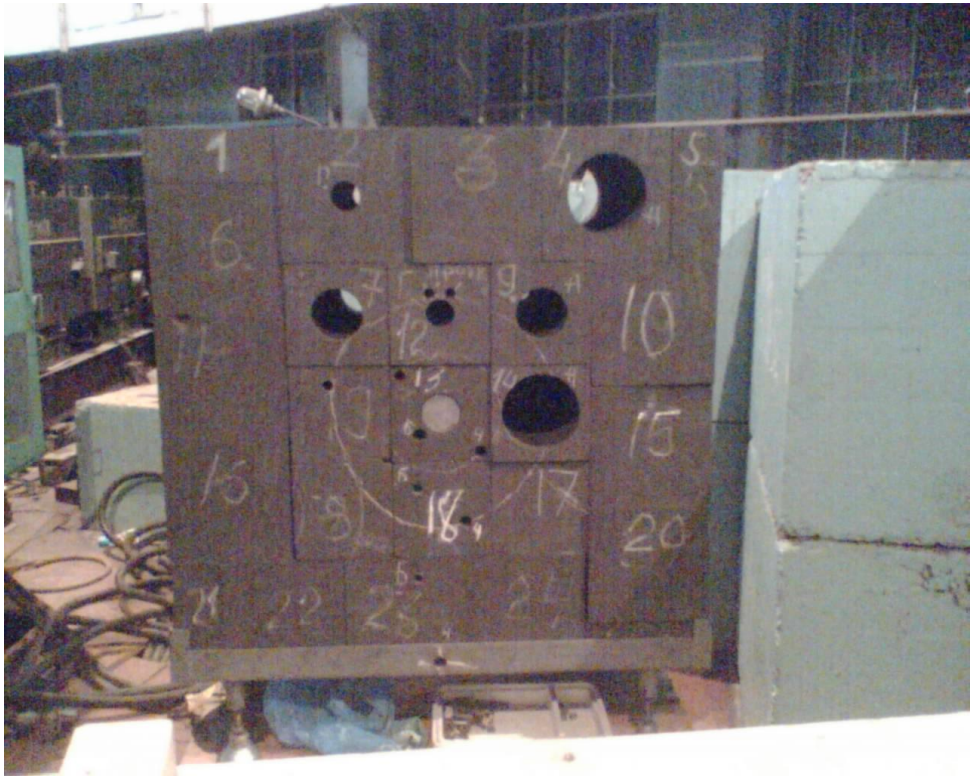
(n,xn) AND (n,γ) REACTION RATES IN IODINE-129 EXPOSED TO SPALLATION NEUTRONS OF GAMMA-3 SETUP

J. Adam, V.S. Pronskikh, V.M. Tsoupko-Sitnikov, V.G. Kalinnikov, A.A. Solnyshkin, V.I. Stegailov, V.M. Golovatiouk, N.M. Vladimirova, V.A. Babkin, W. Westmeier, H. Robotham, A.M. Khilmanovich, B.A. Martsynkevich, K. Katovsky, M. Majerle

		GRAPHIT c- channel			GRAPHIT b-channel			GRAPHIT a-channel		
Isotope E_γ [keV]	I_γ [%]	**$T_{1/2}$ (Lib)** $T_{1/2}$ (Exp)	**<R>** R	**N**	**$T_{1/2}$ (Lib)** $T_{1/2}$ (Exp)	**<R>** R	**N**	**T (Lib)** $T_{1/2}$ (Exp)	**<R>** R	**N**
Na-24		**14.959(1)h**	**2.78(12)E-28**		**14.959(1)h**	**1.10(06)E-28**		**14959(1)h**	**4.77(16)E-29**	
1368.63	100	14.71(2)h	2.78(21)E-28	3	15.34(14)h	1.11(09)E-28	5	14.71(17)h	4.77(22)E-29	5
2754.03	99.9	14.6(3)h	2.78(14)E-28	3	15.0(4) h	1.09(08)E-28	4	14.6(3)h	4.77(22)E-29	5
I-124		**4.176 d**	**1.22(8)E-27**		**4.176 d**	**1.20(19)E-28**		**4.176 d**	**6.46(181)E-29**	
602.73(3)	63	-----	1.30(18)E-27	1	4.48 d	1.20(19)E-28	2	---------	6.46(181)E-29	1
722.79	10.3	-----	1.07(21)E-27	1	---------	----------		---------	----------	0
1690.98	10.8	-----	----------	0	---------	----------		---------	----------	0
1-126		**13.11(5)d**	**1.06(18)E-27**		**13.11(5)d**	**3.35(15)E-28**		**13.11(5)d**	----------	
388.66(1)	34	-------	1.03(14)E-27	1	--------	3.15(41)E-28	2	----------	----------	0
666.33(1)	33	-------	1.08(10)E-27	1	17(5) d	3.39(16)E-28	2	----------	----------	0
1-130		**12.36(3)h**	**7.33(16)E-25**		**12.36(3)h**	**5.70(34)E-25**		**12.36(3)h**	**1.189(038)E-25**	
418.01(3)	34.2	11.6(4)h	7.36(57)E-25	4	11.8(5)h	5.23(52)E-25	5	11.6(4)h	1.057(094)E-25	5
536.09(3)	99	11.8(3)h	6.80(42)E-25	5	11.70(27)h	5.52(43)E-25	5	11.8(3)h	1.139(073)E-25	5
668.54(3)	96	11.8(2)h	7.43(42)E-25	4	12.40(05)h	5.92(35)E-25	5	11.88(24)h	1.189(064)E-25	5
739.48(3)	82	11.9(2)h	7.43(42)E-25	4	12.38(04)h	5.95(33)E-25	5	11.92(20)h	1.204(050)E-25	5
1157.473	11.3	12.0(2)h	7.42(24)E-25	4	11.39(19)h	7.05(44)E-25	4	12.0(19)h	1.329(082)E-25	5

