FURTHER TESTS OF INTERNAL-CONVERSION THEORY WITH PRECISE γ- AND X-RAY SPECTROSCOPY

TEXAS A&M PROGRAM TO MEASURE ICC: $^{134}Cs^{m}$, ^{137}Ba

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ICC's:

- **Essential role in balancing nuclear decay schemes (crucial in precision applications)**
- **Theory vs. experiment discrepancies: *up to 10%***
  - **Theory**
    - ***Relativistic Dirac-Fock* (*RDF*) - best**
    - ***Sensitive to ' hole'/'no-hole' treatment:***

K-shell filling time *vs*. time to leave atom

$\sim 10^{-15} - 10^{-16}$ s » $\sim 10^{-18}$ s

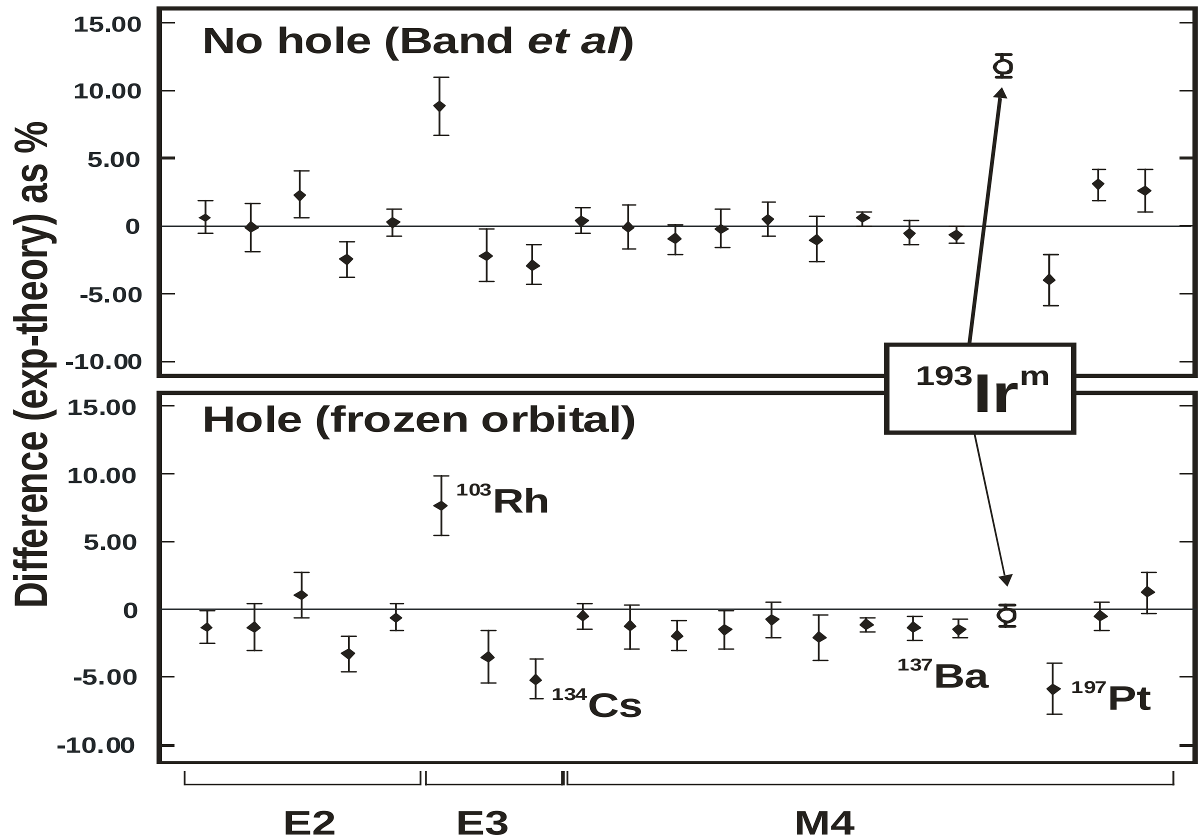
- ***Theory alone can not decide which hole treatment is best***

- **Experiment (review of world data, *Raman et al.*)**
  - **100 ICCs of 0.5%-5% precision**
  - **Average difference from theory is ≤ 1% whether or not the hole is included**
  - ***The 'no-hole' calculation was slightly favored***
  - **Recommended precise re-measurement of *80.2-keV M4 transition of $^{193}Ir^{m}$***

- **Completed at Texas A&M (*Nica et al. 2004*): α_K=103.0(8)**

Theory	α_K	Δ (%)
No hole	92.3(1)	10.4(8)
Hole, frozen orbitals	103.5(1)	-0.5(8)
Hole, SCF of ion	99.7(1)	3.2(8)

