Precise Measurement of α_T for the 39.76-keV *E*3 transition in ^{103}Rh

A Further Test of Internal Conversion Theory

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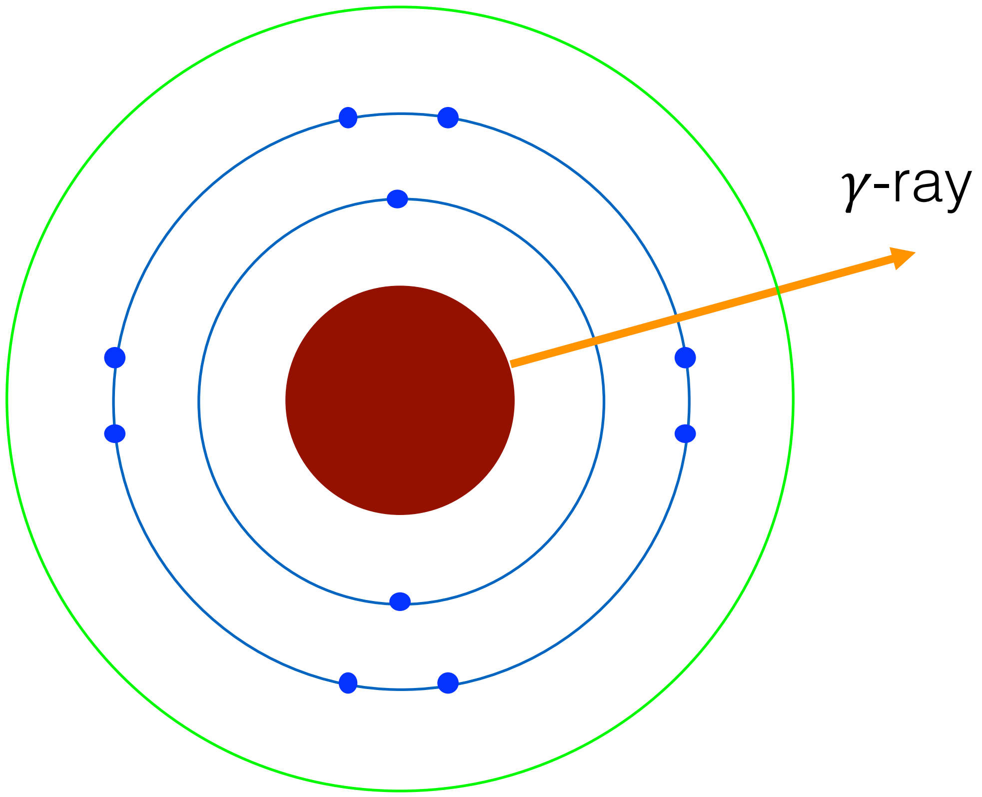
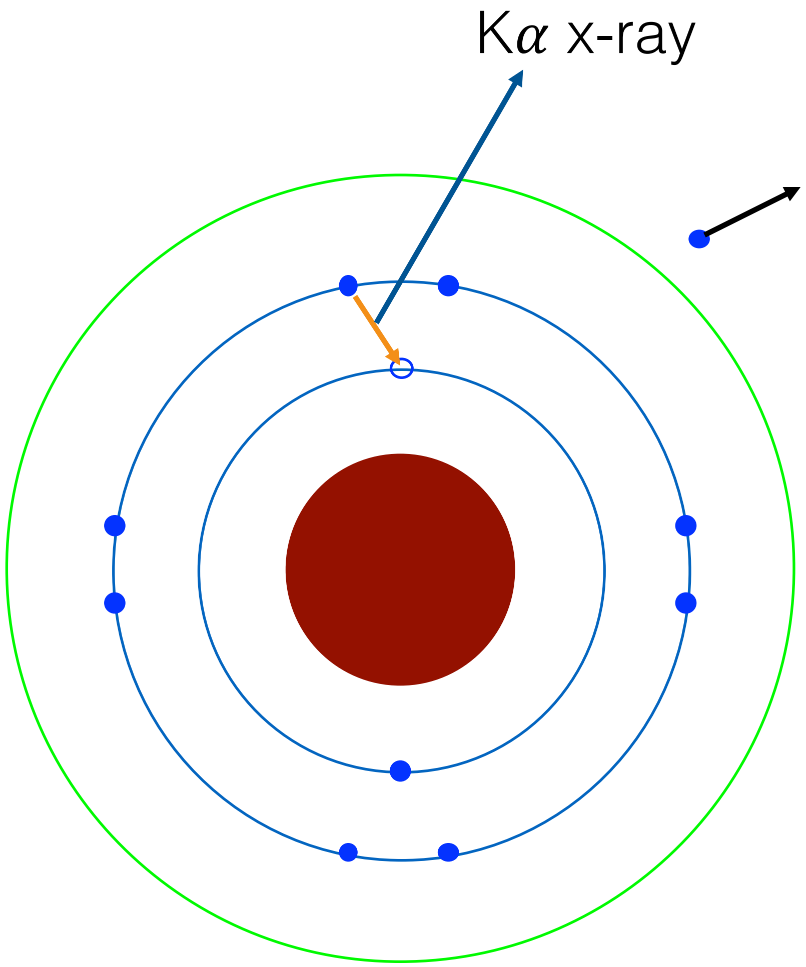
Internal Conversion

In the radioactive gamma decay of an atom, the energy of the transition is given either to a photon or to an electron in the atomic shell, a property called internal conversion.



