CALCOLI DI DOSE
con esempi

Relazioni dose-esposizione e dose-kerma

Se si verifica la condizione di equilibrio di particelle cariche:

$$D = K_{coll}$$

→ si possono relazionare la dose assorbita e la fluenza di energia.

Allora: $$D = \left(\frac{\mu_{en}}{\rho}\right) \Psi$$

in particolare in aria $$D_{aria} = \frac{W_{aria}}{e} X$$

In queste condizioni, se ho lo stessa fluenza di energia in due mezzi diversi:

$$D_1 = \left(\frac{\mu_{en}}{\rho}\right)_1 \Phi E_\gamma \quad \text{e} \quad D_2 = \left(\frac{\mu_{en}}{\rho}\right)_2 \Phi E_\gamma \quad \Rightarrow \quad D_2 = D_1 \frac{(\mu_{en}/\rho)_2}{(\mu_{en}/\rho)_1}$$

Posso così passare da una misura di esposizione, necessariamente in aria, ad una misura di dose in un materiale *M* qualsiasi:

$$D_M = D_{aria} \frac{(\mu_{en}/\rho)_M}{(\mu_{en}/\rho)_{aria}} = X \frac{W_{aria}}{e} \frac{(\mu_{en}/\rho)_M}{(\mu_{en}/\rho)_{aria}}$$

Se uso il kerma:

$$X = K_{coll,aria} \cdot \frac{e}{W_{aria}} = K_{aria} \cdot \frac{e}{W_{aria}} \cdot (1-g)$$

$$\frac{\mu_{en}}{\rho} = \frac{\mu_{tr}}{\rho} \cdot (1-g)$$

$$\longrightarrow \quad K_{aria} = X \frac{W_{aria}}{e} \frac{1}{(1-g)} = X \frac{W_{aria}}{e} \frac{(\mu_{tr}/\rho)_{aria}}{(\mu_{en}/\rho)_{aria}}$$

quindi:

$$D_M = K_{aria} \frac{(\mu_{en}/\rho)_M}{(\mu_{tr}/\rho)_{aria}}$$

W_{aria} = 34 eV: 34 eV $\rightarrow$ 1 coppia = 1.6 × 10^{-19} C $\Rightarrow$ 1 C = 2.13 × 10^{20} eV

$\Rightarrow$ 1 R = 2.58 × 10^{-4} [C/kg] • 2.13 × 10^{14} [MeV/C] • 10^{-3} [kg/g] = 5.5 × 10^{7} MeV/g

$$\Rightarrow \qquad \underbrace{X}_{[\mathrm{R}]} = 1.8 \times 10^{-8} \; \underbrace{\Phi}_{[\mathrm{cm}^{-2}]} \, \underbrace{E_\gamma}_{[\mathrm{MeV}]} \; \underbrace{\left(\frac{\mu_{en}}{\rho}\right)_{E,\,aria}}_{[\mathrm{cm}^2/\mathrm{g}]}$$

Qualche utile relazione

$$D = \left(\frac{\mu_{en}}{\rho}\right) \Phi E_\gamma$$

$$D = 1.6\times10^{-10}\ \Phi E_\gamma \left(\frac{\mu_{en}}{\rho}\right)$$

[**J**/**kg**]=[Gy] [cm^{-2}] [**MeV**] [cm^2/**g**]

$$\dot{D} = 5.76\times10^{-4}\ \dot{\Phi} E_\gamma \left(\frac{\mu_{en}}{\rho}\right)$$

[**m**Gy/**h**] [cm^{-2}/**s**]

$$D_{aria} = \frac{W_{aria}}{e}\ X$$

$$D_{aria} = 8.8\times10^{-3}\ X$$

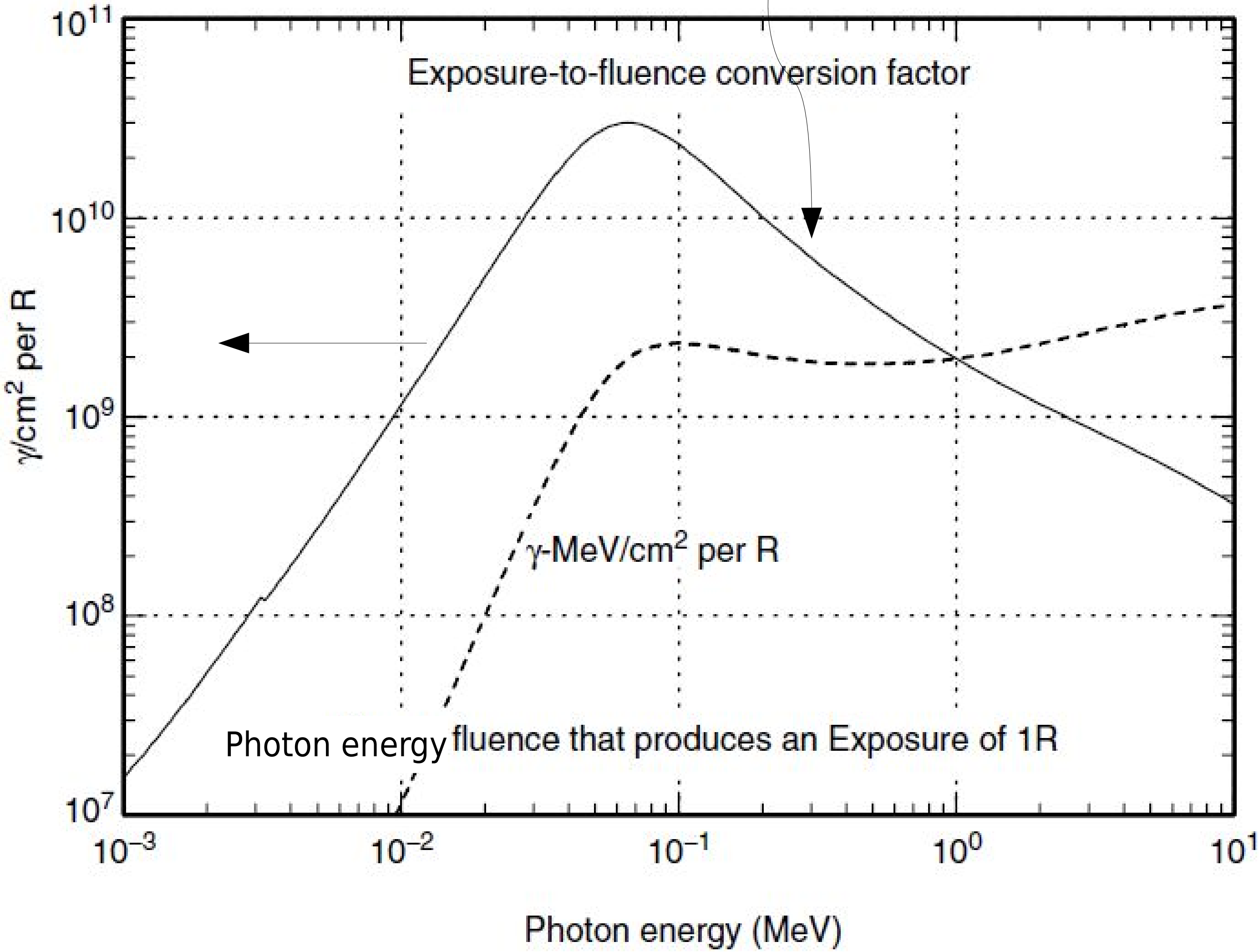
[**Gy**] [**R**]

$$D_M = D_{aria}\ \frac{(\mu_{en}/\rho)_M}{(\mu_{en}/\rho)_{aria}} = X\frac{W_{aria}}{e}\frac{(\mu_{en}/\rho)_M}{(\mu_{en}/\rho)_{aria}}$$

$$D_M = 8.8\times10^{-3}\frac{(\mu_{en}/\rho)_M}{(\mu_{en}/\rho)_{aria}}\ X$$

[Gy] [R]

$$X = 1.8\times10^{-8}\ \Phi E_\gamma \left(\frac{\mu_{en}}{\rho}\right)_{E,aria} \qquad \frac{\Phi}{X} = 1/\left(1.8\times10^{-8} E_\gamma \left(\frac{\mu_{en}}{\rho}\right)_{E,aria}\right)$$



$$\frac{\Phi}{X} E_\gamma$$

FIGURE 2.70 Solid curve: photon fluence that produces an Exposure of 1 R; that is, photon fluence that produces a dose of 0.877 rad air. When multiplied by photon energy there results the dashed curve, the photon energy fluence per R; above 100 keV it is slowly varying, near 2×10^9 γ-MeV/cm^2 per R.

Relazione fra rateo di esposizione ed intensità di fluenza

$$\dot{X} = \left(\frac{\mu_{en}}{\rho}\right)_{E,\,aria} \cdot \underbrace{\frac{e}{W_{aria}}}_{\text{costante}} \cdot \dot{\Phi} E_\gamma = 0.065 \cdot \dot{\Phi} E_\gamma \left(\frac{\mu_{en}}{\rho}\right)_{E,\,aria} \quad \text{[mR/h]}$$

