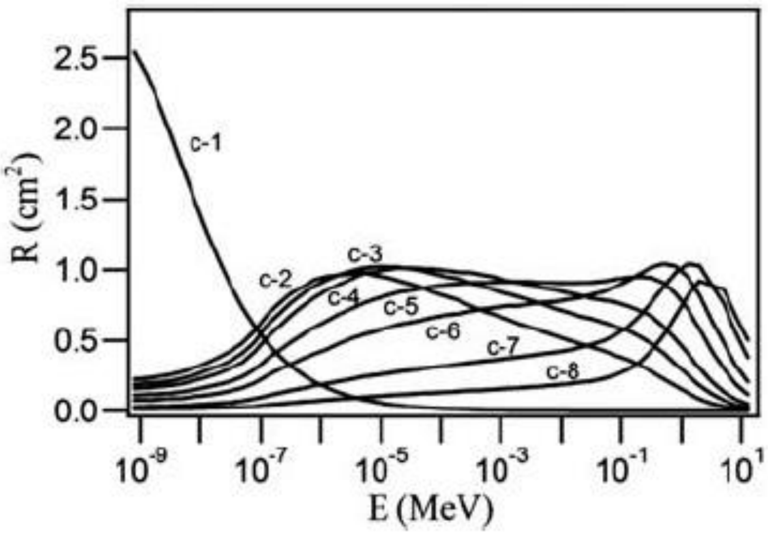
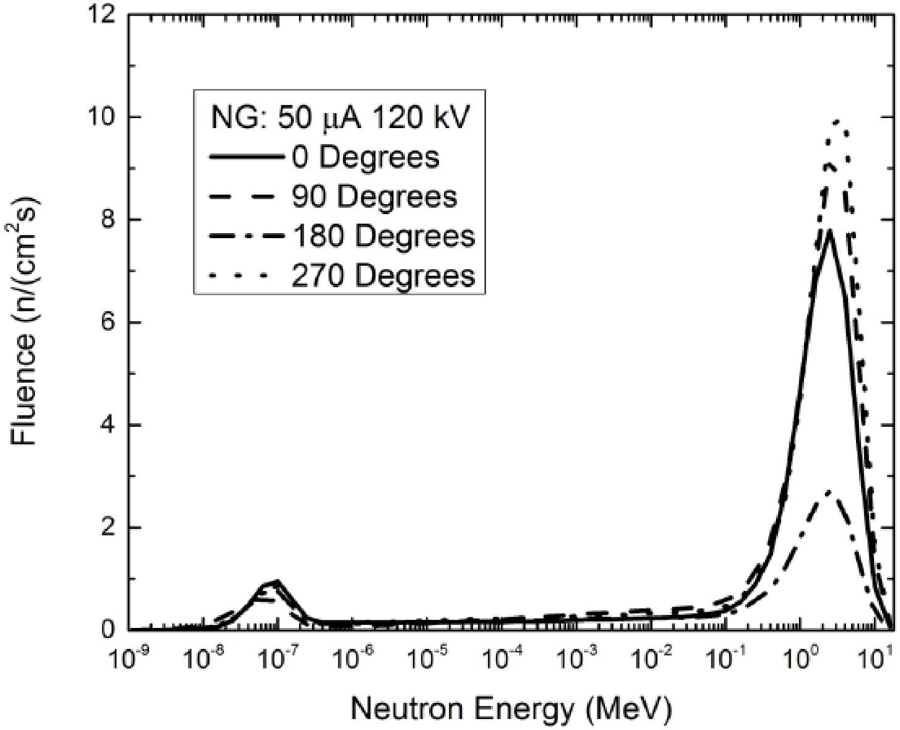
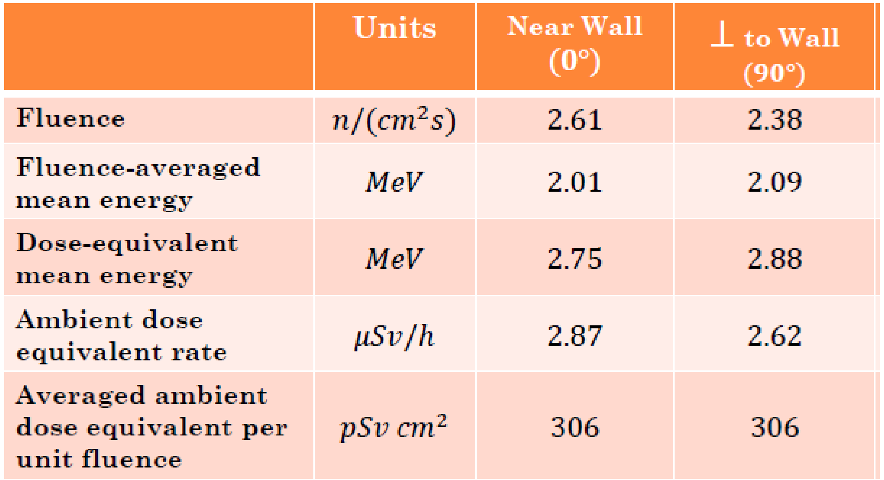


