Precise α_K and α_T Internal Conversion Coefficients Measurements of 39.752(6)-keV E3 Transition in ^{103m}Rh: Test of Internal Conversion Theory

TEXAS A&M PROGRAM TO MEASURE ICC

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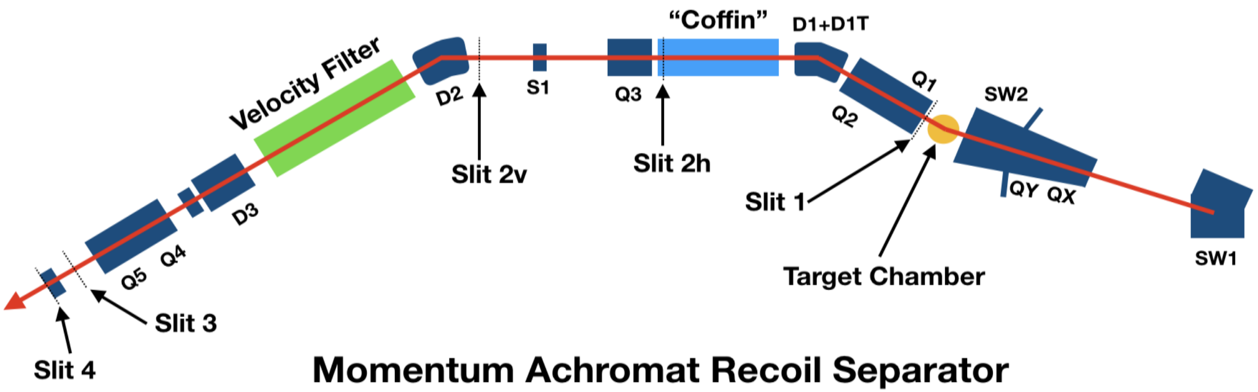
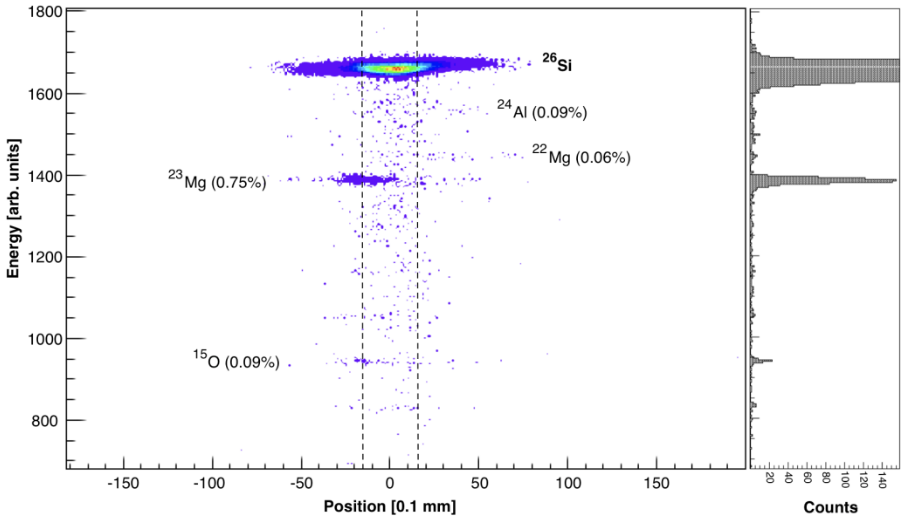
Texas A&M - Cyclotron Institute

