MEASUREMENT OF K FLUORESCENCE YIELDS OF NIOBIUM AND RHODIUM USING MONOCHROMATIC RADIATION

Link to LNHB posters

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Context

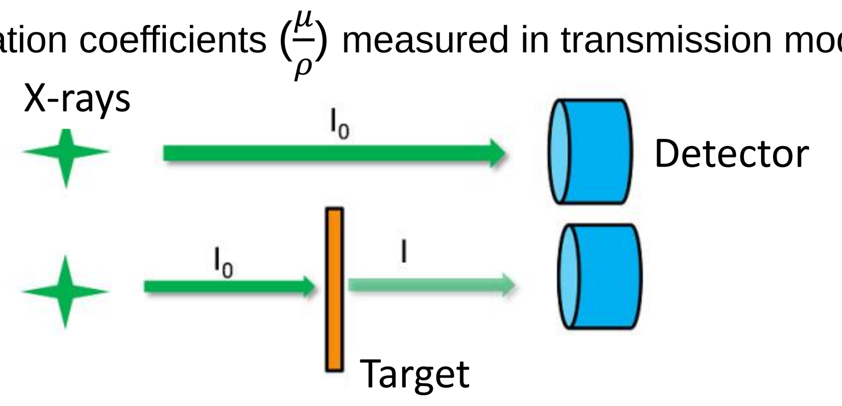
- Reactor dosimetry: - small metal samples irradiated and activated by neutrons
  - allows: characterization of flux and energy distribution of neutrons; validation of neutron codes; assessment of reactor vessel aging
- Each of these dosimeters has a specific neutron energy reaction threshold (see Table 1)
- Nb and Rh: information on neutrons with energies around 1 MeV
- Reaction of interest in dosimeters: ^{93}Nb(n,n')^{93m}Nb and ^{103}Rh(n,n')^{103m}Rh
- Activity measurement conventionally performed by X-ray spectrometry
- X-ray emission intensities determined from the γ-ray transition probabilities and fluorescence yields.

Table 1: Dosimeters characteristics

Dosimeter	Energy of emitted photons (keV)	Neutron energy region
^{54}Fe(n,p)^{54}Mn	834.85 (γ)	Fast (3.1 MeV)
^{58}Ni(n,p)^{58}Co	810.76 (γ)	Fast (2.8 MeV)
^{197}Au(n, γ)^{198}Au	441.8 (γ)	Thermal
^{93}Nb(n,n')^{93m}Nb	16.59 (XK_{α}) and 18.67 (XK_{β})	Fast (1.2 MeV)
^{103}Rh(n,n')^{103m}Rh	20.17 (XK_{α}) and 22.84 (XK_{β})	Fast (1 MeV)

Mass-attenuation coefficients

- Mass-attenuation coefficients $\left(\frac{\mu}{\rho}\right)$ measured in transmission mode:



- Use of a monochromatic (E) parallel photon beam under normal incidence
- Photon flux intensity measurement in front of the target (I_0), and behind (I)
- Beam attenuation follows the Beer-Lambert law:

$$I = I_0\, e^{-\frac{\mu}{\rho}(E)\rho x} = I_0 e^{-\frac{\mu}{\rho}(E)\frac{M}{A}}$$

- Target characteristics: x = thickness, ρ = density, M = mass, A = area
- Relative combined standard uncertainties on $\left(\frac{\mu}{\rho}\right)$: about 2%
- Results used for the fluorescence yield measurements