Graphite Block – a model of reactor core



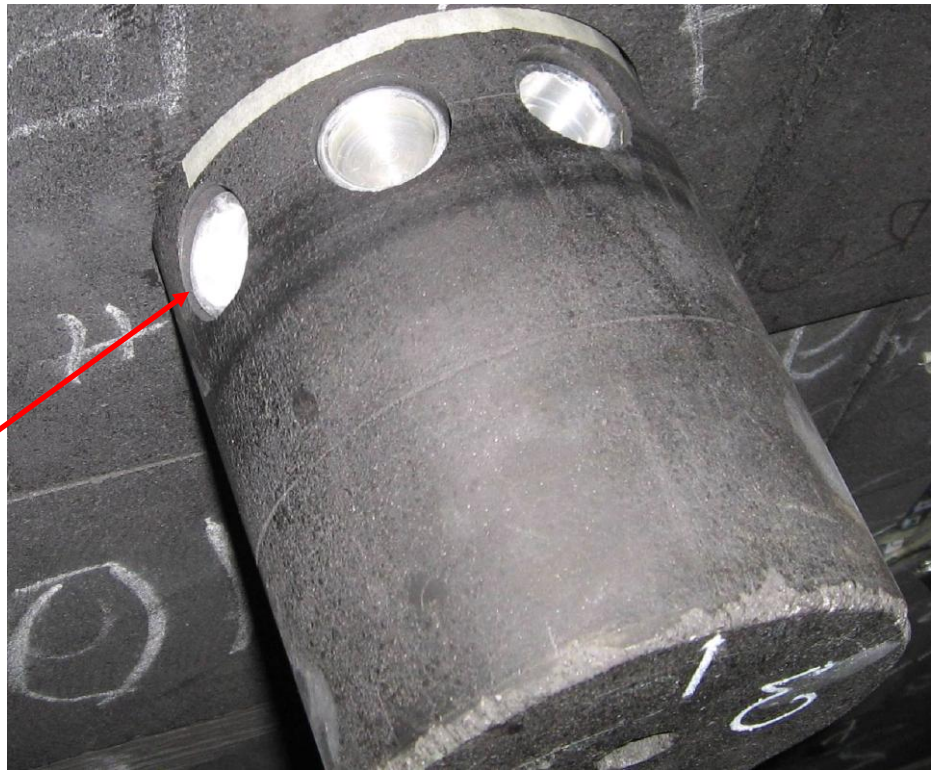
Sizes: 110×110×60 cm (blocks 25×25×60 cm and 20×20×60 cm, lead target d=8 cm, 60 см length

T_{ml} = 3800 °C, T_{fire} (air) = 750 °C (safe) σ(absorb, term)=0,0035 b, λ = 50 cm(water σ = 0,33 b, λ = 5 cm)

Deuteron total kinetic energy, GeV	Gaussian beam FWHM parameters (cm)		Coordinates of the beam center (cm)		Intergral deuteron fluence	Beam percent hit the lead target (%)	
	X	Y	Xc	Yc			
2.33	1,5±0,1	2,4±0,1	0,7±0,1	0,2±0,1	$1{,}85\cdot10^{13}$	$1{,}7\cdot10^{13}$	92.2%

Graphite Block at the Nuclotron beam

Location of the samples within the block



Block No	I-129	Np-237	Pu-239	Pu-238
	L (cm)	L (cm)	L (cm)	L (cm)
14	13,8	17,5	23,3	26
9	24	29,3	33	30,8
4	51,3	56,3	59,8	58,5

Other samples used in the experiment:

threshold detectors Mg, Fe, Al, Co, Cu, Bi, Au, In, Y,Nb, W, V, Au, Lu, Dy, Ni, Sb

radiochemical sensor La-139, 11 samples

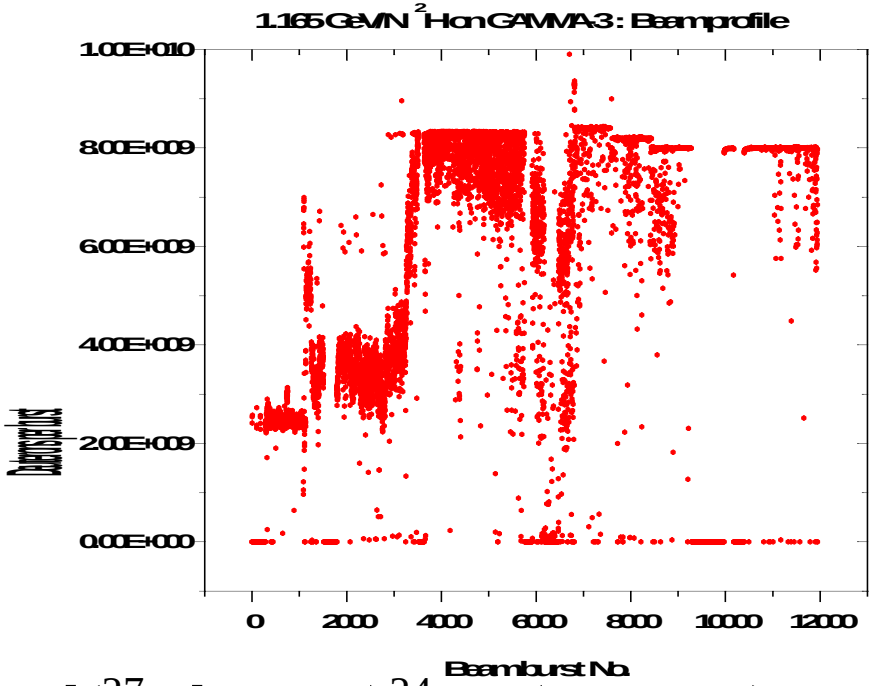
He-3, He-4 neutron counters, track detectors CR39+B-10 (+Cd) Lexan+U-5, Th-232, Au-197, Bi-209 U-8, Au-197, Cd foils