$[s^{-1}cm^{-2}]$ [MeV] $[cm^2/g]$

γ ray/cm^2/s per mR/h

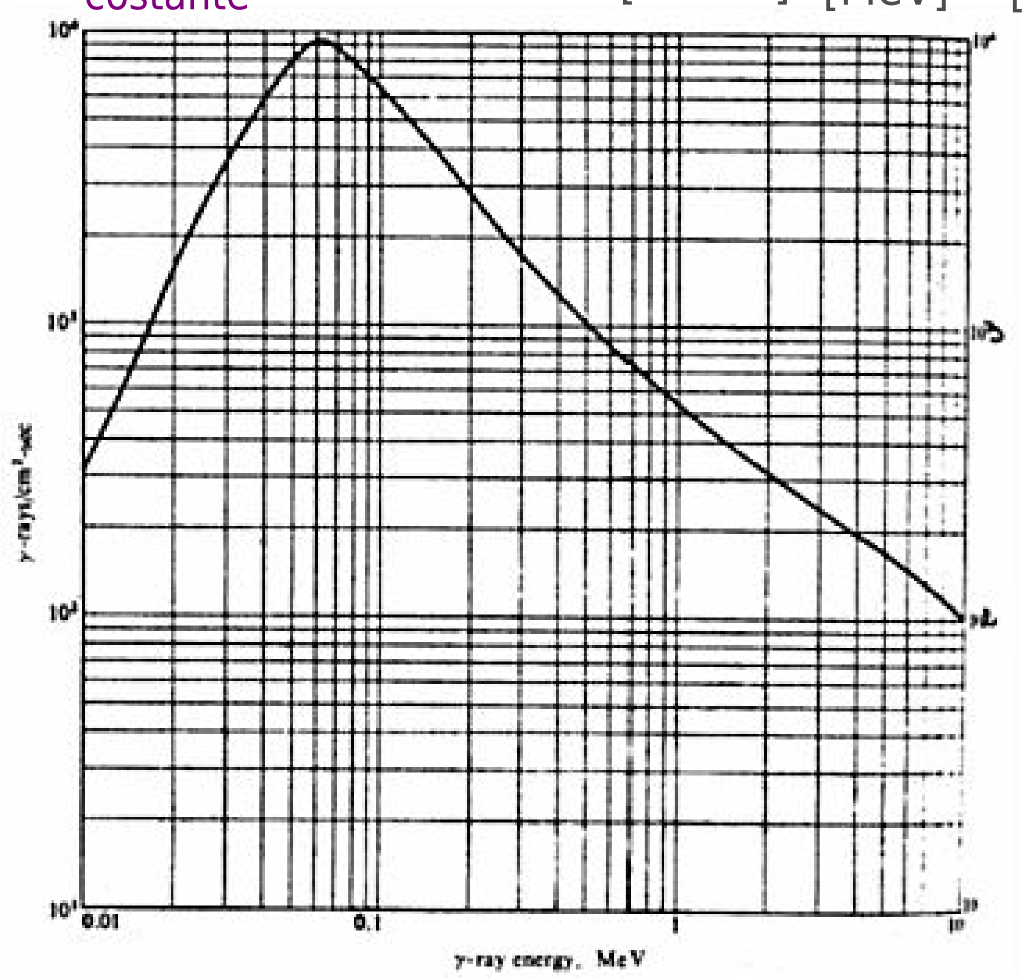


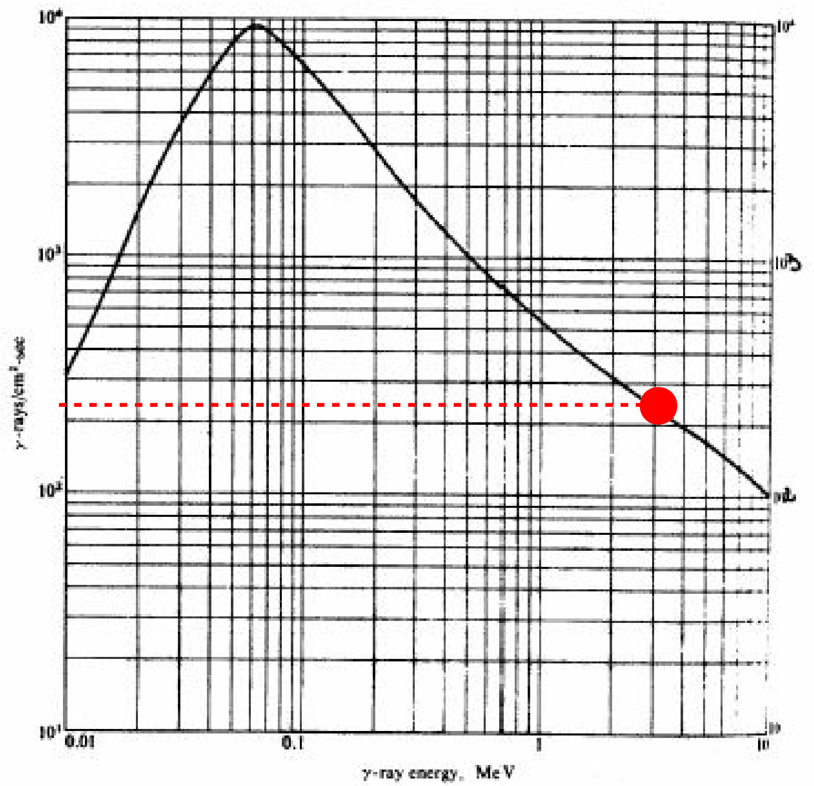
Fig. 18.3 intensità di fluenza di fotoni ($cm^{-2}s^{-1}$) di energia E_γ corrispondente ad una intensità di Esposizione pari ad 1 mR/h

Esempio

Calcolare il rateo di dose in aria, acqua e tessuto per un fascio di fotoni monoenergetico di energia E_γ = 3 MeV e intensità di flusso pari a $10^7\ \gamma\ cm^{-2}\ s^{-1}$

Dal grafico che relazione rateo di esposizione e intensità di flusso γ:

flusso per 1mR/h



1 mR/h con ≈240 $\gamma\ cm^{-2}\ s^{-1}$

quindi:

$$\dot{X} = \frac{10^7}{240} = 4.2\times 10^4 \text{ mR/h}$$

Oppure: $\dot{X} = 0.065 \cdot \dot{\Phi}\, E_\gamma \left(\frac{\mu_{en}}{\rho}\right)_{E\,,\,aria}$ [mR/h] = $4\text{x}10^4$ mR/h

$[s^{-1}cm^{-2}]$ [MeV] $[cm^2/g]$

poiché: $\dot{D}_{aria} = 8.8\times 10^{-3}\ \dot{X}$ $\quad \dot{D}_{aria} = 8.8\times 10^{-3}\times\ 4.2\times 10^{4} = 369\, mGy/h$

[mGy/h] [mR/h]

$$\boxed{\dot{D}_{aria} = 0.103\ \ mGy/s}$$

da:

$$\dot{D}_{M} = \dot{D}_{aria}\ \frac{(\mu_{en}/\rho)_{M}}{(\mu_{en}/\rho)_{aria}}$$

$$\left(\frac{\mu_{en}}{\rho}\right)_{aria\ ,\, 3\mathrm{Mev}} = 0.0205\, cm^{2}/g$$

$$\left(\frac{\mu_{en}}{\rho}\right)_{acqua\ ,\, 3\mathrm{Mev}} = 0.0227\, cm^{2}/g$$

$$\boxed{\dot{D}_{acqua} = 0.114\, mGy/s}$$

$$\left(\frac{\mu_{en}}{\rho}\right)_{tessuto\ ,\, 3\mathrm{Mev}} = 0.0225\, cm^{2}/g$$

$$\boxed{\dot{D}_{tessuto} = 0.113\, mGy/s}$$

Esercizio n. 1

Si consideri un fascio di γ di 3 MeV incidenti perpendicolarmente su un sottile foglio di Fe, il cui spessore è molto inferiore al range degli elettroni secondari:

a) calcolare K, K_{coll} e K_{rad} nel foglio per una fluenza Φ pari a $5.6\times10^{15}\ \gamma/m^2$ (μ_{tr}/ρ = 0.00212 m^2/kg, μ_{en}/ρ = 0.00204 m^2/kg)

b) approssimativamente, quant'è la dose assorbita nel foglio, assumendo che non vi siano particelle cariche provenienti da altre fonti?

Esercizio n. 2

Un fascio di raggi X di bassa energia con una fluenza di energia pari a 3.7×10^{-4} J/cm^2/s incide perpendicolarmente su una lastra di Al e viene completamente assorbito:

a) quanta energia viene assorbita per cm^2 in 5 minuti?

b) se la lastra ha spessore pari a 2 cm e densità ρ = 2.7 g/cm^3, qual è il valor medio di K_{coll} nel mezzo (in 5 minuti)?

c) qual è il valor medio della dose assorbita?

d) quale sarebbe il valor medio della dose assorbita se lo spessore fosse pari a 4 cm?

Esercizio n. 3

Si considerino due contenitori riempiti con 5 e 25 cm^3 di acqua, rispettivamente. Essi vengono irraggiati omogeneamente con raggi γ e il valor medio del kerma nel contenitore più piccolo è pari a 1 Gy:

a) a quanto ammonta il valor medio del kerma nel contenitore più grande?

b) quant'è l'energia trasferita in ciascuno dei due volumi di acqua?

IRRADIAZIONE ESTERNA

FOTONI:
→ condizione di "quasi equilibrio"

$$D = \left(\frac{\mu_{en}}{\rho}\right) \Phi E_\gamma \quad \Rightarrow \quad \dot{D} = \frac{A \cdot E_\gamma}{4\pi r^2} \cdot \frac{\mu_{en}}{\rho}$$

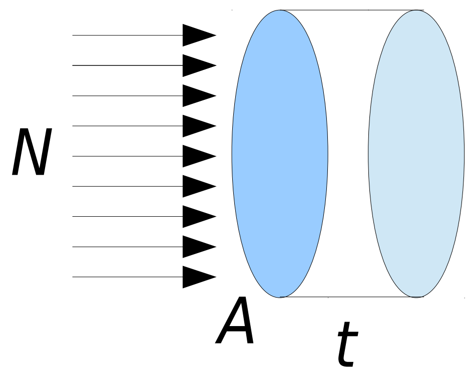
Poiché fra 60 keV e 2 MeV il coefficiente di assorbimento massico in aria è all'incirca costante e vale ~ 0.027 cm^2/g, si ha con A in [MBq], E in [MeV] e r in [m]:

$$\dot{D} = 1.24 \times 10^{-7} \frac{A \cdot E}{r^2} \quad [Gy/h]$$

Per ottenere una stima della dose nel tessuto (caso semplificato di irradiazione uniforme al corpo intero) moltiplico per 1.12 (rapporto fra i coefficienti massici di assorbimento tessuto-aria).

IRRADIAZIONE ESTERNA

Particelle direttamente ionizzanti:



$$D \approx N \frac{\frac{dE}{\rho\, dx} \cdot \rho\, t}{A\, t\, \rho} = \Phi \cdot \frac{\frac{dE}{\rho\, dx} \cdot \rho\, t}{\rho\, t} = \Phi \cdot \frac{dE}{\rho\, dx}$$

ρt [g/cm^2]
dE/ρdx [$MeV/cm^2/g$]
D [MeV/g]

→ i calcoli di dose non sono affatto semplici: il potere frenante cambia con lo spessore attraversato (e dunque la dose). Si usa l'approssimazione CSDA.
→ i calcoli di dose sono particolarmente complicati per gli elettroni

Esistono tabulazioni per le varie sorgenti di β^-.

$$D \approx \Phi \cdot \frac{dE}{\rho\, dx}$$

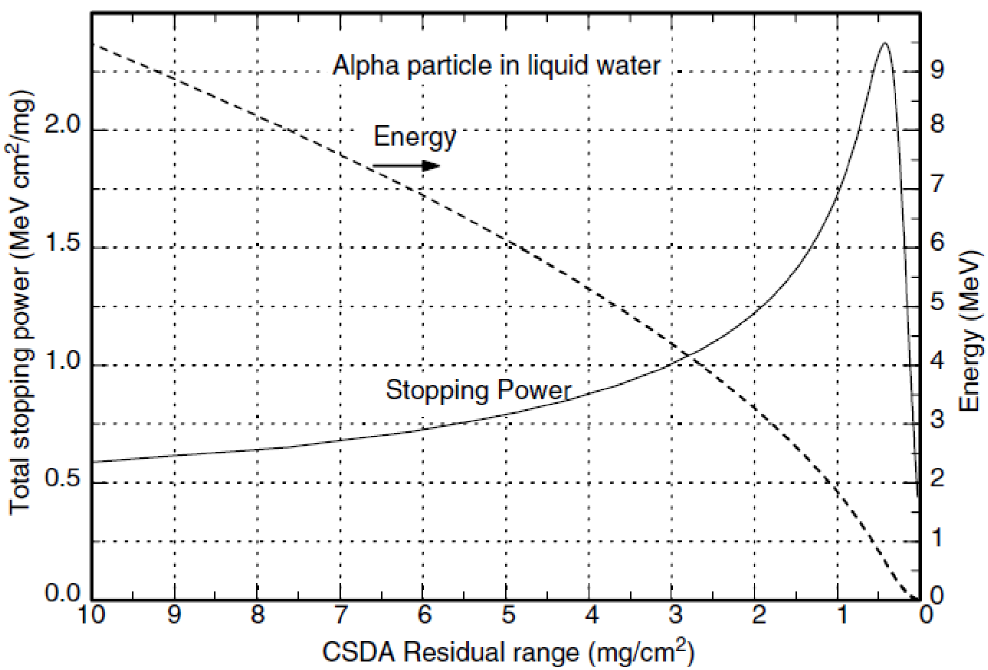


FIGURE 4.3 Bragg curve of alpha particle in liquid water. Bragg peak is the maximum of the stopping power near the end of the range. As graphed, the particle starts with kinetic energy 9.5 MeV and CSDA range of 10 mg/cm^2 = 0.01 cm. Near the end of its range, its energy loss rate peaks at four times its starting rate. It deposits about 1.8 MeV in the last 10 μm of its range. (Data from SRIM [SR03].)