β-γ Precision Measurements

K500 and K150 cyclotrons + ***MARS***

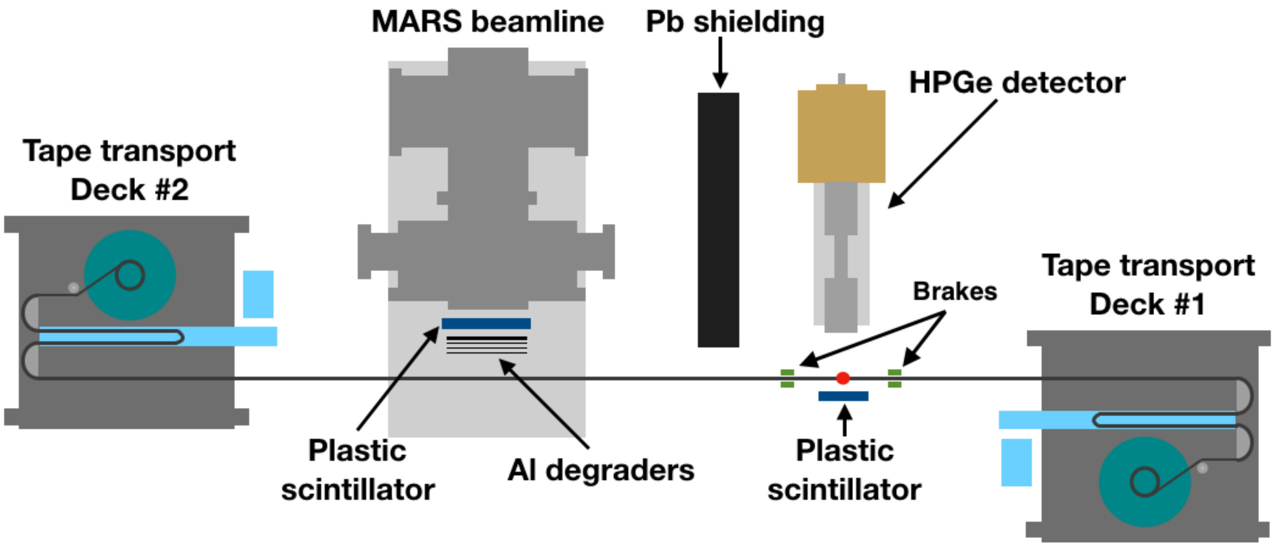


Momentum Achromat Recoil Separator



Texas A&M - Cyclotron Institute
β-γ Precision Measurements

HPGe detector (γ)
Gas detector (β)
Plastic Scintillator detector (β)
Tape transport
Kamax NT acq



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TEXAS A&M PROGRAM TO MEASURE ICC

Internal Conversion Coefficients (ICC):

- Big impact on quality of nuclear science
- Central for the nuclear data evaluation programs
- Intensely studied by theory and experiment
- Important result: hole calculation now standard

2002RA45 survey ICC’s theories and measurements

- **Theory:** **RHFS and RDF comparison**

  Exchange interaction, Finite size of nucleus, ***Hole treatment***

- **Experiment:**

  100 *E2*, *M3*, *E3*, *M4*, *E5* ICC values, 0.5%-6% precision,

  very few <1% precision!

- **Conclusions, Δ(exp:theory)%:**

  No hole*: +0.19(26)% *BEST!

  (bound and continuum states - SCF of neutral atom)

  ***Hole-SCF*: -0.94(24)%**

  (continuum - SCF of ion + hole (full relaxation of ion orbitals))

  ***Hole-FO*: -1.18(24)%**

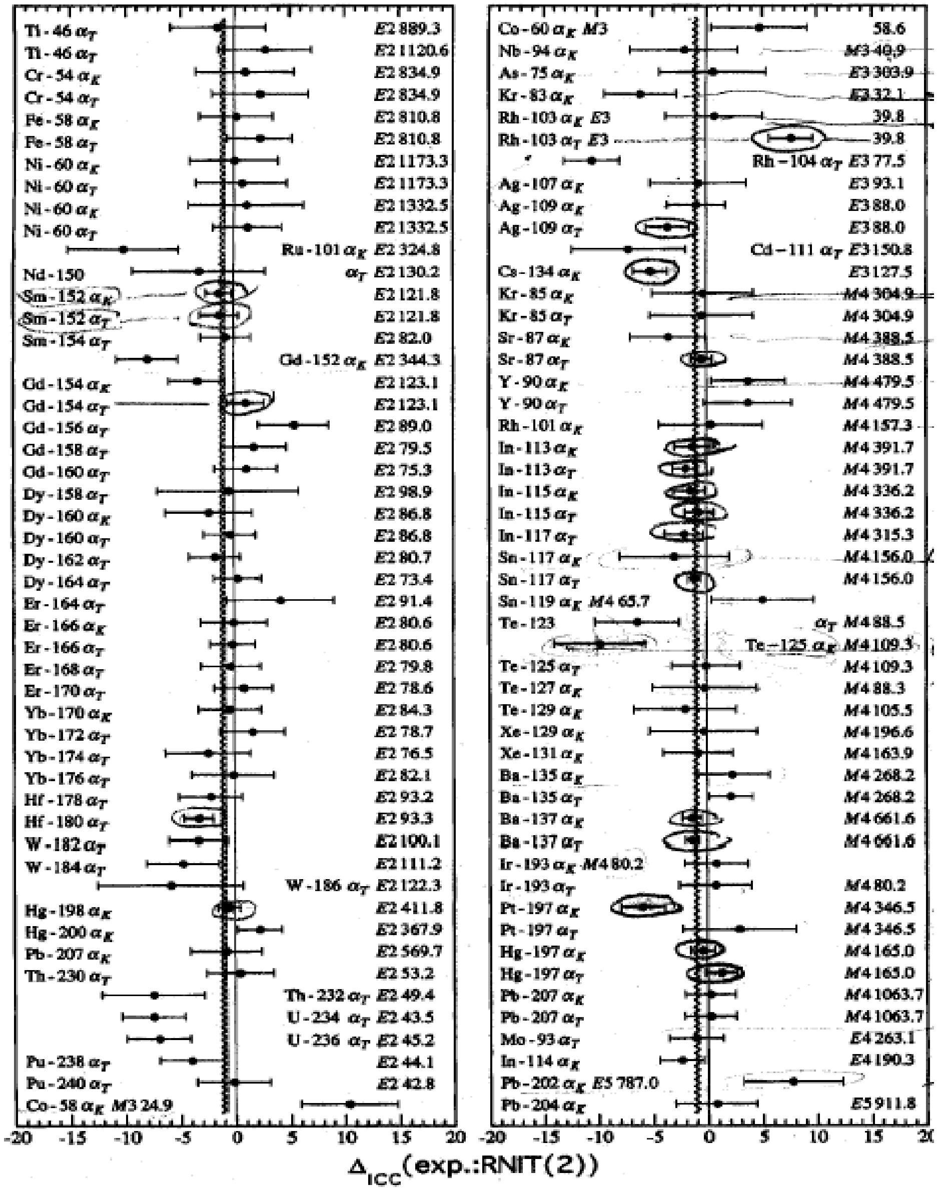
  (continuum - ion field from bound wave functions of neutral atom (no relaxation of ion orbitals))

