Measurement of cross-section of the p + ^{7}Li, d + Li, p + ^{11}B, and d + B reactions at ion energies up to 2.2 MeV

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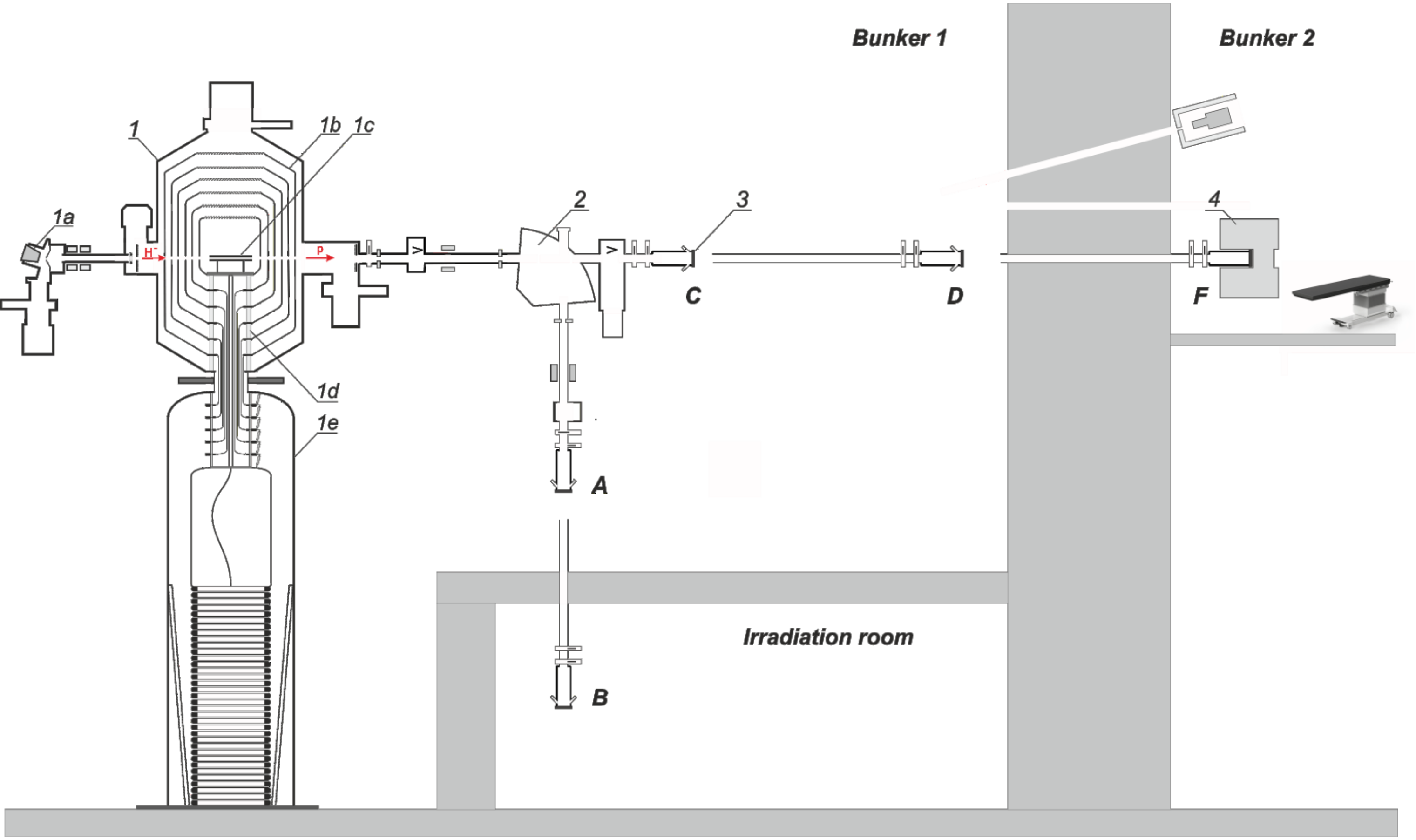
Accelerator based Neutron Source VITA is hand-made state-of-art device comprising

- Vacuum Insulated Tandem Accelerator (VITA)
- solid lithium target
- beam shaping assemblies
- set of gamma, alpha and neutron spectrometers and detectors



Accelerator based Neutron Source VITA produces:

High power DC proton/deuteron beam (20 kW):
Energy: ranges from 0.1 MeV to 2.3 MeV
Monochromaticity and stability: 0.1%
Current: ranges from 1 nA to 10 mA
Current stability: 0.4 %

High flux neutron beam (2 10^{12} s^{-1}):
- ✓ cold (D_2O moderator @ cryo temp.)
- ✓ thermal (D_2O or Plexiglas moderator)
- ✓ epithermal (MgF_2 moderator)
- ✓ exclusively epithermal (no fast and thermal)
- ✓ over-epithermal
- ✓ monoenergetic (kinematic collimation)
- ✓ fast

Bright source of photons – $^{7}Li(p,p'\gamma)^{7}Li$, $^{19}F(p,\alpha e^+e^-)^{16}O$

Bright source of α-particles – $^{7}Li(p,\alpha)\alpha$, $^{11}B(p,\alpha)\alpha\alpha$

Bright source of positrons – $^{19}F(p,\alpha e^+e^-)^{16}O$

Bright source of neutrons – up to 10^4 n/cm^3 (in future)

Boron Neutron Capture Therapy is a promising technique for treating malignant tumors by accumulating boron-10 in tumor cells and subsequent irradiation with neutrons. As a result of the capture of a neutron by boron, a nuclear reaction occurs with a large release of energy in the cell, which leads to its death.

The technique is beginning to enter clinical practice:

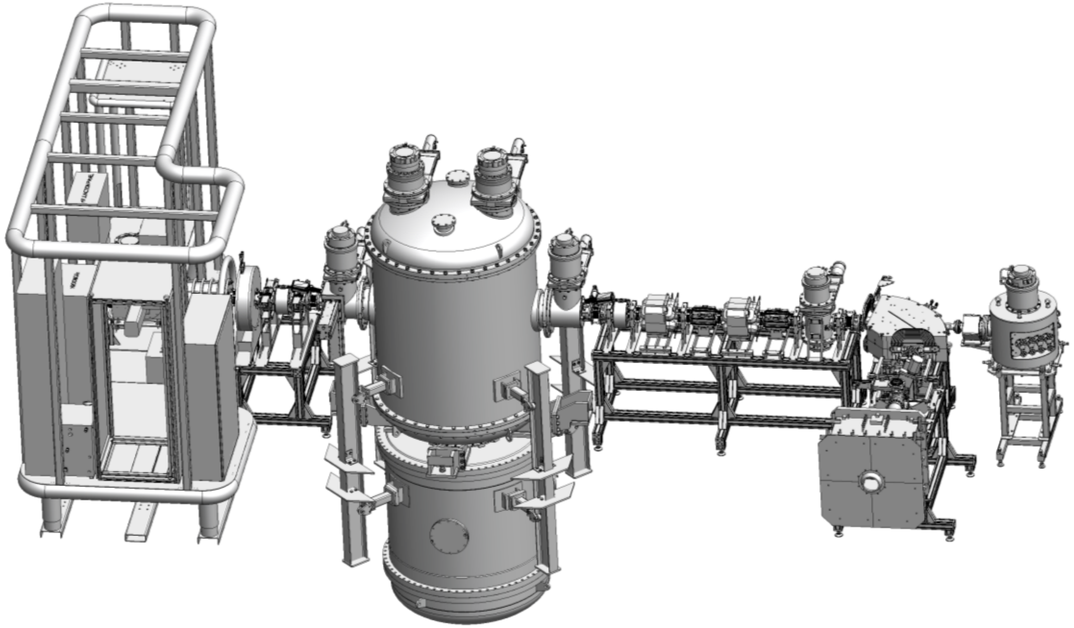
1. Japan, 2020
2. China, 2022 (VITA)
3. South Korea, 2022

4 or 5 Finland, ?

4 or 5 Russia, 2025

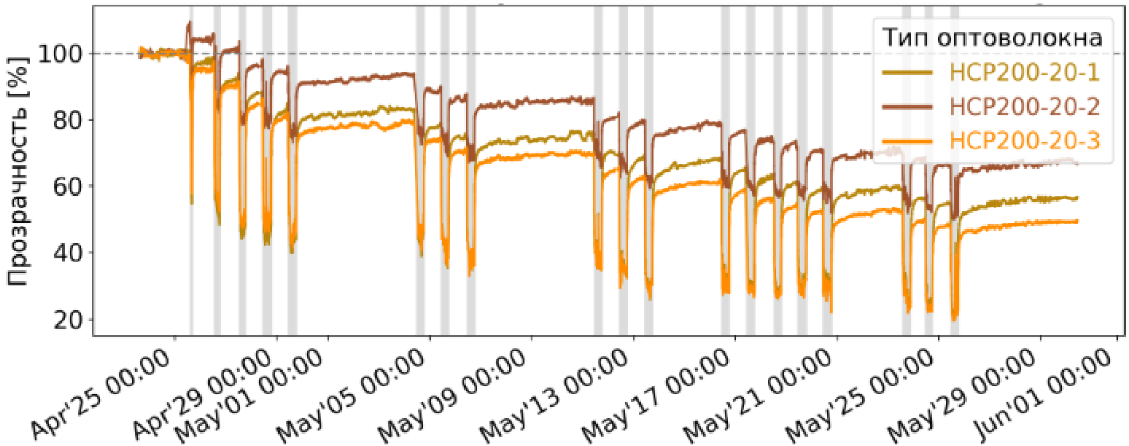
NEUBORON

НМИЦ ОНКОЛОГИИ им. Н. Н. Блохина

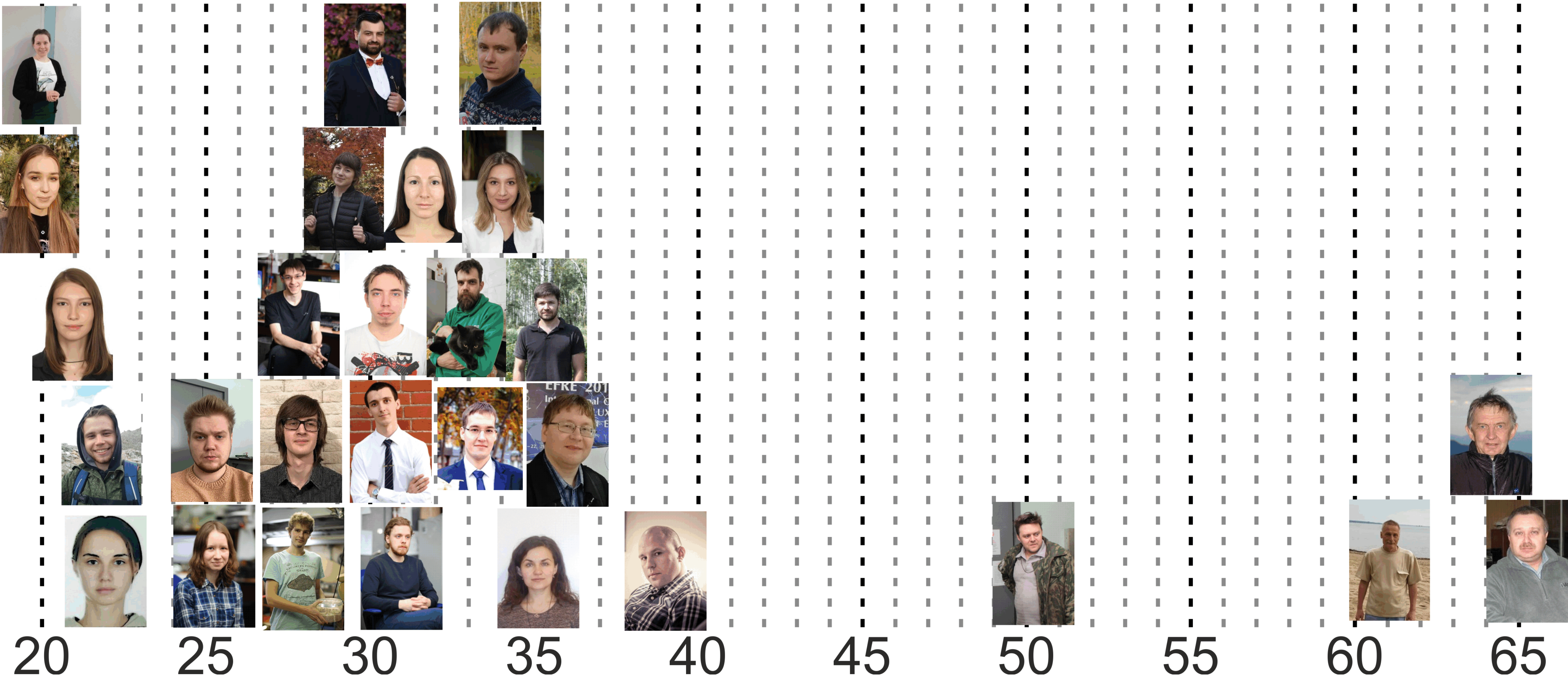


Accelerator based neutron source VITA

1. Development of dosimetry tools and methods for BNCT
2. Testing of new boron delivery drugs
3. Treatment of cats and dogs with spontaneous tumors
4. Development of lithium neutron capture therapy
5. Study of radiation blistering of a metal surface during proton implantation
6. Radiation testing of boron carbide and steel samples for ITER
7. Radiation testing of optical fiber for CERN