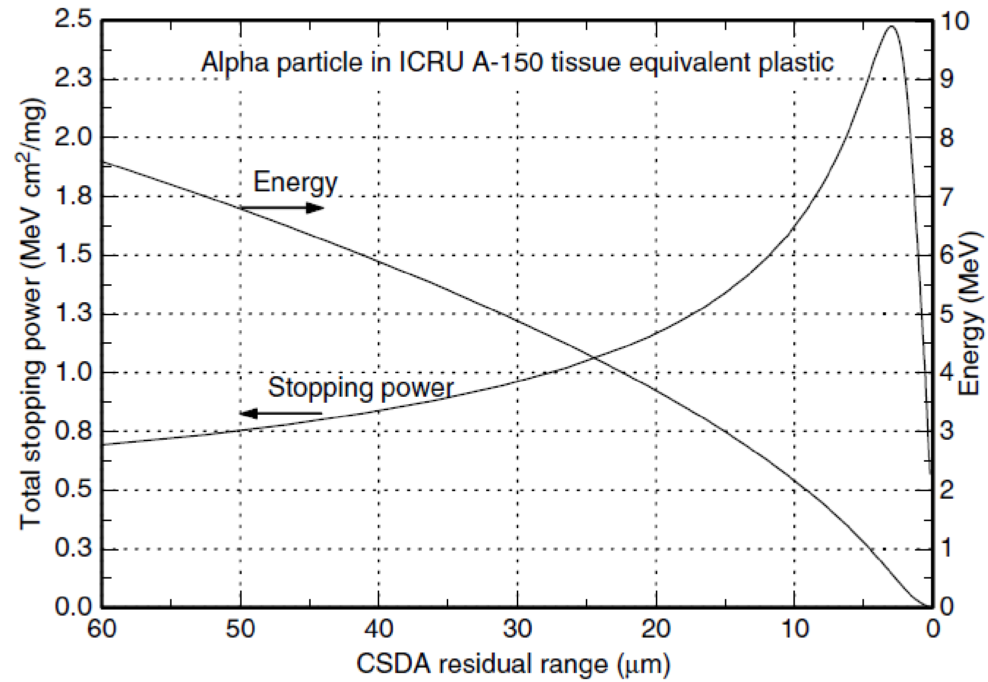


FIGURE 4.4 Bragg curve of alpha particle in ICRU A-150 tissue equivalent plastic. About 2.1 MeV is deposited in the last 10 μm of the particle range.

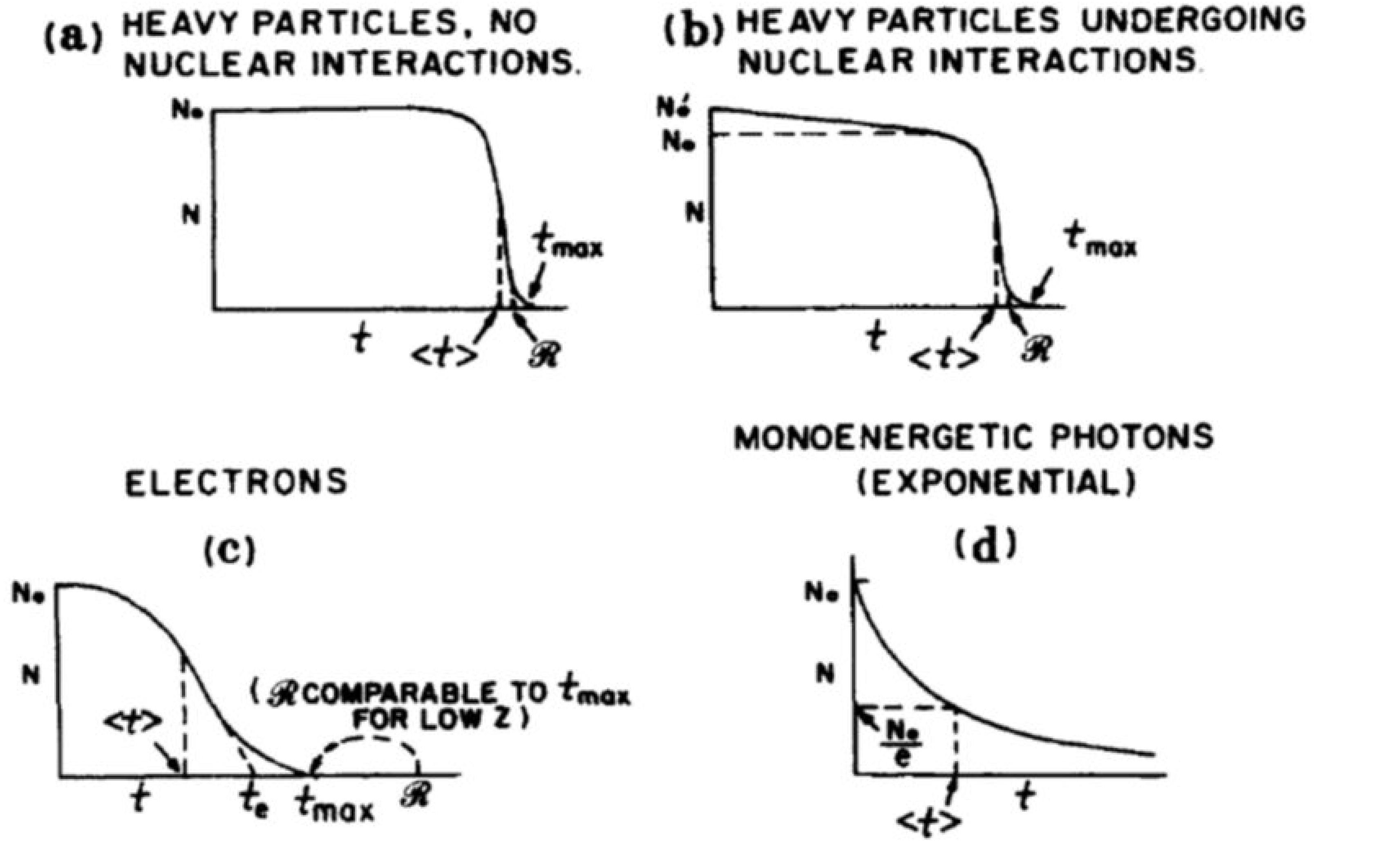
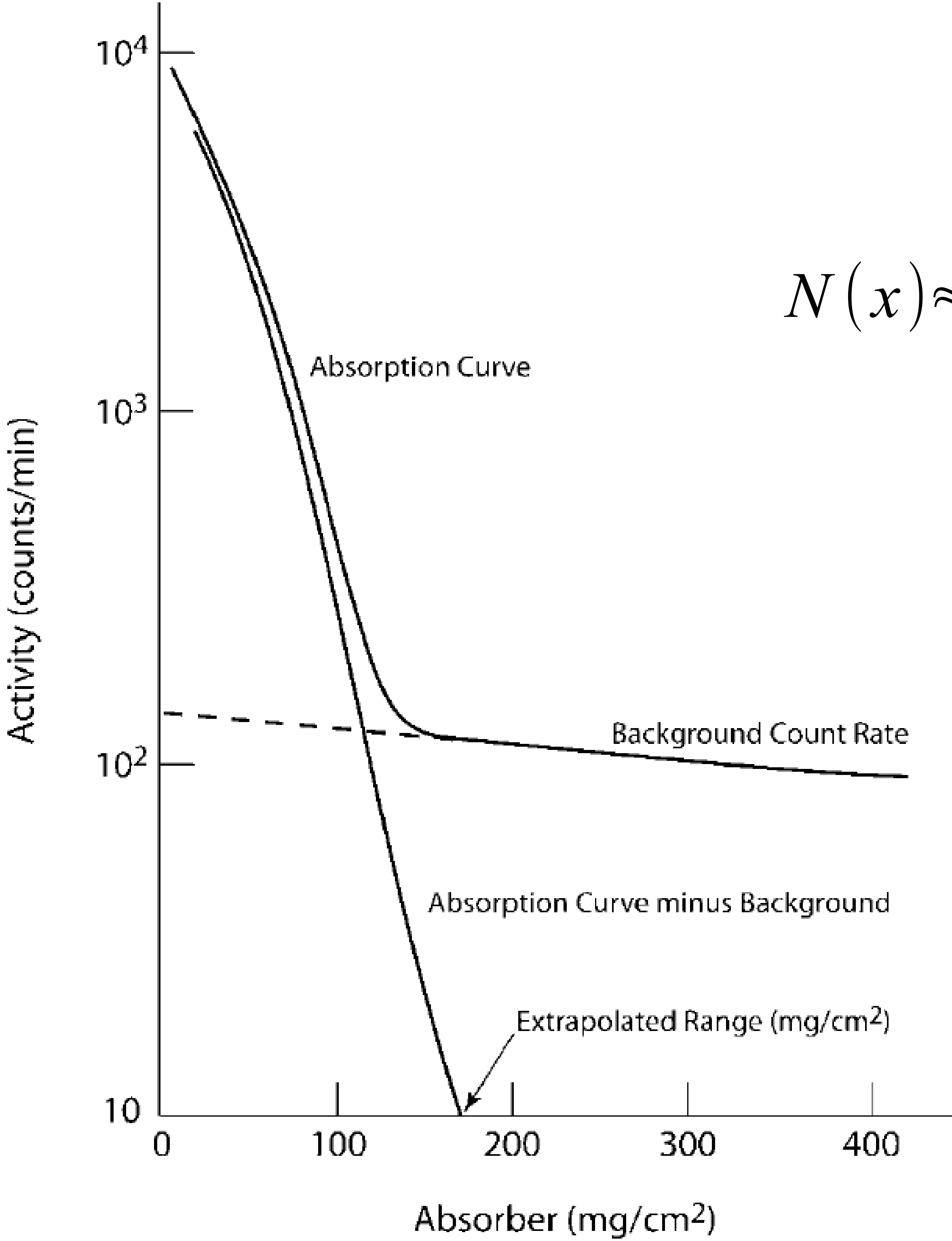


FIGURE 8.9. Numbers of monoenergetic charged particles or photons penetrating through a slab thickness t of absorbing medium. Scattered photons are assumed to be ignored in *d*. $\langle t \rangle$ is the projected range, t_e is the extrapolated penetration depth, t_{max} is the maximum penetration depth, and R is the range ($\cong R_{CSDA}$).



$$N(x) \approx N_0 e^{-\mu_\beta (\rho x)}$$

IRRADIAZIONE ESTERNA

ELETTRONI:

→ l'assorbimento, anche dell'aria, è importante (modifica dello spettro, in caso di sorgenti β).

Formule empiriche che stimano la frazione di energia depositata per unità di massa (in cm^2/g):

$$\mu_{\beta,\,air} = 16\left(E_{\beta,\,max} - 0.036\right)^{-1.4}$$

E [MeV]

$$\mu_{\beta,\,tissue} = 18.6\left(E_{\beta,\,max} - 0.036\right)^{-1.37}$$

$$\dot{D} = \mu_\beta \, \dot{\Phi} \, \bar{E}_\beta$$

$$\mu_{\beta,\,i} = 17\left(E_{\beta,\,max}\right)^{-1.14}$$

ALFA:

→ non costituiscono un rischio.