  PHYSICAL ARGUMENT

  K-shell filling time vs. time to leave atom

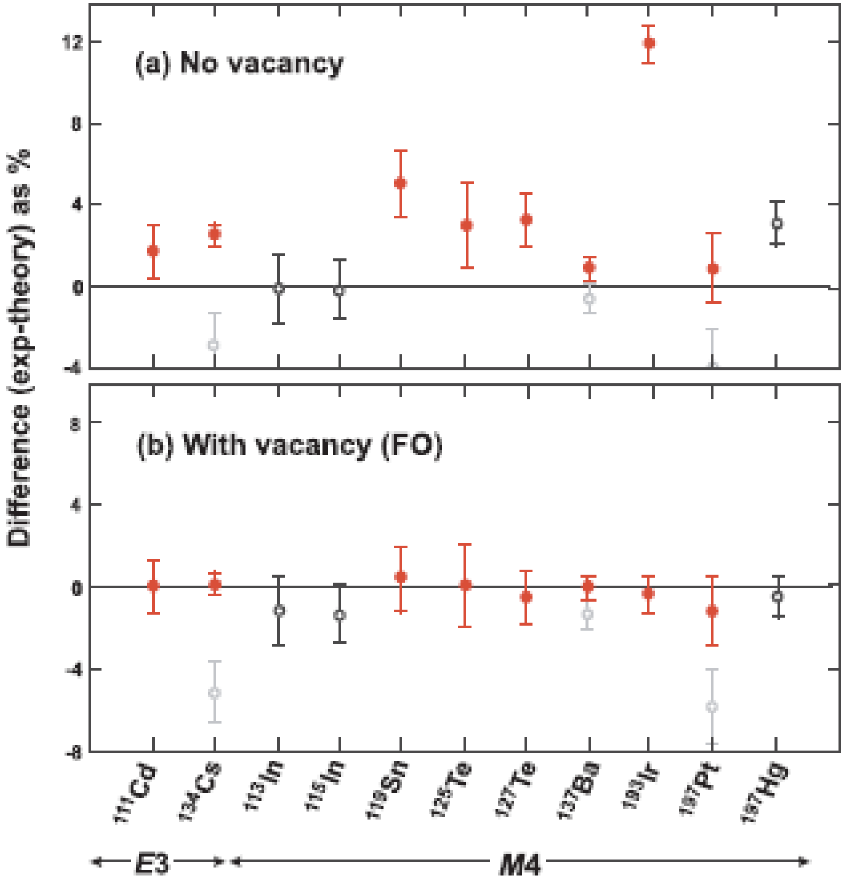
  $\sim 10^{-15} - 10^{-17}$ s » ~ 10-^{18} s

