Estimation of deposition positions of α-emitters in the body by L X-ray analysis

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Introduction

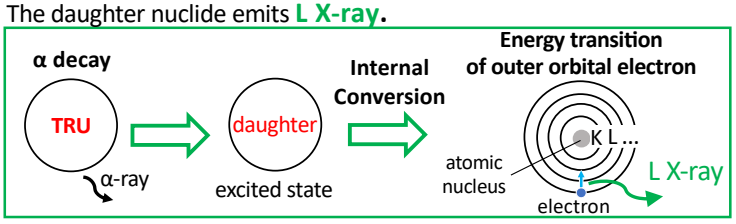
In a accident involving radiation

Evaluation of transuranium (TRU) nuclides quantities such as ^{239}Pu and ^{241}Am

α-emitters

α-ray → stops immediately ↪ difficult to measure from outside the body

The daughter nuclide emits **L X-ray**.

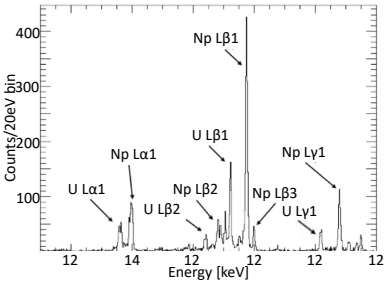


L X-ray

● Multiple peaks between 10~30keV ↓ **TES*** can measure them.

ΔE<100keV

***TES** : Transition Edge Sensor -type microcalorimeter



Spectrum of L X-ray measured by TES[1]

Energy spectrum + **deposition position**

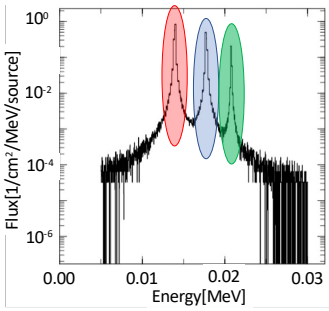
The amount of deposition in the body will be determined.

Thickness of body tissue through which L X-ray passes ↓ **Attenuation of L X-ray intensity** by body tissues

Simulation

PHITS ver.3.27[2] EGS5

L X-ray source (Three L X-rays emitted from **^{237}Np**)



L X-ray spectra measured in vacuum

^{241}Am's daughter nuclide

TRU → emits **γ-ray**

Possibility to use for positions estimation

Lorenz distribution

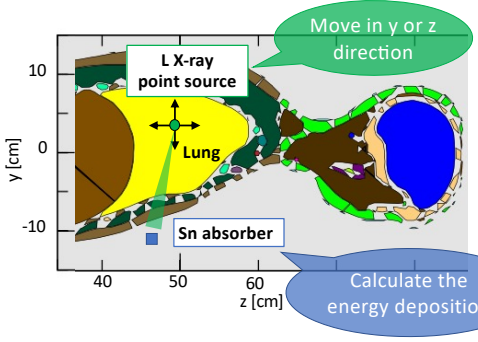
$$L(E) = (\Gamma/2\pi)/((E - E_0)^2 + (\Gamma/2)^2)$$

E : Energy E_0 : Peak Energy

Γ : natural width

Peak	E_0 [keV][2]	Γ [eV][2]	Emission probability[4]
Lα1	13.946	11.8	14.9
Lβ1	17.751	13.4	8.37
Lγ1	20.784	15.9	1.92

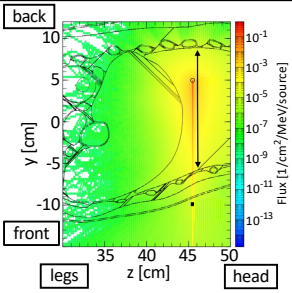
ICRP Pub. 145[5]
Adult Mesh-Type Reference Computational Phantom

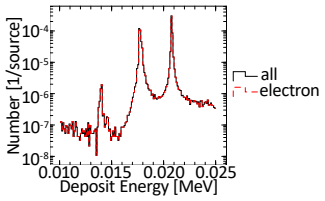


Calculation conditions
- L X-ray point source
- Cubic Sn absorber (0.5×0.5×0.5 mm³)
- narrow beam covering the absorber
- Histories = 10^6* 93
- Cut-off energy
  - for electrons 1.0 [keV]
  - for positrons 1.0 [keV]
  - for photons 1.0 [keV]