γ-ray emission



internal conversion

Internal Conversion Coefficient

- The ICC is the ratio of emitted electrons to gamma rays during the decay of a certain nuclide.

$$\alpha_T = \alpha_K + \alpha_L + \alpha_M + \ldots$$

- It is more difficult to measure the electrons emitted from Internal Conversion, so we measure the number of x-rays given off in its place.

- We are taking advantage of the very precisely efficiency calibrated High Purity Germanium (HPGe) detector.

$$\alpha_T = (\frac{1}{\omega_K}\frac{N_x}{N_\gamma}\frac{\epsilon_\gamma}{\epsilon_x} - \alpha_K)\frac{1}{P_{EC,K}} - 1$$

fluorescence yield

K-shell ICC

probability of K-shell EC

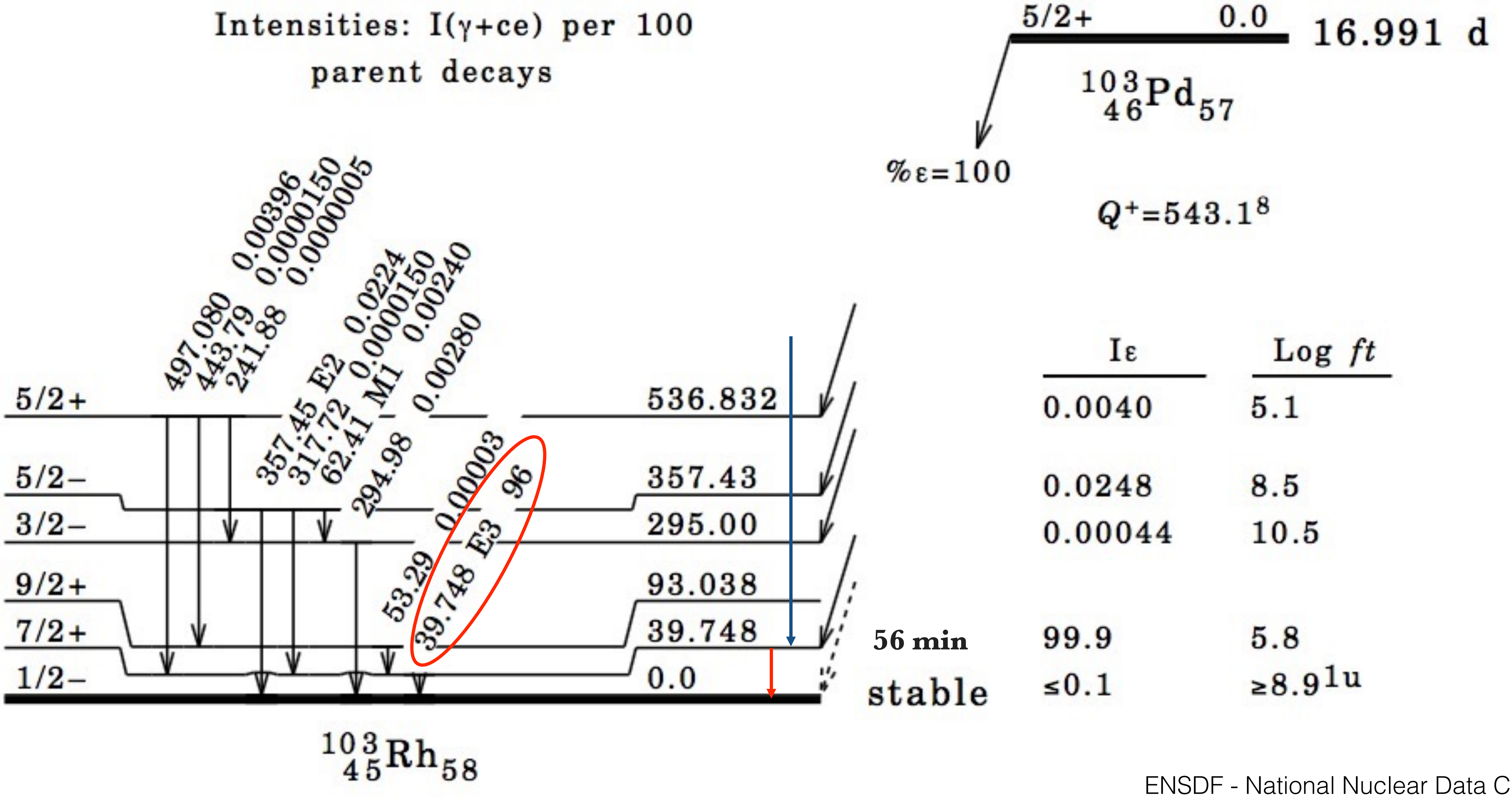
Motivation

- Internal Conversion is a general phenomenon of gamma nuclear decay and should be calculated precisely, especially for lower energies, where the value will be much larger.
- ICC's can be theoretically calculated using two methods, which yield different results:
    - Considering the atomic vacancy (hole approach)
    - Assuming the atomic vacancy is filled so rapidly that it has no effect (no hole approach)
- Our previous measurements demonstrate that the atomic vacancy must be considered in calculation.
- Our aim with this work was to extend the applicability of that statement to $Z=45$.
- This experiment is possible with ^{103}Rh as the two values for the ICC are far enough apart to be measurable.

^{103}Pd ε Decay (16.991 d)

Decay Scheme

Intensities: I(γ+ce) per 100 parent decays

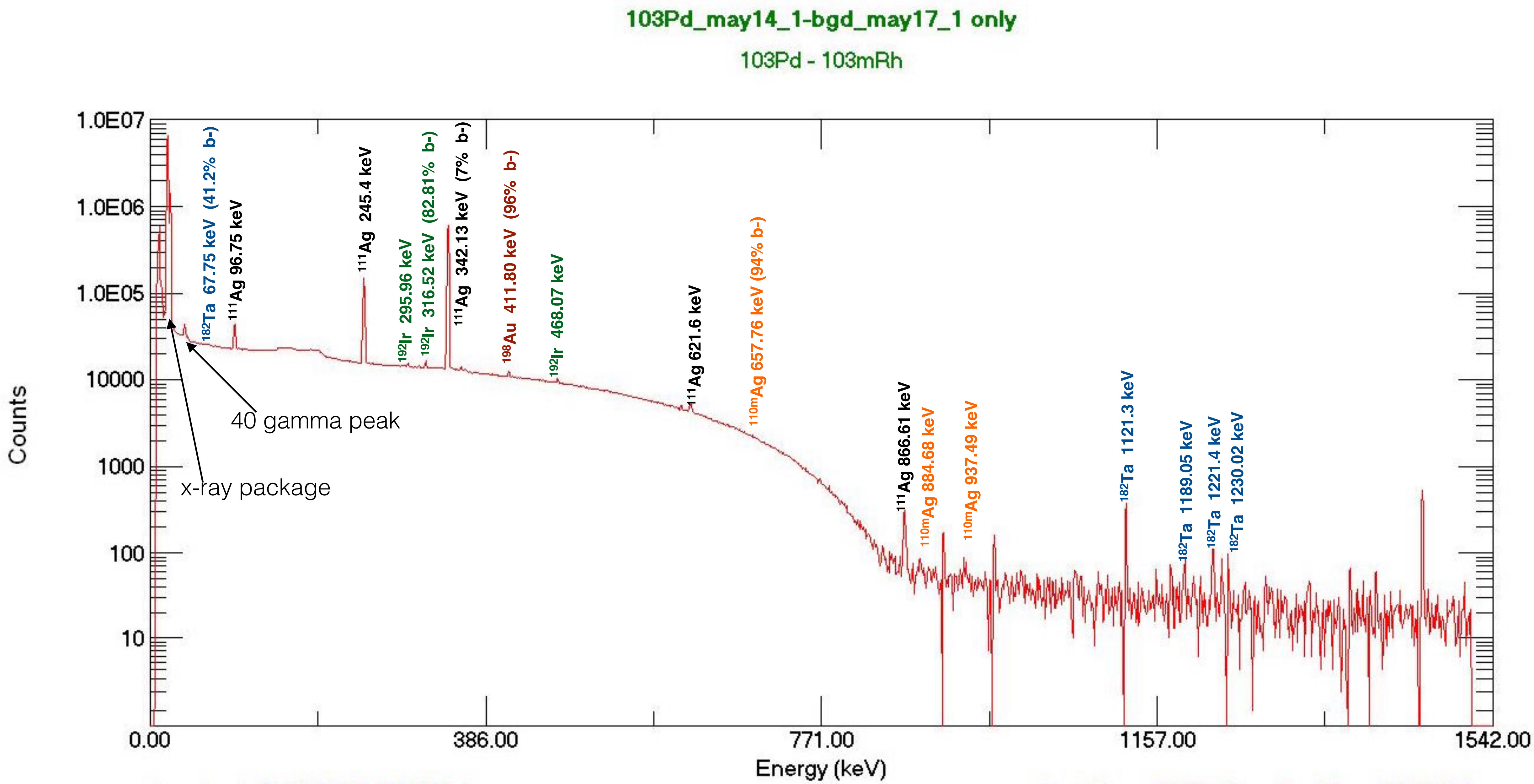


ENSDF - National Nuclear Data Center

Our Measurement

- We activated our source of ^{103}Pd with thermal neutrons in the TRIGA reactor and let it “cool down” for three weeks.
- We started taking spectra with the goal of measuring the impurities of our sample to see if we could extract a reasonably accurate α from this source.
- Our spectra were recorded using the High-Purity Germanium Detector in three series over the course of 80 days.

