Cross-section measurements in the Institute of Isotopes

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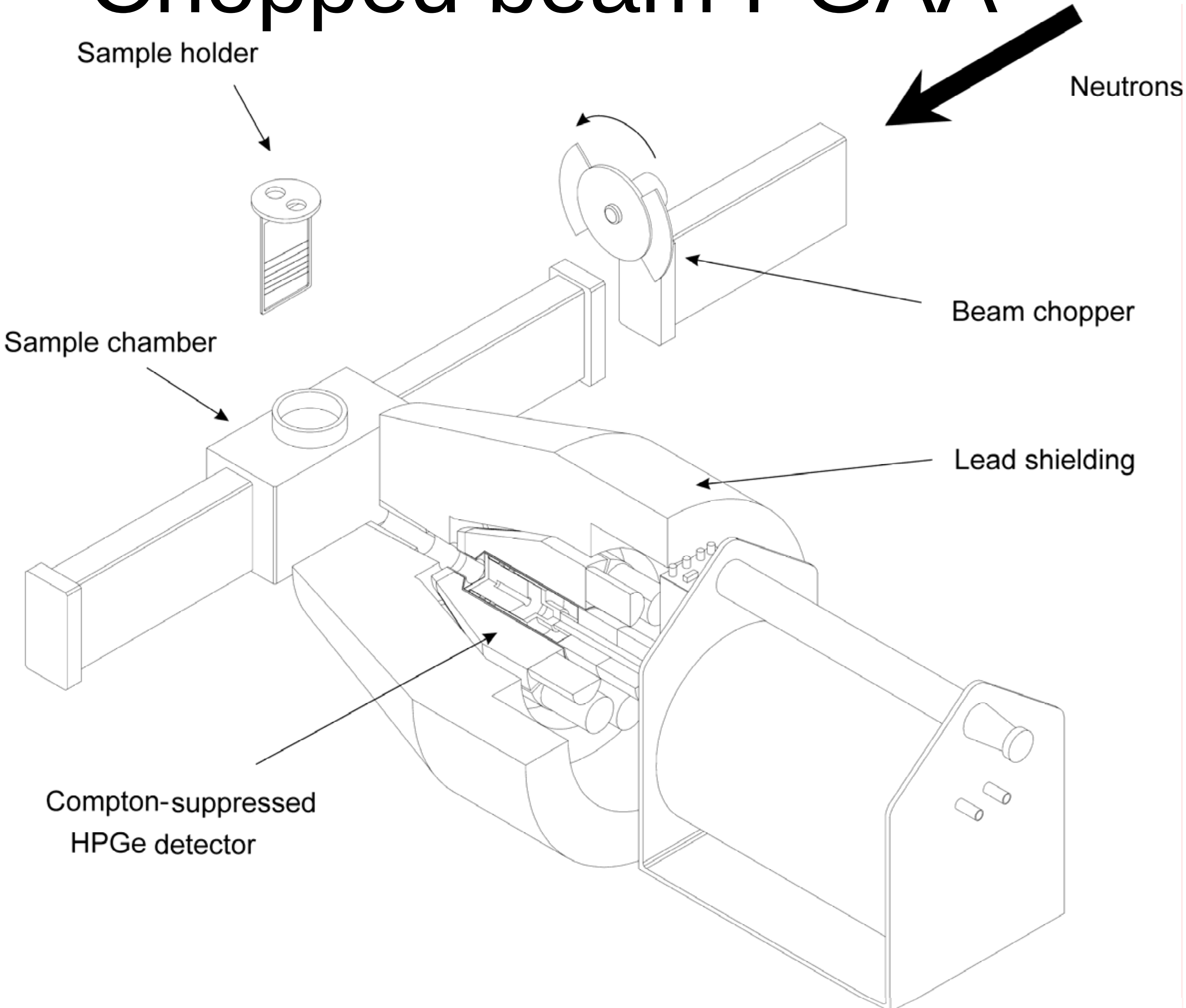
Budapest PGAA facility