Figure 2. Typical response functions. The curve labelled C-1 corresponds to bare ^{3}He detecto,r while C-2 to C8 correspond to increasing amounts of HDPE moderator, from 0.2 to 8 kg.

Radiation Protection Dosimetry Through Neutron Spectrometry

NNS-NG DISTANCE:1 METER





	Units	Near Wall (0°)	⊥ to Wall (90°)
Fluence	$n/(cm^2 s)$	2.61	2.38
Fluence-averaged mean energy	MeV	2.01	2.09
Dose-equivalent mean energy	MeV	2.75	2.88
Ambient dose equivalent rate	$\mu Sv/h$	2.87	2.62
Averaged ambient dose equivalent per unit fluence	$pSv\ cm^2$	306	306

Radiation Protection Dosimetry Through Neutron Monitoring

REM BALL Ludlum Model 2241-4

DETECTOR: 2 Atm ^{3}He tube LND 25185 or equivalent

MODERATOR: 22.9 cm (9 in.) diameter cadmium-loaded polyethylene sphere
SENSITIVITY: typically 100 cpm/mrem/hr (^{241}AmBe fast neutrons)

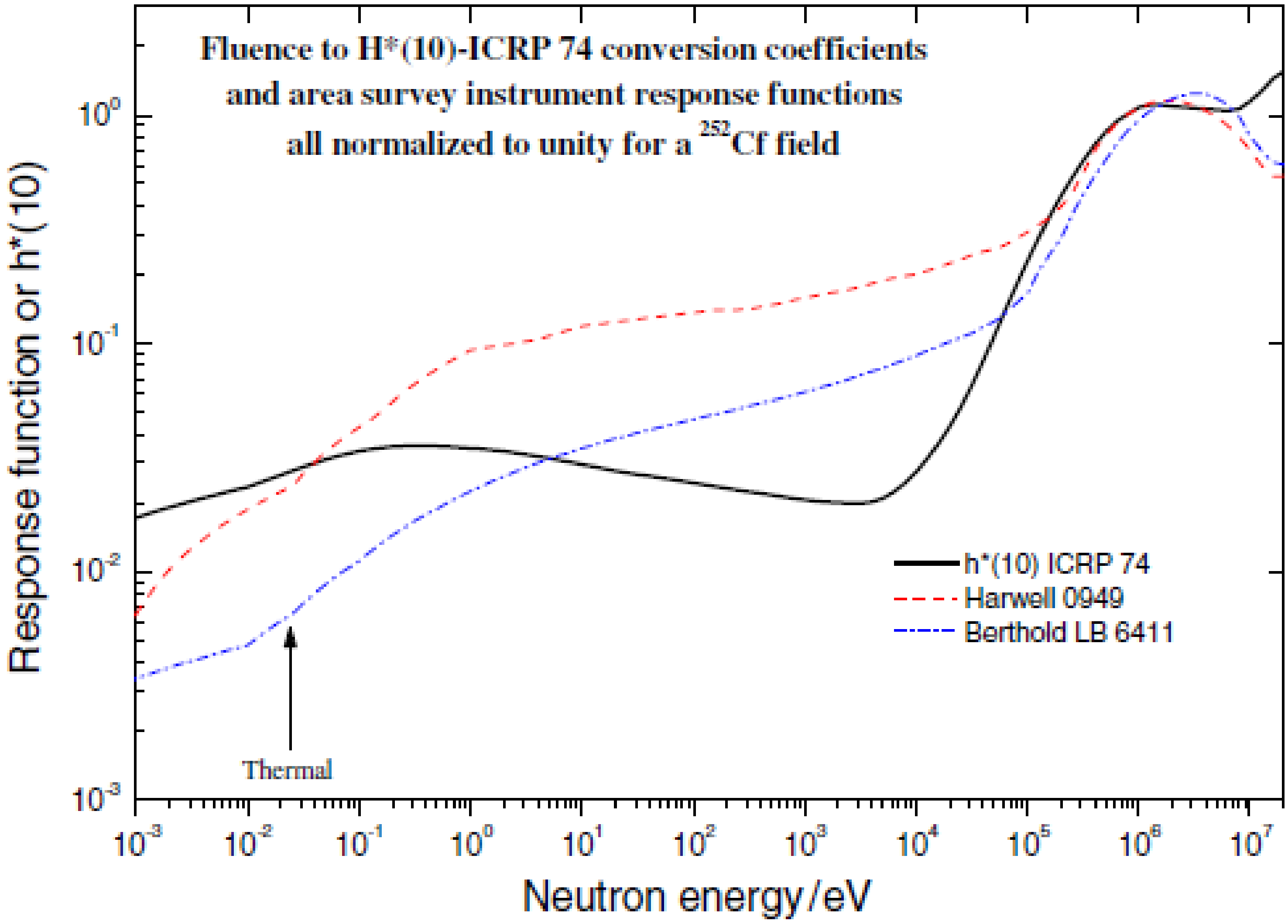
TOTAL WEIGHT of MODEL 2241-4: 8.3 kg (18.3 lb); with battery