Impurity Analysis of ^{103}Pd Sample



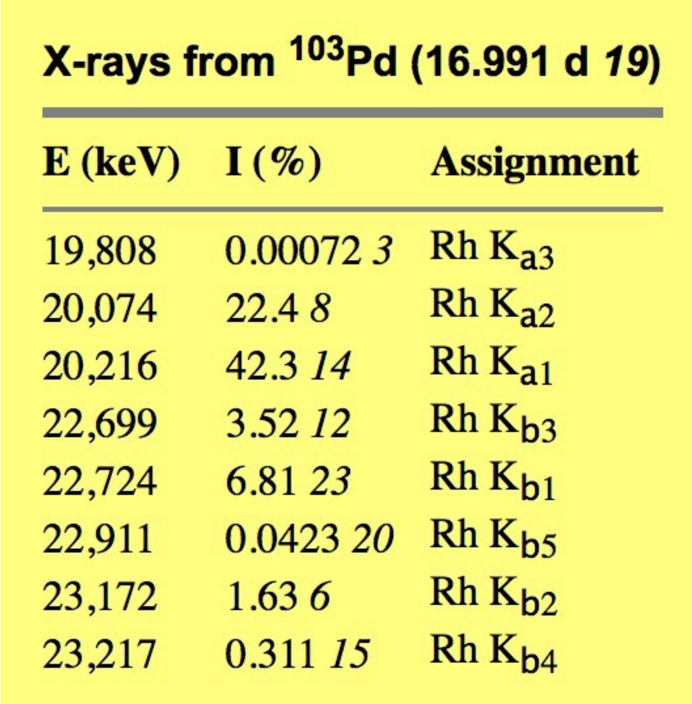
- Analyzed our 23 spectra in Maestro (taken from 14 May-11 July)

- ^{198}Au faded by Series 2 (24 May)

	$t_{1/2}$
^{103}Pd	16.991 d *19*
^{111}Ag	7.45 d *1*
^{182}Ta	114.43 d *3*
^{192}Ir	73.831 d *8*
^{198}Au	2.69517 d *21*
^{110m}Ag	249.79 d *20*

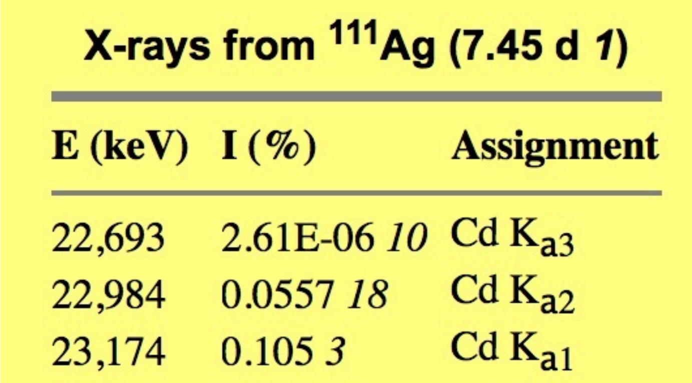
X-Ray Analysis

- Our ^{103}Rh x-ray package is located at 19.8-23.2 keV
- ^{110m}Ag has x-rays at 21.7-23.2 keV
    - 0.0006% of x-ray package area → negligible
- ^{111}Ag has x-rays at 22.6-23.2 keV
    - 0.03% of x-ray package area



X-rays from ^{103}Pd (16.991 d *19*)

E (keV)	I (%)	Assignment
19,808	0.00072 *3*	Rh K_{a3}
20,074	22.4 *8*	Rh K_{a2}
20,216	42.3 *14*	Rh K_{a1}
22,699	3.52 *12*	Rh K_{b3}
22,724	6.81 *23*	Rh K_{b1}
22,911	0.0423 *20*	Rh K_{b5}
23,172	1.63 *6*	Rh K_{b2}
23,217	0.311 *15*	Rh K_{b4}



X-rays from ^{111}Ag (7.45 d *1*)

E (keV)	I (%)	Assignment
22,693	2.61E-06 *10*	Cd K_{a3}
22,984	0.0557 *18*	Cd K_{a2}
23,174	0.105 *3*	Cd K_{a1}

The Lund/LBNL Nuclear Data Search

- Using the Radware program gf3 we found precise peak areas and corrected for the ^{111}Ag impurity

$$A(Cd\ K_x) = \frac{A(342\gamma)}{\epsilon_{ph}(342\gamma) \times I(342\gamma)} \times \epsilon_{ph}(23.6keV) \times I(23.6keV)$$