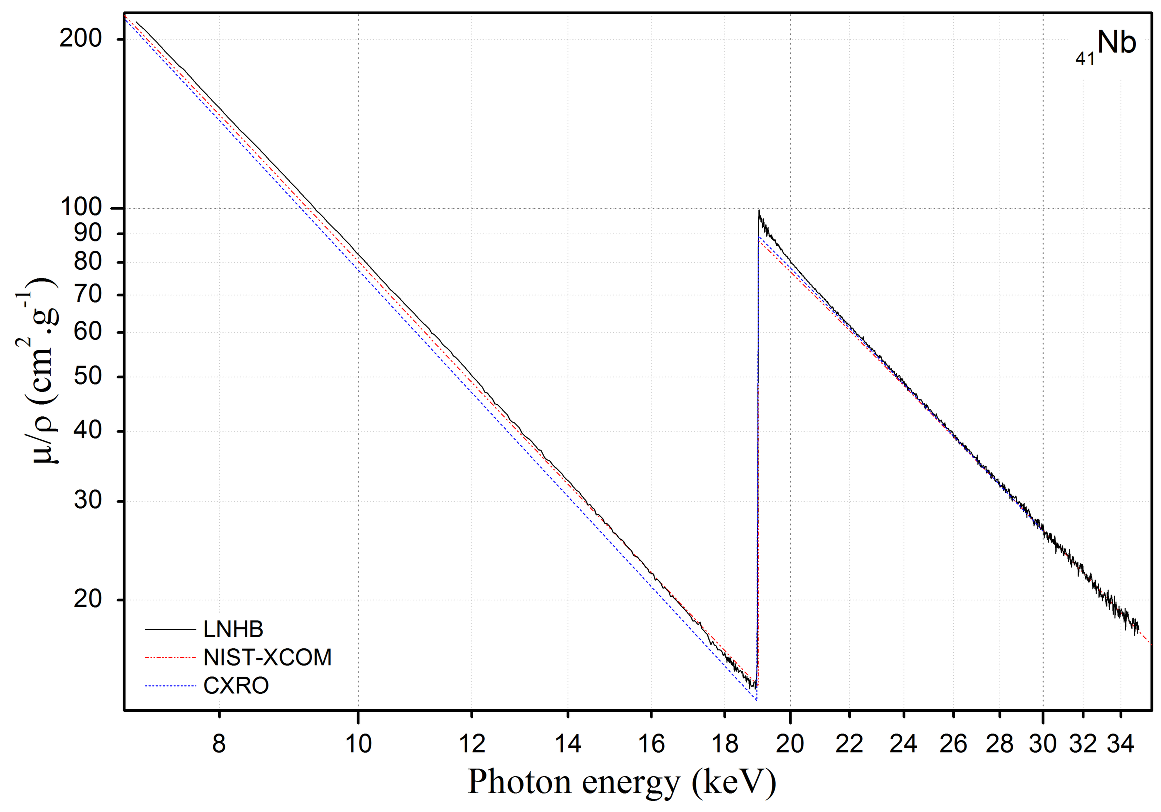


Figure 1: Niobium mass attenuation coefficients

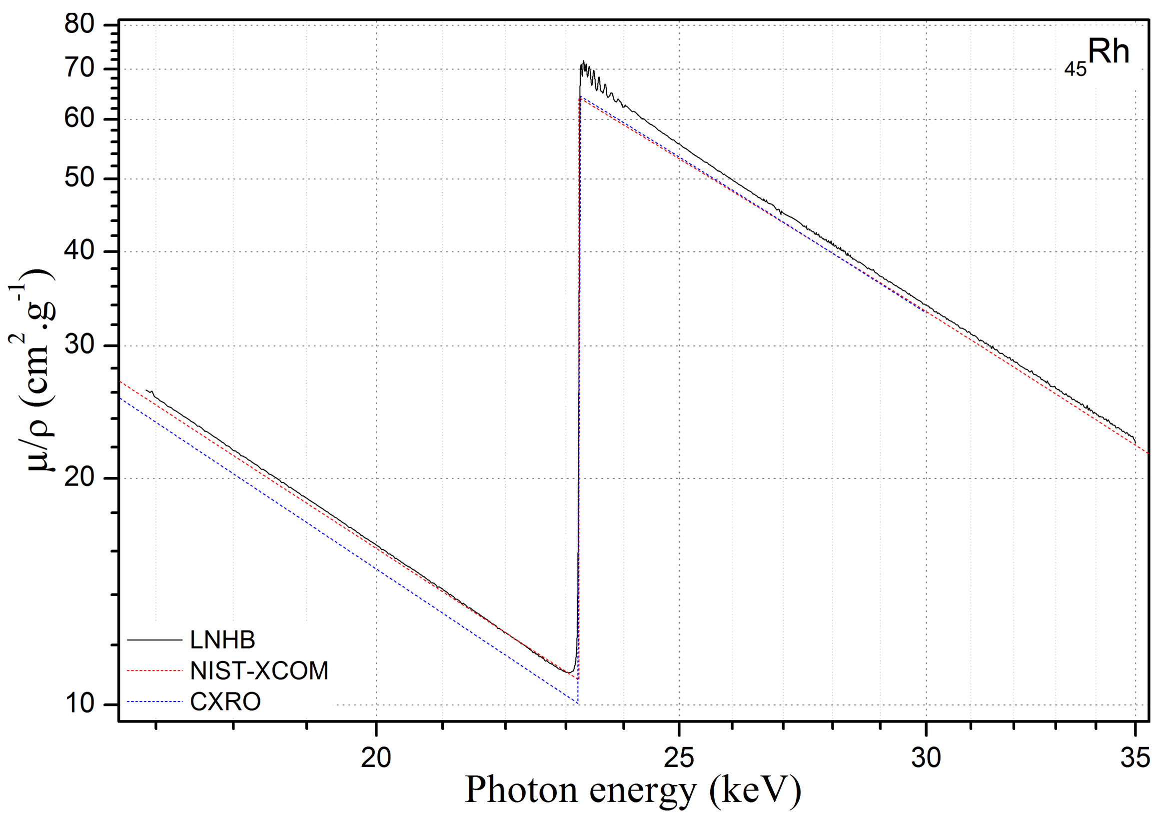


Figure 2: Rhodium mass attenuation coefficients

Experimental procedure