2002Ra45: 100 α_K(exp) cases compared with ‘hole FO’ calculations



Overview of the scope and completeness of the method

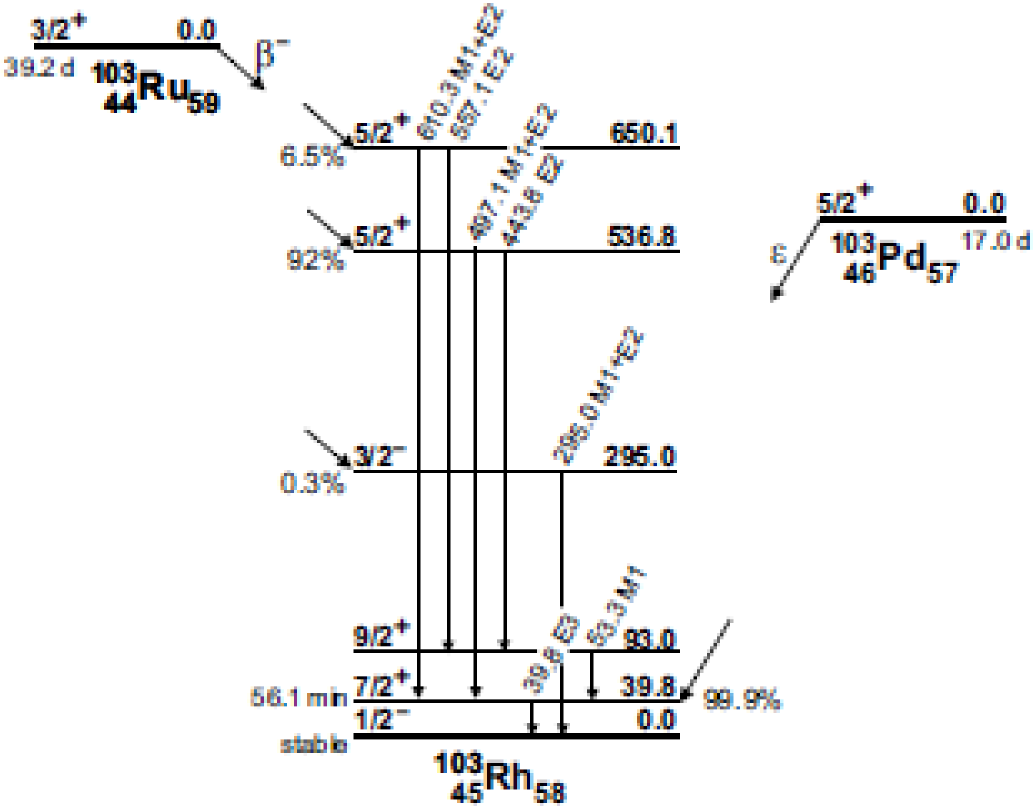
- **Scope:** *Minimize* ICC measurement unc (~1%) and *maximize* Δ_{theory}(FO,NH)% (>4%, *E3, M4*)
- **Completeness:** There is no criterion to reach the scope of comparison between ICC theories “with hole” and “no hole” except for measuring precisely as many relevant cases as practically possible



III. ^{103m}Rh 39.748 keV, E3 transition

- $\alpha(K)$exp: 153 *6* [1], 127 *6* [2]
- $\alpha(K)_{\text{hole\_FO}} = 135.3(1)$, $\alpha(K)_{\text{no\_hole}} = 127.5(1)$, $\Delta_{Theory}(\text{FO,NH}) = 5.9\%$
- $\alpha(T)$exp: 1531 *30* [2], 1430 89 [3]
- $\alpha(T)_{\text{hole\_FO}} = 1388(2)$, $\alpha(T)_{\text{no\_hole}} = 1404(1)$, $\Delta_{Theory}(\text{FO,NH}) = 1.1\%$

[1] M. Sainath *et al*, Ind. J. Pure and Appl. Physics 37, 87 (1999); [2] K.H. Czock *et al*, Int. J. Appl. Radiat. Isotop. 26,417 (1975); [3] R. Vaninbroukx *et al*, Progress Report 1978, Central Bureau for Nuclear Measurements, Geel, Belgium, NEANDC(E)-202U, Vol. III, p. 28 (1979).



Texas A&M precision ICC measurements:

- **KX to γ rays ratio method**

$$\beta^-: \alpha_K = \frac{N_K}{N_\gamma} \cdot \frac{\varepsilon_\gamma}{\varepsilon_K} \cdot \frac{1}{\omega_K}$$

$$\epsilon: \alpha_K + (1 + \alpha_T) P_{ec,K} = \frac{N_K}{N_\gamma} \cdot \frac{\varepsilon_\gamma}{\varepsilon_K} \cdot \frac{1}{\omega_K}$$

$$\sum_i (1 + \alpha_{Ti}) \cdot \frac{N_{\gamma i}}{\varepsilon_{\gamma i}} = (1 + \alpha_{T39.8}) \cdot \frac{N_{\gamma 39.8}}{\varepsilon_{\gamma 39.8}}$$

  - N_K, N_γ **measured from *only one K-shell converted transition***
  - ω_K **from 1999SCZX (**compilation and fit**)**