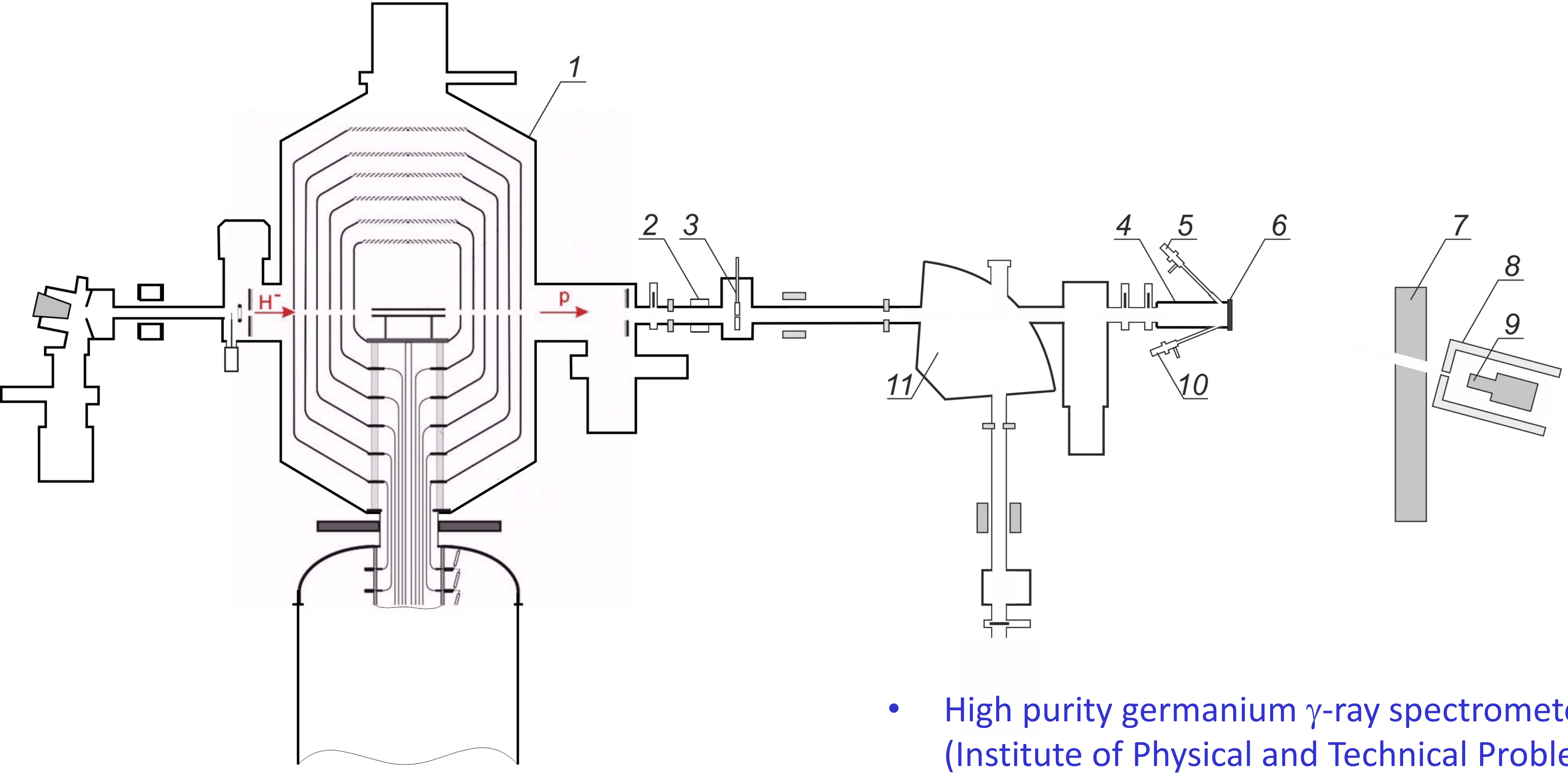


BNCT team




PIANO
CONCERTO
NO. 3
IN D
MINOR

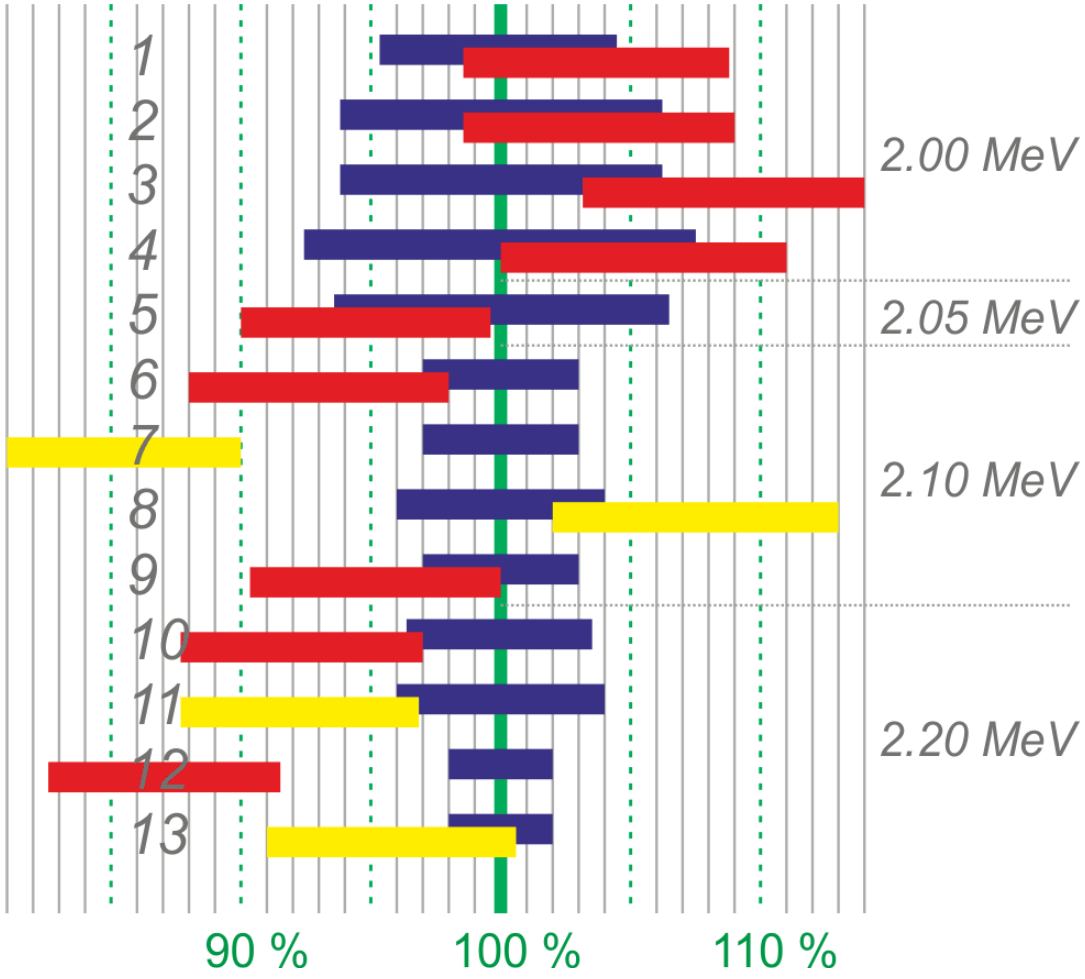
p + Li	$^{7}Li(p,n)^{7}Be$, $^{7}Li(p,p'\gamma)^{7}Li$, $^{7}Li(p,\alpha)^{4}He$	for BNCT
d + ^{6}Li	$^{6}Li(d,\alpha)^{4}He$, $^{6}Li(d,p)^{7}Li$, $^{6}Li(d,p)^{7}Li^{*}$,	powerful source
d + ^{7}Li	$^{7}Li(d,\alpha)^{5}He$, $^{7}Li(d,n\alpha)^{4}He$, $^{7}Li(d,n)^{8}Be$	of fast neutrons
p + ^{11}B	$^{11}B(p,\alpha_0)^{8}Be$, $^{11}B(p,\alpha_1)^{8}Be^{*}$	3-α – neutron-free fusion
d + B	$^{10}B(d,\alpha)^{8}Be$, $^{10}B(d,p)^{11}B$, $^{11}B(d,\alpha)^{9}Be$, $^{11}B(d,p)^{12}B$	?