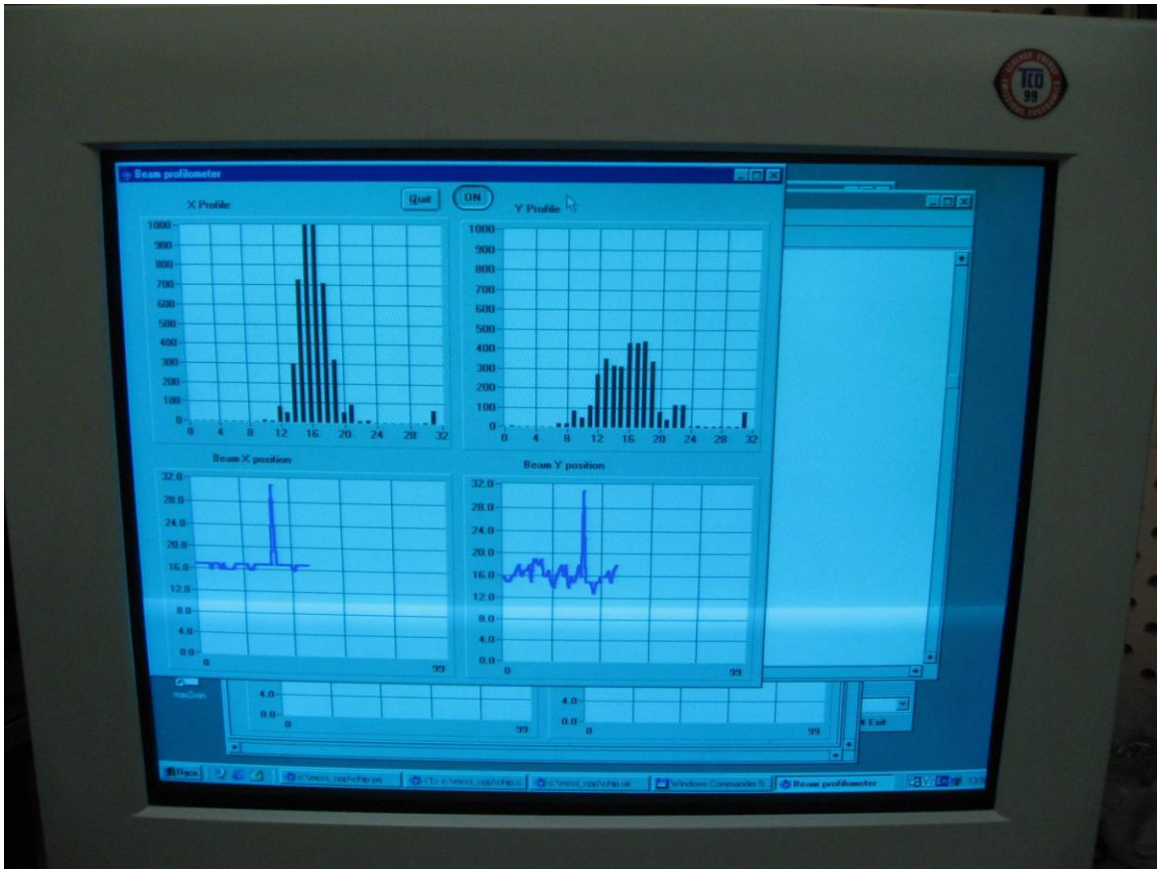
Samples used in the irradiation of the block

Маркировка образцов	Чистый вес, г		Лигатурный вес, г		Активность, МБк (мКи)	Удельная Активность, МБк/г (мКи/г)
I-129-1 1,57·E7 лет	I-129	0,521	NaI	0,739	3,4 (0,092)	5,24 (0,147)
I-129-2	I-129	0,591	NaI	0,838	3,86 (0,10)	5,24 (0,147)
I-129-3	I-129	0,339	NaI	0,480	2,2 (0,06)	5,24 (0,147)
I-129-4	I-129	0,218	NaI	0,309	1,42 (0,038)	5,24 (0,147)
Np-237-1 α-2,14·E6 лет	Np-237	0,987	NpO_2	1,121	25,5 (0,69)	25,9 (0,7)
Np-237-2	Np-237	1.115	NpO_2	1,266	28,86 (0,78)	25,9 (0,7)
Np-237-3	Np-237	1,085	NpO_2	1,232	28,12 (0,76)	25,9 (0,7)
Np-237-4	Np-237	1,011	NpO_2	1,147	26,27 (0,71)	25,9 (0,7)
Pu-239-1 α-2,44·E4 лет	Pu-239	0,503	PuO_2	0,571	ГБк (мКи) 1,15 (31,19)	МБк/мг (мКи/мг) 2,3 (0,062)
Pu-239-2	Pu-239	0,511	PuO_2	0,579	1,17 (31,68)	2,3 (0,062)
Pu-239-3	Pu-239	0,455	PuO_2	0,516	1,04 (28,2)	2,3 (0,062)
Pu-239-4	Pu-239	0,456	PuO_2	0,506	1,02 (27,65)	2,3 (0,062)
Pu-239-5	Pu-239	0,462	PuO_2	0,524	1,06 (28,64)	2,3 (0,062)
Pu-239-6	Pu-239	0,454	PuO_2	0,515	1,04 (28,15)	2,3 (0,062)
Am-241-1 α-432 года	Am-241	0,183	AmO_2	0,208	ГБк (мКи) 23,2 (627)	МБк/мг (мКи/мг) 127 (3,43)
Am-241-2	Am-241	0,183	AmO_2	0,208	23,2 (627)	127 (3,43)
Am-241-3	Am-241	0,186	AmO_2	0,211	23,6 (638)	127 (3,43)
Pu-238-1 87,7 лет	Pu-238	0,0517	PuO_2	0,0734	879	17,1
Pu-238-2	Pu-238	0,0516	PuO_2	0,0733	877	17,1
Pu-238-3	Pu-238	0,0477	PuO_2	0,0677	811	17,1