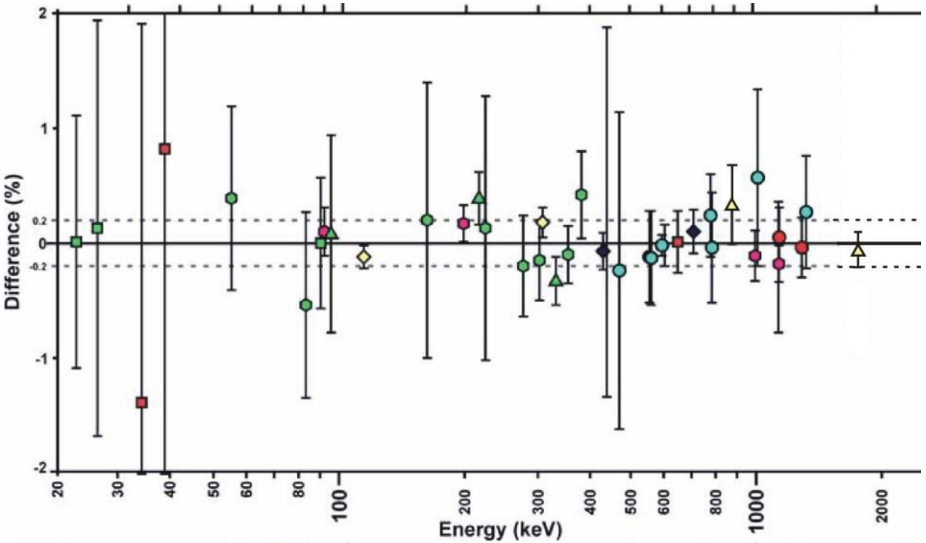
- **Very precise detection efficiency for ORTEC γ-X 280-cm^3 coaxial HPGe at standard distance of 151 mm:**
  - **0.2% , 50-1400 keV**
  - **0.4% , 1.4-3.5 MeV**
  - **~1% , 10-50 keV (KX rays domain)**

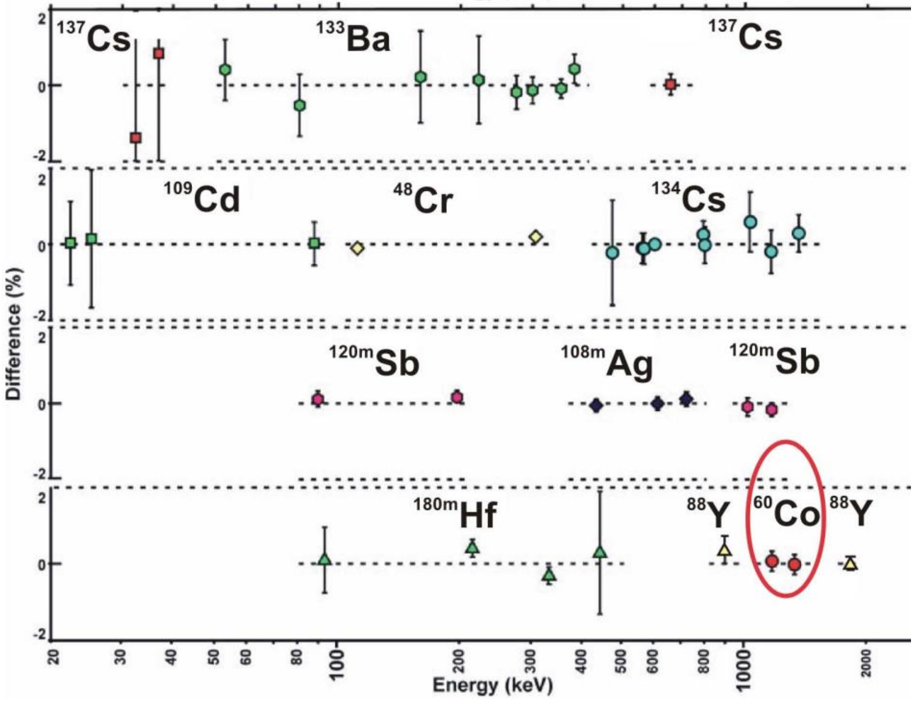
DETECTOR EFFICIENCY
50 keV < E_γ < 1.4 MeV