- High purity germanium γ-ray spectrometer SEG-1KP-IPTP 12 (Institute of Physical and Technical Problems, Dubna, Russia)
- α-spectrometer with silicon semiconductor detector PDPA-1K (Institute of Physical and Technical Problems, Dubna, Russia)
- Fast neutron radiometer with diamond detectors RBN-A1-001-AD-01 and B68 (ITER Project Center, Troitsk, Russia)

$^{7}Li(p,n)^{7}Be$

- Best reaction for BNCT is $^7Li(p,n)^7Be$
- There are calculated data on the neutron yield
- There were no measurements from lithium targets for BNCT



Neutron yield measured by ^7Be activation.

Result: The neutron yield from the developed lithium target, measured at proton energies from 2 to 2.2 MeV, agrees with the calculated one with an accuracy of 5%.

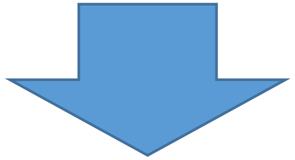
M. Bikchurina, *et al*. The measurement of the neutron yield of the $^7Li(p,n)^7Be$ reaction in lithium targets. Biology 10 (2021) 824.

$^{7}Li(p,p'\gamma)^{7}Li$

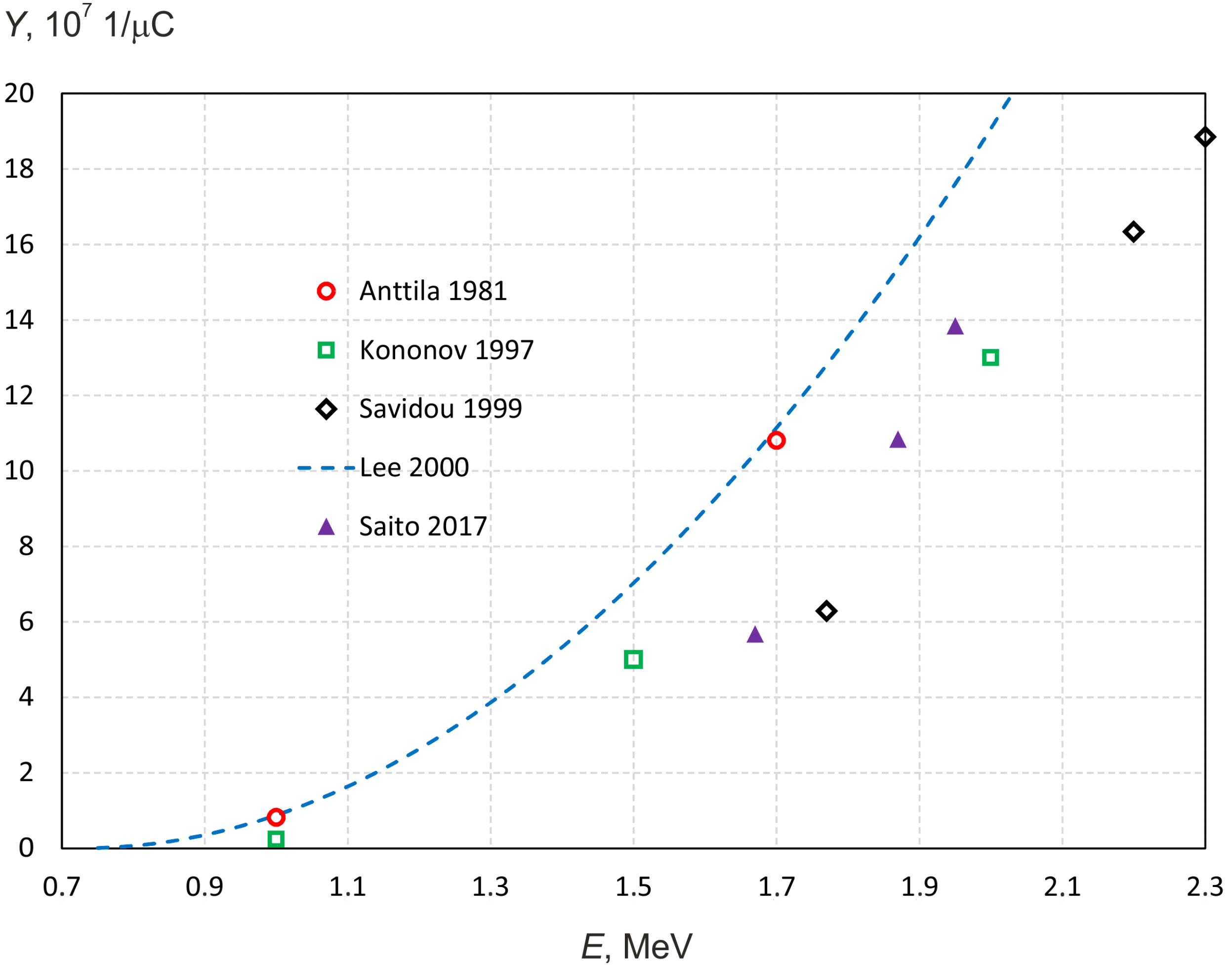
478 keV photon yield from thick lithium target