Radiation Protection Dosimetry Through Neutron Monitoring

Berthold LB 6411 Neutron Probe

Harwell 0949 survey meter

Radiation Protection Dosimetry Through Neutron Monitoring



V Gressier[1] and G C Taylor[2] Metrologia **48** (2011) S313–S327

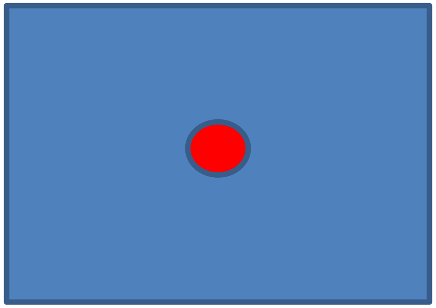
Radiation Protection Dosimetry Through Cavity Dose Determination

FWT REM500 based on a 5.08 cm spherical Tissue Equivalent Proportional Counter (TEPC)

Measures neutron dose equivalent/rate

Radiation Protection Dosimetry Through Cavity Dose Determination

$$D_{matter} = D_{cavity} \cdot \left\{\frac{S}{\rho}\right\}\frac{matter}{cavity}$$



For tissue equivalent walls and gas (homogeneous counters) the stopping power ratio is unity and absorbed dose in wall is given by the absorbed dose to the gas cavity

A150 TE-plastic atomic composition by % weight

H	C	N	O
muscle (10.2)	muscle (12.3)	muscle (3.5)	muscle (72.9)
10.1	**77.6**	**3.5**	**5.2**

Radiation Protection Dosimetry Through Cavity Dose Determination

- **Propane based Tissue Equivalent Gas**
  - C_3H_8 (55% partial pressure)
  - CO_2 (39.6% partial pressure)
  - N_2 (5.4% partial pressure)
  - By %weight: **H (10.3); C (56.9); N (3.5); O (29.3)**