Raman et al: PRC 66, 044312 (2002)
Nica et al: PRC 70, 054305 (2004), PRC 71, 054305 (2005)



RDF	Raman *et al.* (2002)		Best 20 cases		Best 20 plus $^{193}Ir^{m}$	
	Δ_{avg} (%)	χ^2/N	Δ_{avg} (%)	χ^2/N	Δ_{avg} (%)	χ^2/N
No hole	+0.19(26)	1.7	+0.46(39)	2.4	**+0.97(79)**	**10.6**
Hole, frozen orbitals	-1.18(24)	1.4	-1.25(36)	2.2	**-1.18(34)**	**2.1**

II. METHOD

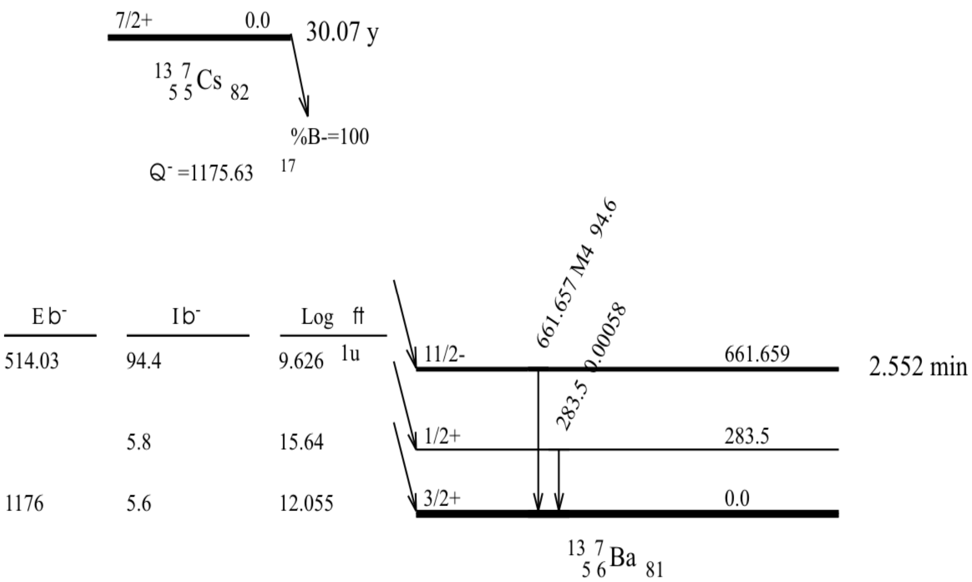
$$\alpha_K \omega_K = \frac{N_K}{N_\gamma} \cdot \frac{\varepsilon_\gamma}{\varepsilon_K}$$

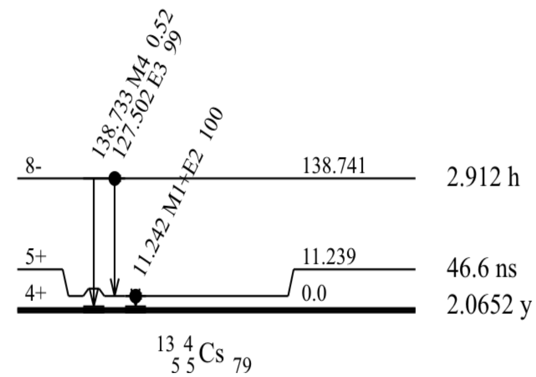
- **Suitable for only one K-shell converted transition**
- **N_K, N_γ measured**
- **ω_K from *Schönfeld and Rodloff***
- **ε at 151 mm for ORTEC γ-X 280-cm^3 coaxial HPGe:**
  - **0.2% , 50-1400 keV *Hardy et al., Helmer et al. 2003***
  - **0.4% , 1.4-3.5 MeV *Helmer et al. 2004***
  - **Not know precisely for K x-rays (30-35 keV)**

=> Ratio $\alpha_K(Cs)/\alpha_K(Ba)$

Schönfeld and Rodloff: Report PTB-6.11-1999-1, (1999)
Hardy et al: Appl. Rad. Isot. 56, 65 (2003)
Helmer et al. 2003: NIM A 511, 360 (2003)
Helmer et al. 2004: Appl. Rad. Isot. 60, 173 (2004)

III EXPERIMENT





A. Source Preparation

Designed to ensure:

- **Small absorption (<0.1%)**
- **Dead time (< 5%)**
- **Statistics (> 10^6 for γ or x-rays)**
- **High spectrum purity**
- **Minimize activation time (0.5 h)**

$^{134}Cs^m$ Sources:

- 17.5 µg (0.11 µm) CsCl, 20 µg (0.14 µm) $CsNO_3$, 99.999+% pure, 100% ^{133}Cs natural abundance, hygroscopic
- 76 µm mylar backing
- Aqueous solutions dried under vacuum, on dry diluted insulin for homogeneity, checked at microscope
- Covered with 64 µm adhesive kapton (after activation)
- Activated at Triga/NSC of Texas A&M at ~7×10^{12} n/cm^{2}s
- T1(4.5 µCi), T3(2 µCi) @ start ACQ

^{137}Cs Sources for ^{137}Ba:

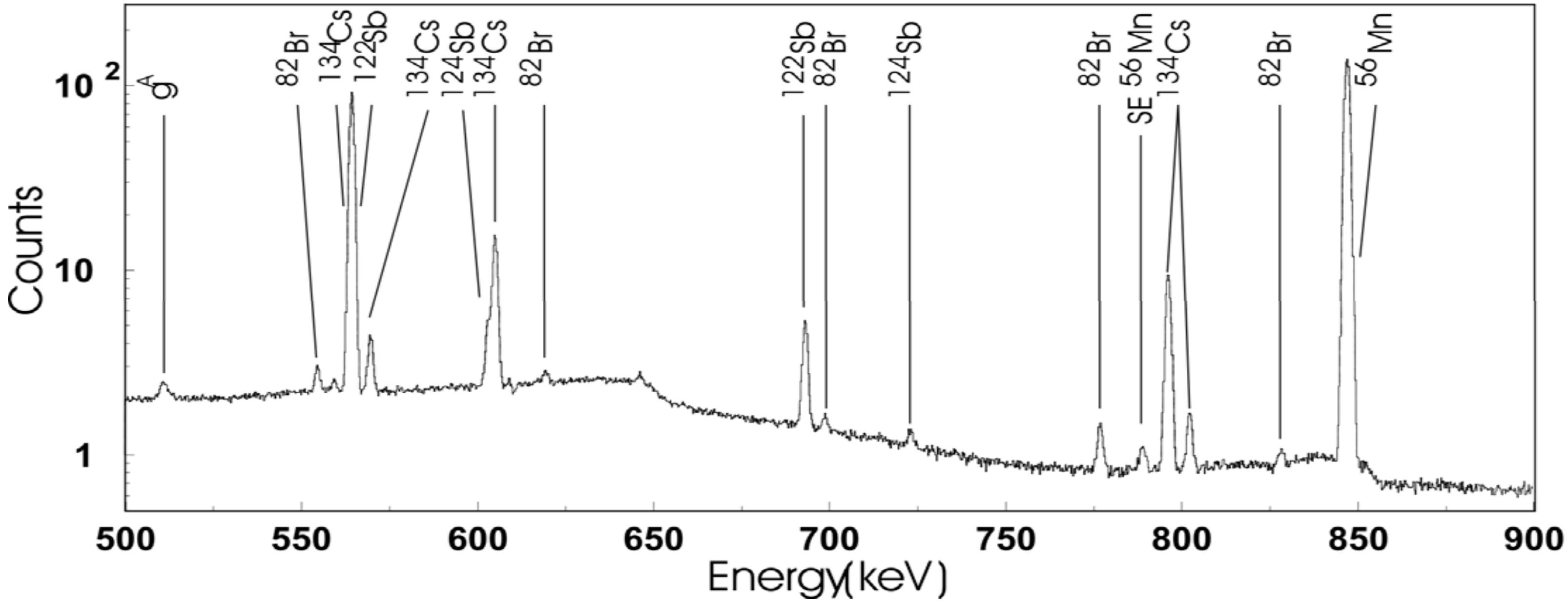
- 1 µCi β sources (open) commercially available from IPL
- 6.4 µm mylar backing

B. Spectra

- ADC: TRUMP™-8k/2k / MAESTRO™ (Gedcke-Hale DT)
- Energy range: 10 keV – 2 MeV
- Acquired: 80 spectra, 1000 h, decay curve analysis

III ANALYSIS

A. Impurity Analysis



Based on ENSDF data, and n-activation and decay analysis:

- ^{134}Cs, $T_{1/2} = 2.0652(4)$ y
  - o %β^- = 100, ^{134}Ba x-rays
  - o %ε negligible, (^{134}Xe)
- ^{122}Sb, $T_{1/2} = 2.7209(3)$ d
  - o %ε = 2.41(12), ^{122}Sn x-rays
  - o %β^- =97.59(12), ^{122}Te x-rays

