43-Tc-99

Tc-99 is a pure beta emitter. This nuclide is useful for thickness gauge of film and lether. Tc-99m is used extensively in medical nuclear imaging.

- Atomic Mass: 98.9062546 +- 0.0000021 amu = 1.00E-04
- Excess Mass: -87323.307 +- 1.916 keV
- Binding Energy: 852743.069 +- 1.921 keV
- Beta Decay Energy: B- 293.651 +- 1.417 keV

"The 1995 update to the atomic mass evaluation" by G.Audi and A.H.Wapsta, Nuclear Physics A595 vol. 4 p.409-480, December 25, 1995.

- Spin: 9/2+
- Half life: 211100 Y
- Mode of decay: Beta to Ru-99
  - Decay energy: 0.294 MeV

Meta state at 0.143 Mev

- Spin: 1/2-
- Half life: 6.01 H
- Mode of decay: IT
  - Decay energy: 0.143 MeV
- Mode of decay: Beta to Ru-99
  - Branch ratio: 0.0037 %
  - Decay energy: 0.437 MeV

- Possible parent nuclides:
  Beta from Mo-99

R.R.Kinsey, et al., *The NUDAT/PCNUDAT Program for Nuclear Data*, paper submitted to the 9 th International Symposium of Capture-Gamma_raySpectroscopy and Related Topics, Budapest, Hungary, Octover 1996.Data extracted from NUDAT database (Dec.18, 1997).

Fission Yields

Fissile with Neutron Energy	Yields (sum = 2)	
	Direct	Accumulated
U-235 with 0.0253 eV	1.17335E-08	6.11047E-02
U-235 with 1.0 MeV	3.77921E-09	5.71393E-02
U-238 with 1.0 MeV	8.30069E-11	6.19569E-02
Pu-239 with 0.0253 eV	8.50639E-08	6.14029E-02
Pu-239 with 1.0 MeV	5.66225E-08	5.98386E-02

Fission Yields to Meta State

Fissile with Neutron Energy	Yields (sum = 2)	
	Direct	Accumulated
U-235 with 0.0253 eV	2.71323E-09	5.31610E-02
U-235 with 1.0 MeV	7.60750E-10	4.97112E-02
U-238 with 1.0 MeV	1.67092E-11	5.39025E-02
Pu-239 with 0.0253 eV	1.96699E-08	5.34205E-02
Pu-239 with 1.0 MeV	1.13980E-08	5.20595E-02

CSWEG, *ENDF/B-VI Summary Documentation*, Report BNL-NCS-17541 (ENDF-201) (1991)

Cross section graphs:

Tc99(N,G) *JEF-2.2

Most of cross section data are adopted from NGATLAS - Atlas of Neutron Capture Cross Sections (Courtesy of IAEA NDS)

Total Cross Section

- at 0.0253 eV = 23.06 b
- Maxwell avg. at 0.0253 eV = 20.91 b
- at 14 MeV = 4.537 b
- Fission spectrum avg. = 5.614 b
- g-factor = 1.0230

Elastic Scattering Cross Section

- at 0.0253 eV = 3.422 b
- Maxwell avg. at 0.0253 eV = 3.419 b
- at 14 MeV = 3.060 b
- Fission spectrum avg. = 4.196 b
- g-factor = 1.1276

Total Inelastic Cross Section

- at 14 MeV = 214.8 mb
- Fission spectrum avg. = 1.324 b

(n,2n) Cross Section

- at 14 MeV = 1.233 b
- Fission spectrum avg. = 1.336 mb

(n,3n) Cross Section

- Fission spectrum avg. = 0.7922 micro barn

(n,na) Cross Section

- at 14 MeV = 550.7 micro barn
- Fission spectrum avg. = 0.1318 micro barn

(n,nd) Cross Section

- at 14 MeV = 2.496920e-18 b
- Fission spectrum avg. = 0.001605 micro barn

(n,nt) Cross Section

- Fission spectrum avg. = 1.559880e-10 b

Radiative Capture Cross Section

- at 0.0253 eV = 19.64 b
- Maxwell avg. at 0.0253 eV = 17.49 b
- Resonance integral = 311.6 b
- at 14 MeV = 1.007 mb
- Fission spectrum avg. = 87.10 mb
- g-factor = 1.0047

