$(n, x\gamma)$ reaction cross-section measurement on Sb and Cr

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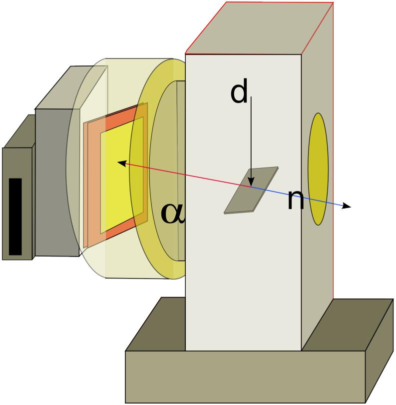
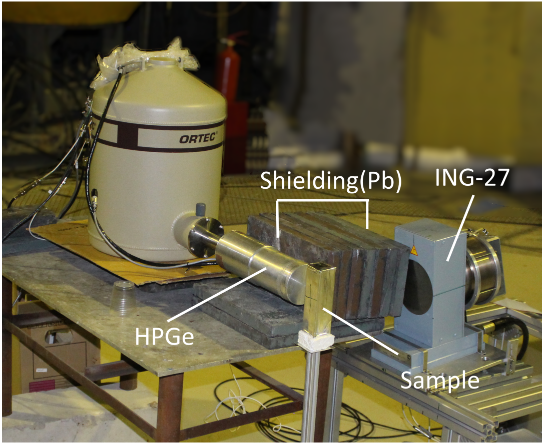
The Idea of the ”tagged” neutron method



- $d + t \to \alpha + n + 17.6\text{MeV}$
- In the center-of-momentum frame n and α fly in opposit directions.
- For registration of the α-particles 64-pixel silicon detector is used. The dimensions of a single pixel are 6×6 mm. The α-particle registration allows one to determine the directon of neutron’s momentum.

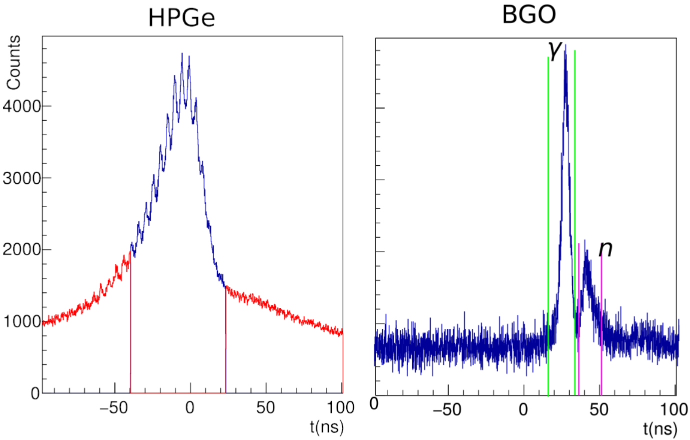
Experimental setup



- Sample: $4 \times 4 \times 14$ aluminum foil box filled by antimony or Cr_2O_3
- Sample was placed at 28cm from ING-27
- Distance form sample to detector: 5 cm
- 2 X-strips were used in this experiment

Events separation (inside and outside the sample)

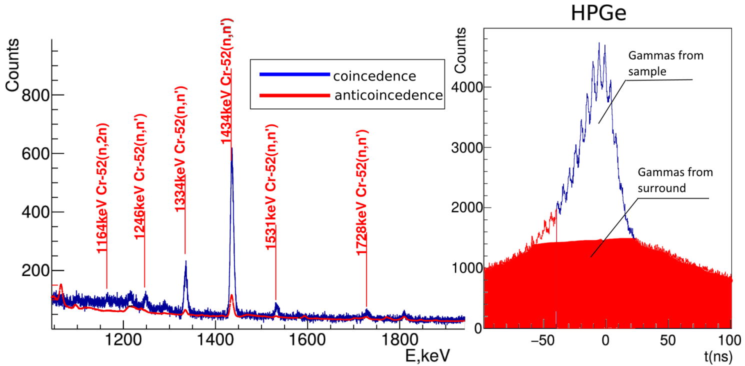
TOF separation problem



Events inside and outside irradiated sample cannot be distinguished using ToF method only. We need second criteria.