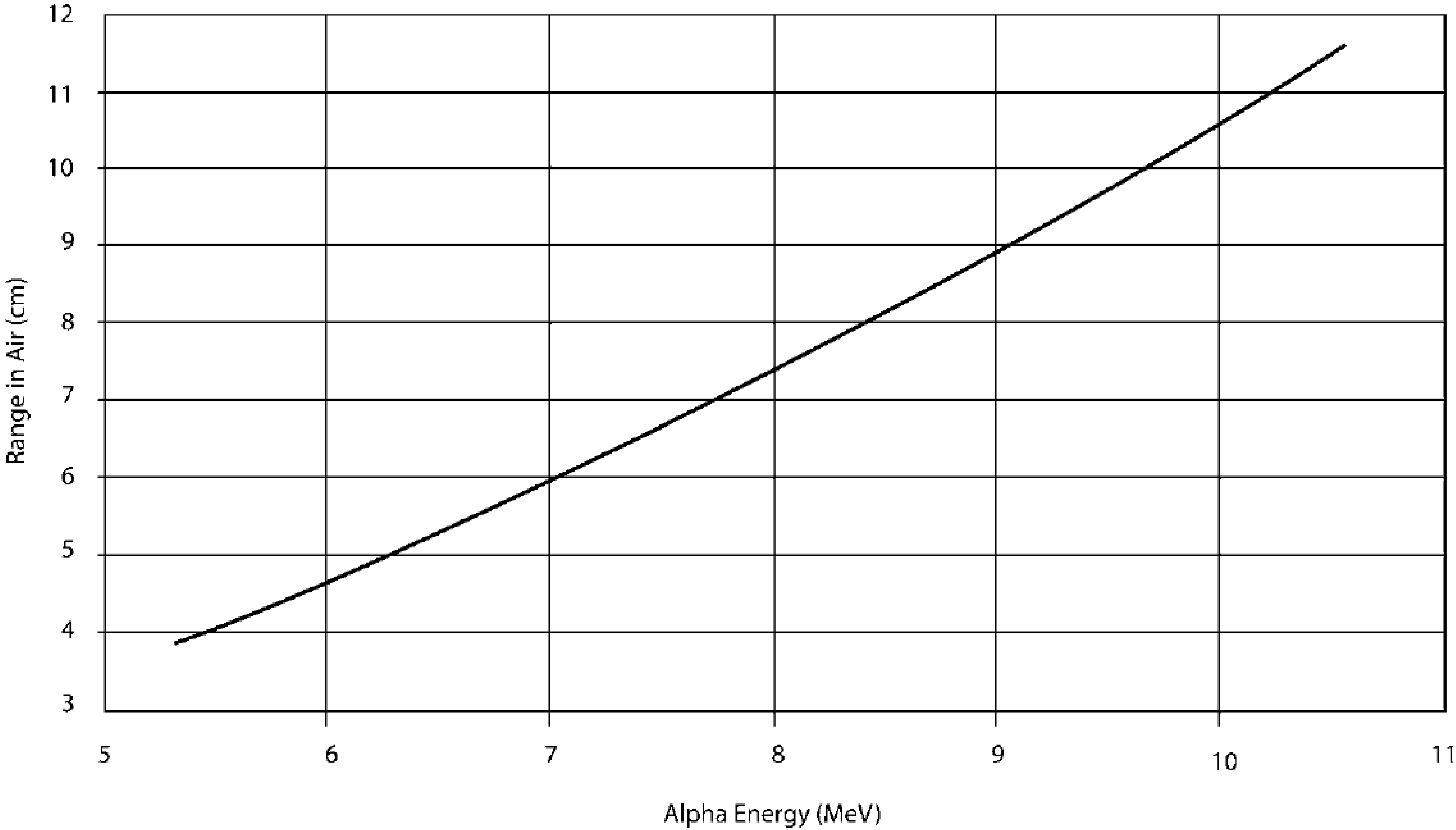
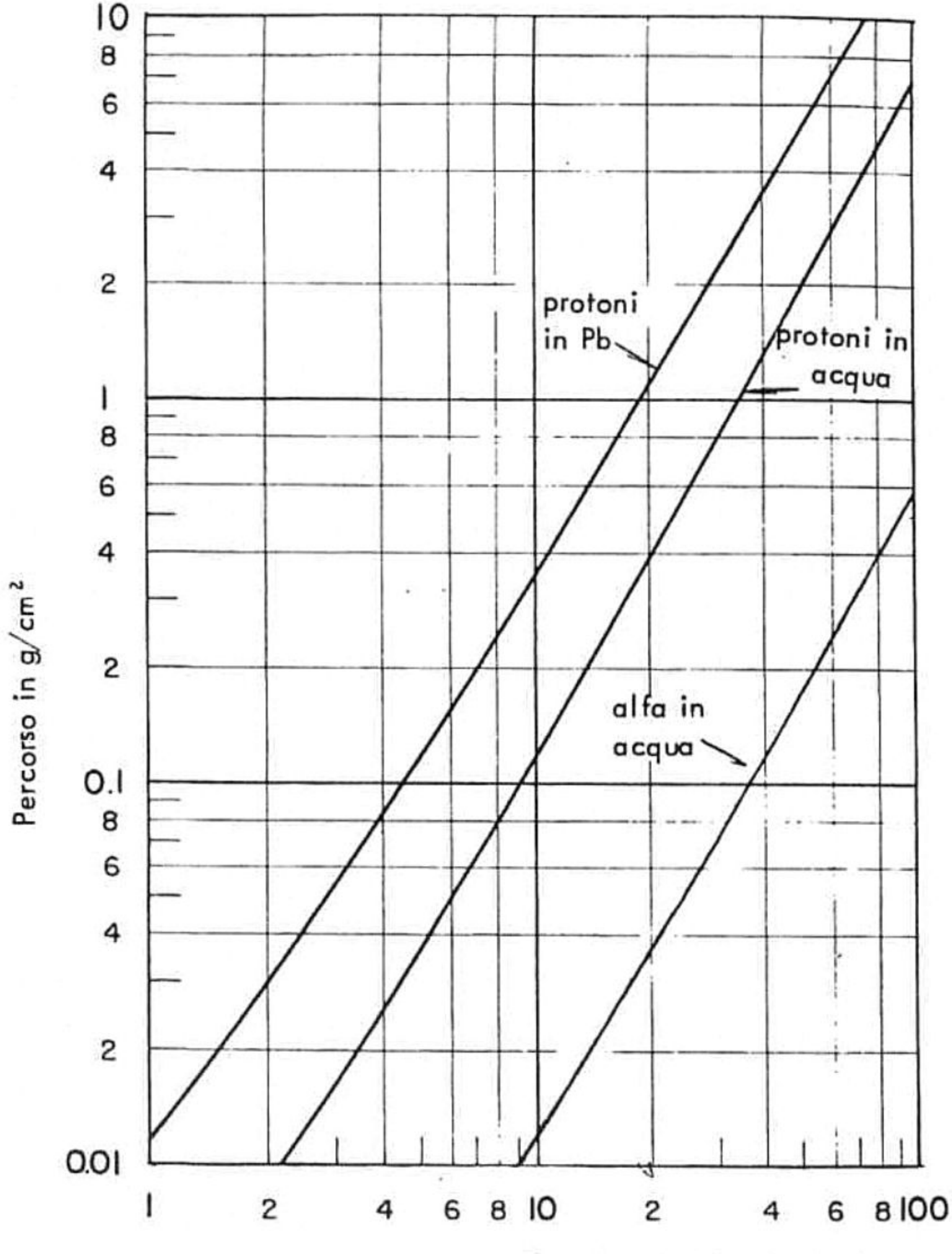


Fig. 7-4 Range versus energy of alpha particles in air.



Percorso in g/cm²
Energia cinetica in MeV
protoni in Pb
protoni in acqua
alfa in acqua
10
8
6
4
2
1
0.1
0.01
1
2
4
6
8
10
100

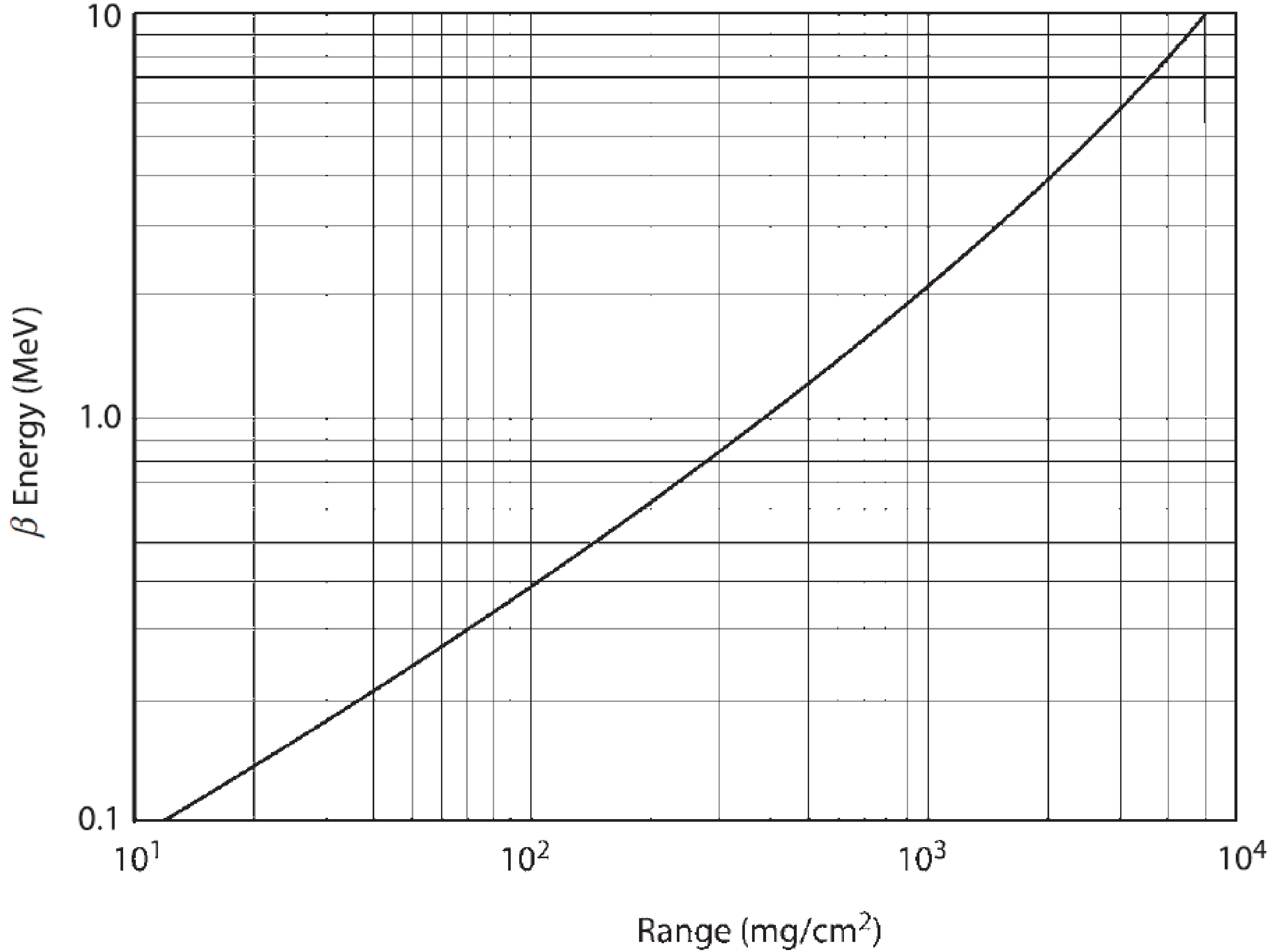


Fig. 7-9 Equivalent range of electrons in mg/cm² of low-*Z* absorbers.