(n,p) Cross Section

- at 14 MeV = 13.41 mb
- Fission spectrum avg. = 58.07 micro barn

(n,d) Cross Section

- at 14 MeV = 1.050 mb
- Fission spectrum avg. = 0.2284 micro barn

(n,t) Cross Section

- at 14 MeV = 94.79 micro barn
- Fission spectrum avg. = 0.03123 micro barn

(n,He3) Cross Section

- at 14 MeV = 1.078180e-13 b
- Fission spectrum avg. = 5.943110e-12 b

(n,alpha) Cross Section

- at 14 MeV = 6.605 mb
- Fission spectrum avg. = 24.12 micro barn

XS averaged from JENDL3.2 ,Coutesey of T.Nakagawa at JAERI

Element Tc

Back to the Table of the Nuclides main chart

44-Ru-100

- Atomic Mass: 99.9042197 +- 0.0000021 amu
- Excess Mass: -89218.795 +- 2.003 keV
- Binding Energy: 861927.526 +- 2.007 keV
- Beta Decay Energy: B- -3630.000 +- 20.000 keV

"The 1995 update to the atomic mass evaluation" by G.Audi and A.H.Wapsta, Nuclear Physics A595 vol. 4 p.409-480, December 25, 1995.

- Atomic Percent Abundance: 12.6%
- Spin: 0+
- Stable Isotope

- Possible parent nuclides:
  Beta from Tc-100
  Electron capture from Rh-100

R.R.Kinsey, et al., *The NUDAT/PCNUDAT Program for Nuclear Data* ,paper submitted to the 9 th International Symposium of Capture-Gamma_raySpectroscopy and Related Topics, Budapest, Hungary, Octover 1996.Data extracted from NUDAT database (Dec.18, 1997).

Fission Yields

Fissile with Neutron Energy	Yields (sum = 2)	
	Direct	Accumulated
U-235 with 0.0253 eV	3.30926E-11	3.02965E-07
U-235 with 1.0 MeV	7.10681E-12	1.17954E-07
U-238 with 1.0 MeV	1.00117E-13	3.29396E-09
Pu-239 with 0.0253 eV	3.89125E-10	2.07106E-06
Pu-239 with 1.0 MeV	1.83055E-10	1.33058E-06

CSWEG, *ENDF/B-VI Summary Documentation*, Report BNL-NCS-17541 (ENDF-201) (1991)

Cross section graphs:

Ru100(N,G) * JEF-2.2

Most of cross section data are adopted from NGATLAS - Atlas of Neutron Capture Cross Sections (Courtesy of IAEA NDS)

Total Cross Section

- at 0.0253 eV = 11.50 b
- Maxwell avg. at 0.0253 eV = 10.92 b
- at 14 MeV = 4.537 b
- Fission spectrum avg. = 5.611 b
- g-factor = 1.0719

Elastic Scattering Cross Section

- at 0.0253 eV = 6.465 b
- Maxwell avg. at 0.0253 eV = 6.465 b
- at 14 MeV = 2.567 b
- Fission spectrum avg. = 4.386 b

Fission Product Decay*

(6) $I_1 t_1^{+1.2} = I_2 t_2^{+1.2}$

where I_1 = radiation intensity at time t_1 (>4h) after fission

I_2 = radiation intensity at time t_2 (<200 days) after fission

F. SPECIFIC ACTIVITY (Isotopic)

Specific Activity

$$\lambda N = 0.693N/T_{\frac{1}{2}} = \text{dis/sec/gm}$$

where $T_{\frac{1}{2}}$ = half-life (seconds)

N = number of atoms per gram

Specific Activity

$$\lambda N/(3.7 \times 10^{10}) = \frac{N \times 1.873 \times 10^{-11}}{T_{\frac{1}{2}}} = \text{curies/gm}$$

G. RADIATION ABSORPTION

(1) Alpha Particle Range

$R_\alpha = 0.56E$ (E<4 MeV)