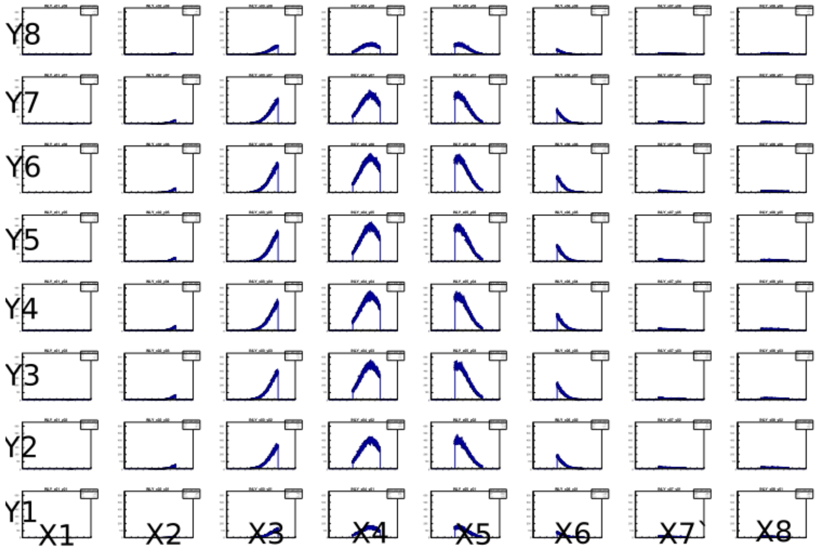
Events separation (inside and outside the sample)

Coincedence/Anticoincedence criteria

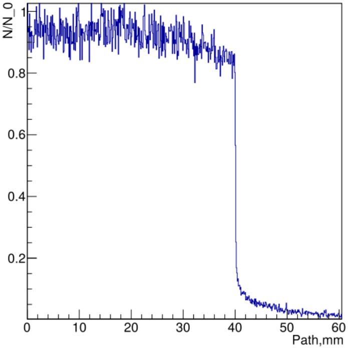


We use the fact that events generated in surrounding object forms substrate (red area on ToF) have almost flat ToF distribution, therefore Peak/Substrate ratio for peaks formed by that "background" events will be same inside coincedence and anticoincedence

Features of the tagged beam distribution (Geant4 calculation)



Cross-section calculation



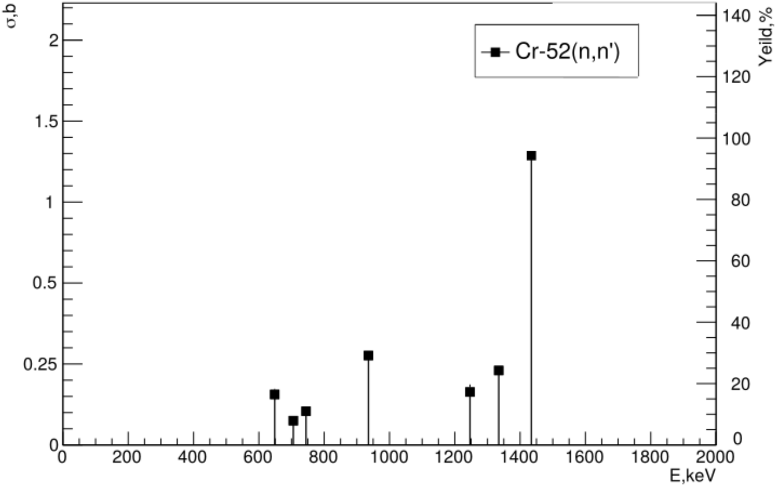
- We assume that sample is thick
- $dN_\gamma = \epsilon N_n(x) \sigma_\gamma \frac{\rho N_A}{A} dx$, where ϵ takes into account absorption of γ-quanta in sample and efficincy of the γ-detector, $N_n(x)$ describes dependence of quantity of neutrons on the path inside the sample. Then $\sigma_\gamma = \frac{N_\gamma A}{\epsilon \rho N_A \int_0^\infty N_n(x) dx}$
- Due to complex spatial distribution of the tagged beams $\int_0^\infty N_n(x) dx$ and ϵ were calculated using Geant4

γ-line identification

Reaction	σ(Talys),mb
^{52}Cr(n,n')^{52}Cr	860
^{52}Cr(n,2n)^{51}Cr	380
^{52}Cr(n,p)^{52}V	77
^{52}Cr(n,a)^{48}Ti	0.00718
^{52}Cr(n,np)^{51}V	42
^{121}Sb(n,n')^{121}Sb	460
^{121}Sb(n,2n)^{120}Sb	1480
^{121}Sb(n,p)^{121}Sn	16.2
^{121}Sb(n,a)^{117}In	0.0217
^{121}Sb(n,np)^{120}Sn	4.75
^{123}Sb(n,n')^{123}Sb	380
^{123}Sb(n,2n)^{122}Sb	1580
^{123}Sb(n,p)^{123}Sn	114
^{123}Sb(n,a)^{119}In	0.0018