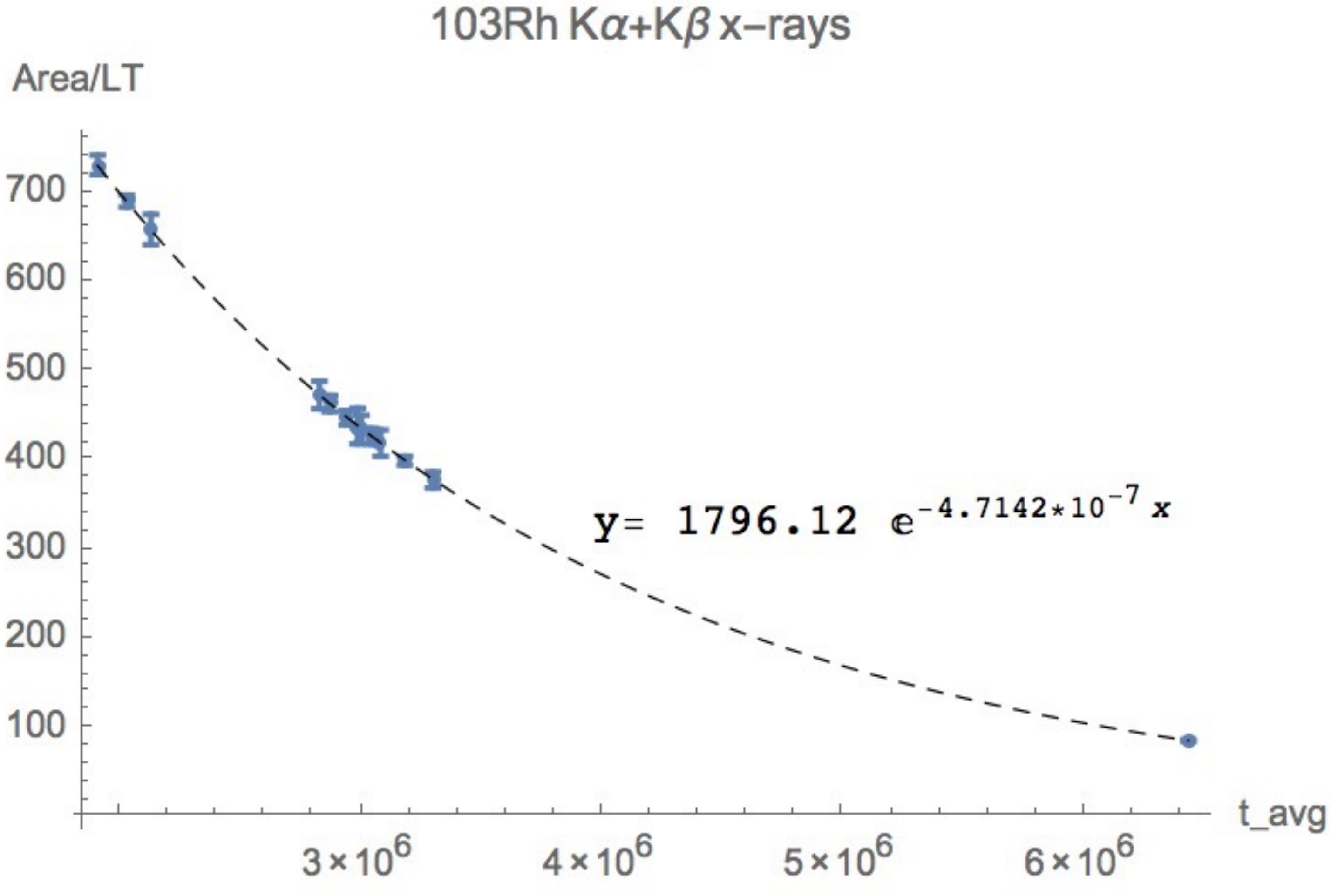
$$\epsilon_{ph}(342\gamma) = 0.5230\% \qquad \epsilon_{ph}(23.6\ keV) = 0.9365\%$$

$$I(342\gamma) = 7\%(0) \qquad I(23.6\ keV) = 0.1929\%$$

- Subtracting this area from the total x-ray package area gives the clean x-ray area for our decay from ^{103}Pd → ^{103}Rh

Half-Life Extraction

Extracting the half-life of our x-ray package told us that we accurately corrected for impurities.