ICRU Tissue (Muscle) atomic composition by % weight

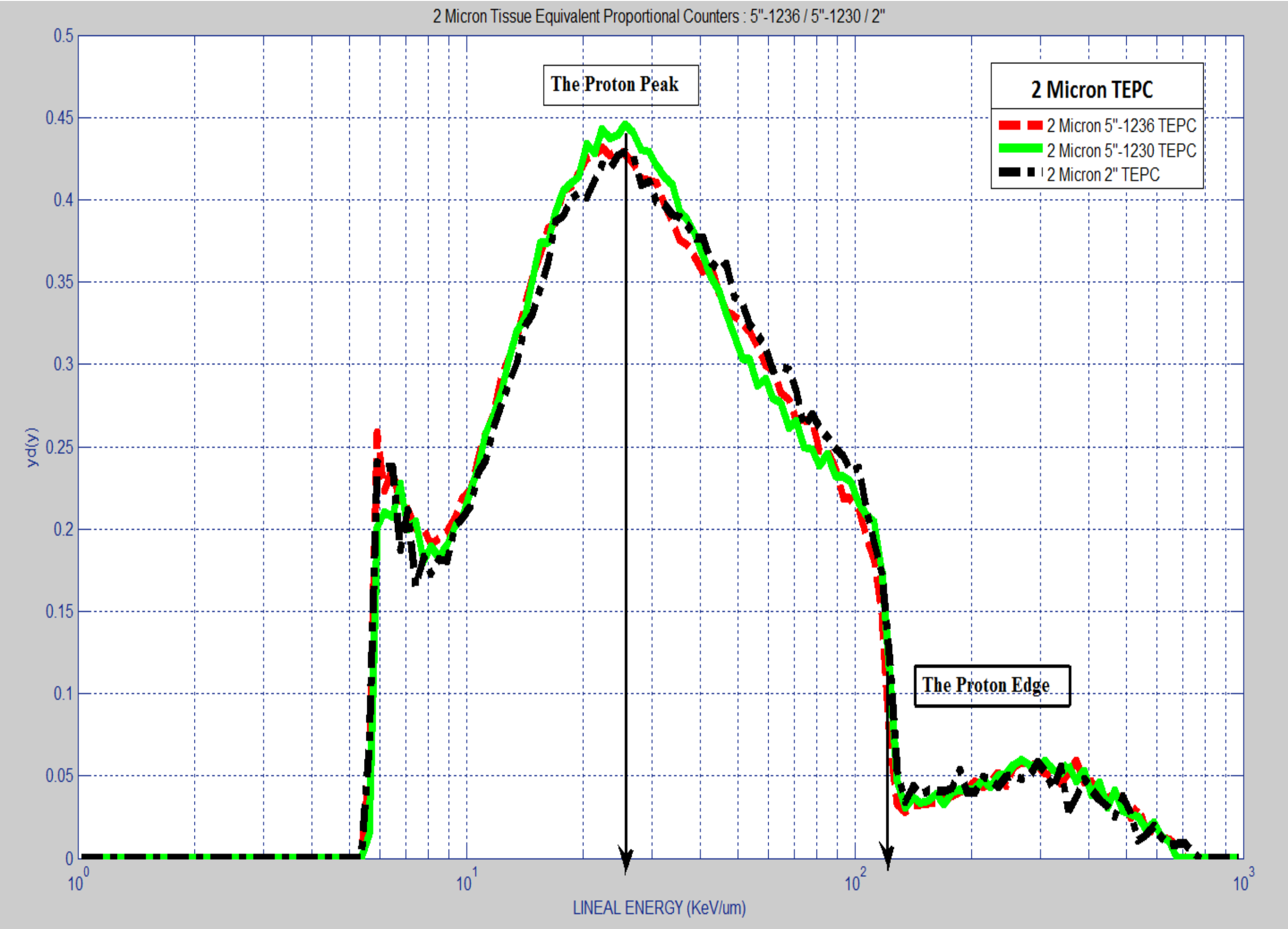
H	C	N	O
10.2	12.3	3.5	72.9

Radiation Protection Dosimetry Through Cavity Dose Determination

Fraction
of dose
per log
interval of
Lineal Energy

yf(y) vs d(logy)

yd(y)



Saad Al Bayati; MASc. Thesis, UOIT, 2012

Radiation Protection Dosimetry Through Cavity Dose Determination

The absorbed dose to the counter gas cavity is derived from the measured *yd(y)* event-size spectrum:

$$D = \frac{energy\ deposited\ [J]}{mass\ of\ gas\ [kg]}$$

$$D = \frac{\sum_i y_i\, d(y)[keV/\mu m]\ x\ \overline{l}\,[keV/\mu m]}{\rho_g\ x\ V}\ 1.602\ \mathrm{E}-16\ [J/keV]$$