- **We cannot register secondary particles with HPGe only**
- We have to use external information to identify diffrent γ-lines: list of levels (from ENSDF) and cross-section estimation (articles or Talys)
- We assign reactions and γ-transitions with highest cross-sections and closest energies to the observed γ-line

Cross-sections and yeilds of gamma-ray emission for Cr (Very preliminary)

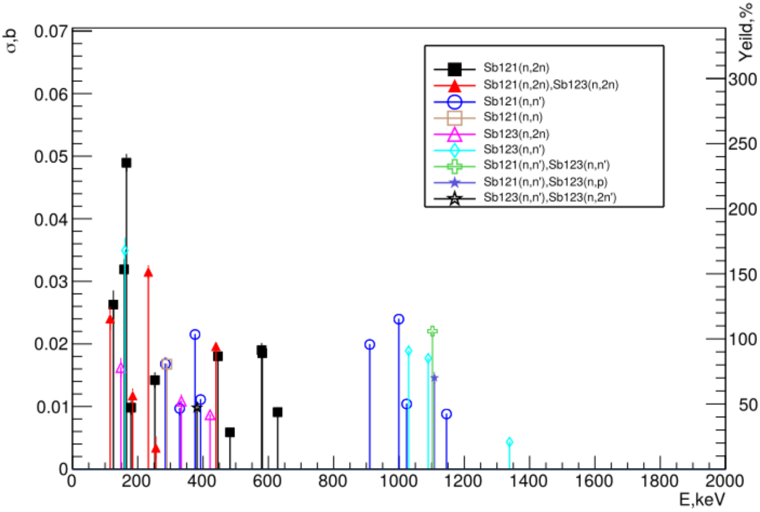


Most intensive lines (Cr, very Preliminary)

Reaction	E,keV	Yeild,%	σ,mb	σ,mb[1]	σ(Talys),mb
^{52}Cr(n,n')	649	16.9±1.9	156±35	70±4	33
^{52}Cr(n,n')	706	6.9±0.6	75±12.4	42±3	42
^{52}Cr(n,n')	745	11.5±0.7	104.3±11.4	71±4	64
^{52}Cr(n,n')	936	30.8±0.6	276.2±11.5	237±2	238
^{52}Cr(n,n')	1247	17.7±2.5	163.5±46.5	39±4	22
^{52}Cr(n,n')	1335	25.9±0.6	230±11.2	205±8	163.8
^{52}Cr(n,n')	1435	100±0.9	893.4±16.8	783±30	768.9

1. S. Simakov, A. Pavlik, A. Vonach и S. Hlavac, Status of experimental and evaluated discrete γ-ray production at En=14.5 MeV, Vienna: IAEA NUCLEAR DATA SECTION, 1998.

Cross-sections and yeilds of gamma-ray emission for Sb (Preliminary)



Normalization on the 946.9keV$(9/2^+)$ →37.1keV$(7/2^+)$ (E_γ =910keV)

Most intensive lines (Sb, Yeild>70%, Preliminary)