- Cold neutron beam
- Pure cold beam until now
  - (at moment we f=60,000 due to partial direct sight)
- Beam chopper
- Flux: —2000: 2×10^{6} cm^{-2} s^{-1}
  - 2000—2006: 3×10^{7} cm^{-2} s^{-1}
  - 2007– : 10^{8} cm^{-2} s^{-1}

Chopped beam PGAA



To-Do List

Advice from Greg Kennedy, Canada

András Simonits, Budapest

1.Suspicious nuclides
(G. Kennedy)

- Cd-115, 53.46h, 528 keV, 4.486h, 336 keV
  - Difficult to measure Q0 for this one. Need to re-measure k0 with well-thermalised neutron spectrum.
- Ir-192, 73.83d, 296, 308, 316, 468 keVs
  - No k0 values given in De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47.

- Hg-197, 2.67d, 77keV
  - No k0 value given in De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47. Difficult case because gamma-ray peak overlaps with x-ray peak but it is important to have a k0 value.
- Se-75, 119.8d, 121, 136, 265, 279, 401keVs
  - Previous k0 measurements used poor efficiency curve or were not corrected for coincidence summing, see my paper JRNC 257, 3 (2003) 475-480.

- Gd-153, 240.4d, 97, 103keVs
  - My paper JRNC 257, 3 (2003) 475-480 suggests that the k0 values of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47 may be about 7% low, probably because of thermal neutron self-shielding.
- Gd-159, 18.56h, 363keV
  - Published k0 value may be OK, but it should be re-measured at the same time as Gd-153.
- Ba-131, 11.5d, 124, 134, 216, 373, 486, 496, 620keVs
  - k0 values of our k0 Workshop paper are in disagreement with those of X. Lin (MTAA11), and 4 to 6% lower than those of Smodis , De Corte, De Wispelaere, JRNC 186 (1994) 183.

- Pd-109, 13.46h (4.69m 2.5%), 39.6s, 88keVs
  - The k0 value of our k0 Workshop paper is 1.52E-3, 6% lower than the value1.62E-3 calculated from Van Lierde et al. JRNC 245, 1 (2000) 179-184. (converting type Va to type Vc gives 1.58E-3 x 1.025 = 1.62E-3)
- Ag-110m, 249.8d, 658, 764, 884, 1384keVs
  - The values of our k0 Workshop paper are 5% higher than those of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47.
- In-116m, 54.15m, 417, 1097, 1293keVs
  - The values of our k0 Workshop paper are 5% higher than those of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47.

- In-116m2, 2.18s, 162keVs
  - Very short half-life, only measured once, Roth et al., JRNC 169, 1 (1993)159-175.
  - A good case for chopped-beam.
- Cs-134m, 2.91h, 127keVs
  - The value of our k0 Workshop paper is 5% higher than that of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47, probably due to error in efficiency curve at low energy.

- Cs-134, 2.062y, 563, 569, 605, 796, 802keVs
  - The values of our k0 Workshop paper are 0 to 5% lower than those of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47, probably due to errors in calculating areas of closely spaced peaks.
- Tm-170, 128.6d, 84keV
  - The value of our k0 Workshop paper is 6% higher than that of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47, probably due to error in efficiency curve at low energy.
- Re-186, 90.64h, 137keV
  - The value of our k0 Workshop paper is 3% higher than that of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47, probably due to error in efficiency curve at low energy.

- Sm-153, 46.5h, 103keV
  - The measurements of my paper JRNC 257, 3 (2003) 475-480 suggest that the k0 value of De Corte, Simonits, Atomic Data and Nuclear Data Tables 85 (2003) 47 may be about 5% high.
- S-36, 5.05m, 3103keV
  - Should be re-measured with system with accurate efficiency curve at high energy.
- Ca-49, 8.718m, 3084keV
  - Should be re-measured with system with accurate efficiency curve at high energy.
- Co-60m, 10.47m, 59, 1332keV
  - Should be re-measured with system with accurate efficiency curve at low energy.
- U-239, 23.45m, 75keV
  - Should be re-measured with system with accurate efficiency curve at low energy.