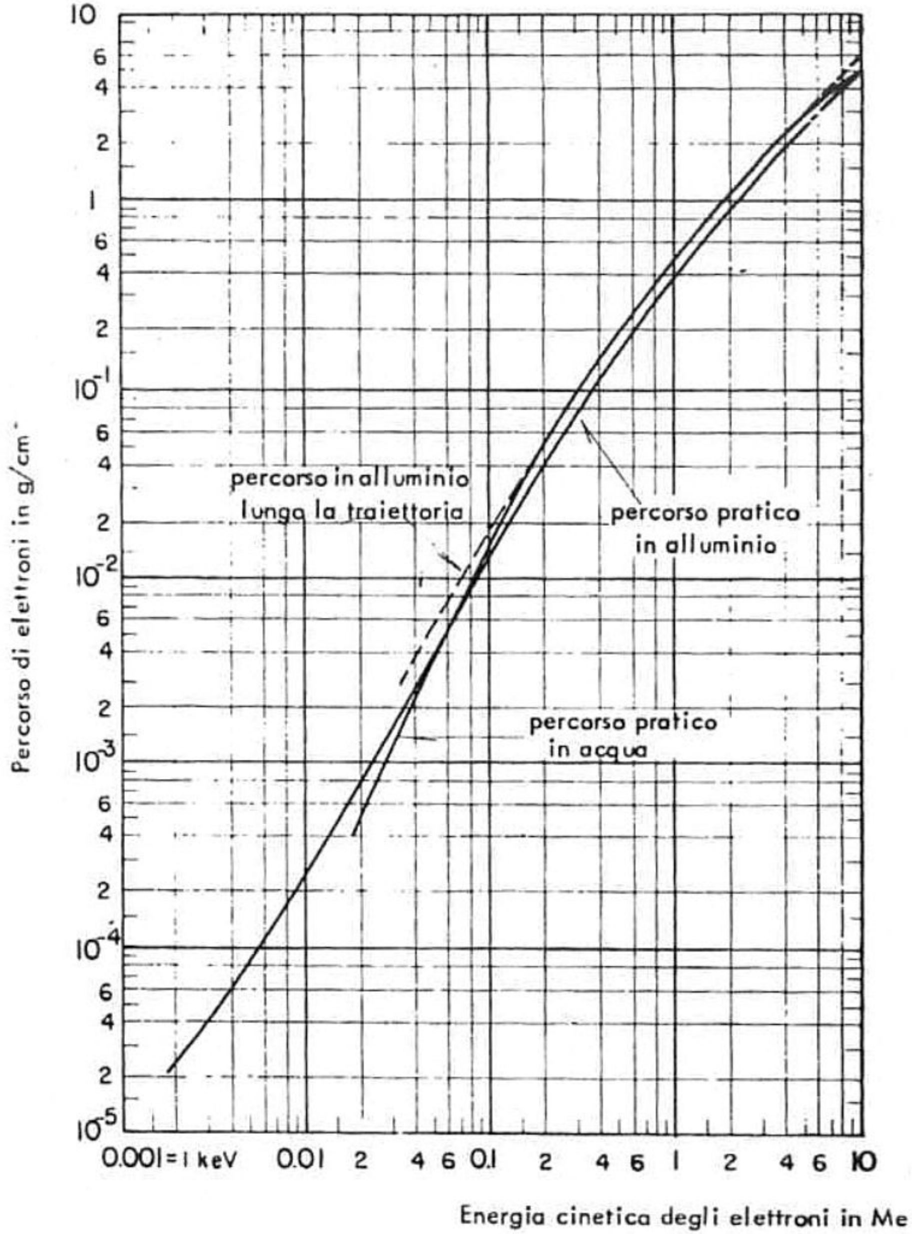
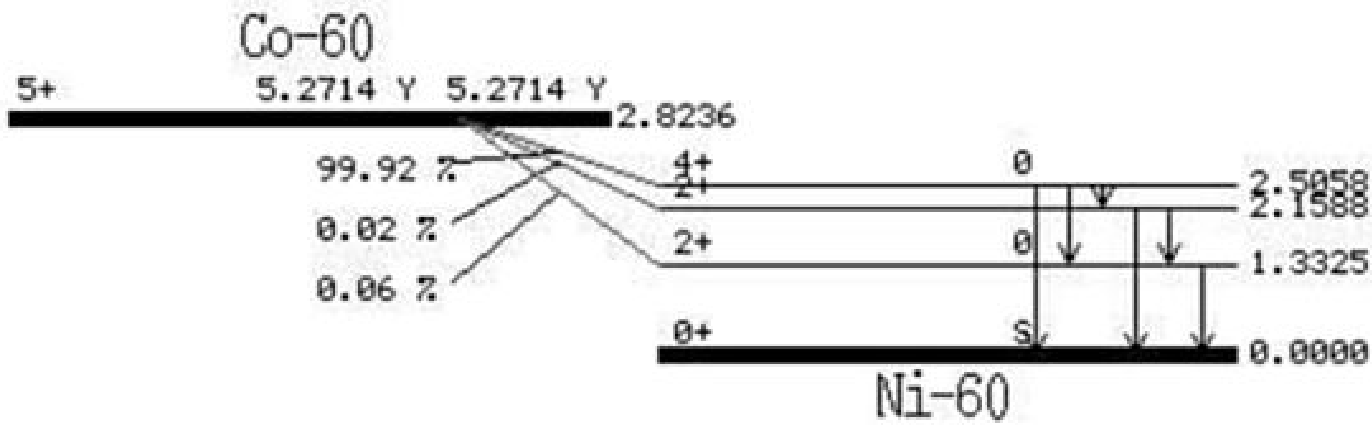


Figura 8.24. Percorso di elettroni monoenergetici in alluminio e acqua in funzione dell'energia cinetica. La curva tratteggiata, che coincide per un tratto con la curva continua relativa all'acqua, rappresenta il percorso in alluminio calcolato a partire dalla conoscenza del potere frenante.

60CO B- DECAY (5.2714 Y)

Parent state: G.S.
Half life: 5.2714 Y(5)
Q(gs): 2823.64(11) keV
Branch ratio: 1.0



Beta ray:

Max.E(keV)	Avg.E(keV)	Intensity(rel)	Spin	5+
1492(20)	625.87(5)	0.057(20)		2+
670(20)	274.93(5)	0.022(LT)		2+
317.88(10)	95.77(4)	99.925(20)		4+

Gamma ray:

Energy(keV)	Intensity(rel)
346.93(7)	0.0076(5)
826.28(9)	0.0076(8)
1173.237(4)	99.9736(7)
1332.501(5)	99.9856(4)
2158.77(9)	0.00111(18)
2505	2.0E-6(4)

Cobalt - 60

$^{60}Co_{27}$

Half life: 5.27 years
Specific activity: 4.18E+13 Bq.g^{-1}

Risk group: 2
Risk colour: Orange

Main emissions (keV)								
	Gamma or X		Beta (Emax)		Electrons		Alpha	
	E	%	E	%	E	%	E	%
E1	1173	100	318	100				
E2	1333	100	1491	<1				
E3								
% omitted		<1		0				

Exemption levels	
Quantity (Bq)	1E+05
Concentration (Bq.g^{-1})	1E+01

Transport (TBq)	
IAEA ST1 A_1 value	4E-1
IAEA ST1 A_2 value	4E-1

EXTERNAL EXPOSURE (mSv.h^{-1}) for an activity of 1 MBq or 1 MBq.m^{-2} (as appropriate)

Point source (30 cm)

Betas, electrons (skin dose): 1.26E-2

Gammas, X rays (deep tissue dose): 3.86E-3

Infinite plane source

Betas, electrons (skin)	
10 cm	2.6E-02
1 m	0.0E+00
Photons (skin)	
10 cm	1.6E-02
1 m	1.0E-02
Photons (deep dose)	
10 cm	1.5E-02
1 m	9.6E-03

10 ml glass vial

100 cm

3.32E-4

Contact with 50 ml glass beaker

1.19E+0

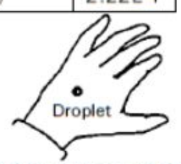
Contact with 5 ml plastic syringe

5.67E+0

The values above do not include Bremsstrahlung radiation.

CONTAMINATION

Contamination skin dose (mSv.h^{-1})	
Uniform deposit (1kBq.cm^{-2})	7.84E-1
0.05 ml droplet (1 kBq)	2.22E-1



Detection

Recommended probes*	
Alpha	
Beta	++
Gamma	++
X rays	+

Derived limits (Bq.cm^{-2})
Removable contamination
9E+0
Fixed contamination
1E+1

*** If no probes are indicated the recommended technique is to use a wipe test in association with a probe or liquid scintillation technique**

SHIELDING (mm)

Betas and electrons (Total absorption)	
Glass	0.4
Plastic	0.7

Gamma and X rays (half and tenth value thickness)

	½	1/10
Lead	16	46
Steel	36	93

INTERNAL EXPOSURE FOR WORKERS

COMMITTED EFFECTIVE DOSE PER UNIT INTAKE (Sv.Bq^{-1})

Ingestion	f_1	
All unspec. compounds	0.100	3.4E-09
Oxid., hydrox. & inorg. compounds	0.050	2.5E-09

Inhalation		1 µm	5 µm
	F		
All unspec. compounds	M	9.6E-09	7.1E-09
Oxid., hydrox., halid. & nitrat.	S	2.9E-08	1.7E-08

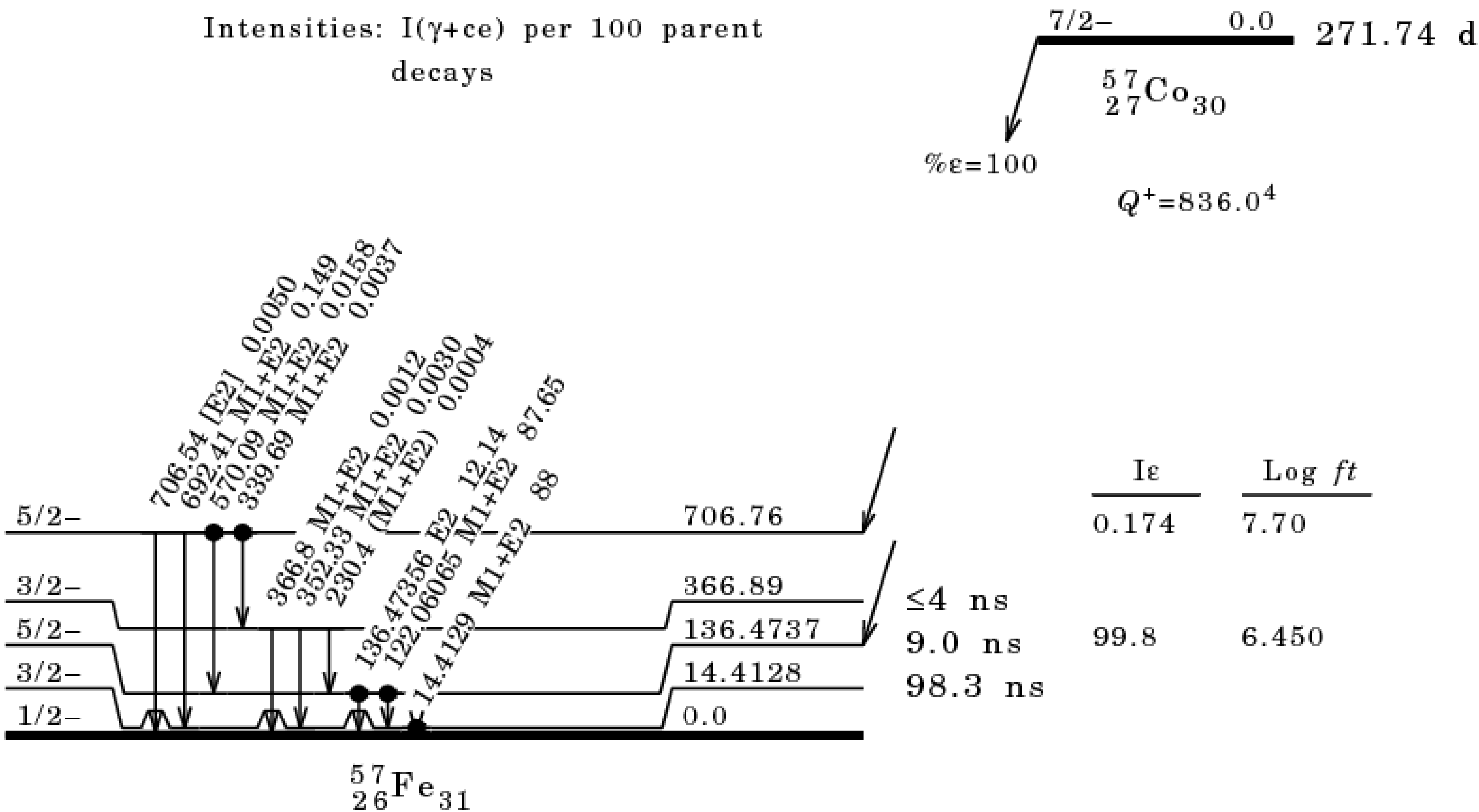
Highest dose organ: Lungs — **20 mSv ALI$_{ingestion}$** 5.9E+06 (Bq) **20 mSv ALI$_{inhalation}$** 6.9E+05 (Bq)

MAXIMUM RECOMMENDED ACTIVITIES IN LOW LEVEL OR INTERMEDIATE LEVEL LABORATORIES (Bq)