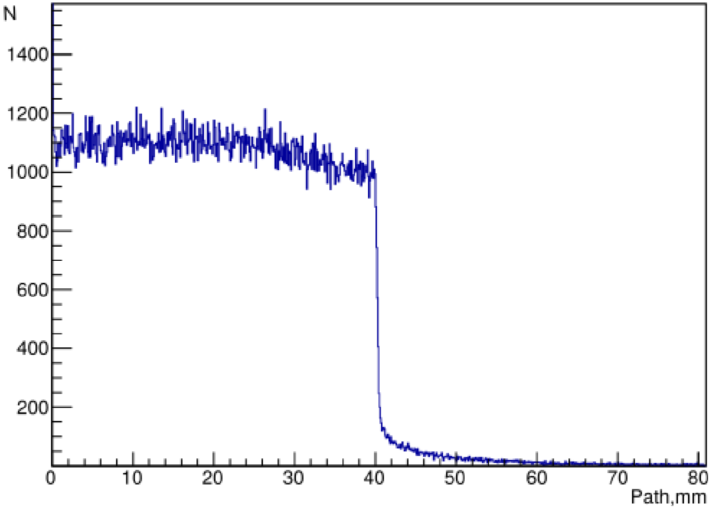
Reaction	E,keV	Yeild,%	Yeild[2],%	σ,mb	σ(Talys),mb
^{121}Sb(n,2n),^{123}Sb(n,2n)	115	107.4±8.4		24±1.9	104.7
^{121}Sb(n,2n)	125	139.8±12.6		26.3±2.3	
^{121}Sb(n,2n)	158	155.8±8.6		31.9±1.7	205
^{123}Sb(n,n')	160	156±9.3	360	34.9±2.1	66
^{121}Sb(n,2n)	165	235.3±7.6		49±1.4	75
^{121}Sb(n,2n),^{123}Sb(n,2n)	232	156.5±5.7		31.5±1.1	24.26
^{121}Sb(n,2n)	252	73±6.4		14.2±1.2	52.2
^{121}Sb(n,2n),^{123}Sb(n,2n)	255	15.2±8.2		3.4±1.8	
^{121}Sb(n,n')	284	84.4±6		16.8±1.1	6.7
^{121}Sb(n,n)	289	83.6±5.7		16.8±1.1	2.052
^{121}Sb(n,n')	375	109.1±4.1	31	21.5±0.8	95.7
^{123}Sb(n,n'),^{123}Sb(n,2n')	381	43.9±3.8		9.8±0.9	11.7
^{121}Sb(n,2n),^{123}Sb(n,2n)	439	99.9±3.8	16	19.6±0.7	
^{121}Sb(n,2n)	445	91.3±3.8		18±0.7	
^{121}Sb(n,2n)	579	109±6.7		19±1.2	
^{121}Sb(n,2n)	581	82.8±4.2		18.5±0.9	
^{121}Sb(n,n')	910	100±4	100	19.9±0.8	123.7
^{121}Sb(n,n')	999	121.4±3.9	77	24±0.8	28.52
^{123}Sb(n,n')	1029	94.9±4.3	101	18.9±0.8	
^{123}Sb(n,n')	1089	88.2±4.1	72	17.7±0.8	46.9
^{121}Sb(n,n'),^{123}Sb(n,n')	1102	110.7±5	59	22±0.9	59.8
^{121}Sb(n,n'),^{123}Sb(n,p)	1108	74.5±4.9	39	14.6±0.9	9.69

2. Atlas of gamma-ray spectra from the inelastic scattering of reactor fast neutrons, Moscow, Atomizdat 1978

Conclusion

- The experiment to study $(n, x\gamma)$ reactions on Cr and Sb was carried out
- The first version of cross-section extraction procedure was developed. This procedure takes into account:
    1. Spatial distribution of neutron beams
    2. Thickness of the sample$\rightarrow$ n,γ absorption
    3. Efficiency of the γ-ray registration as function of emission point distribution
- Cross-sections for $(n, x\gamma)$ reactions were measured on TANGRA setup for the first time
- Disagreement with previous experiments is found, check of data processing procedure is needed

$N_n(x)$



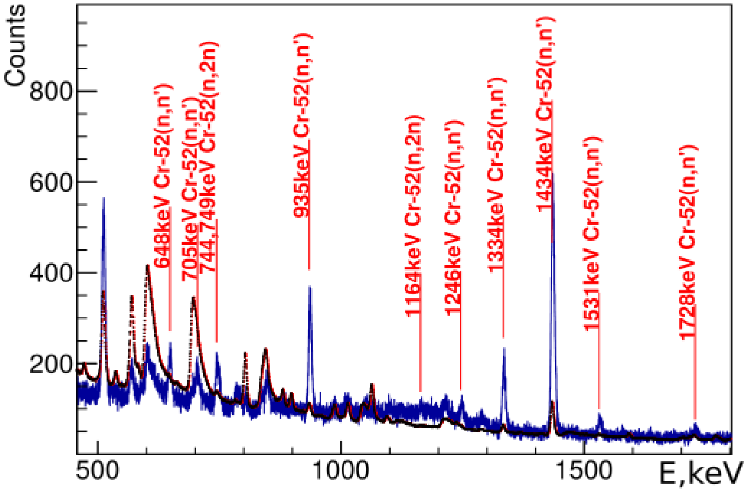
Most intensive lines (Preliminary)