Other suspicious nuclides (A. Simonits)

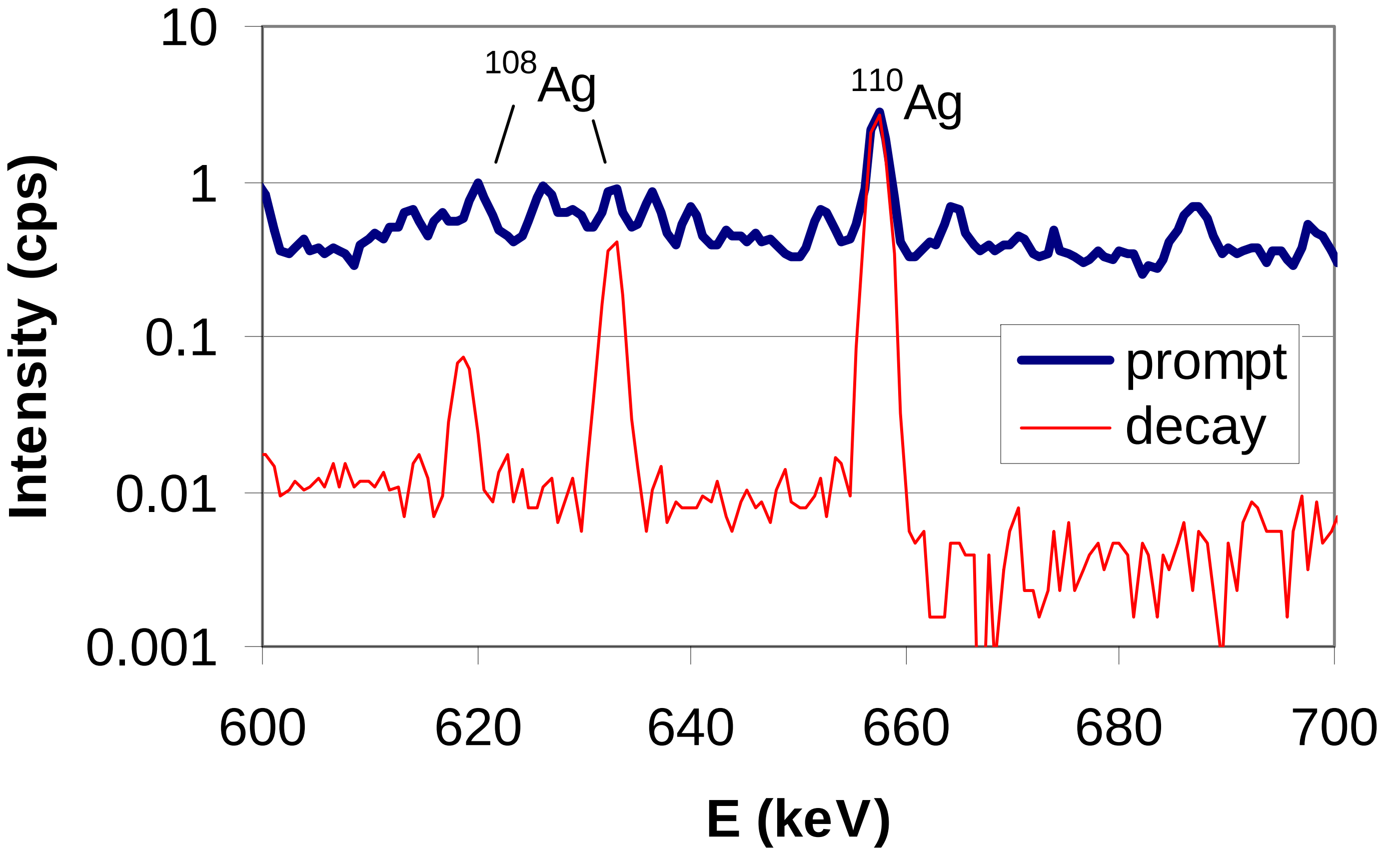
Q0	Er	Isot
1.12	2280	37S
1.14	1040	64Cu
1.908	2560	65Zn
2.38	3540	75mGe
1.57	3540	75Ge
5.93	4300	90mY
5.05	6260	95Zr
1.8	2950	131I
1.2	1540	143Ce