From IPPE, Obninsk

Deuteron beam properties and monitoring techniques





$d(^{27}Al, 3p2n)^{24}Na$ (Banaigs)

monitored by Dr. W.Westmeier

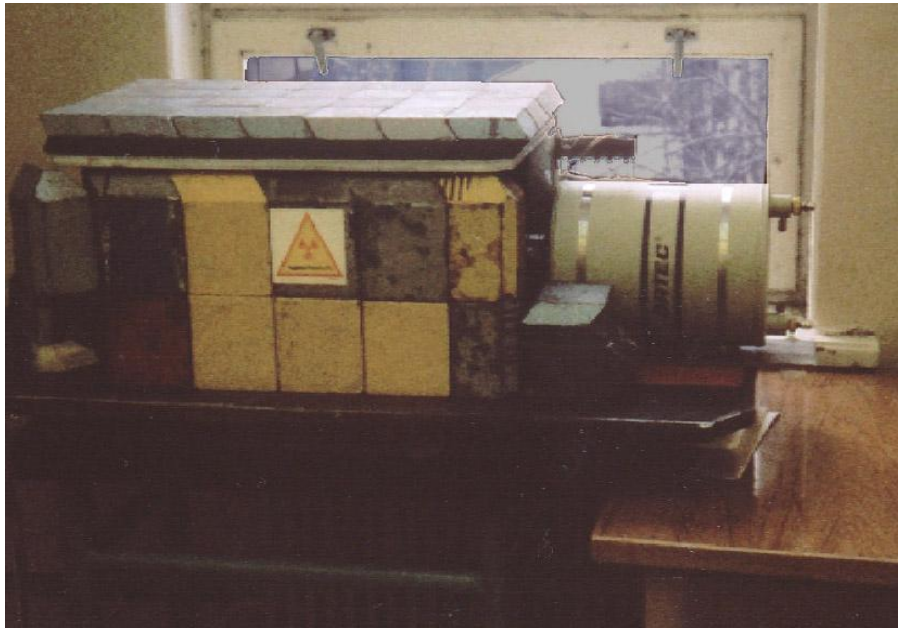
σ = 15.38±1.12 mb

Start at 13:44 on 17.03.08

Stop at 15:01 on 18.03.07

Ring dimensions	^{24}Na activity in Bq	Deuterons per cm^2
r=10.5 mm to r=40 mm	307.1 ± 13.4	3.593E11 ± 1.568E10
r=40 mm to r=60 mm	20.2 ± 1.2	1.760E10 ± 1.045E9
r=60 mm to r=80 mm	5.978 ± 0.566	3.721E9 ± 3.523E8
r=0 mm to r=10.5 mm	4.217 ± 0.998	6.673E10 ± 1.579E10

Spectrometry with HPGe detectors



Gamma-spectra analysis was performed using
The following program codes:
GAMMAW (Dr. Westmeier GMBH), monitors
DEIMOS32 (Dr. Frana, Rez near Prague),
Fitzpeaks (Dr. Fitzgerald, math of SAMPO80)

Program package J. Adam, V.S. Pronskikh,
A.R. Balabekyan et al, P10-2000-28,
Measurement Techniques, 44(2001) 93-100.
Energy, efficiency calibration, background correction,
surplus peaks removal, nuclide identification,
cross section calculations, selective averaging

HPGe detector	CANBERRA GR1819 (DLNP)	ORTEC GMX-23200 (DLNP)	ORTEC GMX-20190-P (DLNP)	CANBERRA GC1520 (LPHE)
Rel. efficiency	18.9 %	27.7 %	28.3 %	15%
Resolution at (E_g 1332 keV)	1.78 keV	1.86 keV	1.80 keV	2.0 keV
Amplifier	ORTEC 973	CANBERRA 2024	CANBERRA 2026	CANBERRA 2002
ADC	ORTEC 921 SPECTR. MASTER	ORTEC 919 SPECTR. MASTER	ORTEC 919 SPECTR. MASTER	CANBERRA