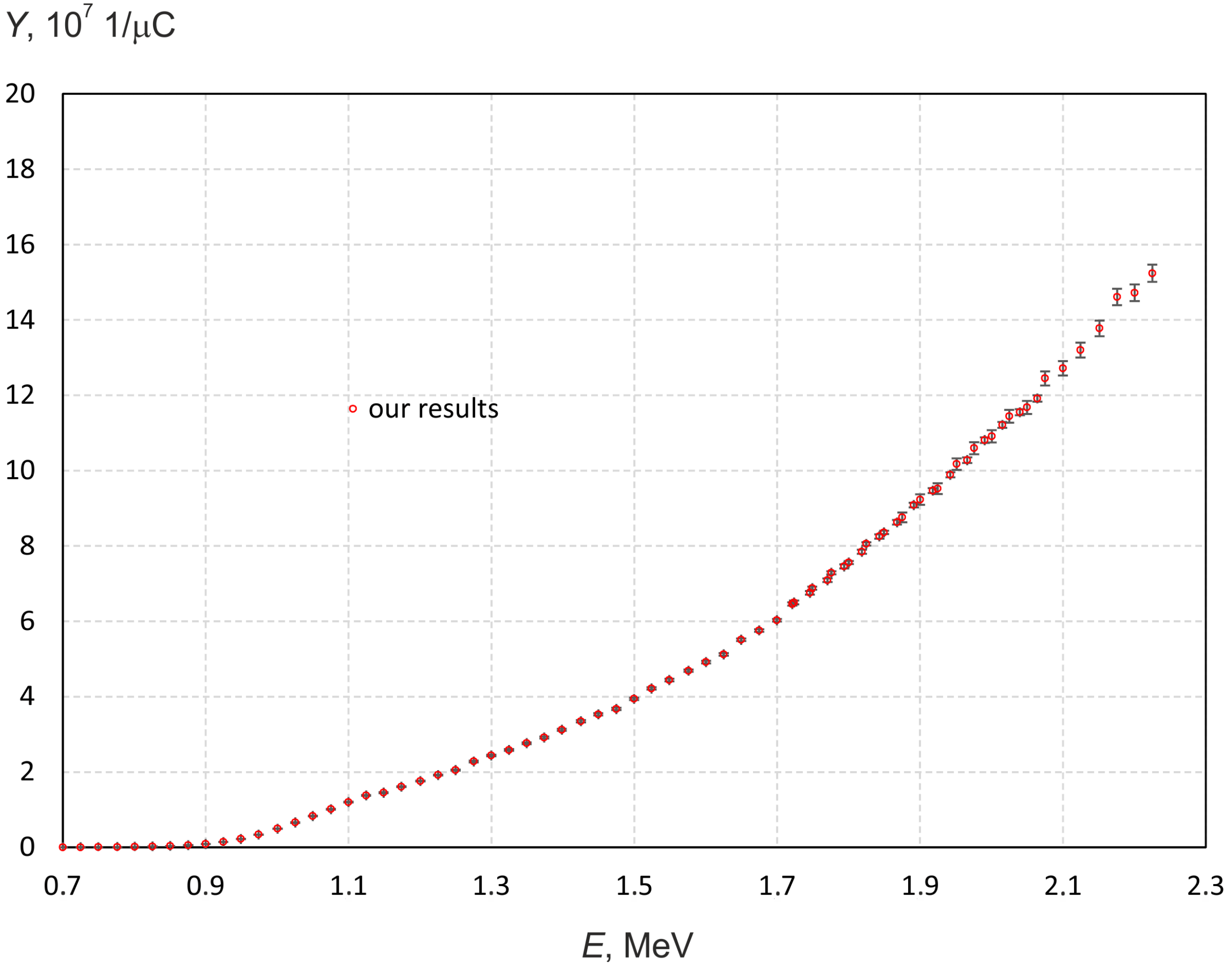
It is important for assessing the contribution to the γ-ray dose during BNCT