$R_\alpha = 1.24E - 2.62$ (4<E<8 MeV)

where R_α = range in cm of air at 1 atm and 15°C

E = energy, MeV

(2) Beta Particle Range

For $0.01 \leq E \leq 2.5$ MeV

$R = 412\ E^{1.265\ -\ 0.0954\ \ln E}$

$\ln E = 6.63 - 3.2376\ [10.2146 - \ln R]^{\frac{1}{2}}$

where R = range in mg/cm²

E = max. energy, MeV

For $E \geq 2.5$ MeV

$R = 530\ E - 106$

where R, E same as above

Sargent's rule (E >0.8 MeV)

$R = 0.526\ E - 0.094$

where R = range, gm/cm²

E = max. energy, MeV

Feather's rule (E >0.6 MeV)

$R = 0.542\ E - 0.133$

where R, E same as for Sargeant's rule

(3) Gamma Ray Absorption

The following symbols will be used in this section:

I_o = original radiation exposure rate

I = attenuated radiation exposure rate

μ = linear absorption coefficient (cm^{-1}) $= \frac{0.693}{x_{\frac{1}{2}}}$

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*See "The Effects of Nuclear Weapons," 1962, §9.170-9.177

μ/ρ = mass absorption coefficient (cm^2/gm)

ρ = absorber density (gm/cm^3)

x = absorber thickness (cm)

$x_{\frac{1}{2}}$ = half-value layer of absorber (cm)

e = base of natural logarithms (2.718 . . .)

b = "buildup" factor

For monoenergetic or monochromatic narrow-beam radiation:

$$I = I_o e^{-\mu x} \quad \text{or} \quad I = I_o e^{-(\mu/\rho)(\rho)(x)}$$

For monoenergetic or monochromatic wide-beam radiation:

$$I = bI_o e^{-\mu x}$$

(4) Neutron Absorption (for a collimated beam of monoenergetic neutrons)

$$I = I_o e^{-\sigma N x}$$

where I_o = initial neutron intensities

I = final neutron intensities

N = number of atoms per cc in the absorber

σ = cross section (square centimeters)

x = thickness of absorber (cm)

e = base of the natural logarithm (2.718 . . .)

Since this equation is only an approximation of neutron attenuation, average neutron energies can be used for determining the value of σ. The equation is not accurate enough to justify the use of neutron buildup factors.

(5) Approximate Range - Energy Relation for Protons*

$$R = (E/9.3)^{1.8}$$

where E = energy in MeV (few MeV to 200 MeV)

R = range in meters in air

H. BETA PARTICLE COUNTING

(1) Self-Absorption

$$\frac{R_o}{R} = \frac{1}{mx}(1 - e^{-mx})$$

where R_o = measured counting rate

R = true counting rate

x = sample thickness (mg/cm^2)

m = absorption coefficient (cm^2/mg) [See NBS Handbook No. 51, p. 26]

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*Segre, Emilio, "Experimental Nuclear Physics," Vol. 1, New York: John Wiley & Sons, Inc., 1953.

(2) Resolving Time Determination

$$\tau = \frac{R_1 + R_2 - R_{12}}{2\ (R_1\ R_2)}$$

where τ = resolving time, seconds

R_1 = counting rate, source 1 (c/s)

R_2 = counting rate, source 2 (c/s)

R_{12} = counting rate, combined sources 1 and 2 (c/s)

(3) Resolving Time Correction

$$R = \frac{R_0}{1 - R_0 \tau}$$

where R = true counting rate (c/s)

R_0 = observed counting rate (c/s)

τ = resolving time, seconds

I. STATISTICS OF COUNTING*

n = number of counts, one observation

t = counting time, one observation

$\bar{n}$ = mean number of counts, series of observations

$\bar{t}$ = mean counting time, series of observations

m = number of observations

σ = theoretical standard deviation

S_t = observed standard deviation of the time required to record a preset number of counts

S_n = observed mean standard deviation of the number of counts recorded in a preset time

r = average number of counts per unit time

(1) Theoretical Standard Deviation

(a) $\sigma_n = \sqrt{rt} \cong \sqrt{n}$ for single observation

(b) $\sigma_{\bar{n}} = \sqrt{rt/m} \cong \sqrt{\bar{n}/m}$ for average number of counts/interval

(2) Observed (Experimental) Standard Deviation

(a) Series of observations, preset time

$$S_n = \left[\sum_{i=1}^{m} (n_i - \bar{n})^2 / (m - 1)\right]^{\frac{1}{2}}$$

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* Bleuler, Ernst, and Goldsmith, George J., "Experimental Nucleonics," New York: Holt, Rinehart & Winston, Inc., 1952.