Radiation Protection Dosimetry Through Cavity Dose Determination

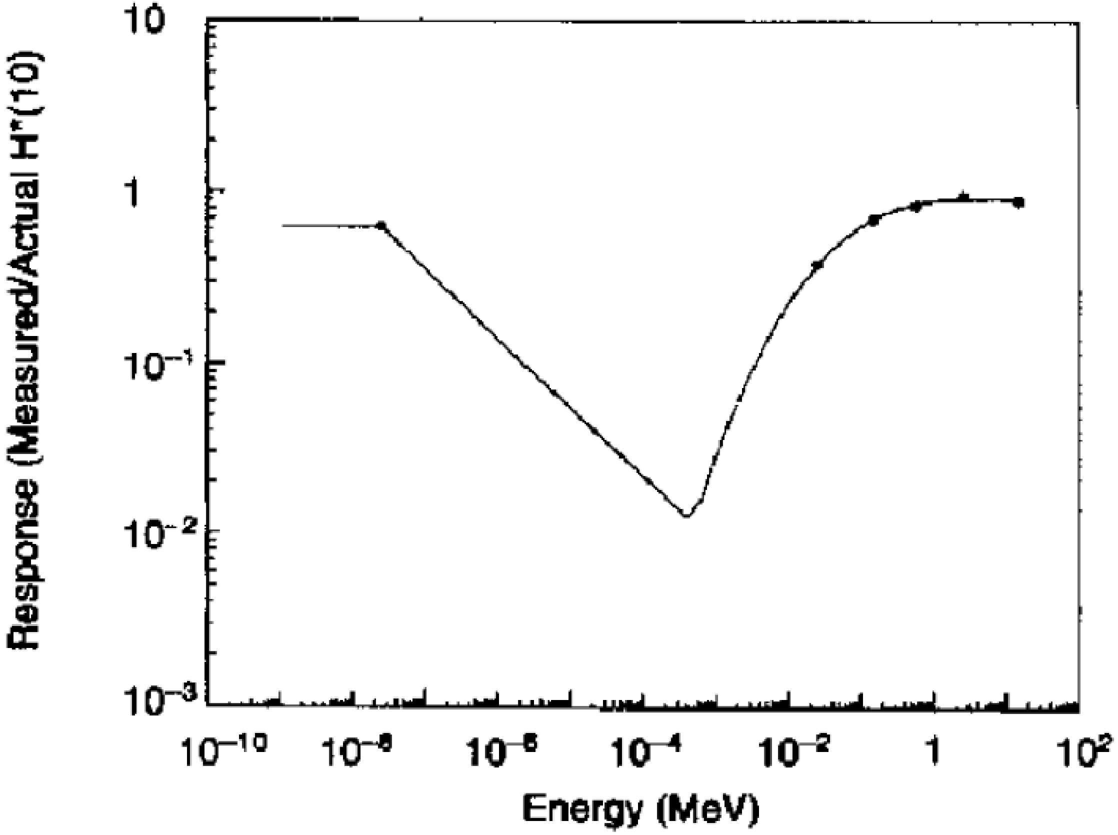
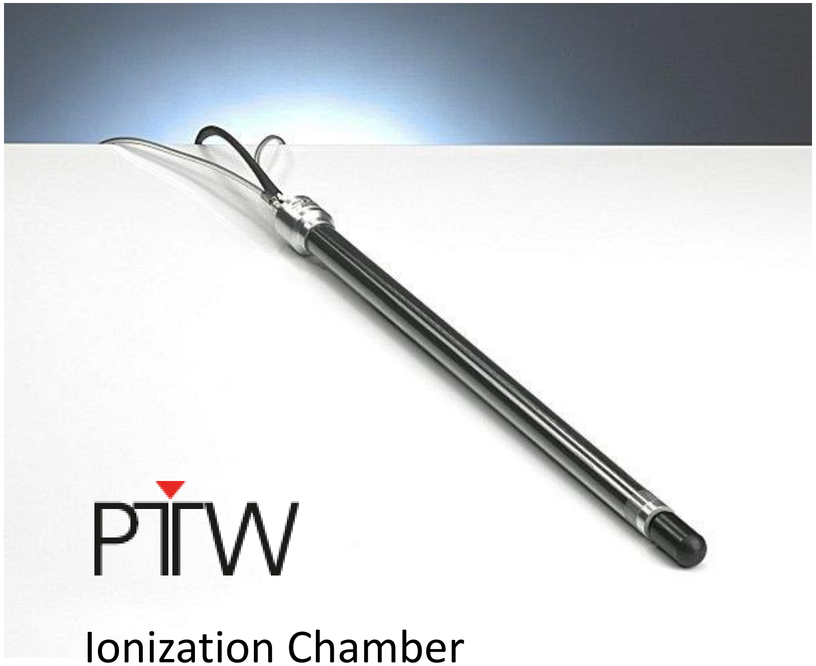


