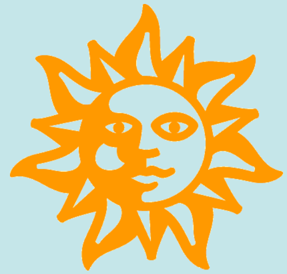

The Half-lives of ^{90m}Y and ^{97}Ru

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Nuclide	ADNDT 2003	ENSDF 10/5/09	% uncert	Remarks
71Zn	2.45 min	2.45 10 min	4.1%	uncertainty too high
97Ru	2.9 d	2.9 1 d	3.4%	uncertainty too high
175Hf	70 d	70 2 d	2.9%	uncertainty too high
90mY	3.19 h	3.19 6 h	1.9%	uncertainty too high
111mPd	5.5 h	5.5 1 h	1.8%	uncertainty too high
205Hg	5.2 min	5.14 9 min	1.8%	diff, signif, uncert. too high
161Gd	3.66 min	3.66 5 min	1.4%	uncertainty too high
77mGe	52.9 s	52.9 6 s	1.1%	uncertainty too high
75mGe	47.7 s	47.7 5 s	1.0%	uncertainty too high
97Nb	72.1 min	72.1 7 min	1.0%	uncertainty too high
104Rh	42.3 s	42.3 4 s	0.9%	uncertainty too high
110Ag	24.6 s	24.6 2 s	0.8%	uncertainty too high
131mTe	30 h	33.25 25 h	0.8%	different, significant
180mHf	5.5 h	5.47 4 h	0.7%	uncertainty too high
20F	11.16 s	11.07 6 s	0.5%	different, significant
176mLu	3.635 h	3.664 19 h	0.5%	different, significant
159Gd	18.56 h	18.479 h	0.4%	different, significant
87mSr	2.803 h	2.815 12 h	0.4%	different, significant
117mSn	13.60 d	13.76 4 d	0.3%	different, significant
233Th	22.3 min	21.83 4 min	0.2%	different, significant
42K	12.36 h	12.360 12 h	0.1%	different, not significant
24Na	14.96 h	14.997 12 h	0.1%	different, not significant
134mCs	2.903 h	2.912 2 h	0.1%	different, not significant
134Cs	2.065 y	2.0652 4 y	0.02%	different, not significant
109Pd	13.46 h	13.7012 24 h	0.02%	different, significant
187W	23.72 h	24.000 4 h	0.02%	different, significant