our result

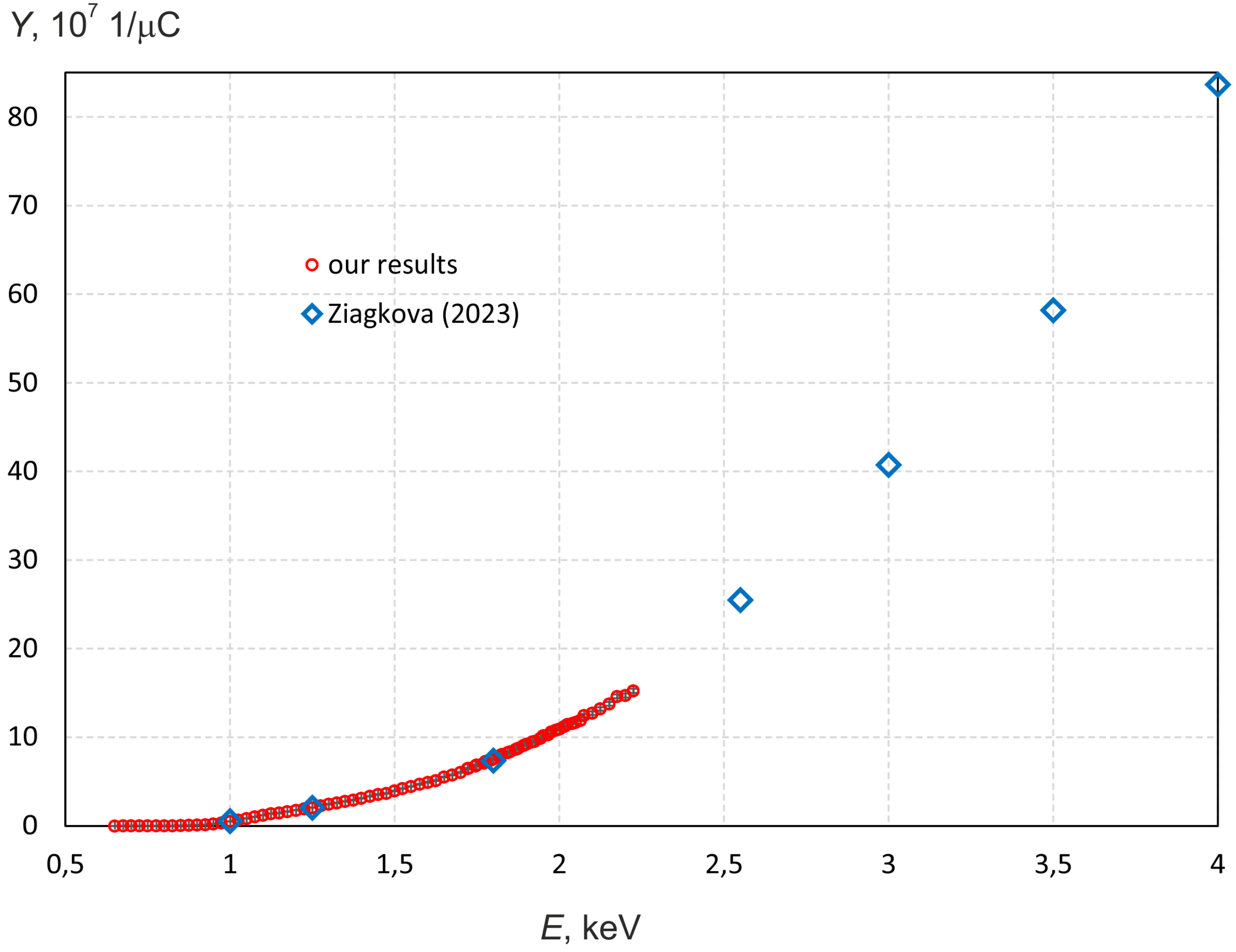


NIM B 502 (2021) 85
IBANDL
EXFOR





Our data is confirmed by the Greek group:
A. Ziagkova et al. NIM B 539 (2023) 113-119



Cross-section of the ^{7}Li(p,p‘γ)^{7}Li reaction

our result NIM B 502 (2021) 85
IBANDL
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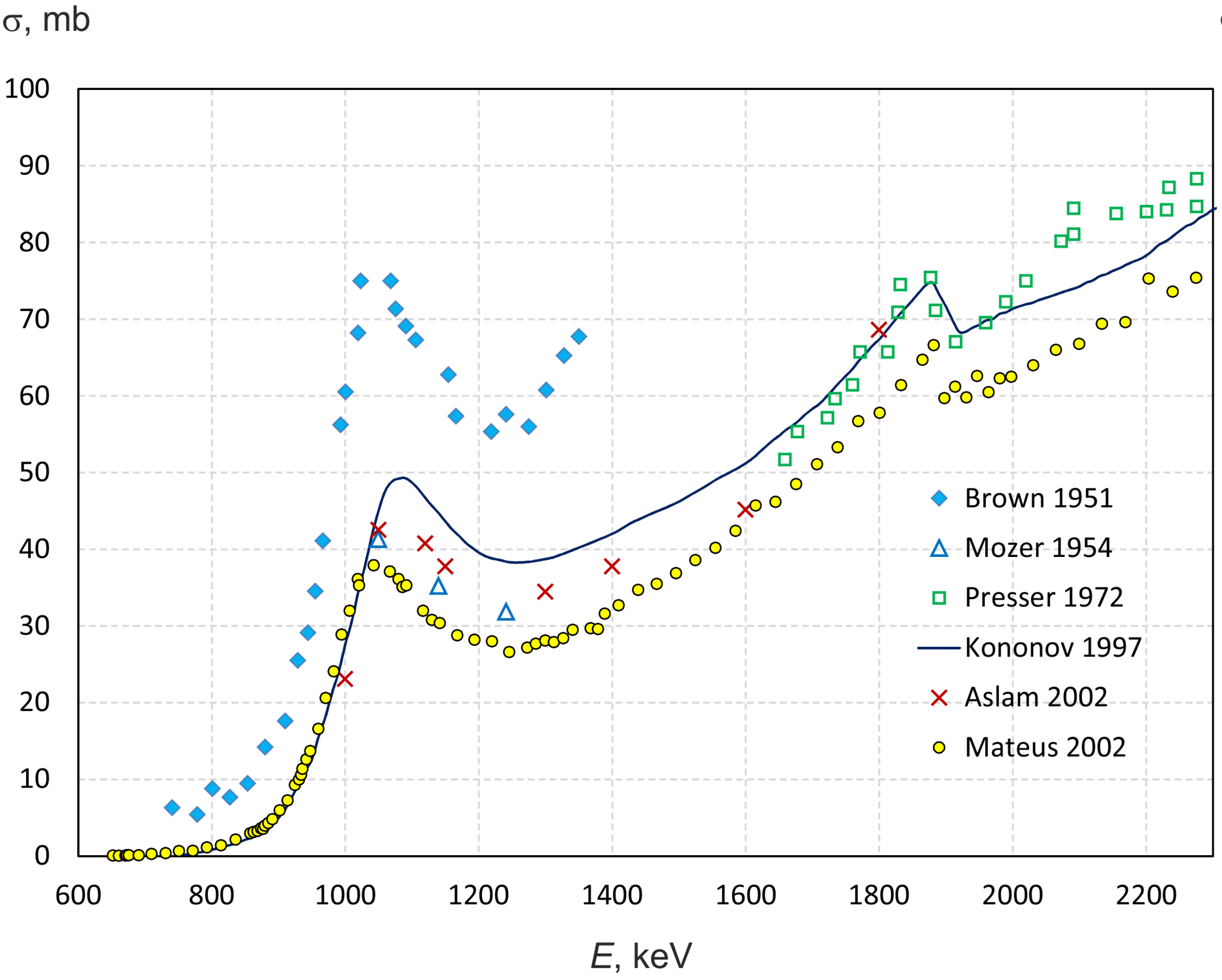