Figure 3. Monoenergetic response of a 5″ TEPC. Response is defined as the fraction of the ambient dose equivalent that is measured by the instrument. Line, analytical fit; symbols, experimental data from Reference 8.

Nunes and Waker, Radiat. Prot. Dosim. 59, No 4, 279-284, 1995

Ionization Chambers for Precision Dosimetry for Radiobiology and Therapy



Ionization Chamber

Measure Kerma in air or in a phantom of fast neutrons

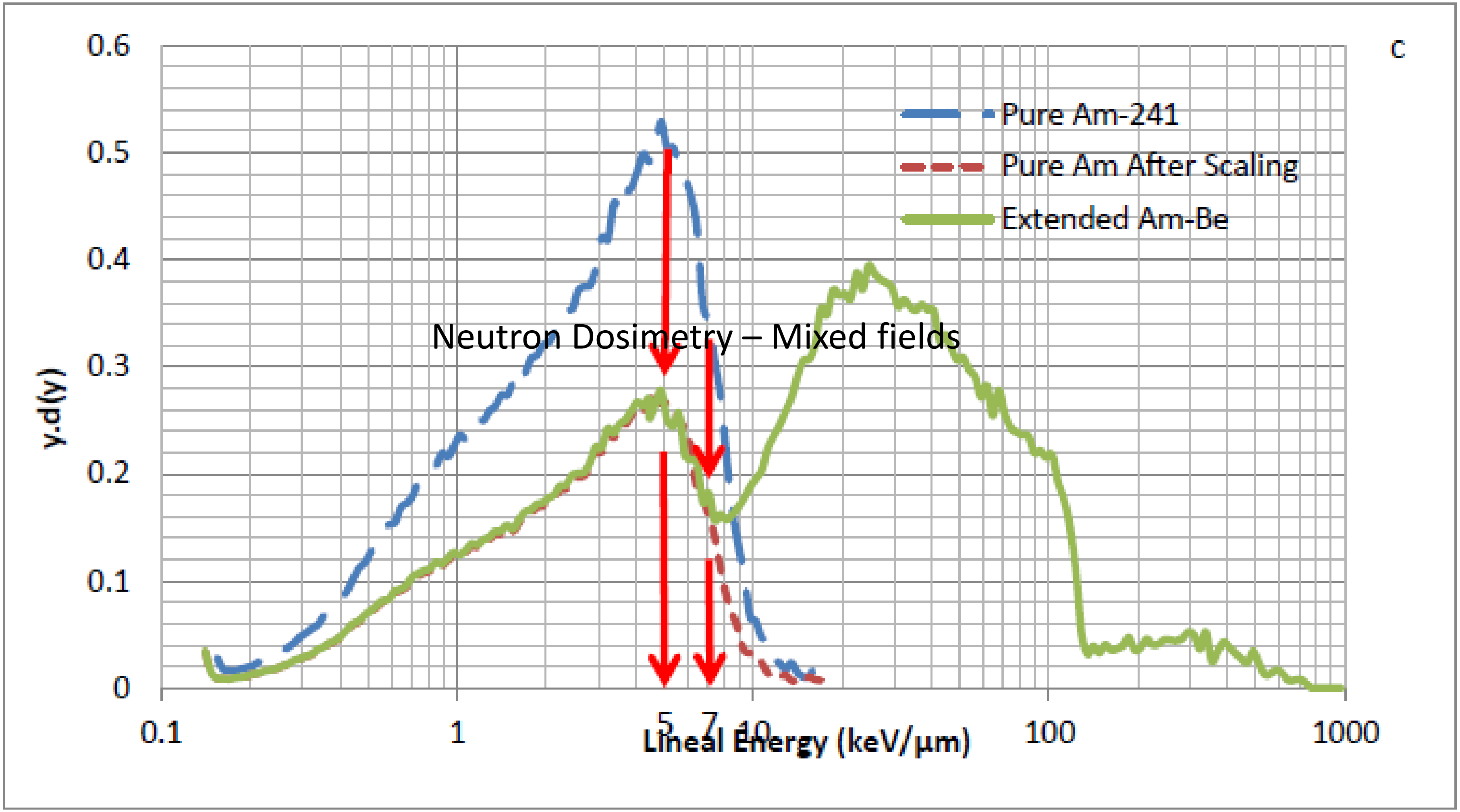
Chamber walls and electrodes are made of tissue-equivalent material or aluminum
Include provisions for gas flow