k_0 Nuclear Data Committee
F. De Corte and Z. Révay, pers. comm., 2010

Nuclide issues

3-h ^{90m}Y activity is only 1/60 of 3-d ^{90}Y

- But ^{90}Y is a pure β emitter; use low-Z absorber

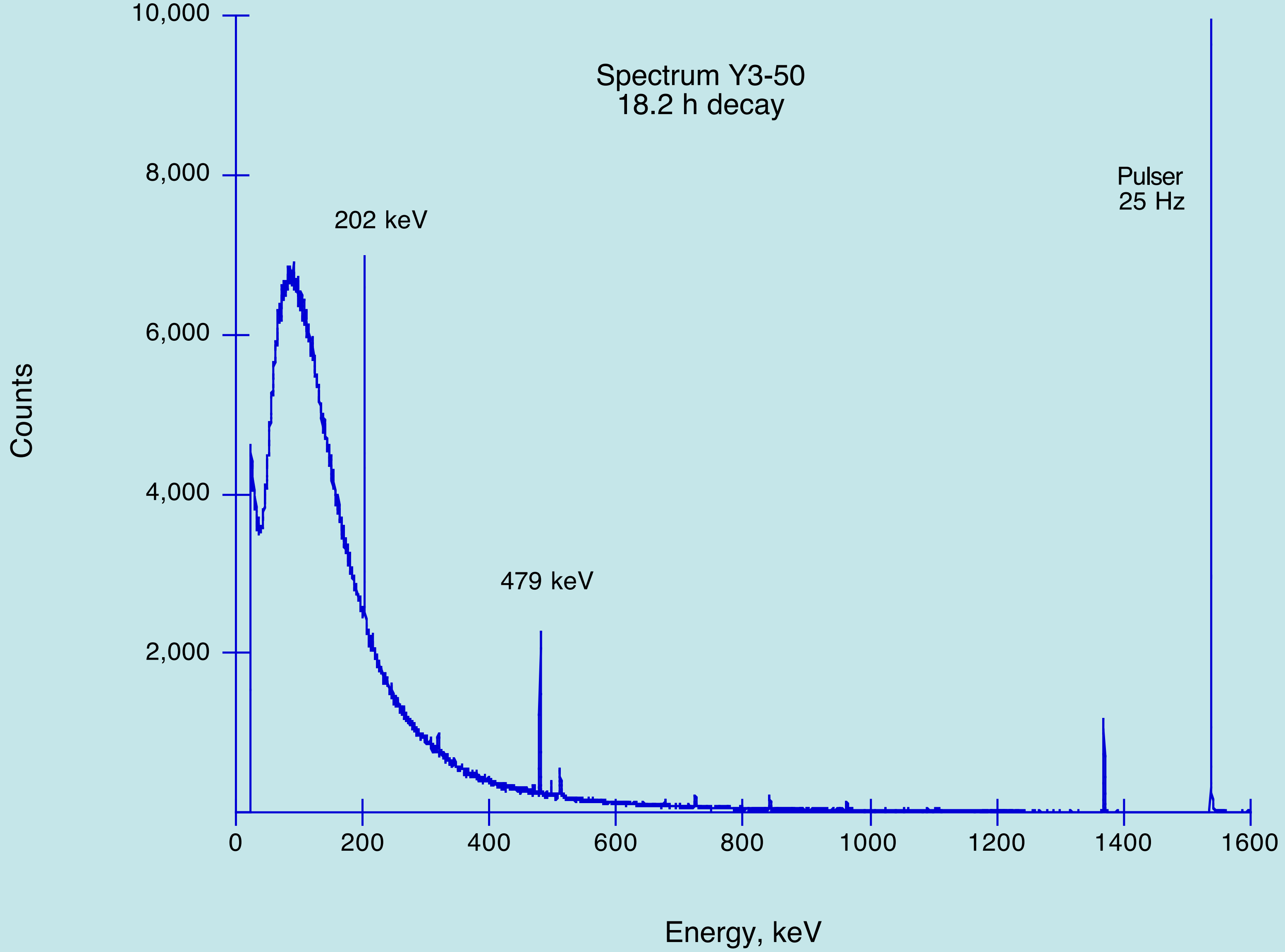
Two clean gammas at 202 and 479 keV

3-d ^{97}Ru dominated by 4-h ^{105}Ru and 39-d ^{103}Ru

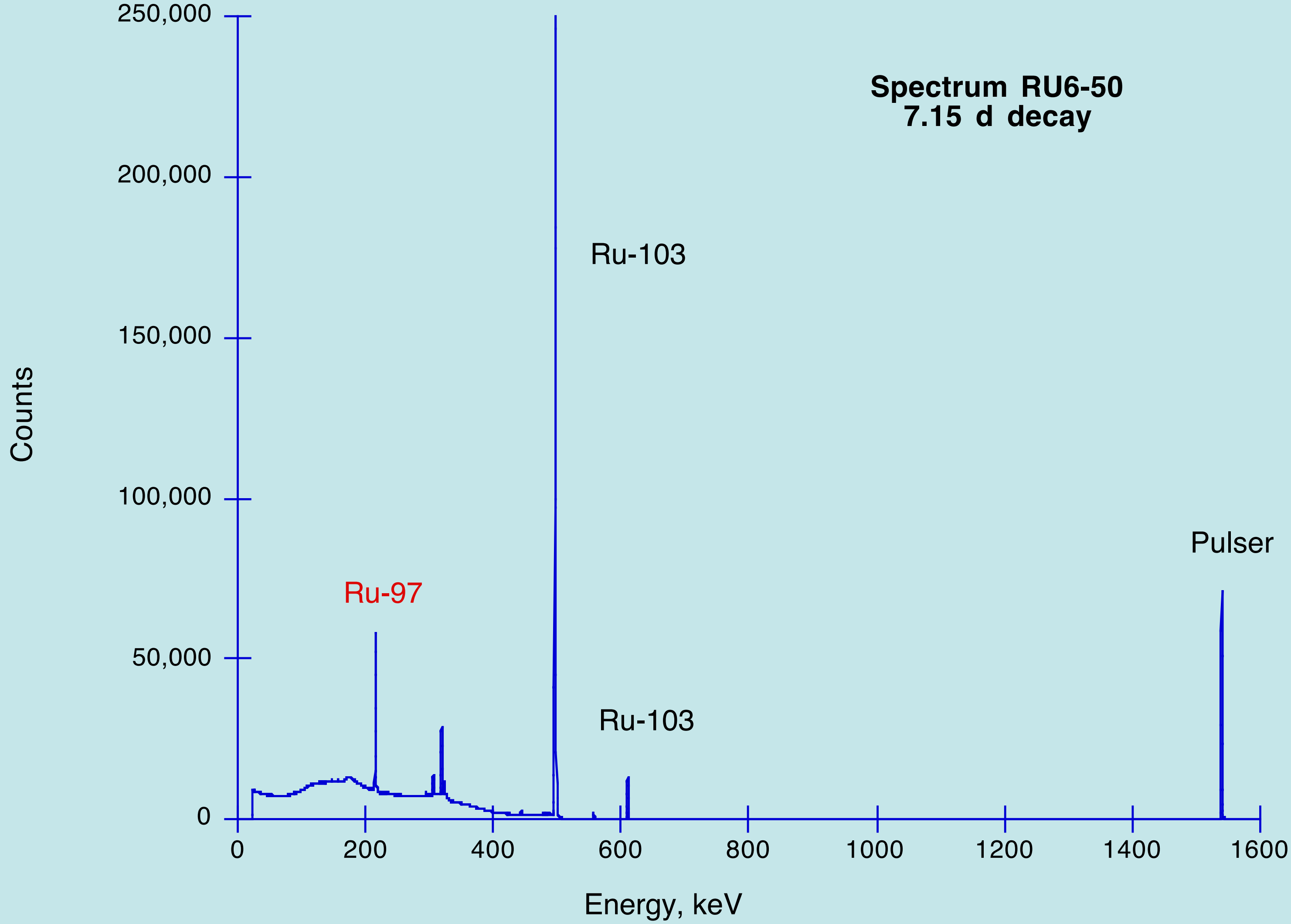
One useful gamma at 216 keV

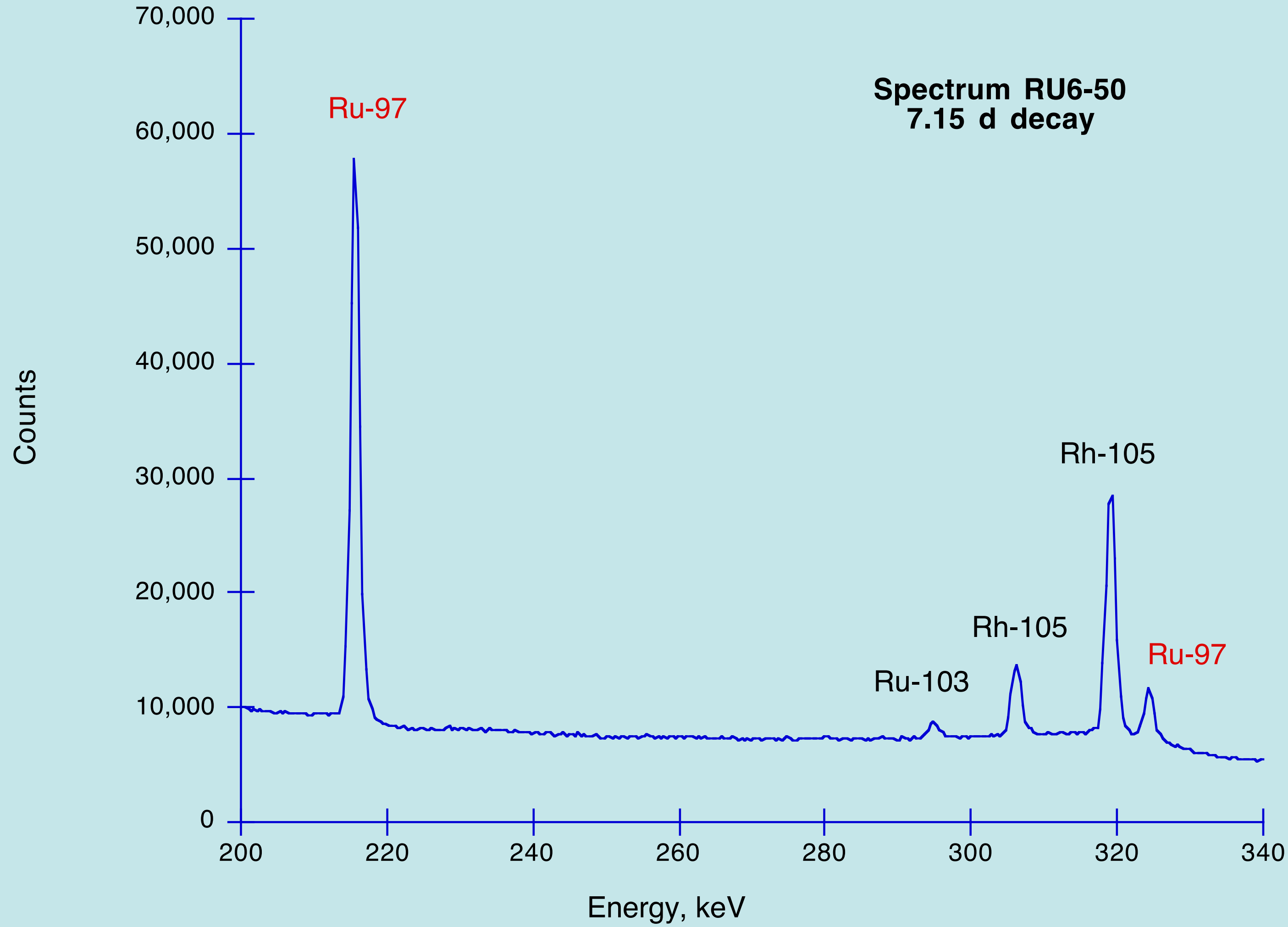
- 324 keV interfered by ^{105}Ru and trace ^{105}Rh