- Nuclides with Q_0>1 and Er>1000keV

Determination of cross-sections (k_0-s) with PGAA

- In-beam measurement
  - Decay peaks appear in prompt spectra
- Chopped beam measurements
  - Decay peaks appear with a higher sensitivity

Prompt and decay spectrum of Ag



In-beam measurements

k_0-s for short lived nuclides

Final nuclide	Energy (keV)	Half-life	Theoretical k_0	k_0 De Corte *et al*	k_0 Roth *et al*	k_0 in-beam
^{20}F	1633.6	11.03 ± 0.06 s	$(1.06\pm0.05)\times10^{-3}$		$(1.01\pm0.007)\times10^{-3}$	$(1.06\pm0.04)\times10^{-3}$
^{24m}Na	472.28	20.2 ± 0.1 ms	$(4.82\pm0.05)\times10^{-2}$		$(3.63\pm0.02)\times10^{-2}$	$(4.34\pm0.03)\times10^{-2}$
^{28}Al	1778.99	2.2414 ±0.0001 m	$(1.79\pm0.02)\times10^{-2}$	$(1.75\pm0.01)\times10^{-2}$		$(1.80\pm0.02)\times10^{-2}$
^{38m}Cl	671.33	0.715 ±0.003 s	$(6.7\pm1.4)\times10^{-3}$		$(7.95\pm0.14)\times10^{-4}$	$(7.6\pm0.8)\times10^{-4}$
^{46}Sc	142.53	18.7 ± 0.05 s	0.282 ±0.033		0.227±.002	0.226 ± 0.002
^{51}Ti	320.08	5.76 ± 0.01 m	$(3.77\pm0.07)\times10^{-4}$	$(3.74\pm0.04)\times10^{-4}$		$(3.66\pm0.11)\times10^{-4}$
^{52}V	1434.08	3.75 ± 0.01 m	0.2 ± 0.005	0.196 ± 0.002		0.197 ± 0.004
^{56}Mn	846.81	2.5785 ± 0.0006 h	0.5 ± 0.008	0.496 ± 0.030		0.502 ± 0.006
^{60m}Co	1332.5	10.47 ± 0.006 m	$3.3\cdot10^{-3}$			$(3.20\pm0.09)\times10^{-3}$
^{66}Cu	1039.35	5.088 ± 0.011 m	$(1.6\pm0.4)\times10^{-3}$	$(1.86\pm0.009)\times10^{-3}$		$(1.97\pm0.04)\times10^{-3}$
^{77m}Ge	215.48	52.9 ± 0.6 s	$2.69\cdot10^{-5}$			$(2.68\pm0.13)\times10^{-5}$
^{77m}Se	161.92	17.45 ± 0.1 s	0.029±0.001		$(2.57\pm0.001)\times10^{-2}$	$(2.24\pm0.04)\times10^{-2}$

Interesting cases

- Na
  - 472 keV line from ^{24m}Na is very intense quasi-prompt peak ($T_{1/2}$= 20 ms)
  - If we are able to determine Na with PGAA, then k_0 for 472 keV is good

theoretical value : $(4.82\pm0.05) \times 10^{-2}$
previous value: $(3.63\pm0.02) \times 10^{-2}$
present value: $(4.34\pm0.03) \times 10^{-2}$