This product is no longer available!

Neutron Dosimetry – Mixed fields

Hydrogen capture of thermal neutrons means that gamma rays are always associated with neutron fields and neutron dosimetry must be carried out under mixed field conditions

Neutron Dosimetry – Mixed fields



Neutron Dosimetry – Mixed fields

$$\mathbf{Q_{n\gamma} = AD_{\gamma} + BD_{n}}$$

A = response of chamber to unit dose of gamma rays

B = response of chamber to unit dose of neutrons

If a mixed n+γ field is measured by two dosimeters having different sensitivities to neutrons and gamma rays i.e different (B/A) values two equations can be set up with two unknowns

Neutron Dosimetry – Mixed fields

$$\mathbf{Q_{n\gamma} = AD_{\gamma} + BD_{n}}$$

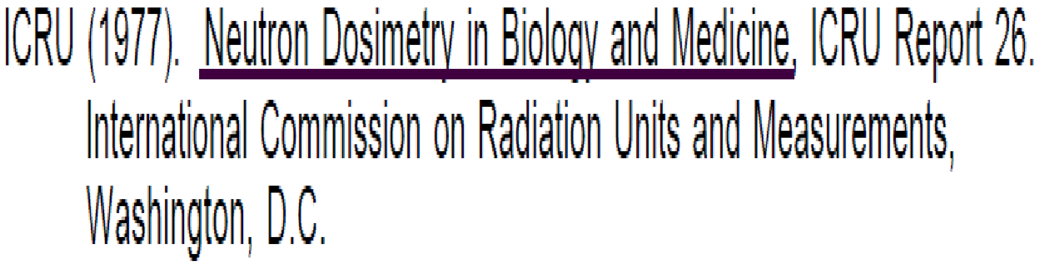
A requires:

Mean mass energy absorption coefficient ratios for wall material and tissue and mean mass stopping power ratios for wall material and gas filling

B requires

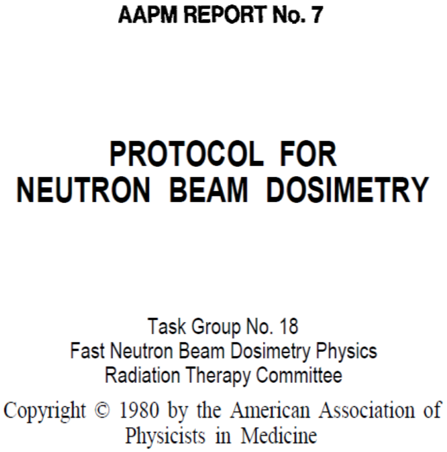
Mean Kerma factors for wall material and tissue and mean mass stopping power ratios for wall material and gas filling

Ionization Chambers for Precision Dosimetry for Radiobiology and Therapy



ICRU (1977). Neutron Dosimetry in Biology and Medicine, ICRU Report 26.
International Commission on Radiation Units and Measurements,
Washington, D.C.

Br J Radiol. 1981 Oct;54(646):882-98.
European protocol for neutron dosimetry for external beam therapy. European Clinical Neutron Dosimetry Group (ECNEU).
Broerse JJ, Mijnheer BJ, Williams JR.



AAPM REPORT No. 7

PROTOCOL FOR
NEUTRON BEAM DOSIMETRY

Task Group No. 18
Fast Neutron Beam Dosimetry Physics
Radiation Therapy Committee

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Physicists in Medicine

Ionization Chambers for Precision Dosimetry for Radiobiology and Therapy

If you want to do precision neutron dosimetry be prepared to build your own ionization chamber and relearn methods and techniques that have probably been forgotten. It could be fun.

Good luck!!