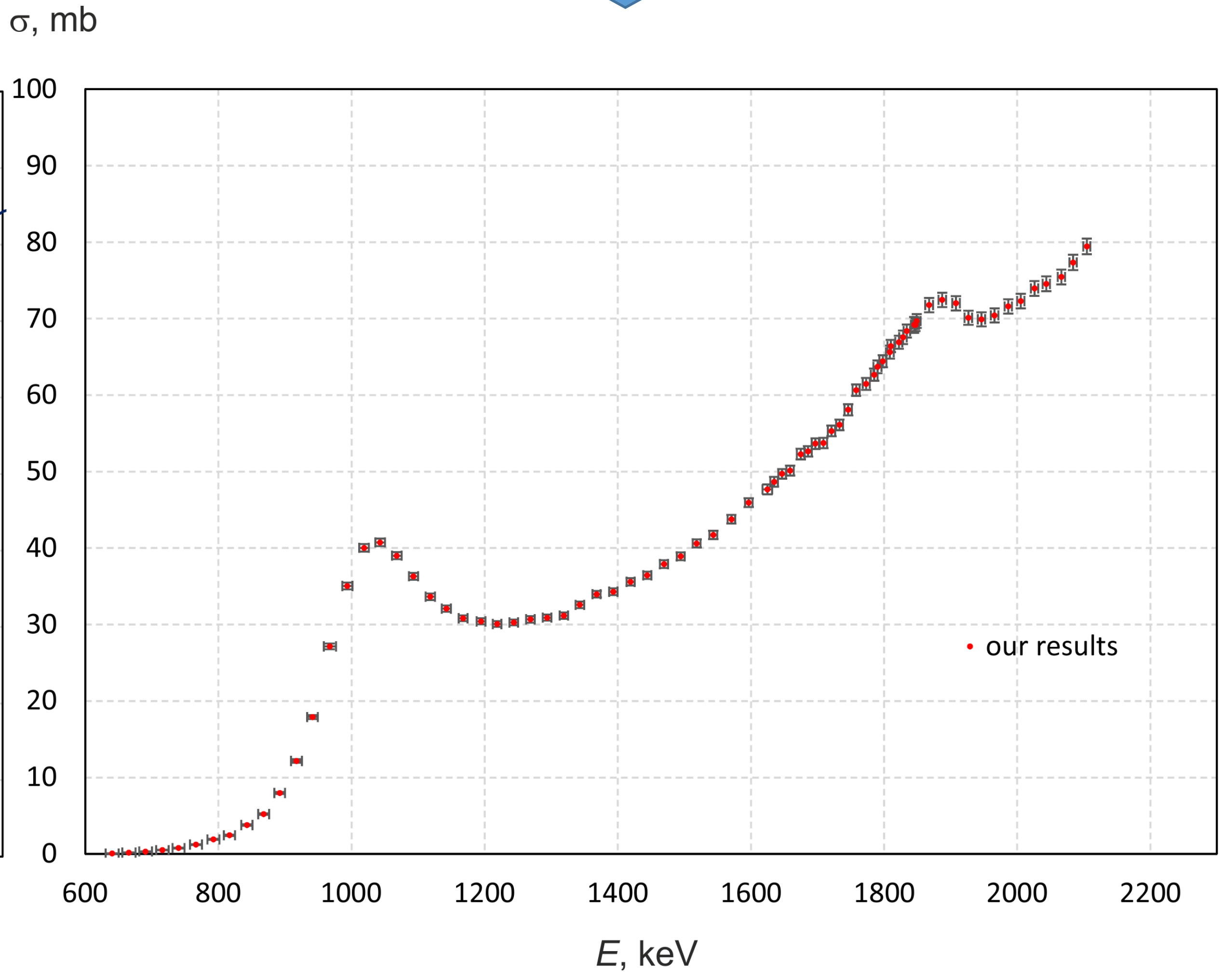

$^{7}Li(p,\alpha)^{4}He$

The cross section we measured is consistent with that given in JENDL and is 2 times larger than those given in ENDF/B and TENDL