Interesting cases

- Co
  - two states are formed:
    - ^{60}Co $T_{1/2}$= 5.3 y
    - ^{60m}Co $T_{1/2}$= 10 m
  - both emit 1332 keV

for rapid chemical analysis use a
k_0 for 1332 keV line of ^{60m}Co

$$k_0 = (3.20 \pm 0.09) \times 10^{-3}$$

Chopped beam measurements

Nuclide	***Half-life* (Abs. Unc)***	***Decay Code***	***Comparator Peak, keV***	***Decay Peak Energy, keV***	***Sigma, barn* (Abs. Unc)***	***$k_{0,Au}$ (Rel. unc %)***	***Literature***	***Z-score***
^{20}F	11.163 (8) s	I	C 4945	1633.53	*0.00932 (22)*	**0.00102 (2.5%)**	**9.98E-4 (1.2%)** **1.01E-3 (0.7%)**	0.89 0.44
^{24}Na	14.9590 (12) h	IV/B	S 841	1368.66	*0.527 (11)*	**0.047646 (2.1%)**	**4.68E-02 (0.6%)**	0.80
		IV/B	S 841	2754.13	*0.526 (13)*	**0.047591 (2.5%)**	**4.62E-02 (0.8%)**	1.12
^{28}Al	2.2414 (1) m	I	H 2223	1778.99	*0.233 (3)*	**0.017946 (1.6%)**	**1.75E-02 (0.8%)**	1.38
^{38m}Cl	0.715 (3) s	IV/B	Cl 1951	671.355	*0.0135 (7)*	**0.000791 (5.2%)**	**7.95E-04 (1.7%)**	-0.09
^{38}Cl	37.24 (5) m	IV/B	Cl 1951	1642.5	*0.0345 (21)*	**0.00202 (6.2%)**	**1.97E-03 (1.4%)**	0.42
		IV/B	Cl 1951	2166.90	*0.0478 (23)*	**0.00280 (4.9%)**	**2.66E-03 (1.3%)**	0.99
^{56}Mn	2.5789 (1) h	I	Cl 1951	846.754	*13.20 (18)*	**0.499 (1.6%)**	**4.96E-01 (0.6%)**	0.39
		I	Cl 1951	1810.72	*3.57 (5)*	**0.1351 (1.6%)**	**1.35E-01 (0.4%)**	0.06
		I	Cl 1951	2113.05	*1.92 (4)*	**0.0728 (2.2%)**	**7.17E-02 (0.2%)**	0.70
^{46}Sc	18.75 (4) s	I	S 841	142.528	*4.88 (11)*	**0.225 (2.4%)**	**0.2270 (0.7%)**	-0.37

Nuclide	***Half-life* (Abs. Unc)***	***Decay Code***	***Comparator Peak, keV***	***Decay Peak Energy, keV***	***Sigma, barn* (Abs. Unc)***	***$k_{0,Au}$ (Rel. unc %)***	***Literature***	***Z-score***
^{80}Br	4,4205 (8) h/ 17.68 (2) m	IV/A	H 2223	616.3[a]	*0.259 (3)*	**0.00675 (1.5%)**	**6.92E-03 (0.3%)**	-1.64
		IV/A	H 2223	665.8[a]	*0.0469 (11)*	**0.00122 (2.6%)**	**1.22E-03 (0.5%)**	-0.03
^{82}Br	6.13 (5)m/ 35.30 (2) h	IV/B	H 2223	554.348	*0.890 (18)*	**0.02315 (2.2%)**	**2.38E-02 (1.1%)**	-1.15
		IV/B	H 2223	619.106	*0.533 (11)*	**0.01387 (2.3%)**	**1.45E-02 (0.8%)**	-1.88
		IV/B	H 2223	698.21	*0.352 (8)*	**0.00917 (2.4%)**	**9.38E-03 (0.9%)**	-0.89
		IV/B	H 2223	776.50	*1.059 (16)*	**0.02756 (1.7%)**	**2.76E-02 (0.8%)**	-0.08
		IV/B	H 2223	827.8	*0.290 (9)*	**0.00753 (3.3%)**	**7.99E-03 (0.9%)**	-1.78
		IV/B	H 2223	1044.0	*0.335 (9)*	**0.00872 (2.9%)**	**9.14E-03 (0.7%)**	-1.59
		IV/B	H 2223	1317.5	*0.318 (10)*	**0.00828 (3.2%)**	**8.91E-03 (0.4%)**	-2.38
		IV/B	H 2223	1474.9	*0.206 (7)*	**0.00536 (3.7%)**	**5.42E-03 (0.5%)**	-0.31
^{127}I	24.99 (2) m	I	H 2223	442.901	*0.712 (9)*	**0.0117 (1.5%)**	**1.12E-02 (1.7%)**	1.79
		I	H 2223	526.6	*0.0676 (14)*	**0.0011 (2.3%)**	**1.07E-03 (1.4%)**	1.25
^{179m1}Hf	18.67 (4) s	I	Cl 1951	214.341[b]	*15.11 (25)*	**0.176 (2.0%)**	**0.1770 (0.2%)**	-0.29