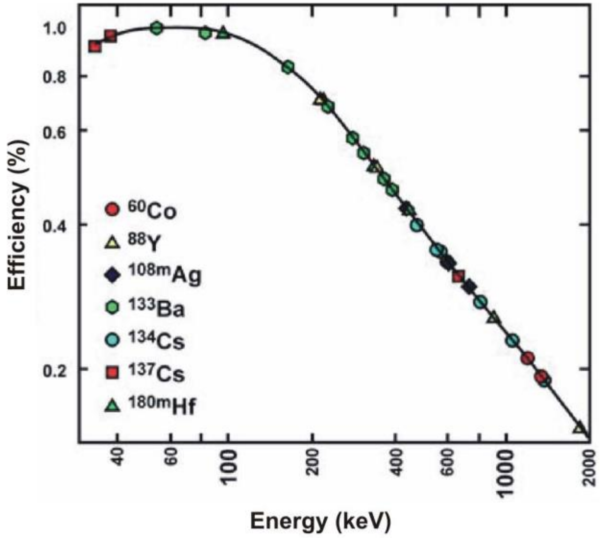
Coaxial 280-cc n-type Ge detector:

- Measured absolute efficiency (^{60}Co source from PTB with activity known to + 0.1%)
- Measured relative efficiency (9 sources)
- Calculated efficiencies with Monte Carlo (Integrated Tiger Series - CYLTRAN code)

0.2% uncertainty for the interval 50-1400 keV







^{109}Cd Efficiency Calibration

22.6-keV AgKx & 88.0-keV E3 γ regions

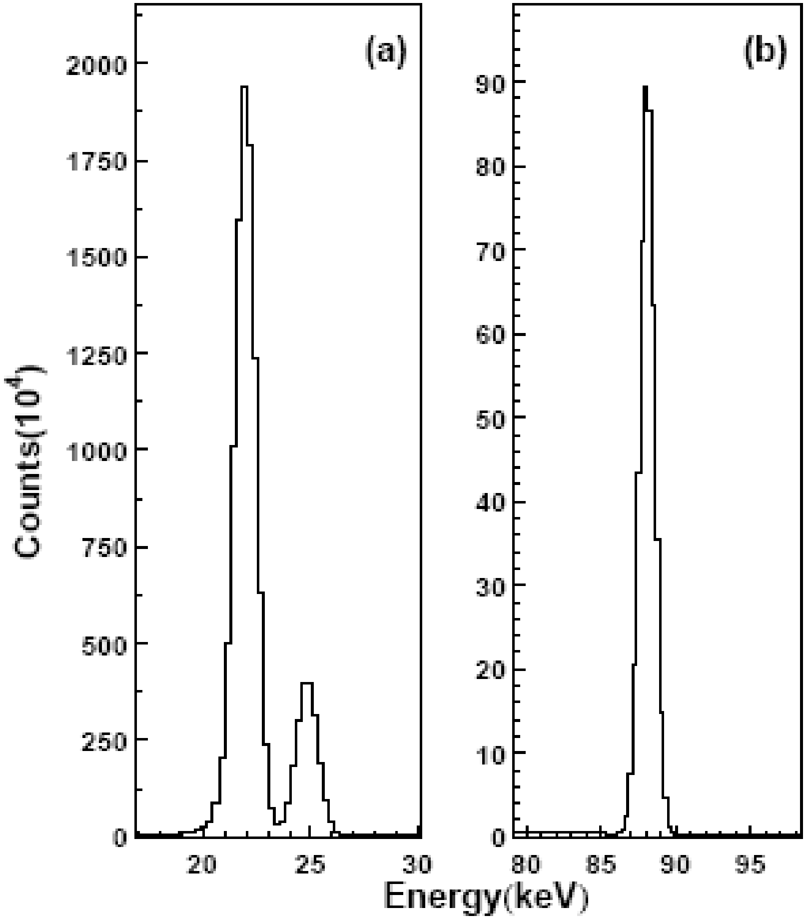
Photopeak efficiency:

^{109}Cd ε Decay: *single 88γ*

-22.6-keV AgKx

-88.0-keV E3 γ ray

$$\frac{\varepsilon_\gamma}{\varepsilon_K} = \frac{\omega_K(\alpha_K P_\gamma + P_{ec,K})}{P_\gamma} \cdot \frac{N_\gamma}{N_K}$$



KX to γ rays ratio method

- Sources for n_{th} activation
  - Small selfabsorption (< 0.1%)
  - Dead time (< 5%)
  - Statistics (> 10^6 for γ or x-rays)
  - High spectrum purity
  - Minimize activation time (0.5 h)
- Impurity analysis - *essentially based on ENSDF*
  - Trace and correct impurity to 0.01% level
  - Use decay-curve analysis
  - Especially important for the K X-ray region
- Voigt-shape (Lorentzian) correction for X-rays
  - Done by simulation spectra, analyzed as the real spectra
- Coincidence summing correction
- Random summing (pile-up) monitoring / correction

^{103m}Rh Run

- *Radioactive Sources were prepared by (n_{th},γ) reaction at TRIGA reactor of Texas A&M Nuclear Science Center at ~ 7.5 ×10^{12} n/cm^{2}s*