Long life requires weeks of measurement


Spectrum Y3-50
18.2 h decay
10,000
8,000
6,000
4,000
2,000
Counts
202 keV
479 keV
Pulser
25 Hz
0
200
400
600
800
1000
1200
1400
1600
Energy, keV

NIST


Spectrum RU6-50
7.15 d decay
Ru-103
Ru-97
Ru-103
Pulser
Counts
250,000
200,000
150,000
100,000
50,000
0
0
200
400
600
800
1000
1200
1400
1600
Energy, keV


Spectrum RU6-50
7.15 d decay
Ru-97
Ru-103
Rh-105
Rh-105
Ru-97
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Counts
200
220
240
260
280
300
320
340
Energy, keV

Measurements

Select pure Y_2O_3 or Ru metal

Irradiate with thermal neutrons

Repackage in clean container

Fix in position near Ge detector

Count repeatedly for 4-10 half-lives

Use precision pulser to monitor losses

$\Delta\nu/\nu < 2\cdot10^{-8}$/d

Repeat

Experimental conditions

Experiment	Geometry, cm	Initial dead time	Counting interval	Number of spectra
Y1	20	15.4%	20 m	50
Y2	30	8.7%	20 m	100
Y3	20	16.1%	20 m	100
Ru1	30	6.5%	3 h	42
Ru2	40	6.3%	3 h	101
Ru3	25	2.5%	3 h	33
Ru6	40	10.9%	3 h	112