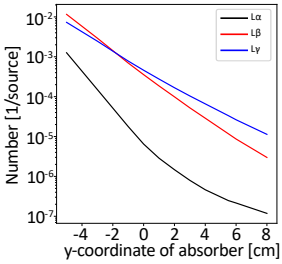
Result

Ⅰ Movement of the source in the lung depth (y) direction

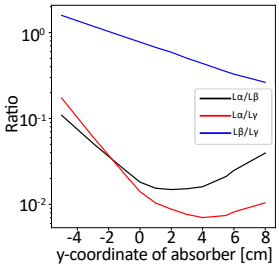




Energy spectrum assigned to Sn absorber when the source coordinate is y=0

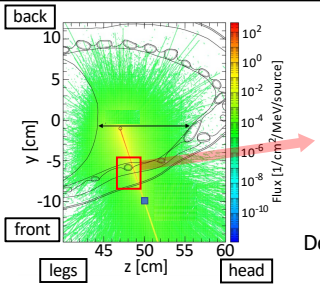


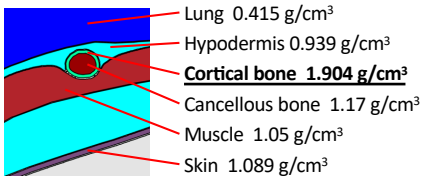
Relative intensities of the three L X-rays



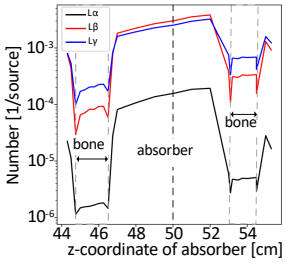
Ratio of the relative intensities

Ⅱ Movement of the source in the lung height (z) direction

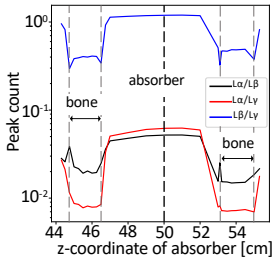




Density of body tissue



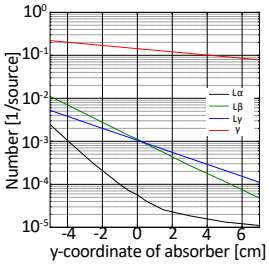
Relative intensities of the three L X-rays



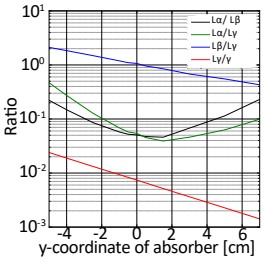
Ratio of the relative intensities

Ⅲ Comparison of γ-ray from ^{241}Am and L X-rays from ^{237}Np (z=50)

^{241}Am γ-ray Energy : 59.54 keV Emission probability : 35.9 %



Relative intensities of the three L X-rays and the γ-ray



Ratio of relative intensities of the three L X-rays and the γ-ray

Conclusion

・If the deposition position is y≦0(Body depth approx. 10 cm), the ratio of Lα to the other L X rays can be used to estimate the deposition position.

・When the measurement volume is extremely low, it indicates the presence of dense body tissue such as cortical bone between the source and absorber, which can be used to estimate the deposition position.

・Using γ-ray emitted from the parent nuclide, it is possible to estimate the location of even deeper deposition.

References
(1) K. Maehata et al., Response of a superconducting transition-edge sensor microcalorimeter with a mushroom-shaped absorber to L X rays emitted by transuranium elements, IEICE Trans. Electron., E98.C, (2015)
(2) T. Sato, et al., Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02, J. Nucl. Sci. Technol. 55, 684-690 (2018).
(3) K. Maehata et al., J. Nucl. Sci. Tech., 47 (2010) 308-310.
(4) BNM-LNHB/CEA Table de Ra- dioneucléides, (http://www.nu- cleide.org/DDEP_WG/DDEPdata.html).
(5) C.H. Kim, et al., ICRP, 2020. Adult mesh-type reference computational phantoms. ICRP Publication 145. Ann. ICRP 49(3).