		GRAPHIT c- channel			GRAPHIT b-channel			GRAPHIT a-channel		
Isotope E_γ [keV]	I_γ [%]	**$T_{1/2}$ (Lib)** $T_{1/2}$ (Exp)	**<R>** R	**N**	**$T_{1/2}$ (Lib)** $T_{1/2}$ (Exp)	**<R>** R	**N**	**T (Lib)** $T_{1/2}$ (Exp)	**<R>** R	**N**
Na-24		**14.959(1)h**	**2.78(12)E-28**		**14.959(1)h**	**1.10(06)E-28**		**14959(1)h**	**4.77(16)E-29**	
1368.63	100	14.71(2)h	2.78(21)E-28	3	15.34(14)h	1.11(09)E-28	5	14.71(17)h	4.77(22)E-29	5
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I-124		**4.176 d**	**1.22(8)E-27**		**4.176 d**	**1.20(19)E-28**		**4.176 d**	**6.46(181)E-29**	
602.73(3)	63	-----	1.30(18)E-27	1	4.48 d	1.20(19)E-28	2	---------	6.46(181)E-29	1
722.79	10.3	-----	1.07(21)E-27	1	---------	----------		---------	----------	0
1690.98	10.8	-----	----------	0	---------	----------		---------	----------	0
1-126		**13.11(5)d**	**1.06(18)E-27**		**13.11(5)d**	**3.35(15)E-28**		**13.11(5)d**	----------	
388.66(1)	34	-------	1.03(14)E-27	1	--------	3.15(41)E-28	2	----------	----------	0
666.33(1)	33	-------	1.08(10)E-27	1	17(5) d	3.39(16)E-28	2	----------	----------	0
1-130		**12.36(3)h**	**7.33(16)E-25**		**12.36(3)h**	**5.70(34)E-25**		**12.36(3)h**	**1.189(038)E-25**	
418.01(3)	34.2	11.6(4)h	7.36(57)E-25	4	11.8(5)h	5.23(52)E-25	5	11.6(4)h	1.057(094)E-25	5
536.09(3)	99	11.8(3)h	6.80(42)E-25	5	11.70(27)h	5.52(43)E-25	5	11.8(3)h	1.139(073)E-25	5
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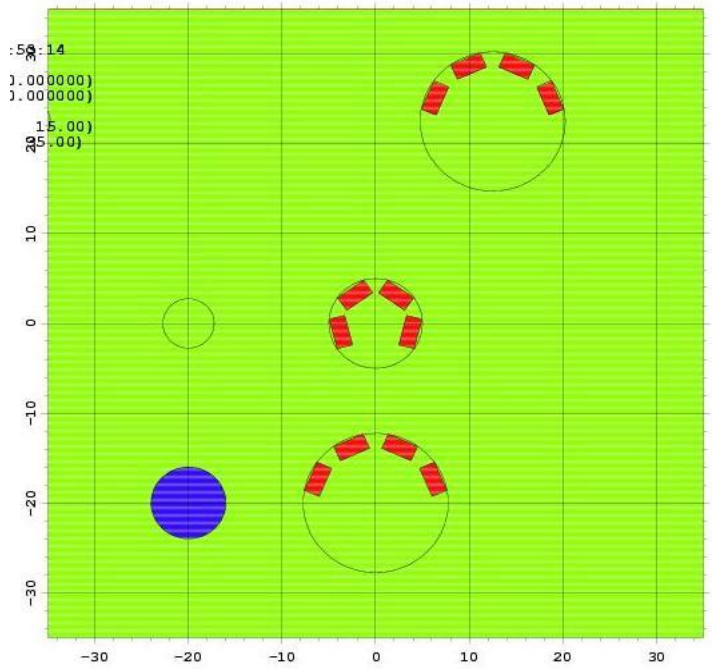
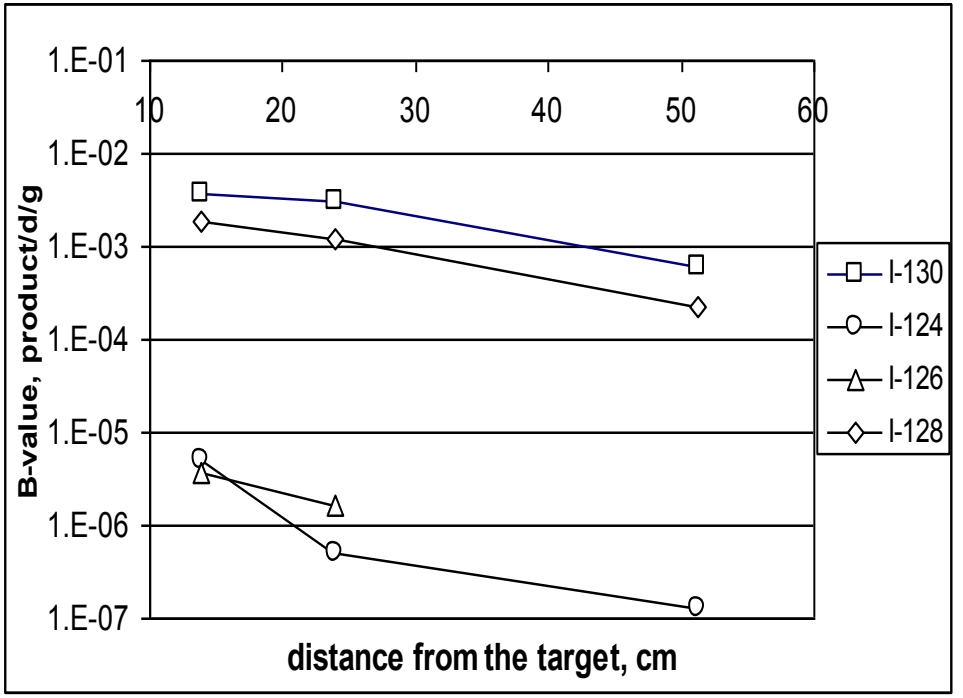
739.48(3)	82	11.9(2)h	7.43(42)E-25	4	12.38(04)h	5.95(33)E-25	5	11.92(20)h	1.204(050)E-25	5
1157.473	11.3	12.0(2)h	7.42(24)E-25	4	11.39(19)h	7.05(44)E-25	4	12.0(19)h	1.329(082)E-25	5

Transmutation rates (B-factors)





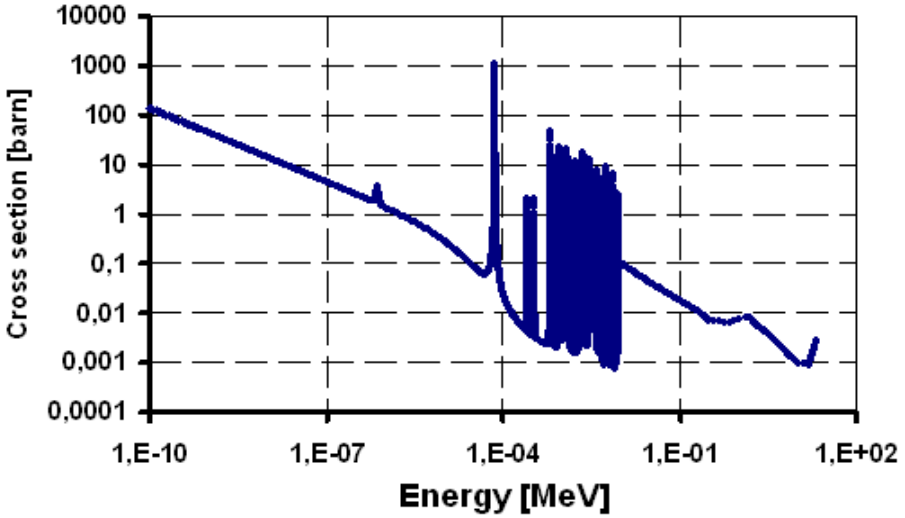
Product	Target	Relative rates B [g^{-1}, d^{-1}]		
		19 cm	29 cm	55 cm
^{130}I	^{129}I	3.8(5)E-3	3.1(4)E-3	6.0(9)E-4
^{124}I	^{129}I	5.1(6)E-6	5.0(7)E-7	1.3(3)E-7
^{126}I	^{129}I	3.8(5)E-6	1.6(1)E-6	----------
^{128}I	^{127}I	1.9(2)E-3	1.2(1)E-3	2.2(3)E-4
Transmutation I=10mA, 30d	^{129}I (%)	23.8	18.8	3.8