Nuclide	***Half-life* (Abs. Unc)***	***Decay Code***	***Comparator Peak, keV***	***Decay Peak Energy, keV***	***Sigma, barn* (Abs. Unc)***	***$k_{0,Au}$ (Rel. unc %)***	***Literature***	***Z-score***
^{187}W	23.72 (6) h	I	H 2223	134.2[c]	*1.037 (19)*	**0.0117 (1.9%)**	**1.13E-02 (0.7%)**	1.70
		I	H 2223	479.55	*2.64 (4)*	**0.0299 (1.8%)**	**2.97E-02 (1.0%)**	0.28
		I	H 2223	551.5	*0.613 (10)*	**0.00693 (1.8%)**	**6.91E-03 (0.5%)**	0.17
		I	H 2223	618.3	*0.757 (13)*	**0.00856 (1.8%)**	**8.65E-03 (0.7%)**	-0.51
		I	H 2223	625.5	*0.133 (3)*	**0.00151 (2.5%)**	**1.48E-03[d] (–)**	–
		I	H 2223	685.73	*3.35 (6)*	**0.0379 (2.0%)**	**3.71E-02 (0.5%)**	0.99
		I	H 2223	772.9	*0.498 (8)*	**0.00563 (1.8%)**	**5.61E-03 (0.7%)**	0.15
^{86m}Rb	1.017 (3)m	I	H 2223	555.61	*0.04104 (9)*	**0.000999 (2.4%)**	**9.96E-04 (1.6%)**	0.12
^{88}Rb	17.78 (11) m	I	H 2223	898.03	*0.00469 (23)*	**0.00011 (4.9%)**	**1.01E-04 (1.5%)**	2.25
		I	H 2223	1836.00	*0.0068 (4)*	**0.00017 (5.3%)**	**1.57E-04 (1.1%)**	0.95
^{108}Ag	2.37 (1) min	I	H 2223	433.96[e]	*0.087 (4)*	**0.00168 (5.0%)**	**1.59E-03 (2.0%)**	1.05
		I	H 2223	618.86[e]	*0.055 (4)*	**0.00105 (6.8%)**	**9.33E-04 (0.8%)**	1.69
		I	H 2223	632.98[e]	*0.303 (6)*	**0.00585 (2.0%)**	**6.01E-03 (0.8%)**	-1.26
^{110}Ag	24.6 (2) s	I	H 2223	657.50[e]	*1.88 (3)*	**0.03627 (1.7%)**	*1.93 b (2.1%) [6]*	-0.98

Further plans

- Short-lived nuclides
  - CPGAA + NAA: ^{116m2}In2 (2.18s), ^{28}Al (2.2min), ^{128}I(25min), ^{110}Ag (25s), ^{24}Na(15h)
  - CPGAA + planar detector: 215-keV triplet of $^{178+179+180}$Hf (19s, 5,5h)
  - CPGAA+PGAA: ^{80}Br, ^{232}Th->^{233}Pa->^{233}U