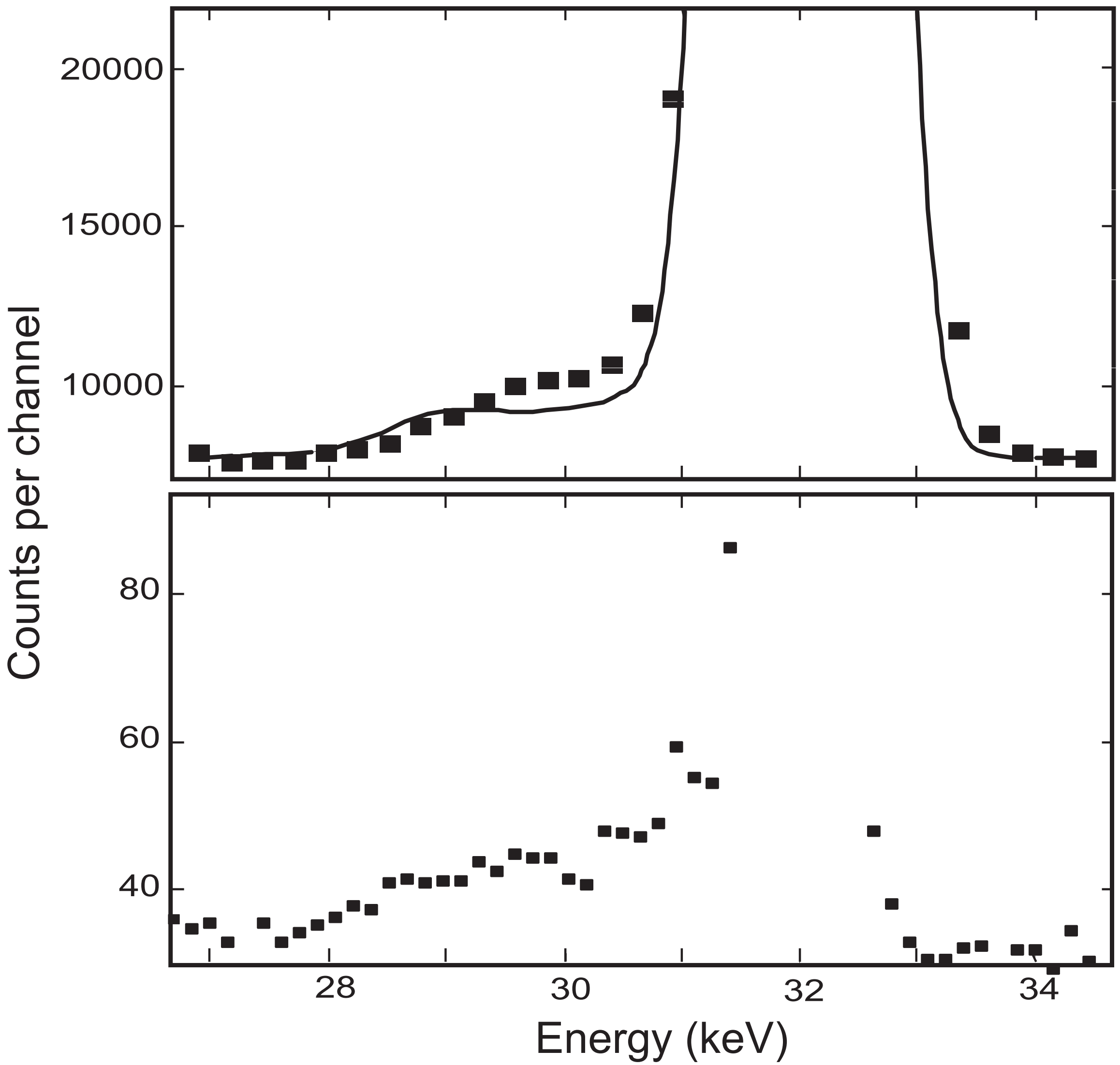
- ^{124}Sb, $T_{1/2}$ = 60.20(3) h
  - %β^- =100, ^{124}Te x-rays
- ^{80}Br^m, $T_{1/2}$ = 4.4205(8) h
  - %IT =100, ^{80}Br^m 37.1γ
  - ^{82}Br, $T_{1/2}$ = 35.282(7) h

Total impurities relative to pure Cs Kx:

T1_2	0.30(2)%
T1_3	0.87(3)%
T3_1	0.52(4)%

B. Corrections

- 138.7γ electronic conversion: -0.81(5)%, Cs Kx
- Attenuation in sample: 0.13(1)%
- Voigt shape of x-rays peaks (simulation): 0.13%, Cs&Ba Kx
- Left-tail backscattering (empirical):-0.8(3), Cs/Ba Kx



20000
15000
10000
80
60
40
Counts per channel
28
30
32
34
Energy (keV)

Comparison

	α_K ratio	Δ, this exp
This experiment	30.01(20)	
hole(frozen orbital)	29.96	0.2 (7) %
hole(SCF)	29.87	0.5 (7) %
no hole	29.52	1.6(7) %
Experiment (*Raman et al.*)	28.82(51)	