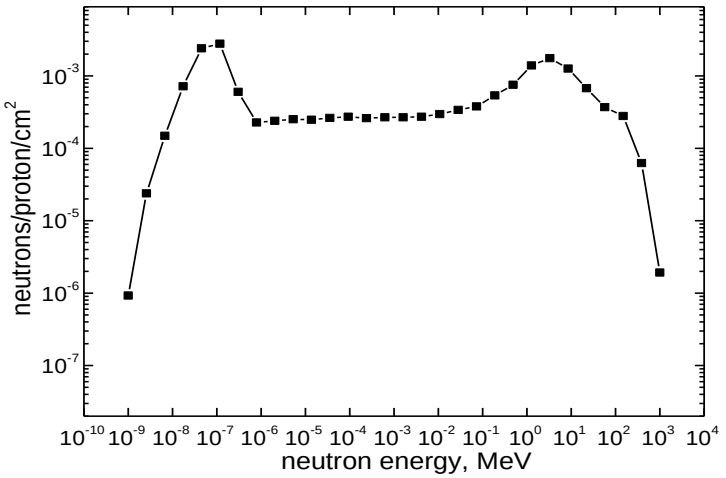
Monte-Carlo simulations with FLUKA code

$$B = \frac{N_{at}}{m \cdot N_p} \qquad [\text{ion}^{-1} \cdot \text{gram}^{-1}]$$

$$R = \frac{B \cdot A}{N_A} =$$

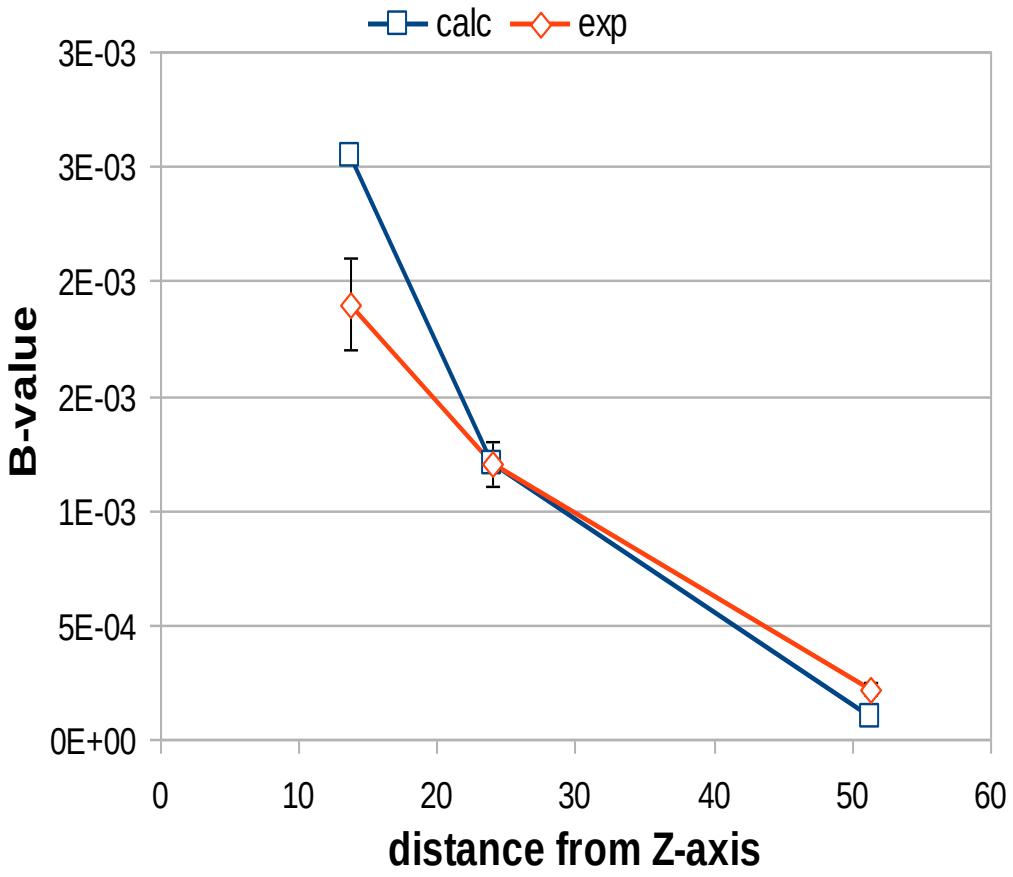
$$= \int_{E_{\min}}^{E_{\max}} \sigma(E)\Phi(E)\mathrm{d}E \qquad [\text{deuteron}^{-1}\text{atom}^{-1}]$$