PHYSICOCHEMICAL STATE	Volatility factor (k)	Supervised area: Bench	Supervised area: Fume hood	Controlled area: Bench	Controlled area: Fume hood	Controlled area: Glove box
	Subject to external exposure requirements which may be more restrictive					
Oxid., hydroxid., halog. & nitrat.	0.01	2E+05	2E+06	5E+05	5E+06	5E+08
Other compounds	0.01	3E+05	3E+06	1E+06	1E+07	1E+09

Decay Scheme

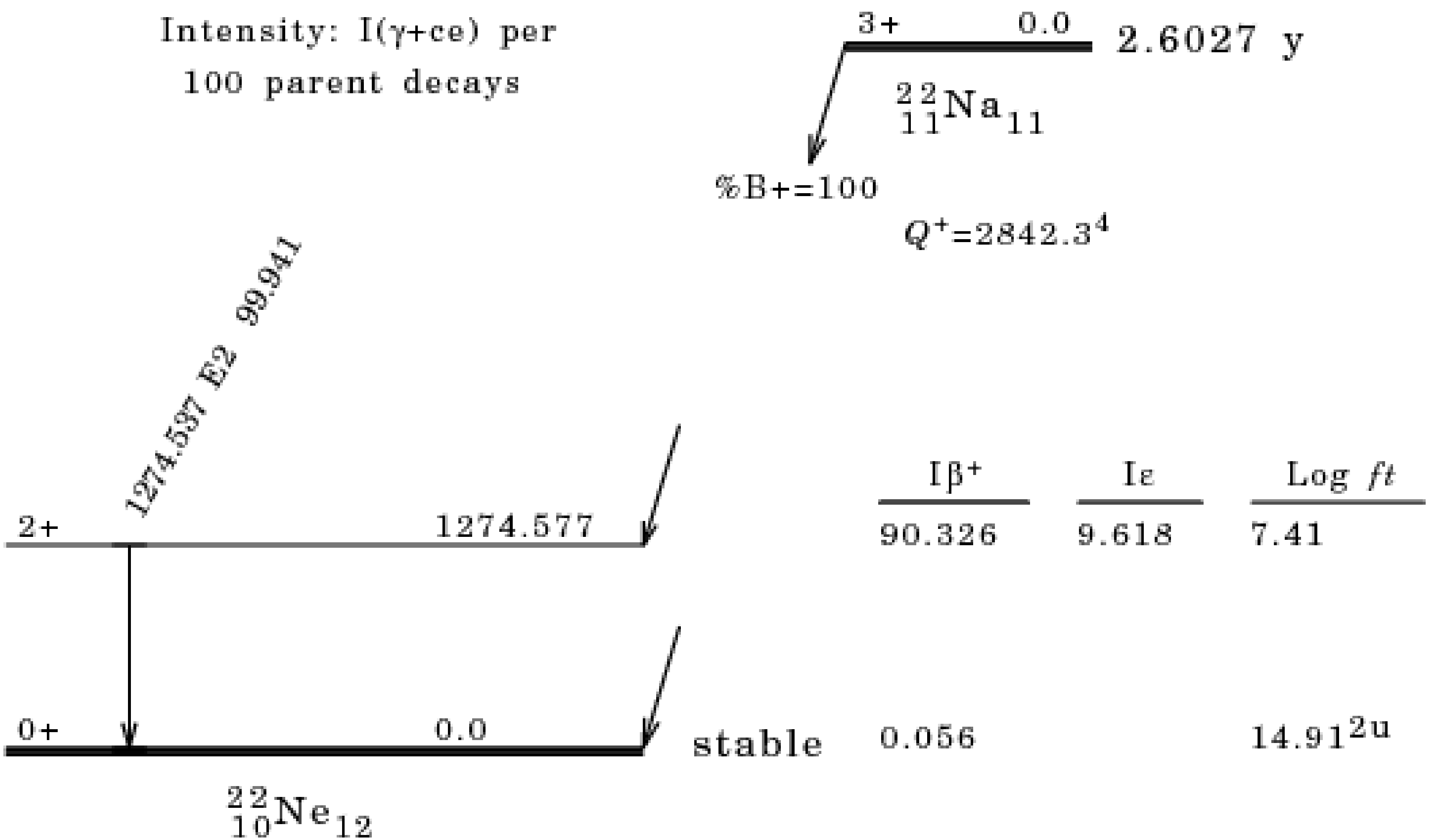
Intensities: I(γ+ce) per 100 parent decays



^{22}Na β^+ Decay

Decay Scheme

Intensity: I(γ+ce) per 100 parent decays



Cobalt - 57 $^{57}Co_{27}$

Half life: 271.8 days
Specific activity: 3.12E+14 Bq.g^{-1}

Risk group: 3
Risk colour: Yellow

Main emissions (keV)	Gamma or X		Beta (Emax)		Electrons		Alpha	
	E	%	E	%	E	%	E	%
E1	14	9			6	106		
E2	122	86			7	70		
E3	137	11						
% omitted		<1				11		

Exemption levels	
Quantity (Bq)	1E+06
Concentration (Bq.g^{-1})	1E+02

Transport (TBq)	
IAEA ST1 A_1 value	1E+1
IAEA ST1 A_2 value	1E+1

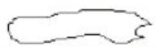
EXTERNAL EXPOSURE (mSv.h^{-1}) for an activity of 1 MBq or 1 MBq.m^{-2} (as appropriate)

Point source (30 cm)

Betas, electrons (skin dose): 0.00E+0

Gammas, X rays (deep tissue dose): 2.52E-4

Infinite plane source



Betas, electrons (skin)	
10 cm	8.4E-06
1 m	0.0E+00

Photons (skin)	
10 cm	2.4E-03
1 m	2.0E-03

Photons (deep dose)	
10 cm	2.3E-03
1 m	2.0E-03

10 ml glass vial

100 cm: 2.17E-5

Contact with 50 ml glass beaker

7.47E-2

Contact with 5 ml plastic syringe

3.35E-1

The values above do not include Bremsstrahlung radiation.

CONTAMINATION

Contamination skin dose (mSv.h^{-1})	
Uniform deposit (1kBq.cm^{-2})	1.19E-1
0.05 ml droplet (1 kBq)	1.62E-3

Detection: Recommended probes*	
Alpha	
Beta	
Gamma	+
X rays	++

Derived limits (Bq.cm^{-2})	
Removable contamination	2E+2
Fixed contamination	2E+2

* If no probes are indicated the recommended technique is to use a wipe test in association with a probe or liquid scintillation technique

SHIELDING (mm)

Betas and electrons (Total absorption)	
Glass	<0.1
Plastic	<0.1

Gamma and X rays (half and tenth value thickness)	½	$^1/_{10}$
Lead	<1	1
Steel	6	18

INTERNAL EXPOSURE FOR WORKERS

COMMITTED EFFECTIVE DOSE PER UNIT INTAKE (Sv.Bq^{-1})

Ingestion	f_1	
All unspec. compounds	0.100	2.1E-10
Oxid., hydrox. & inorg. compounds	0.050	1.9E-10

Inhalation		1 μm	5 μm
	F		
All unspec. compounds	M	5.2E-10	3.9E-10
Oxid., hydrox., halid. & nitrat.	S	9.4E-10	6.0E-10

Highest dose organ: Lungs — 20 mSv $ALI_{ingestion}$ 9.5E+07 (Bq) — 20 mSv $ALI_{inhalation}$ 2.1E+07 (Bq)

MAXIMUM RECOMMENDED ACTIVITIES IN LOW LEVEL OR INTERMEDIATE LEVEL LABORATORIES (Bq)

Subject to external exposure requirements which may be more restrictive

PHYSICOCHEMICAL STATE	Volatility factor (k)	Supervised area: Bench	Supervised area: Fume hood	Controlled area: Bench	Controlled area: Fume hood	Controlled area: Glove box
Oxid., hydroxid., halog. & nitrat.	0.01	4E+06	4E+07	1E+07	1E+08	5E+09
Other compounds	0.01	6E+06	6E+07	2E+07	2E+08	5E+09

Sodium - 22 $^{22}Na_{11}$

Half life: 2.6 years
Specific activity: 2.31E+14 Bq.g^{-1}

Risk group: 3
Risk colour: Yellow

Main emissions (keV)	Gamma or X		Beta (Emax)		Electrons		Alpha	
	E	%	E	%	E	%	E	%
E1	511	181	546	90				
E2	1275	100						
E3								
% omitted		0		0				

Exemption levels	
Quantity (Bq)	1E+06
Concentration (Bq.g^{-1})	1E+01

Transport (TBq)	
IAEA ST1 A_1 value	5E-1
IAEA ST1 A_2 value	5E-1

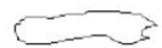
EXTERNAL EXPOSURE (mSv.h^{-1}) for an activity of 1 MBq or 1 MBq.m^{-2} (as appropriate)

Point source (30 cm)

Betas, electrons (skin dose): 1.01E-1

Gammas, X rays (deep tissue dose): 3.64E-3

Infinite plane source



Betas, electrons (skin)	
10 cm	7.2E-02
1 m	0.0E+00

Photons (skin)	
10 cm	1.4E-02
1 m	9.2E-03

Photons (deep dose)	
10 cm	1.3E-02
1 m	8.7E-03

10 ml glass vial

100 cm: 3.14E-4

Contact with 50 ml glass beaker

1.13E+0

Contact with 5 ml plastic syringe

5.36E+0

The values above do not include Bremsstrahlung radiation.

CONTAMINATION

Contamination skin dose (mSv.h^{-1})	
Uniform deposit (1kBq.cm^{-2})	1.68E+0
0.05 ml droplet (1 kBq)	6.69E-1

Detection: Recommended probes*	
Alpha	
Beta	++
Gamma	++
X rays	+

Derived limits (Bq.cm^{-2})	
Removable contamination	1E+1
Fixed contamination	2E+1

* If no probes are indicated the recommended technique is to use a wipe test in association with a probe or liquid scintillation technique

SHIELDING (mm)

Betas and electrons (Total absorption)	
Glass	0.8
Plastic	1.4

Gamma and X rays (half and tenth value thickness)	½	$^1/_{10}$
Lead	10	37
Steel	31	80

INTERNAL EXPOSURE FOR WORKERS

COMMITTED EFFECTIVE DOSE PER UNIT INTAKE (Sv.Bq^{-1})

Ingestion	f_1	
All compounds	1.000	3.2E-09

Inhalation		1 μm	5 μm
All compounds	F	1.3E-09	2.0E-09
	M		
	S		

Highest dose organ: Red marrow — 20 mSv $ALI_{ingestion}$ 6.3E+06 (Bq) — 20 mSv $ALI_{inhalation}$ 1.0E+07 (Bq)

MAXIMUM RECOMMENDED ACTIVITIES IN LOW LEVEL OR INTERMEDIATE LEVEL LABORATORIES (Bq)

Subject to external exposure requirements which may be more restrictive

PHYSICOCHEMICAL STATE	Volatility factor (k)	Supervised area: Bench	Supervised area: Fume hood	Controlled area: Bench	Controlled area: Fume hood	Controlled area: Glove box
All compounds	0.01	4E+05	4E+06	1E+06	1E+07	1E+09

IRRADIAZIONE ALL'INTERNO DI UN MEZZO

ALFA e BETA:

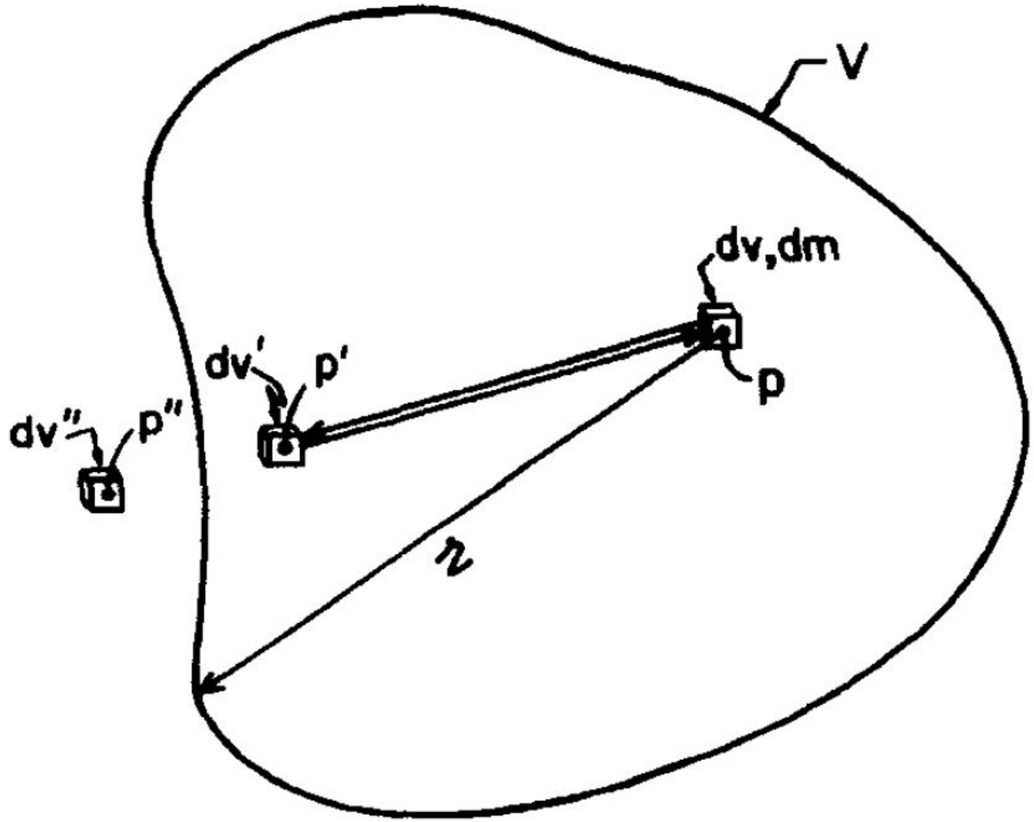
All'interno di un mezzo materiale di dimensioni sufficienti a fermare le particelle:

$$\dot{D}[Gy/s] = A[Bq/g] \cdot \bar{E}[MeV] \cdot 1.6 \times 10^{-13}[J/MeV] \cdot 10^{3}[g/kg]$$

GAMMA:

Bisogna calcolare la frazione AF di fotoni che interagisce nel mezzo (d è la distanza media del punto dalla superficie del mezzo):

$$AF \simeq 1 - \exp(-\mu_{en} d)$$



sorgente γ in volume V immerso in mezzo omogeneo identico e infinito
(teorema della) reciprocità: per ogni P' in V → ε in dv da dv' = ε in dv' da dv
R_{dv} energia γ emessa da dv e $\varepsilon_{dv,V}$ energia impartita in V
$AF_{dv,V} = \varepsilon_{dv,V}/R_{dv} = \varepsilon_{V,dv}/R_{dv}$
$AF_{dv,V} = \varepsilon_{dv,V}/R_{dv} = \int_V (1-e^{-\mu_{en} r})$

FONTI DI DATI

http://atom.kaeri.re.kr/

http://www.nndc.bnl.gov/nudat2/

http://ie.lbl.gov/

http://www.nist.gov/physlab/data/index.cfm

IRRADIAZIONE INTERNA

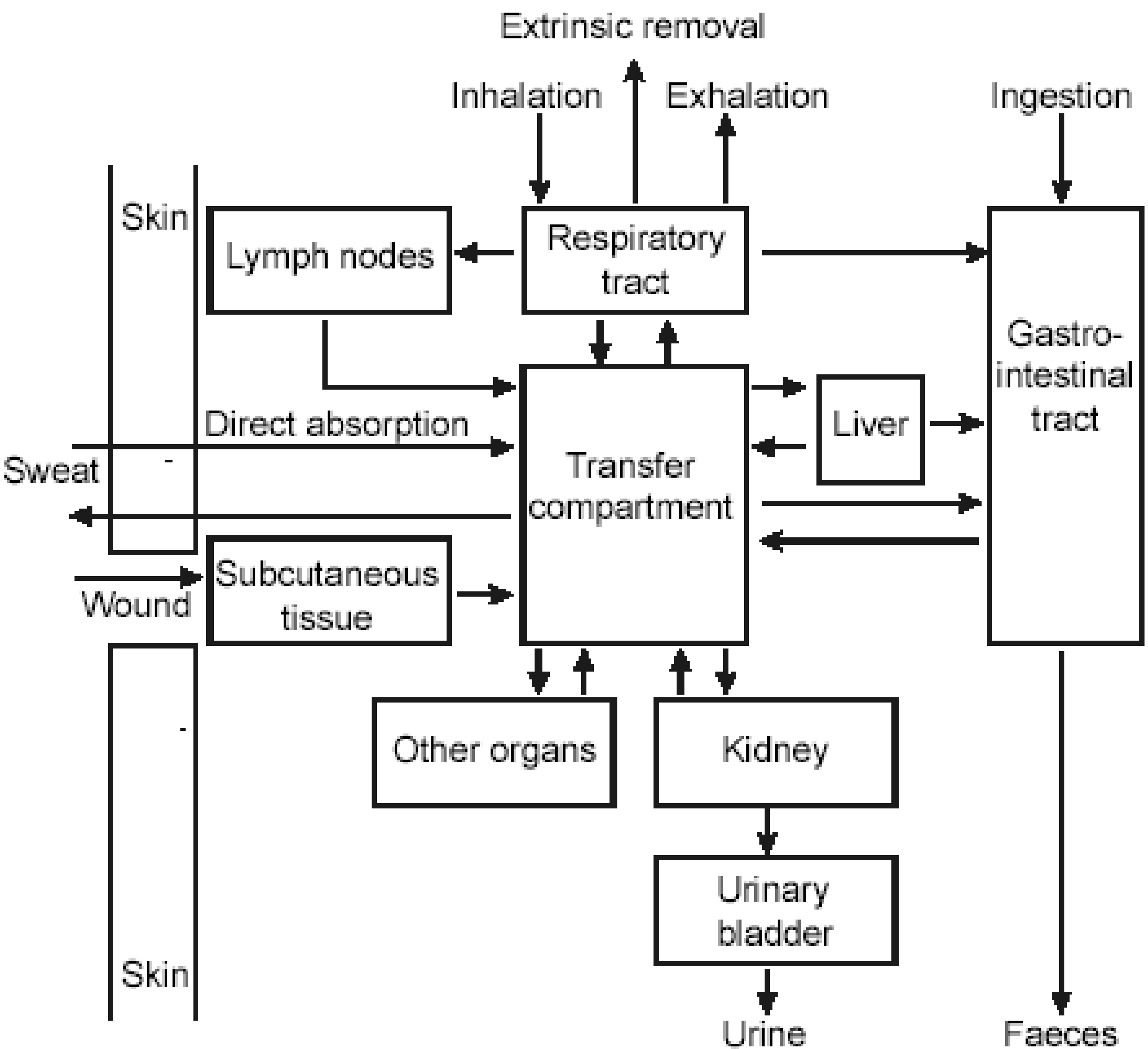


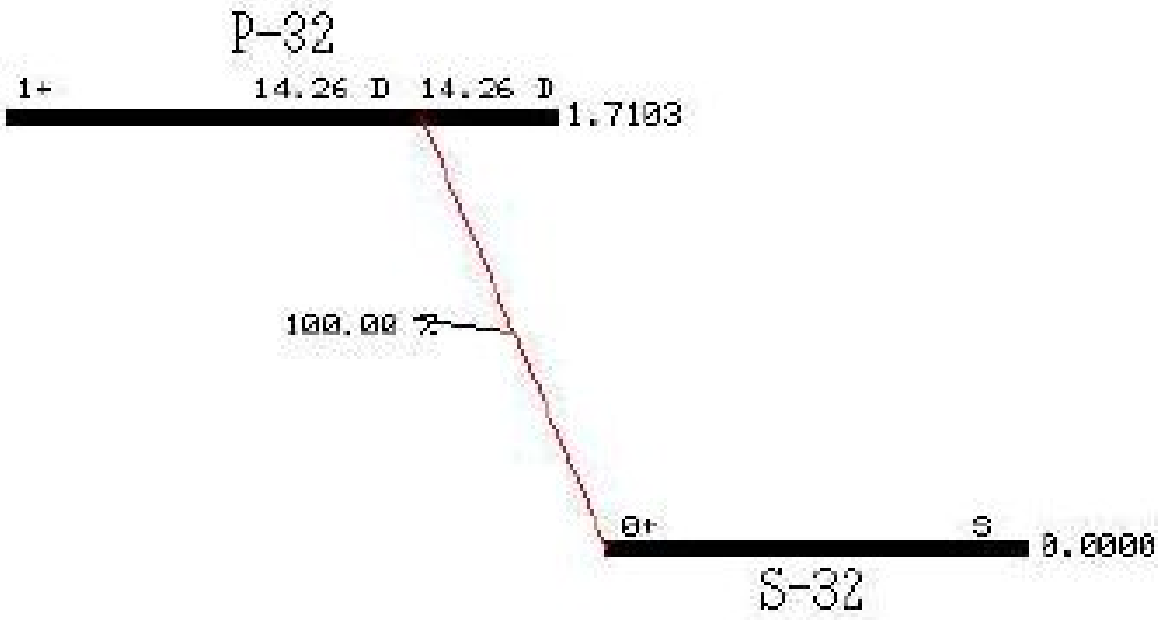
Fig. 7.1. Summary of the main routes in intake, transfers and excretion of radionuclides in the body; [9712].

Esercizio n. 4

Calcolare il rateo di dose (Gy/h) al centro di una sfera di acqua di raggio pari ad 1 cm in cui è omogeneamente diffusa una sorgente radioattiva di ^{32}P, di attività pari a 6×10^{5} Bq/g.

$$^{32}_{15}P \rightarrow {}^{32}_{16}S + \beta^{-} + \bar{\nu}_e$$

32P B- DECAY



Parent state: G.S.
Half life: 14.26 D(4)
Q(gs): 1710.3(6) keV
Branch ratio: 1.0

Beta ray:

Max.E(keV)	Avg.E(keV)	Intensity(rel)	Spin
			1+
1710.3(-)	694.9(3)	100.	0+

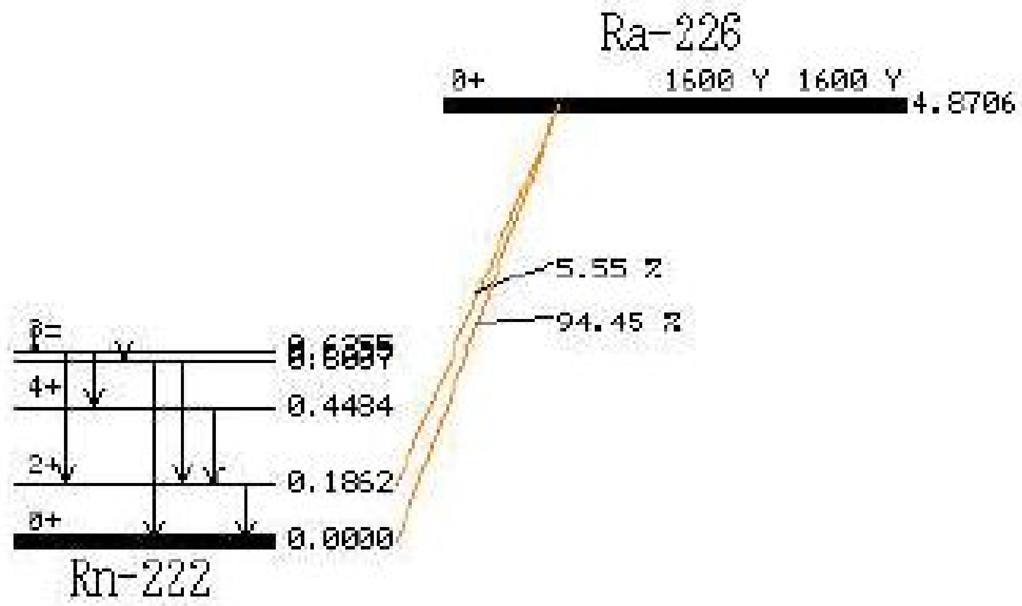
Range e^{-} @1.7 MeV in acqua: ~ 8.4×10^{-1} g/cm^{2}

Esercizio n. 5

Calcolare il rateo di dose (Gy/h) al centro di una sfera di acqua di raggio pari ad 1 cm in cui è omogeneamente diffusa una sorgente radioattiva di ^{226}Ra, di attività pari a 10^3 Bq/g.