Reaction	E,keV	Yeild,%	Yeild[1],%	CrossSection,mb	Talys,mb
^{121}Sb(n,2n),^{123}Sb(n,2n)	115	107.4±8.4		24±1.9	104.7
^{121}Sb(n,2n)	125	139.8±12.6		26.3±2.3	
^{123}Sb(n,2n)	148	72.4±7		16.2±1.6	79.3
^{121}Sb(n,2n)	158	155.8±8.6		31.9±1.7	205
^{123}Sb(n,n')	160	156±9.3	360	34.9±2.1	66
^{121}Sb(n,2n)	165	235.3±7.6		49±1.4	75
^{121}Sb(n,2n)	179	47±6.2		9.8±1.1	
^{121}Sb(n,2n),^{123}Sb(n,2n)	184	56.9±6		11.7±1.1	
^{121}Sb(n,2n),^{123}Sb(n,2n)	232	156.5±5.7		31.5±1.1	24.26
^{121}Sb(n,2n)	252	73±6.4		14.2±1.2	52.2
^{121}Sb(n,2n),^{123}Sb(n,2n)	255	15.2±8.2		3.4±1.8	
^{121}Sb(n,n')	284	84.4±6		16.8±1.1	6.7
^{121}Sb(n,n)	289	83.6±5.7		16.8±1.1	2.052
^{121}Sb(n,n')	328	49.2±5.9	6	9.7±1.1	
^{123}Sb(n,2n)	333	55.3±5.8		10.8±1.1	
^{121}Sb(n,n')	375	109.1±4.1	31	21.5±0.8	95.7
^{123}Sb(n,n'),^{123}Sb(n,2n')	381	43.9±3.8		9.8±0.9	11.7

Most intensive lines (Preliminary)

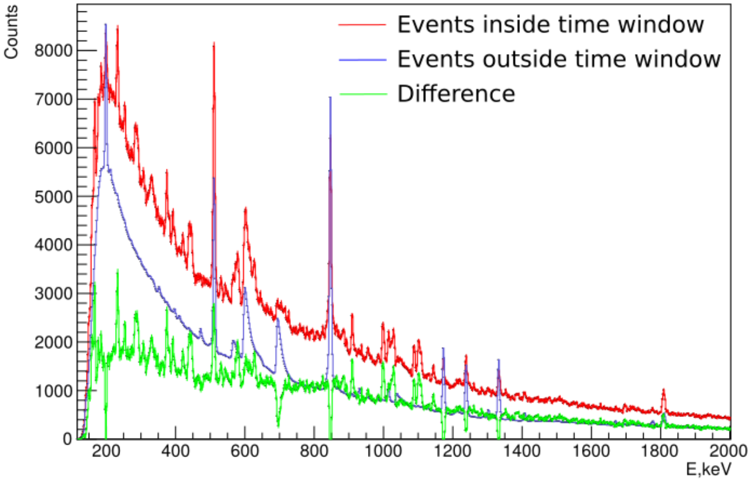
Reaction	E,keV	Yeild,%	Yeild[1],%	CrossSection,mb	Talys,mb
^{121}Sb(n,n’)	392	56.6±4	13	11.1±0.7	12.7
^{123}Sb(n,2n)	421	43.9±3.9		8.7±0.7	
^{121}Sb(n,2n),^{123}Sb(n,2n)	439	99.9±3.8	16	19.6±0.7	
^{121}Sb(n,2n)	445	91.3±3.8		18±0.7	
^{121}Sb(n,2n)	482	30.3±3.9		5.9±0.7	0.25
^{121}Sb(n,2n)	579	109±6.7		19±1.2	
^{121}Sb(n,2n)	581	82.8±4.2		18.5±0.9	
^{121}Sb(n,2n)	628	46.4±4.2	17	9.1±0.8	
^{121}Sb(n,n’)	910	100±4	100	19.9±0.8	123.7
^{121}Sb(n,n’)	999	121.4±3.9	77	24±0.8	28.52
^{121}Sb(n,n’)	1023	52.7±4	34	10.4±0.8	20.9
^{123}Sb(n,n’)	1029	94.9±4.3	101	18.9±0.8	
^{123}Sb(n,n’)	1089	88.2±4.1	72	17.7±0.8	46.9
^{121}Sb(n,n’),^{123}Sb(n,n’)	1102	110.7±5	59	22±0.9	59.8
^{121}Sb(n,n’),^{123}Sb(n,p)	1108	74.5±4.9	39	14.6±0.9	9.69
^{121}Sb(n,n’)	1145	43.8±3.5	31	8.8±0.7	22.96
^{123}Sb(n,n’)	1338	21.5±3.5	33	4.3±0.7	17.6

Cr



Counts
800
600
400
200
500
1000
1500
E,keV
648keV Cr-52(n,n')
705keV Cr-52(n,n')
744,749keV Cr-52(n,2n)
935keV Cr-52(n,n')
1164keV Cr-52(n,2n)
1246keV Cr-52(n,n')
1334keV Cr-52(n,n')
1434keV Cr-52(n,n')
1531keV Cr-52(n,n')
1728keV Cr-52(n,n')

Sb



Events inside time window
Events outside time window
Difference
Counts
0
1000
2000
3000
4000
5000
6000
7000
8000
200
400
600
800
1000
1200
1400
1600
1800
2000
E,keV