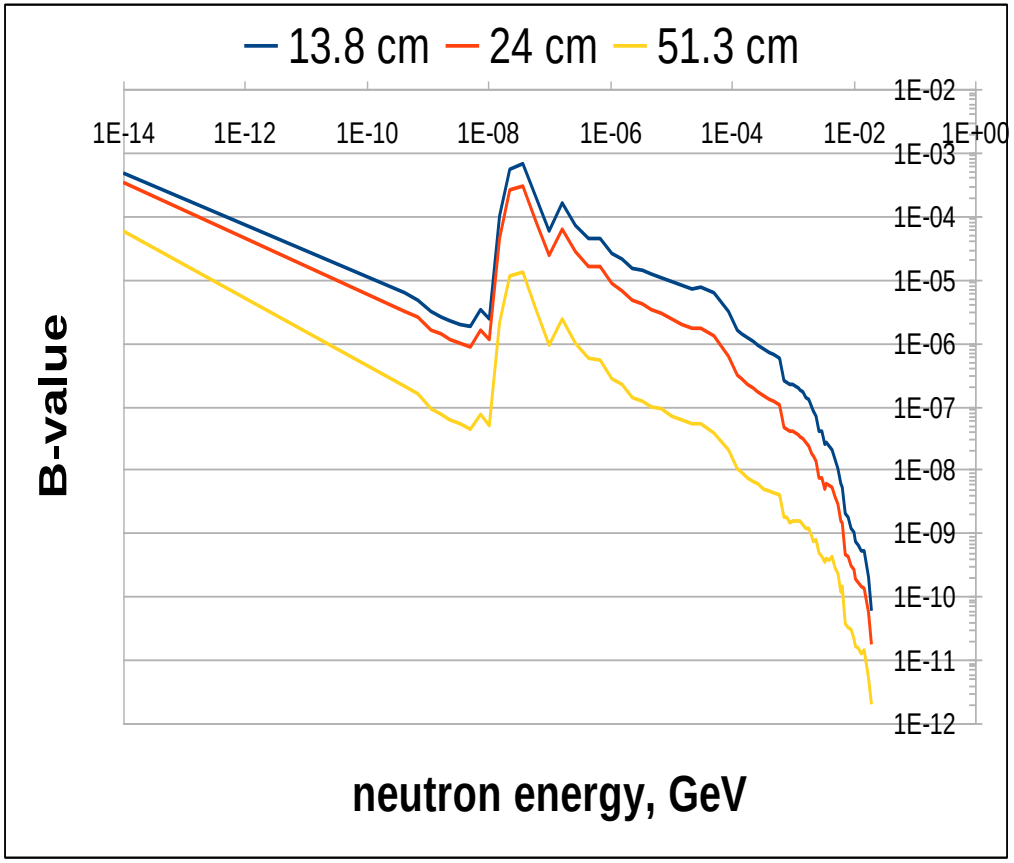


Comparison with the experimental data on ^{130}I production in ^{129}I (n,γ) ^{130}I

B-values for the cylinders at 13.8, 24, and 51.3 cm distances from the Z-axis, respectively



Differential B-values for the three cylinders calculated for each of the 72 neutron groups separately using JEFF-3.1 cross section library and employing NJOY program code



Spallation experiment on thick, lead target: analysis of experimental data with Monte Carlo codes

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V. Henzl [a,b] D. Henzlová [a,b] V. G. Kalinnikov [c]
M.I. Krivopustov [c] A. Krása [a,b] F. Křížek [a,b] A. Kugler [a]
I.V. Mirokhin [c] A. A. Solnyshkin [c] V. M. Tsoupko-Sitnikov [c]
V. Wagner [a,b]

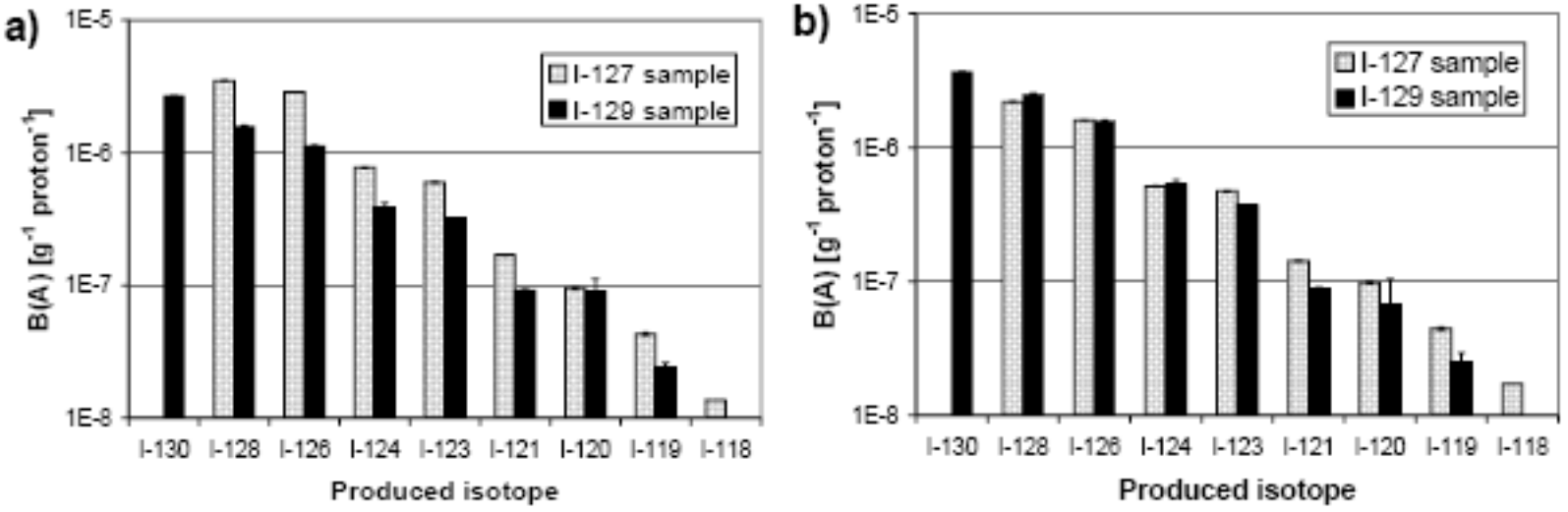

Fig. 4. B-values for different isotopes in ^{127}I and ^{129}I. Samples were placed at the 9^{th} (a) and 21^{st} cm (b).