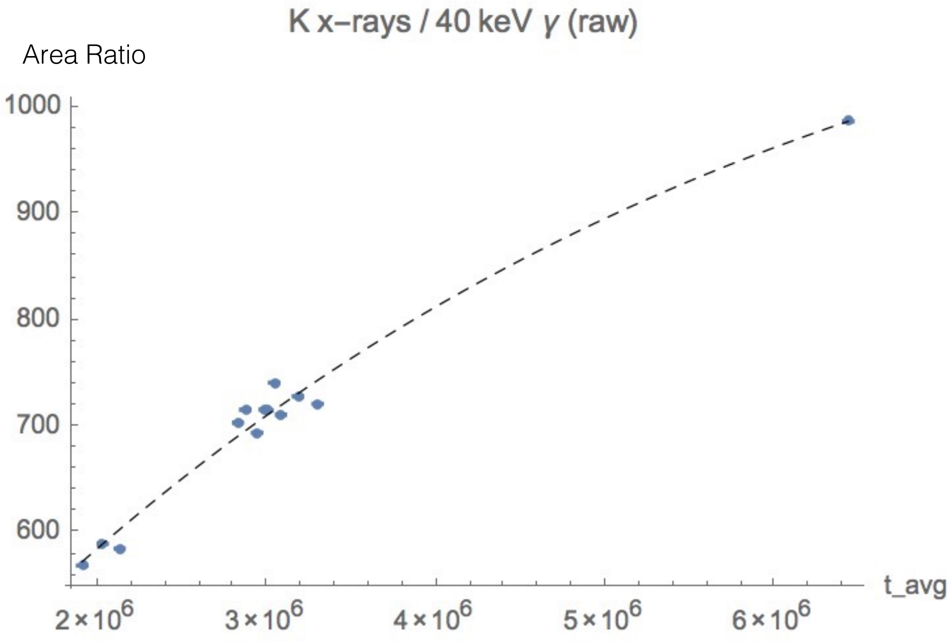


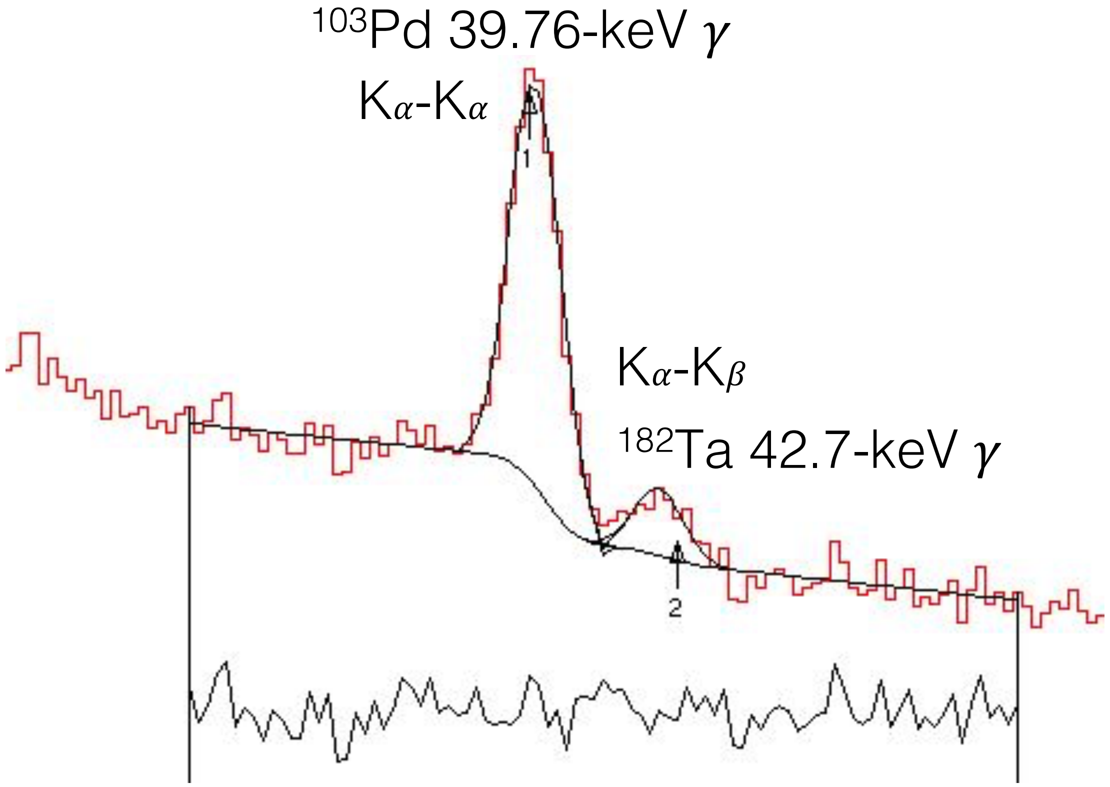
$$\tau_{1/2} = \frac{ln(2)}{\lambda = 4.7142 \times 10^{-7}} \frac{1}{3600s \times 24h}$$

$$\tau_{1/2} = 17.02(2)\ days$$

$$\tau_{1/2}(^{103}Pd) = 16.991\ d$$

40-keV Peak Analysis


K x-rays / 40 keV γ (raw)