- *Sources were prepared of materials with natural isotopic abundance: ^{102}Ru 32%, ^{102}Pd 1%*

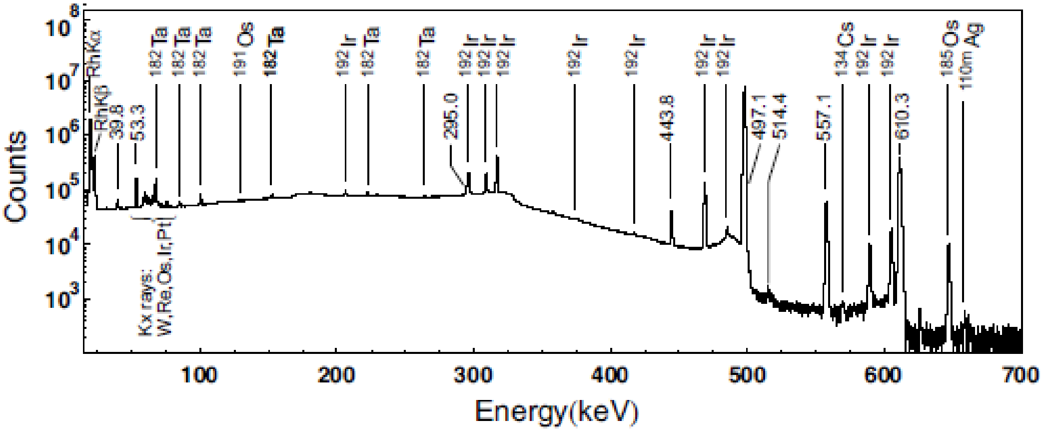
1. **^{103m}*Ru* Source(1),** **545 μg/cm^2** ***RuO_2 on Al backing.*** ***Activated for 20 h, measured after 1 months for ~20 days with HPGe detector. Found ^{153}Gd decay (239 d) 41.3-keV K_α peak affecting the 39.8-keV ^{103m}Rh peak of interest***

2. **^{103m}*Ru* Source(2), 1.1 mg/cm^2 Ru metal on 1.3 mg/cm^2 Cu metal.** *Activated for 32 h, measured after 1 months for ~77 days with HPGe detector and Si(Li) detector.*

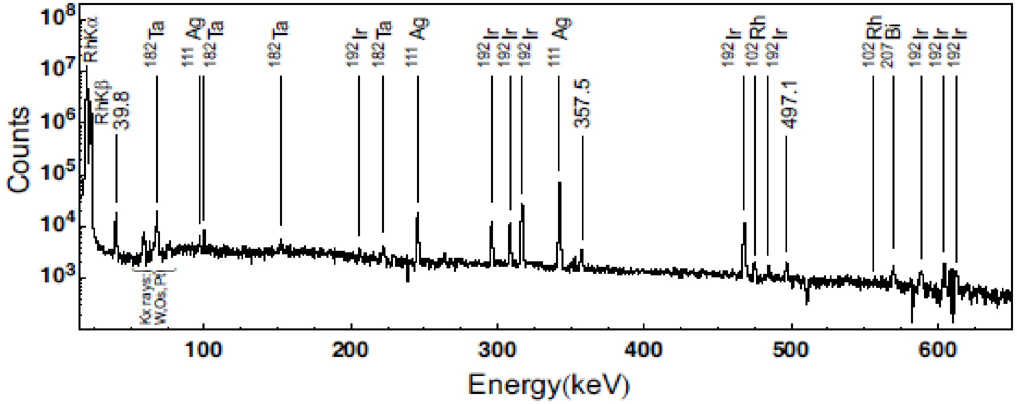
3. **^{103m}*Pd* Source(3), 4.8 mg/cm^2 Pd metal.** *Activated for 4.5 h, measured after 2 months for ~44 days with HPGe detector .*

^{103m}Rh Analysis

Ru/Cu Source(2): *Impurity analysis spectrum*



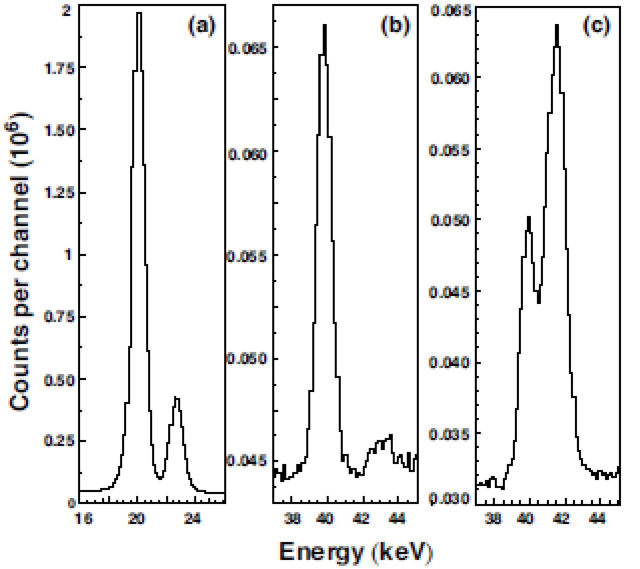
Pd Source(3): *Impurity analysis spectrum*