Data reduction

Determine net peak areas with fixed ROI

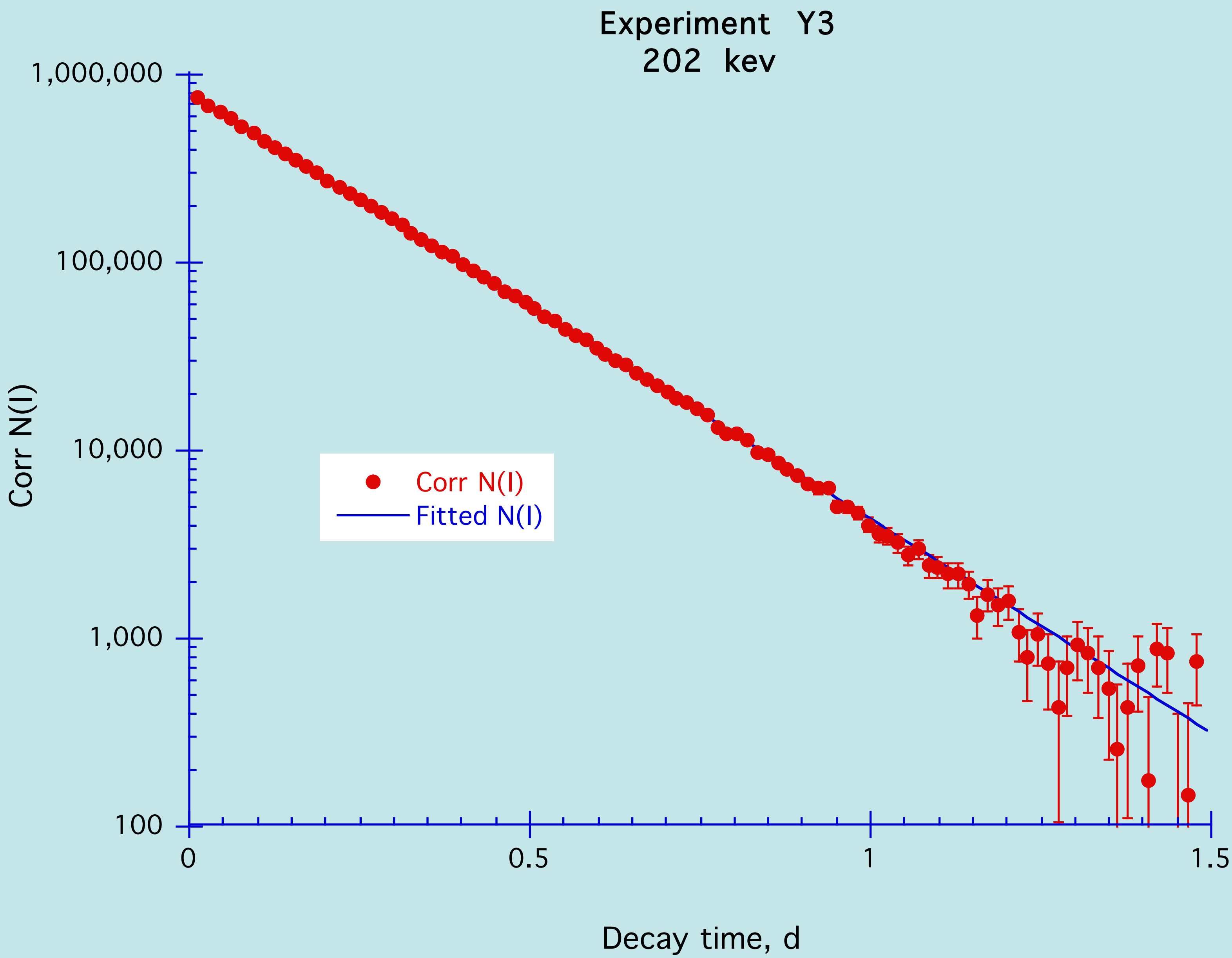
Correct each datum for decay and pileup

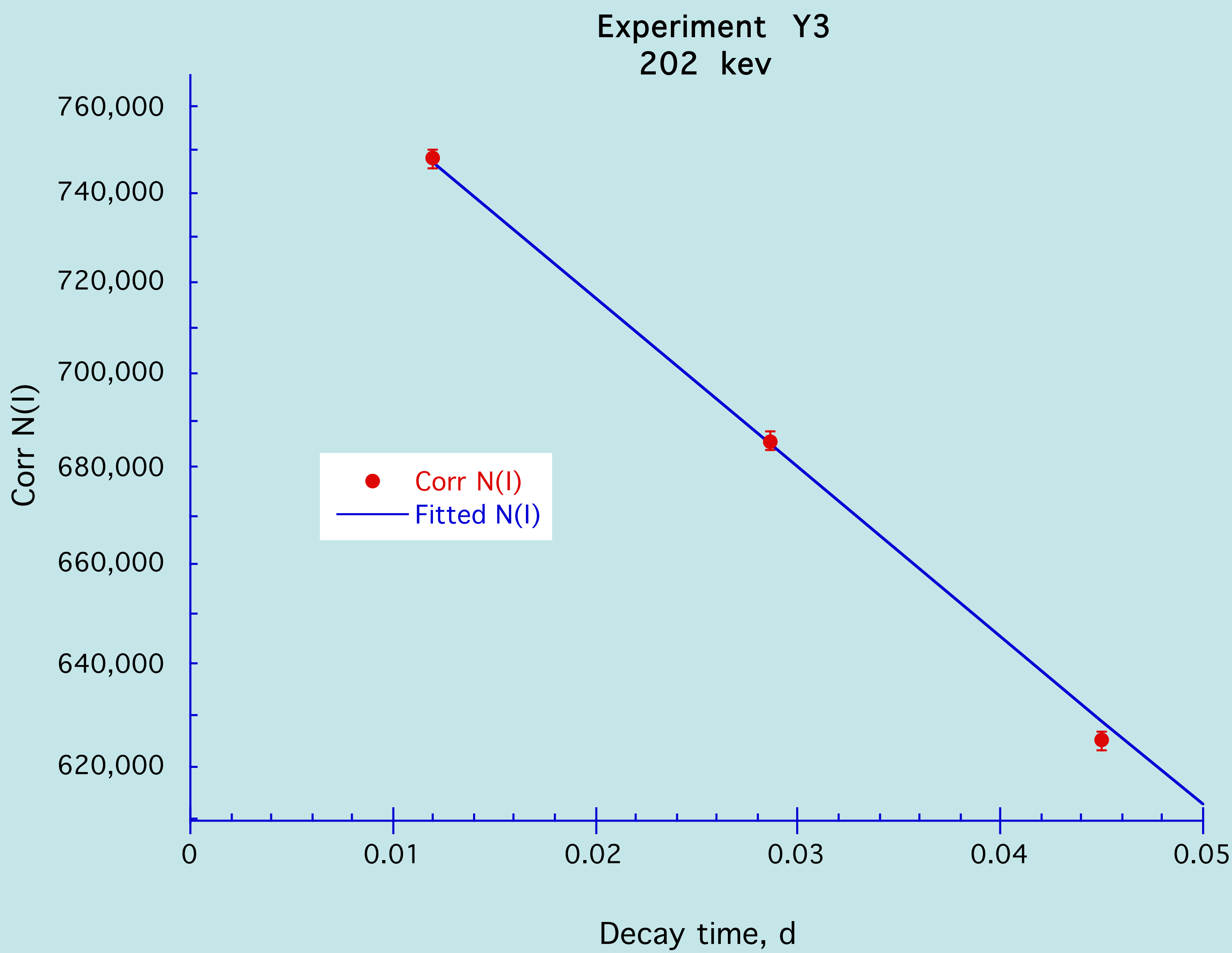
Fit to exponential by χ^2 minimization

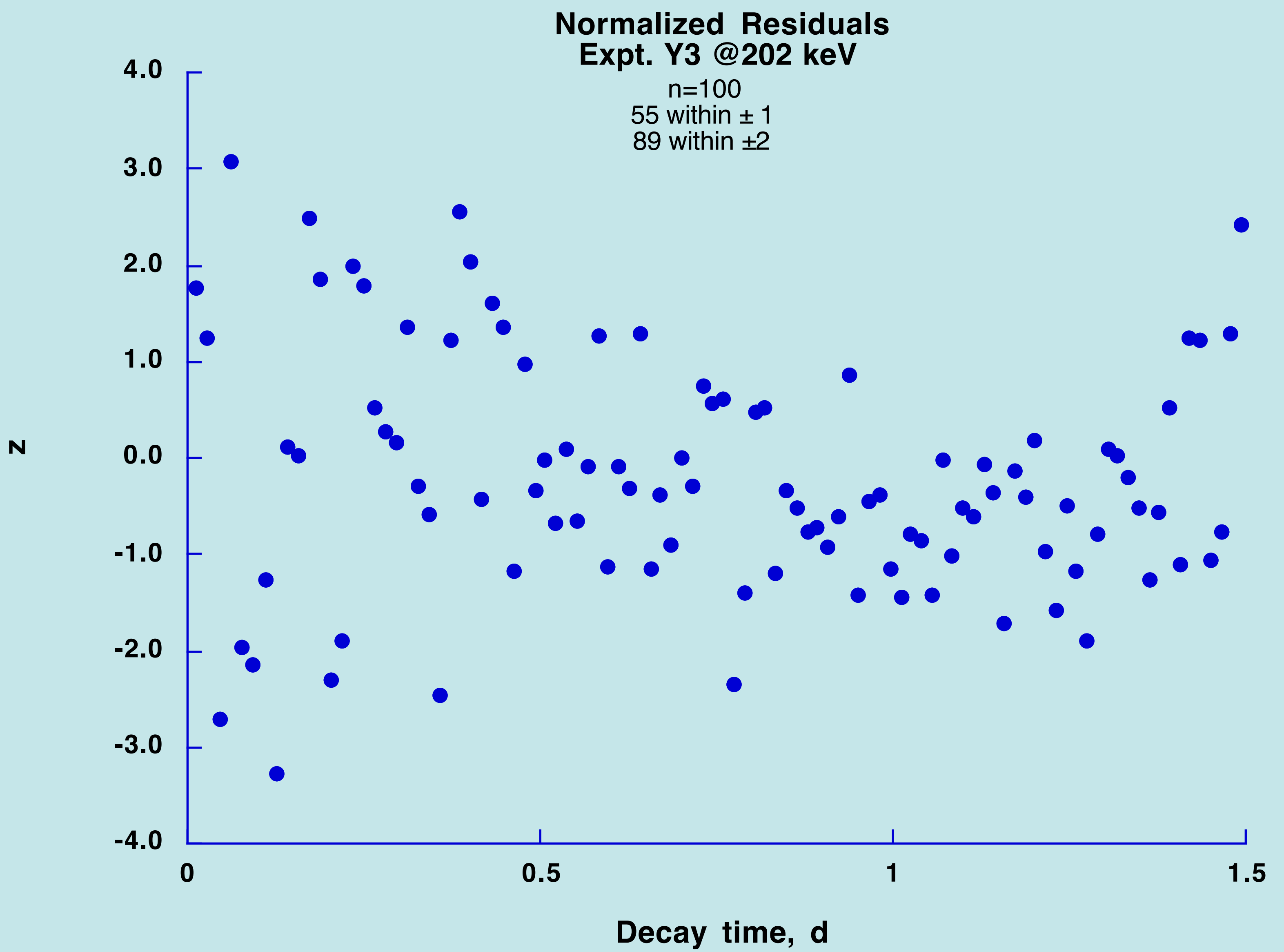
Use Solver to determine $T_{1/2}$ and A_0

Repeat

Evaluate best values and uncertainties


Experiment Y3
202 kev
1,000,000
100,000
10,000
1,000
100
Corr N(I)
Corr N(I)
Fitted N(I)
0
0.5
1
1.5
Decay time, d


Experiment Y3
202 kev
760,000
740,000
720,000
700,000
680,000
660,000
640,000
620,000
Corr N(I)
Corr N(I)
Fitted N(I)
0
0.01
0.02
0.03
0.04
0.05
Decay time, d



Normalized Residuals
Expt. Y3 @202 keV
n=100
55 within ± 1
89 within ±2
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
z
0
0.5
1
1.5
Decay time, d