λ_b ---------- biological decay constant

μ ---------- absorption coefficient, effective or apparent, linear; micro; micron (prefix)

μ_a ---------- $\tau + \kappa + \sigma_a$ = energy absorption coefficient for air

μbar -------- microbar

μCi --------- microcurie

$\mu\mu$ ---------- micromicro; micromicron (use pico)

μs ---------- microseconds

ν ---------- frequency (wave motion quantum theory); neutrino

ρ density, general or vapor

σ ---------- area; barn (cross section) theoretical standard deviation; Compton collision coefficient

σ_a ---------- absorption cross section in barns; Compton absorption coefficient

σ_{ac} --------- activation cross section in barns

σ_{eff} --------- effective cross section in barns

σ_s ---------- Compton scatter coefficient scattering cross section in barns

σ_t ---------- total cross section in barns

τ ---------- resolving time; photoelectric coefficient

ϕ ---------- work function; time increment

Ω ---------- ohm

χ ---------- concentration, air

Prefixes

d	deci	$(= 10^{-1})$	da	deka	$(= 10)$
c	centi	$(= 10^{-2})$	h	hecto	$(= 10^{2})$
m	milli	$(= 10^{-3})$	k	kilo	$(= 10^{3})$
μ	micro	$(= 10^{-6})$	M	mega	$(= 10^{6})$
n	nano	$(= 10^{-9})$	G	giga	$(= 10^{9})$
p	pico	$(= 10^{-12})$	T	tera	$(= 10^{12})$
f	femto	$(= 10^{-15})$			
a	atto	$(= 10^{-18})$			

Tc (N) Ru
am → Be

0.5 μCi Am source (@ 98% α) = 13,244.7 dps

10% α → Be foil = 1,324.47 N ~~ee~~dps

20% N enters Tc mass of 1 cm^3 = 265 n_{ps}

50% leakage (escape without interaction)

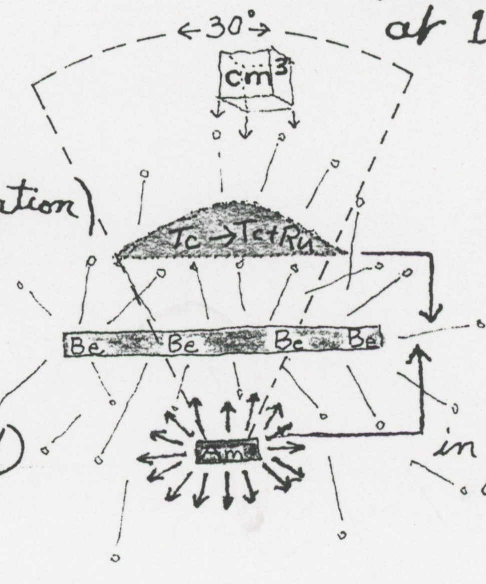
50% absorption (ν) ≅ 132.5 events per. sec.

10% events = Tc (N) Ru ≅ 13 per second

Transmutations per day ≅ 1,123,200

Tc^{99} Total Cross Section
at 0.0253 eV = 23.06 b
at 14 MeV = 4.537 b

(Approximation of attenuation)
Neutron Absorption
$I = I_0 e^{-\sigma N x}$



Alpha particle range.
$R_\alpha = 0.56E$ (E<4 MeV)

Where R_α = range in cm of air at 1 atm and 15°c. E = MeV.

Statistics of Counting

Theoretical Deviation: $\sigma_n = \sqrt{rt/m} \cong \sqrt{\bar{n}/m}$

Observed: $S_n = \left[\sum_{i=1}^{m} (n_i - \bar{n})^2 / (m-1) \right]^{1/2}$

Acorn May 2000