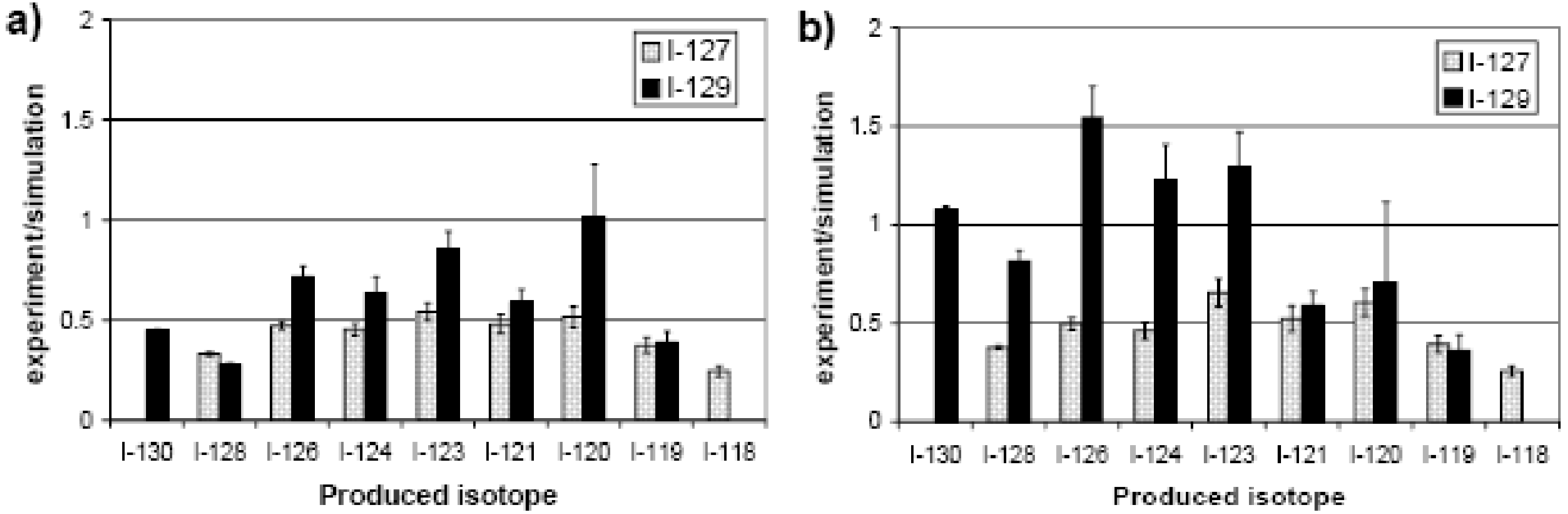

Fig. 13. Ratios between experimental and simulated B-values for different isotopes in ^{127}I and ^{129}I. Samples were placed at 9$^{\text{th}}$ (a) and 21$^{\text{st}}$ cm (b). INCL4/ABLA was used to simulate B-values.

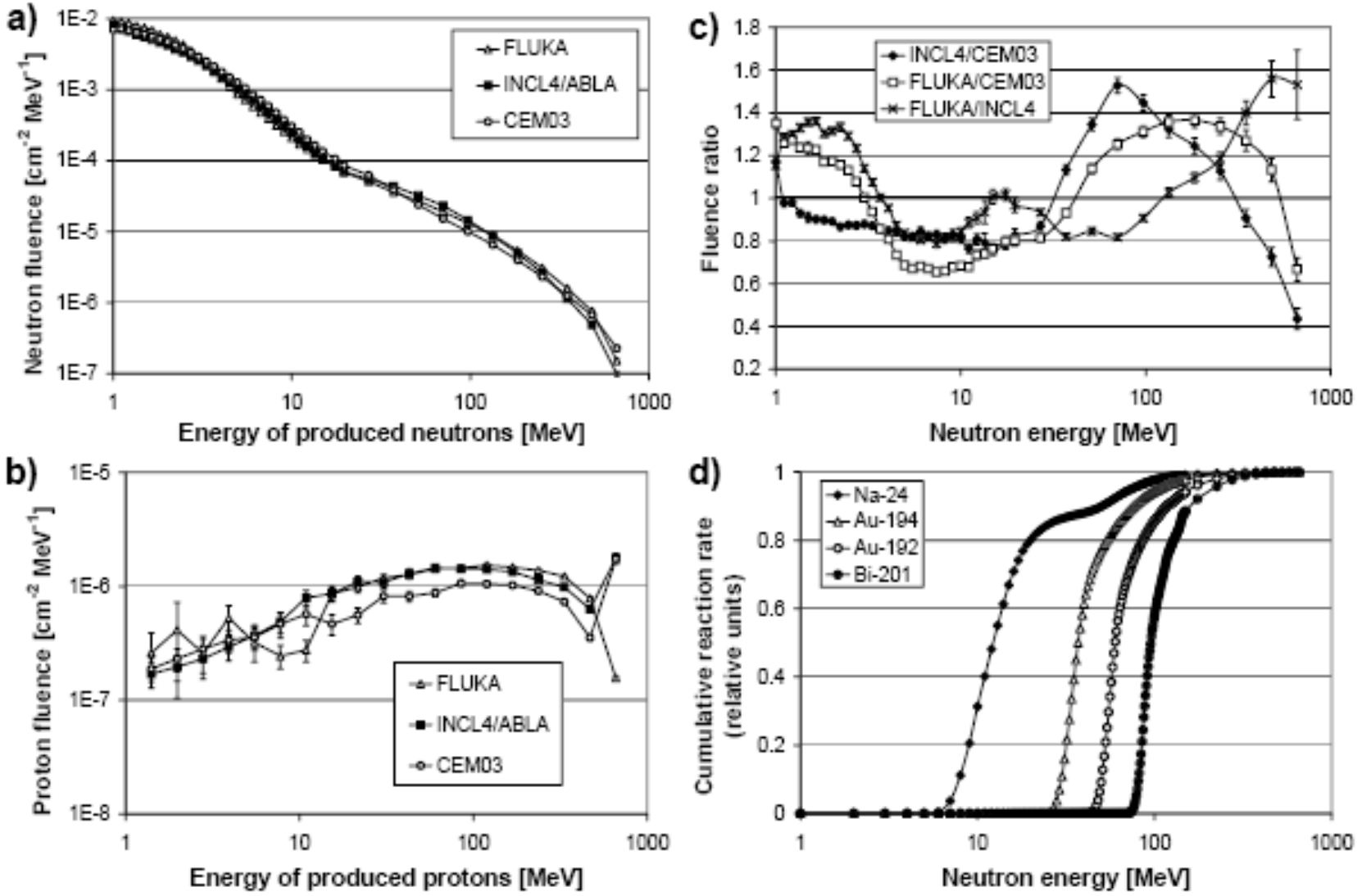

Fig. 12. The neutron (a) and proton (b) spectra in the detector foil on the 9$^{\text{th}}$ cm calculated with the MCNPX CEM03, MCNPX INCL4/ABLA and the FLUKA code, and the ratios between the calculated neutron spectra (c). In (d) are the cumulative reaction rates (in relative units, normalized to 1) calculated with MCNPX CEM03. It can be seen that ^{24}Na, ^{194}Au, ^{192}Au and ^{201}Bi are produced mainly with 10, 30, 60 and 90 MeV neutrons, respectively.