Measurements performed at the metrology beamline of the SOLEIL synchrotron:

- "Hard X-ray" branch
- Equipped with a double Si (111) crystal
- Provides monoenergetic photons in the 3.5 – 35 keV energy range

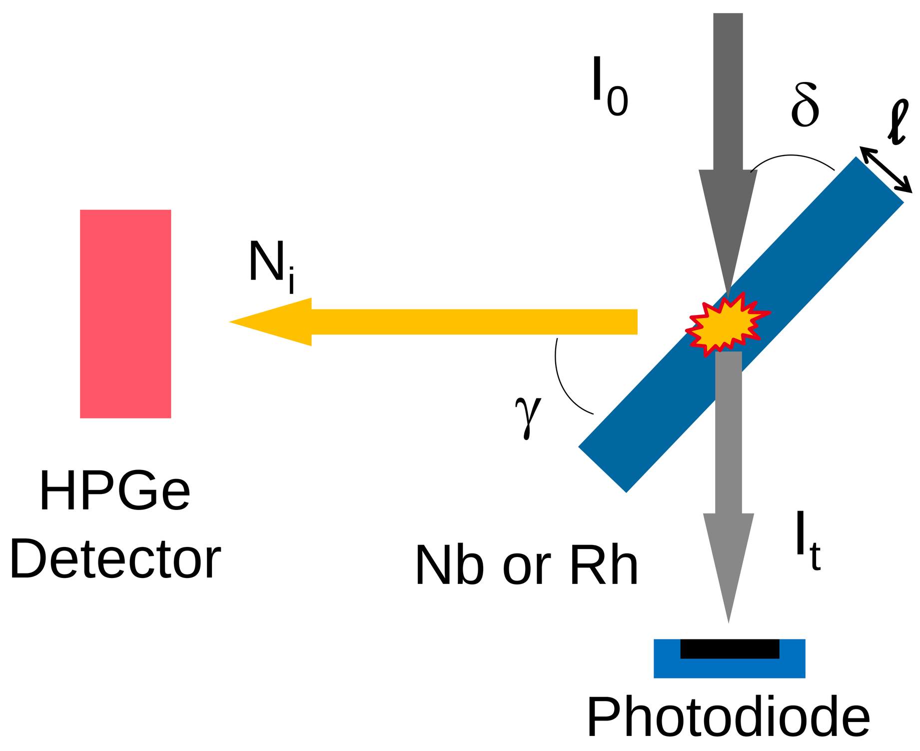
Reflection geometry method:

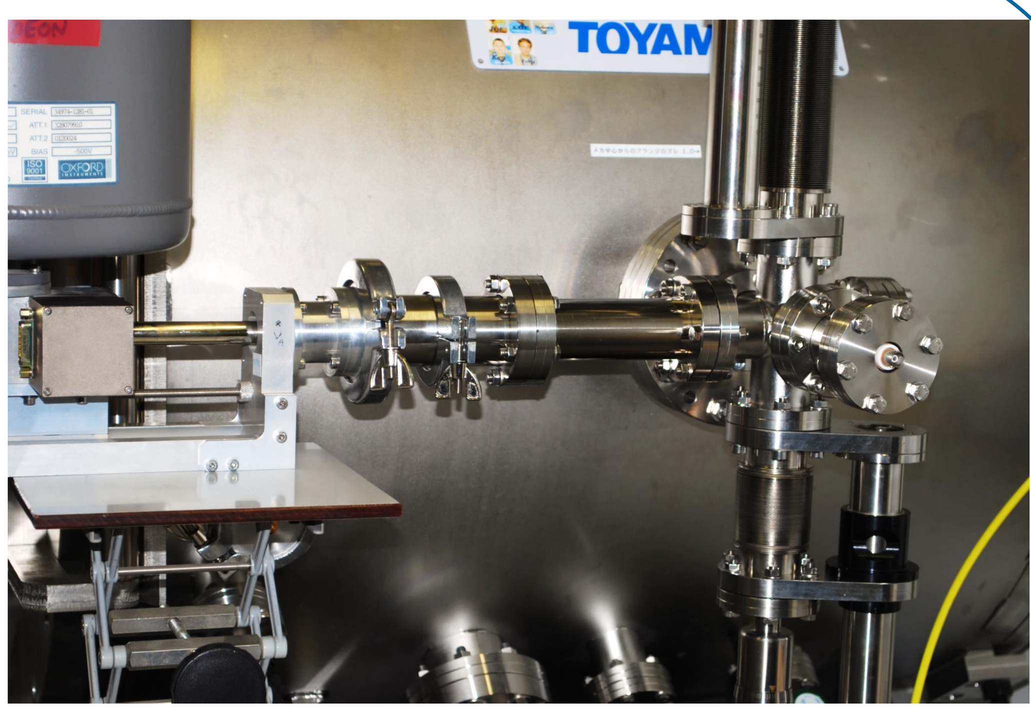
- Monochromatic photon beam with energy E_0
- Linear attenuation (μ_0) and interaction by photoelectric effect with probability τ_K
- Production of characteristic X-rays with energy E_i according to the partial fluorescence yield ω_{Ki}
- Emerging photons measured with a calibrated high-purity germanium (HPGe) detector, depending on the total attenuation coefficient μ_i
- Incident beam intensity (I_0) determined with a calibrated photodiode in transmission mode
- Number of events in the full-energy peak at energy E_i (N_i) is proportional to the detection solid angle (Ω) and HPGe efficiency (ε_i):

$$dN_i = I_0\, e^{-\frac{\mu_0 x}{\sin\gamma}}\, \tau_K \frac{dx}{\sin\gamma}\,\omega_{Ki}\, e^{-\frac{\mu_i x}{\sin\delta}}\frac{d\Omega}{4\pi}\varepsilon_i$$

$$\omega_{Ki} = \frac{4\pi}{\Omega}\frac{N_i}{\varepsilon_i}\frac{1}{I_0\tau_K}\frac{\mu_0+\mu_i}{1-e^{-\frac{\mu_0+\mu_i}{\sin\gamma}l}}$$

- Thickness of target (l): 20 µm (Nb) and 50 µm (Rh)
- Final result: average of results from different incident energies