^{90m}Y Results

Expt, E_γ	Half-lives	Net counts	$T_{1/2}$, hr	±	χ^2/df
Y1 202	5.7	7,275,017	3.211	0.003	1.58
Y2 202	10.8	5,015,603	3.206	0.003	1.41
Y3 202	11.2	8,568,738	3.194	0.002	1.61
Y1 479	5.7	3,647,243	3.202	0.003	1.69
Y2 479	10.8	2,653,289	3.215	0.003	1.07
Y3 479	11.2	4,616,720	3.203	0.002	1.59

^{97}Ru Results

Expt, E_γ	Half-lives	Net counts	$T_{1/2}$, da	±	χ^2/df
Ru1 216	3.8	14,254,210	2.837	0.002	1.46
Ru2 216	4.9	16,715,849	2.847	0.002	1.21
Ru3 216	1.5	8,290,780	2.836	0.005	1.08
Ru6 216	6.1	29,738,916	2.826	0.001	1.10

"We demand guaranteed rigidly defined areas of doubt and uncertainty." – Vroomfondel

D.N. Adams, *Hitchhiker's Guide to the Galaxy,* Pan, London (1979)

Realistic uncertainty assignment

The goodness-of-fit to the decay curve is an underestimate of the true uncertainty as judged from the repeatability of measurements.

Others have found ca. 3-6x underestimate and proposed recipes to assess real uncertainty.

J. A. Becker et al, Nucl. Instrum. Methods **155**, 211 (1978).

K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isot. **34**, 1191 (1983).

S. Pommé, J. Camps, R. Van Ammel, J. Paepen, J. Radioanal. Nucl. Chem. **276**, 335 (2008).

K. Nakamura (Particle Data Group), J. Phys. G: Nucl. Part. Phys. **37**, 075021 (2010).

How good are the Y numbers?

Experiment, energy	$T_{1/2}$, d	Uncertainty, 1s	Normalized residual	Relative weight
Y1 202	3.2107	0.0027	2.59	0.138
Y2 202	3.2061	0.0029	0.81	0.117
Y3 202	3.1942	0.0021	-4.48	0.227
Y1 479	3.2017	0.0027	-0.75	0.141
Y2 479	3.2153	0.0029	4.06	0.125
Y3 479	3.2026	0.0020	-0.52	0.252

Weighted mean	**3.2037**	hours
Unweighted mean	3.2051	
s about weighted mean	0.0075	(0.24% of weighted mean)
Observed s.d. of mean ($s/\sqrt{n}$)	0.0030	(0.09%)
A priori s.d. of mean	0.0010	(0.03%)
$ts/\sqrt{n}$ [P=0.05; t=2.57)	**0.0078**	(0.424%)
Chi squared/d.f.	8.95	for 5 degrees of freedom

Present work 3.204 h ± 0.004 (1s); ENSDF 3.19 ± 0.06

How good are the Ru numbers?

Experiment, energy	$T_{1/2}$, d	Uncertainty, 1s	Normalized residual	Relative weight
Ru1 216	2.8372	0.0020	0.67	0.204
Ru2 216	2.8474	0.0016	7.29	0.332
Ru3 216	2.8356	0.0048	-0.05	0.036
Ru6 216	2.8262	0.0014	-6.87	0.428

Weighted mean	**2.8358**	days
Unweighted mean	2.8366	
s about weighted mean	0.0087	(0.31% of weighted mean)
Observed s.d. of mean (s/√n)	0.0043	(0.15%)
A priori s.d. of mean	0.0009	(0.03%)
ts/√n [P=0.05; t=3.18)	**0.0138**	(0.49%)
Chi squared/d.f.	33.6	for 3 degrees of freedom

Present work 2.836 d ± 0.007 (1s); ENSDF 2.9 ± 0.1

Conclusions

Uncertainties are about an order of magnitude better than ENSDF.

These data should lead to improved accuracy in INAA.

Grazie! Domande?

Questions?

Thanks to Menno Blaauw and Ron Fleming for constructive suggestions in earlier phases of the half-life work.