^{103}Pd 39.76-keV γ

K_α-K_α

K_α-K_β

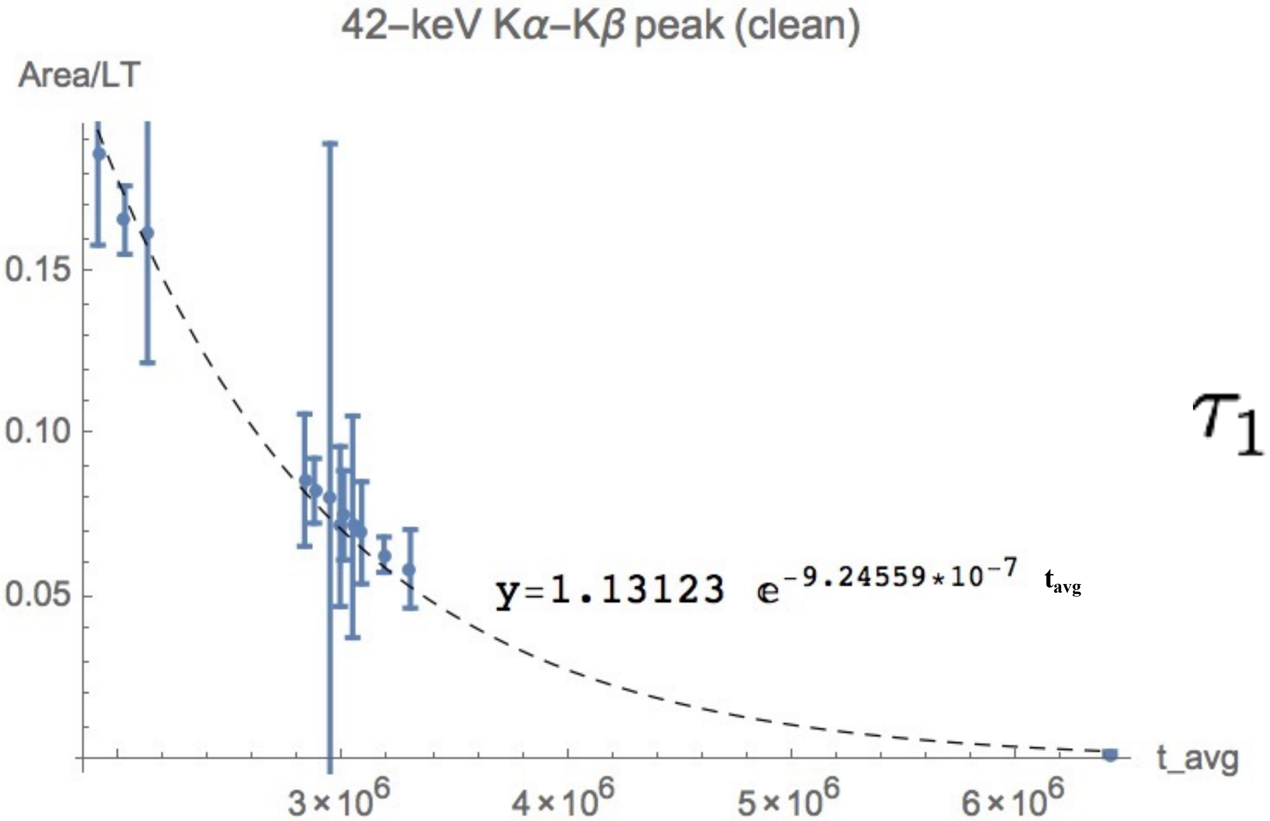
^{182}Ta 42.7-keV γ

- If the 40-keV peak was purely our gamma peak of interest the ratio of x-ray to 40-keV peak areas would be constant.
- Theory: The large size of the 40-keV peak due to random coincidence summing of K_α-K_α ^{103}Pd x-rays.
    - The 42-keV peak would then be the result of K_α-K_β random coincidence summing.
- The area of K_α-K_α peak could be determined though the area of K_α-K_β peak using the ratio of areas between the K_α and K_β peaks in our x-ray package.

Correcting the 42-keV K$_\alpha$-K$_\beta$ Peak

- ^{182}Ta has a γ-peak at 42.7-keV which interferes with our 42-keV K$_\alpha$-K$_\beta$ peak.
- To correct the 42-peak we used the same method as we did for correcting the x-ray package.

$$A(Ta\ in\ 42keV) = \frac{A(67\gamma)}{\epsilon_{ph}(67\gamma) \times I(67\gamma)} \times \epsilon_{ph}(42keV) \times I(Ta\ @\ 42keV)$$