226RA A DECAY

Parent state: G.S.
Half life: 1600 Y(7)
Q(gs): 4870.63(25) keV
Branch ratio: 1.0



Alpha ray:

Energy (keV)	Intensity (rel)	Hindrance
4784.34 (25)	94.45 (5)	1.0
4601 (1)	5.55 (5)	0.96 (1)
4340 (1)	0.0065 (3)	10.4 (5)
4191 (2)	0.0010 (1)	4.4 (5)
4160 (2)	0.00027 (5)	8.6 (16)

Range α in <u>aria</u>: R [cm] = 0.309 $E^{3/2}$ [MeV]

Esercizio n. 6

Una sfera di acqua di raggio pari a 5 cm contiene una distribuzione uniforme di ^{15}O con attività pari a 10^6 Bq/g:

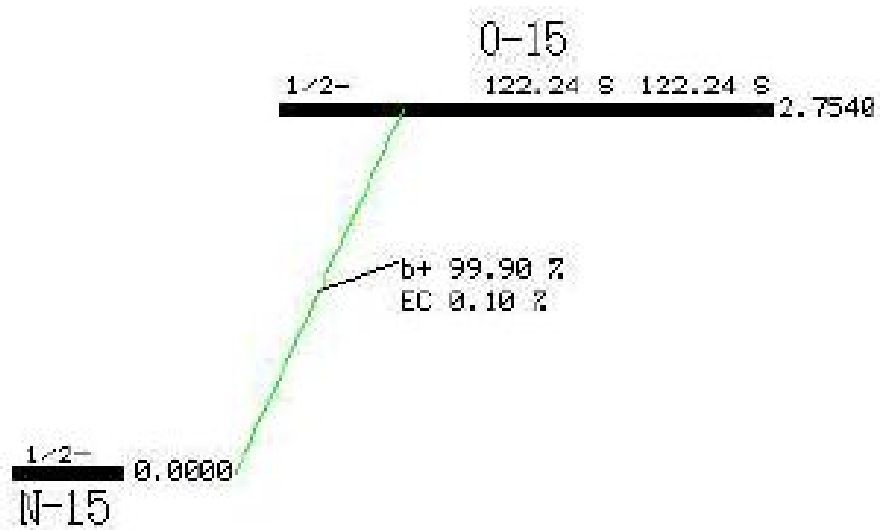
a) qual è il valore del rateo di dose (Gy/s) al centro della sfera?

b) come cambierebbe il valore del rateo di dose se il raggio della sfera fosse pari a 150 cm?

$$^{15}_{8}O \rightarrow ^{15}_{7}N + \beta^{+} + \nu_e$$

15O B+ DECAY

Parent state: G.S.
Half life: 122.24 S(16)
Q(gs): 2754.0(5) keV
Branch ratio: 1



Beta+ ray: total intensity =99.9

Max.E(keV)	Avg.E(keV)	Intensity(rel)	Spin	1/2-
1732.0(-)	735.28(23)	99.9003(10)		1/2-

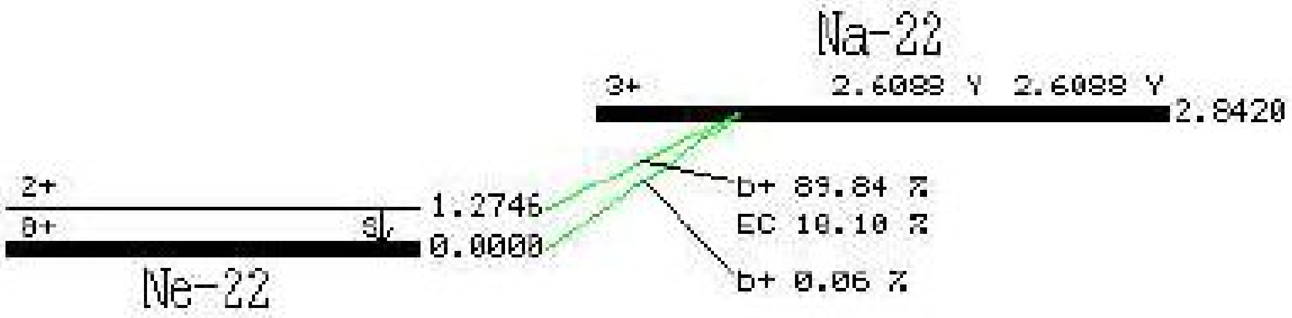
EC: total intensity = 1.0e-01

Esercizio n. 7

Una sfera di acqua di raggio pari a 2 cm contiene una sorgente di ^{22}Na uniformemente distribuita con attività pari a 10^5 Bq/g. Stimare la dose assorbita al centro della sfera in una settimana.

22NA B+ DECAY

Parent state: G.S.
Half life: 2.6088 Y(14)
Q(gs): 2842.0(5) keV
Branch ratio: 1.0



Beta+ ray: total intensity =89.9

Max.E(keV)	Avg.E(keV)	Intensity(rel)	Spin	3+
1820.0(-)	835.00(23)	0.056(14)		0+
545.4(-)	215.54(21)	89.84(10)		2+

EC: total intensity = 10.1

Gamma ray:

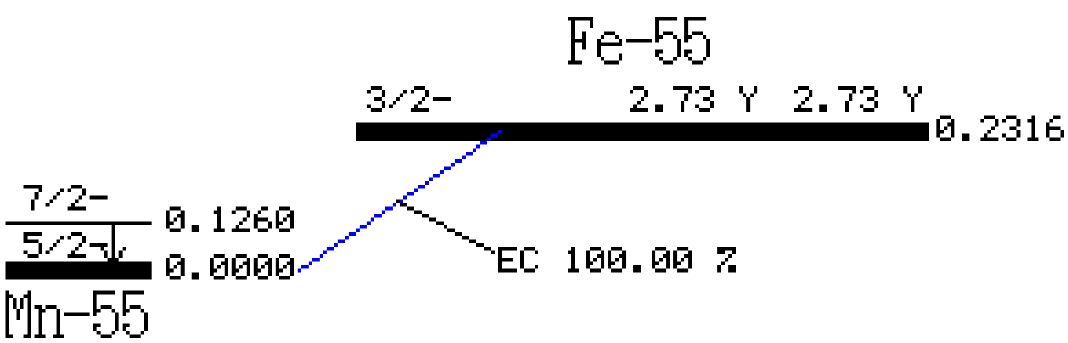
Energy(keV)	Intensity(rel)
1274.53(2)	99.944(14)

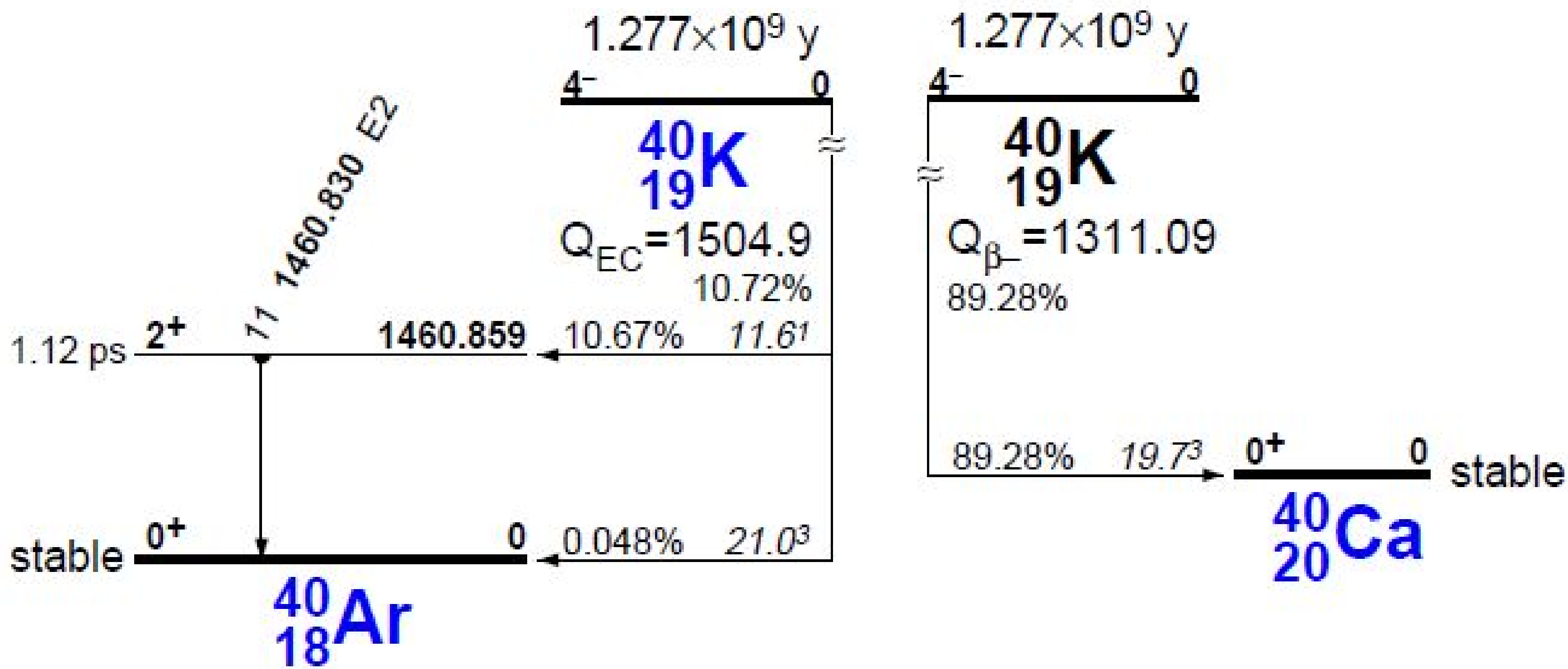
Esercizio n. 8

Una sorgente di ^{55}Fe è uniformemente distribuita in una sfera di acqua di raggio pari a 1 cm. Se l'attività della sorgente è pari a 10^5 Bq/g, stimare la dose assorbita al centro della sfera in 5 giorni.

X-rays from ^{55}Fe (2.73 y *3*)

E (keV)	I (%)	Assignment
0.556	0.037 *10*	Mn L_l
0.568	0.025 *6*	Mn L
0.637	0.028 *7*	Mn L_2
0.637	0.25 *6*	Mn L_1
0.640	0.0022 *6*	Mn L_6
0.648	0.19 *5*	Mn L_1
0.720	0.011 *3*	Mn L_4
0.720	0.017 *5*	Mn L_3
5.770	6.9E-06 *4*	Mn K_3
5.888	8.5 *4*	Mn K_2
5.899	16.9 *8*	Mn K_1
6.490	1.01 *5*	Mn K_3
6.490	1.98 *10*	Mn K_1
6.536	0.00089 *5*	Mn K_5
6.539	8.5E-08 *5*	Mn K_4




1.277×10⁹ y
4⁻
0
40 19 K
Q_EC=1504.9
10.72%
1.277×10⁹ y
4⁻
0
40 19 K
Q_β–=1311.09
89.28%
11 1460.830 E2
1.12 ps
2⁺
1460.859
10.67%
11.6¹
stable
0⁺
0
0.048%
21.0³
40 18 Ar
89.28%
19.7³
0⁺
0
stable
40 20 Ca