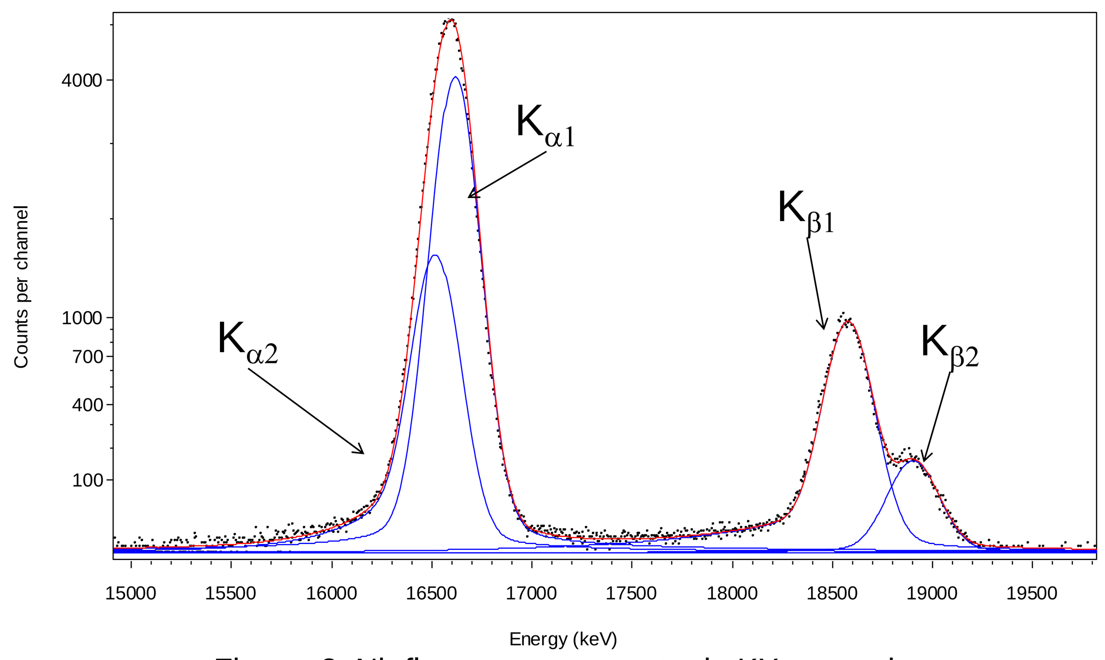


Figure 3: Nb fluorescence spectra in KX-ray region

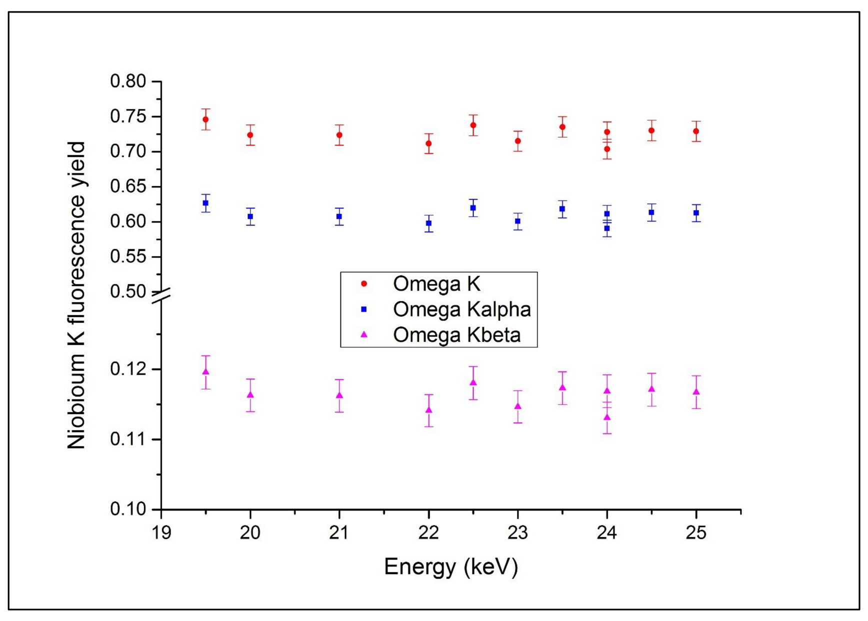


Figure 4: Nb fluorescence yields results

Results

- Limited number of recent experimental values
- Significant differences between experimental and theoretical values
- Evaluations take into account both of them

- Niobium:
  - Measurements in agreement with other experimental values
  - Very close to HUBBELL (1994): fit of experimental values
  - Improvement of experimental uncertainties
- Rhodium:
  - Present result higher than most of the other experimental values
  - High uncertainty on the photon flux intensity
  - Thickness of rhodium sample too large

Further measurements with a thinner sample will be performed

Table 2: Comparison of data for niobium

Niobium			
Author	Year	K fluorescence yield	Method
C.E. ROOS	1954	0.713	Experimental
	1957	0.730 (20)	
S.K. ARORA	1981	0.738 (30)	
S. SINGH	1990	0.722 (44)	
R. DURAK	2001	0.734 (28)	
E.J. CALLAN	1962	0.754	Theory
V.O. KOSTROUN	1971	0.759	
D.L. WALTERS	1971	0.7788	
W. BAMBYNEK	1972	0.748 (32)	Evaluation
M.O. KRAUSE	1979	0.747	
J.H. HUBBELL	1989	0.7512	
	1994	0.724	
E. SCHÖNFELD	1996	0.751 (4)	
PRESENT WORK		ω_K = 0,724 (14)	

Table 3: Comparison of data for rhodium

Rhodium			
Author	Year	K fluorescence yield	Method
I. BACKHURST	1936	0.801	Experimental
R.J. STEPHENSON	1937	0.77	
C.E. ROOS	1954	0.779	
	1957	0.786 (15)	
S. SINGH	1990	0.829 (58)	
E.J. CALLAN	1962	0.812	Theory
V.O. KOSTROUN	1971	0.820	
D.L. WALTERS	1971	0.8367	
M.H. CHEN	1980	0.808	
W. BAMBYNEK	1972	0.807(31)	Evaluation
M.O. KRAUSE	1979	0.808	
J.H. HUBBELL	1989	0.8086	
	1994	0.792	
E. SCHÖNFELD	1996	0.809 (4)	
PRESENT WORK		ω_K = 0,814 (41)	

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