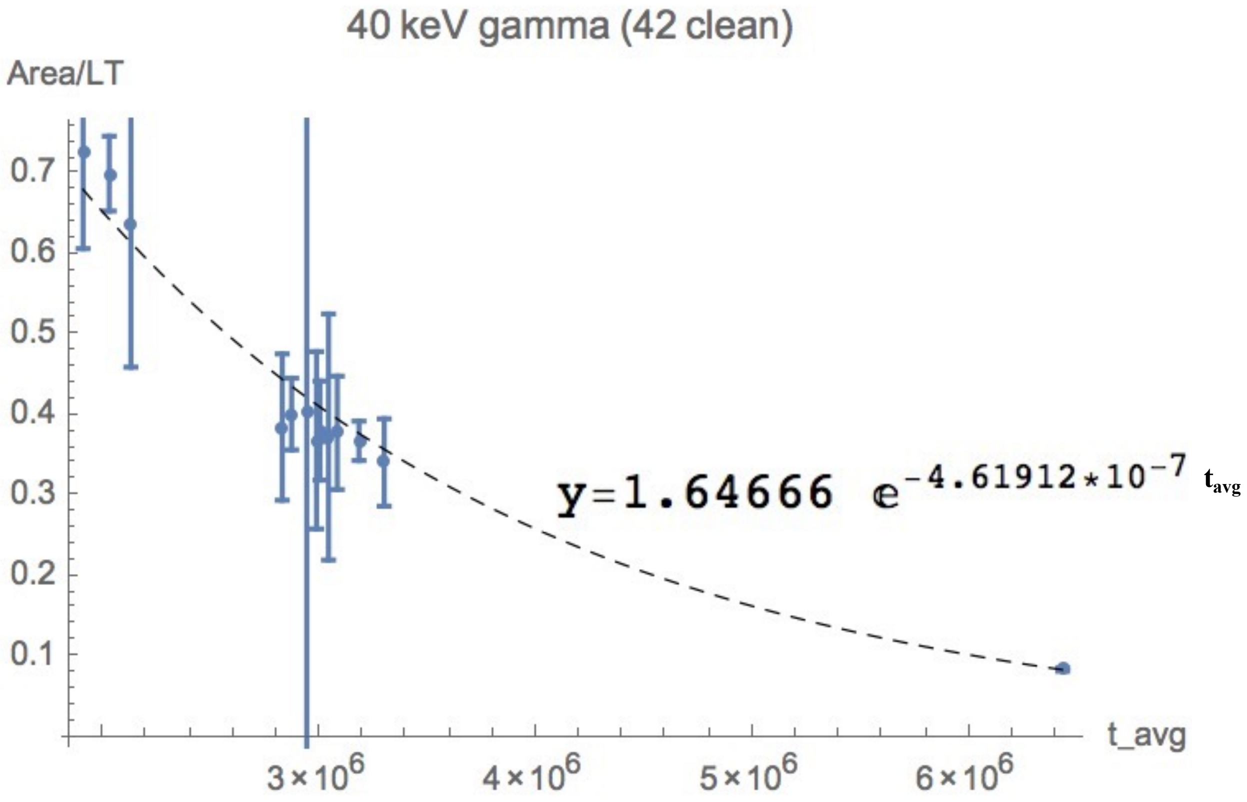
$$\tau_{1/2}(\lambda = 9.246 \times 10^{-7}) = 8.7(5)\ d$$

Correcting the 40-keV Peak

- Using the relationship between the K$_\alpha$ and K$_\beta$ x-ray peaks at 20 and 22 keV we could determine the area of the K$_\alpha$-K$_\alpha$ peak at 40-keV.

$$A_{K_\alpha K_\alpha}(40\ keV) = \frac{A_{K_\alpha}(20\ keV)}{A_{K_\beta}(22\ keV)} \times A_{K_\alpha K_\beta}(42\ keV)$$

- Subtracting this from the raw area of the 40-keV peak we got a clean gamma peak to use in our calculation.



$$\tau_{1/2}(\lambda = 4.619 \times 10^{-7}) = 17.4(5)\ d$$
$$\tau_{1/2}(^{103}Pd) = 16.991\ d$$

Calculation of α_T

$$\alpha_T = \left(\frac{1}{\omega_K}\frac{N_x}{N_\gamma}\frac{\epsilon_\gamma}{\epsilon_x} - \alpha_K\right)\frac{1}{P_{EC,K}} - 1$$

	Value	Uncertainty
Area of x-ray package (N_x)	86444813	9574
Area of 39.76-keV γ-peak (N_γ)	87397	2203

$$\omega_K = 0.809(4)$$
$$\epsilon_\gamma = 1.0103$$
$$\epsilon_x = 0.9042$$
$$\alpha_K = 131.3(39)$$
$$P_{EC,K} = 0.8589$$

Theory (no hole)	Theory (with hole)	Our Result
1389	1404	1437(44)

Our value of 1437 is statistically closer to the theoretical value which accounts for the atomic vacancy. This is consistent with our previous measurements which demonstrated that the hole must be considered.

Conclusions

- The random coincidence summing of Kα-Kα x-rays phenomenon was an unfortunate circumstance in this experiment making it difficult to extract a precise value for α_T.

- The initial goal of obtaining an α_T value to about 1% precision could not be met due to the uncertainty that arose from the random coincidence summing.

- Further work will hopefully result in a more precise value through the measurement of the same transition from the decay of ^{103}Ru to ^{103}Rh. In this measurement we will focus on α_K.

Acknowledgements

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