HPGe detector

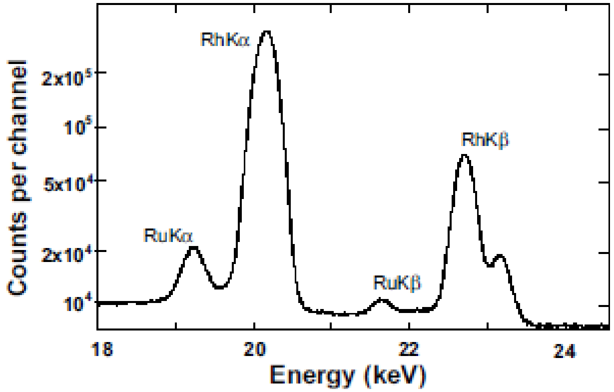
Ru/Cu Source(2): *(a) Rh Kx-rays; (b) 39.8-keV γ ray*

RuO_2 Source(3): *(c) 39.8-keV γ ray + Eu K_α contamination*



(Si)Li detector, Ru/Cu Source(2):

Rh Kx-rays with Ru Kx-rays (fluorescence)



^{103m}Rh Results

Weighted average of seven experimental results:

- ***From Ru run Source(1) and Source(2)***

$\alpha_{K39.8}$ = *141.1(23) (rel. unc. 1.6%)*

$\alpha_{T39.8}$ = *1428(13), (rel. unc. 0.9%)*

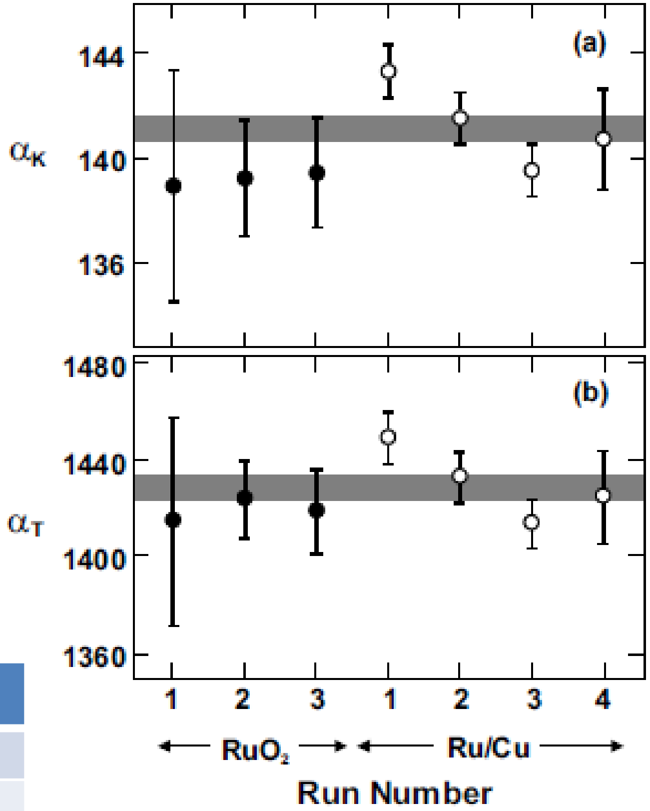
- ***Pd Source(3)***

Consistency check: ^{103}**Pd** ε ? ^{103}**Ru** β^-

$\alpha_K + (1 + \alpha_T)P_{ec,K}$ *:1383(28) ≈ 1369(11)*

Model	α_K	Δ(%)	α_T	Δ(%)
Experiment	141.1(23)		1428(13)	
Theory:				
a) Pure E3				
No vacancy	127.5(1)	+10.7(18)	1388(2)	+2.9(9)
Vacancy(FO)	135.3(1)	+4.3(17)	1404(1)	+1.7(9)
a) E3+M4, δ=0.02 (0.04%)				
No vacancy	131.2(1)	+7.5(18)	1410(2)	+1.3(9)
Vacancy(FO)	*139.3(1)*	*+1.3(17)*	*1426(1)*	*+0.1(9)*

(a) α_K and (b) α_T from Ru Source(1) and Source(2)



Conclusion:

Small M4 admixture:

-Agreement with theory including the vacancy (FO)

-Disagreement with theory ignoring the vacancy