our result

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IBANDL
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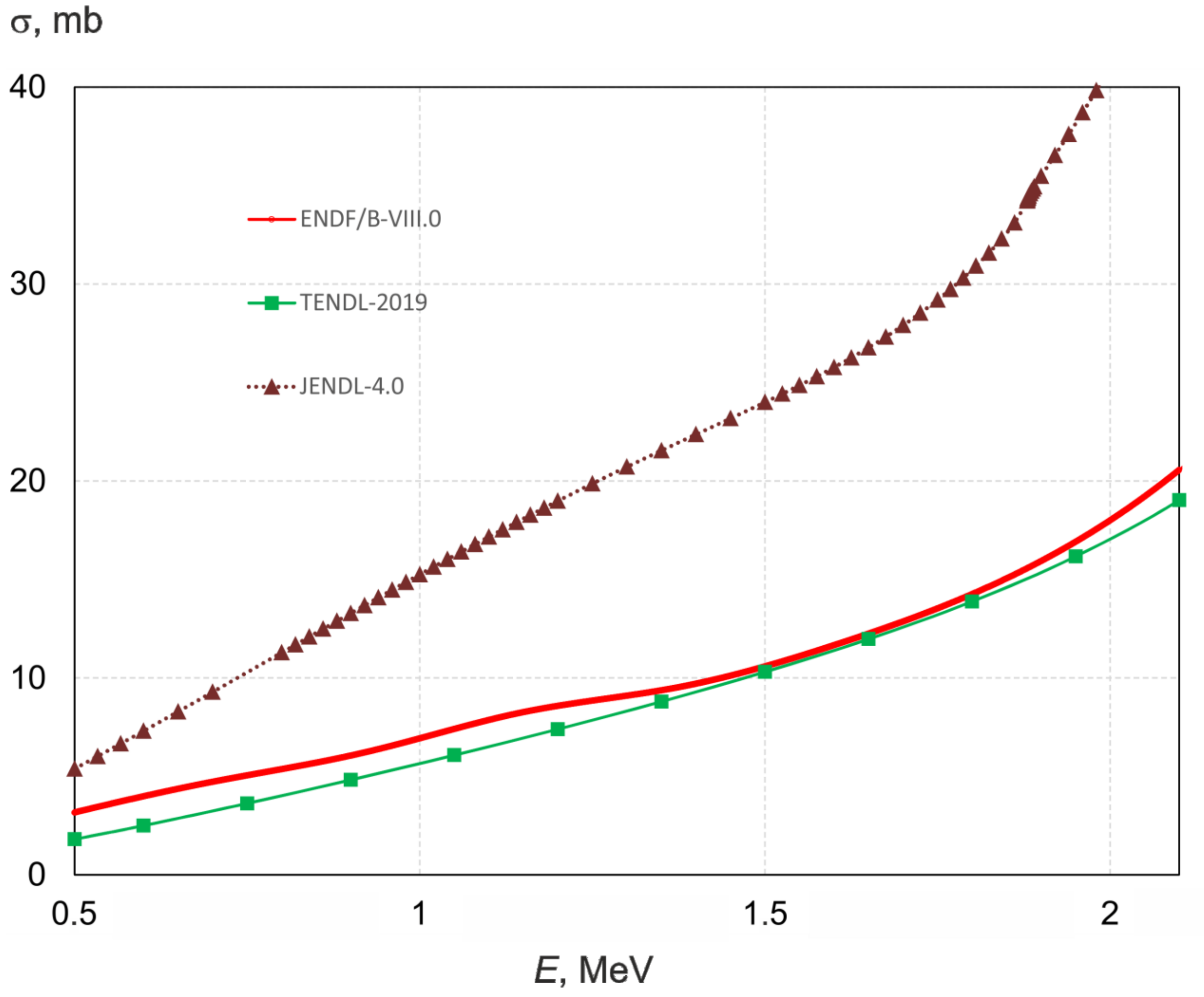
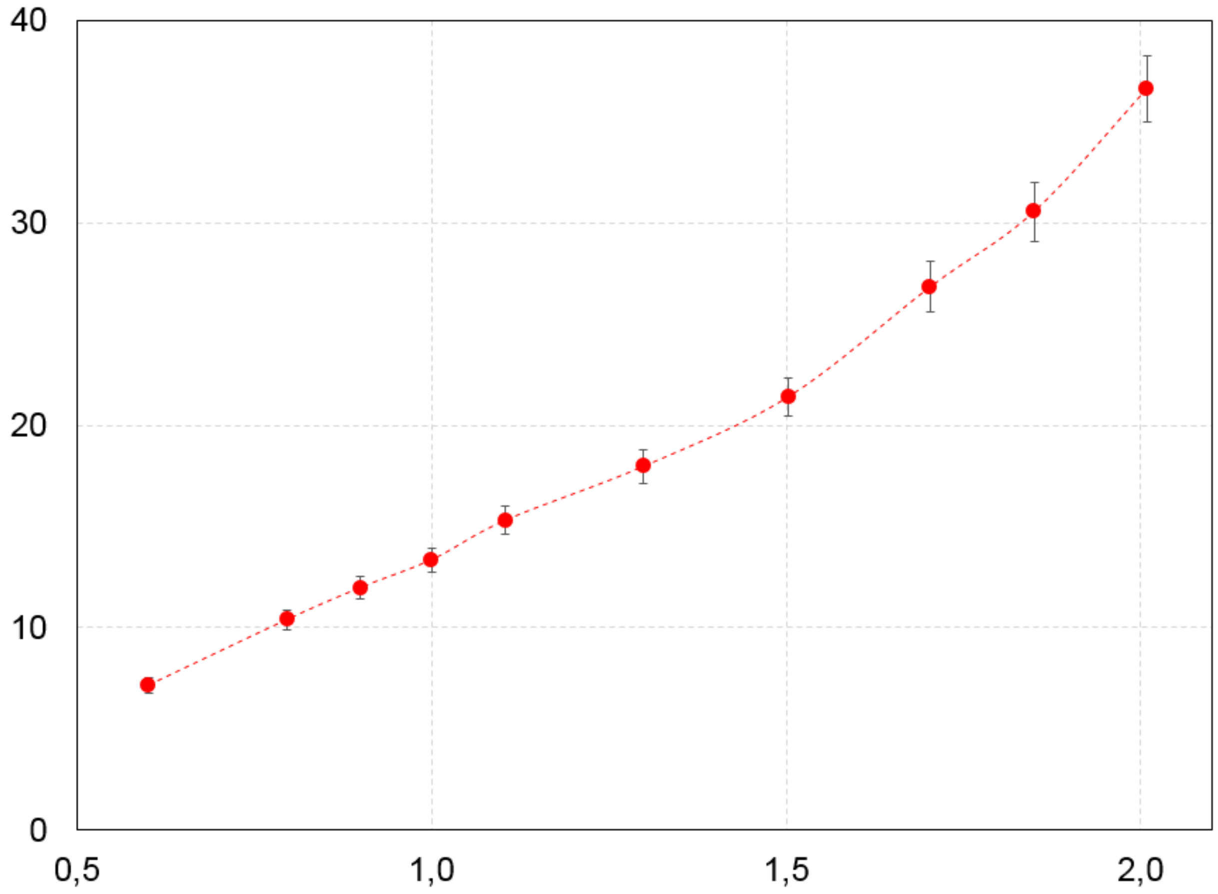
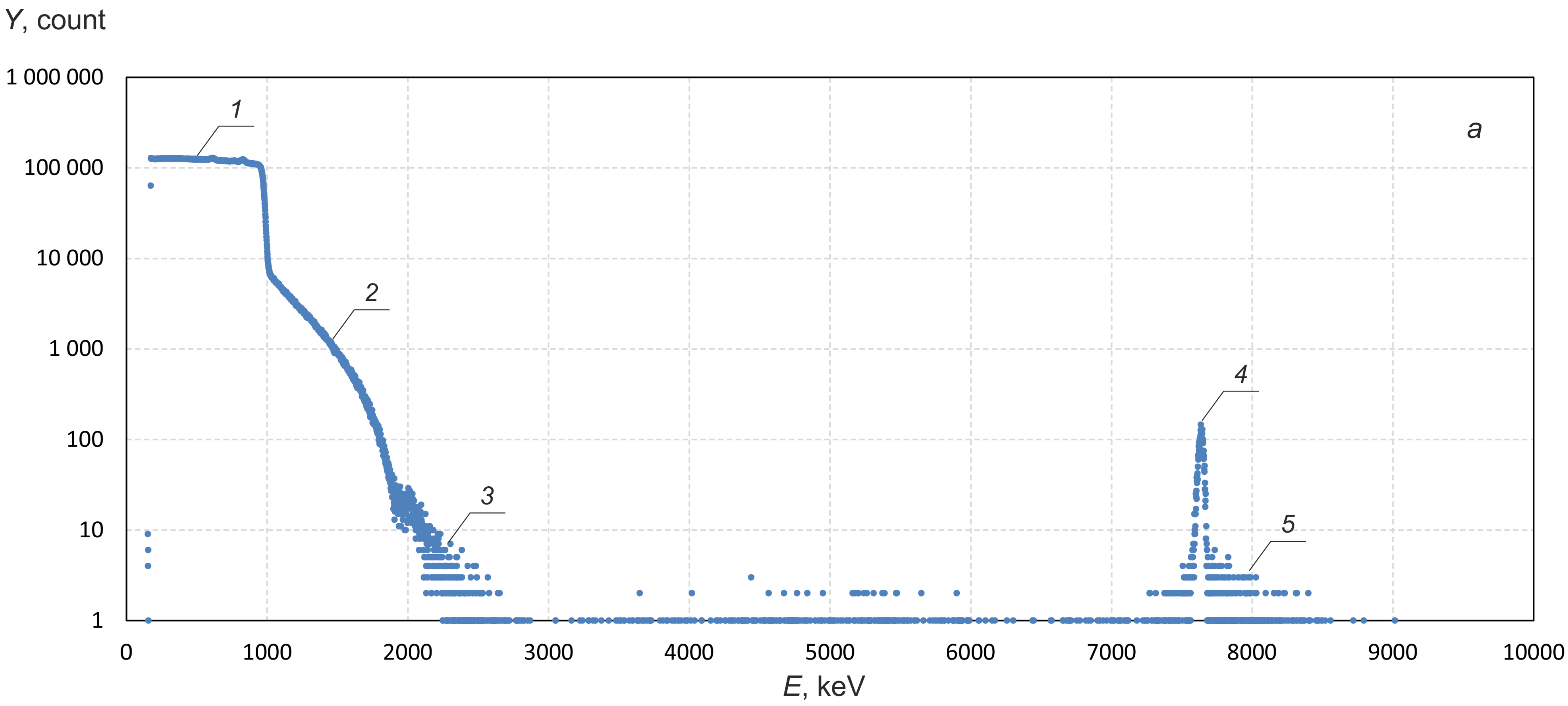




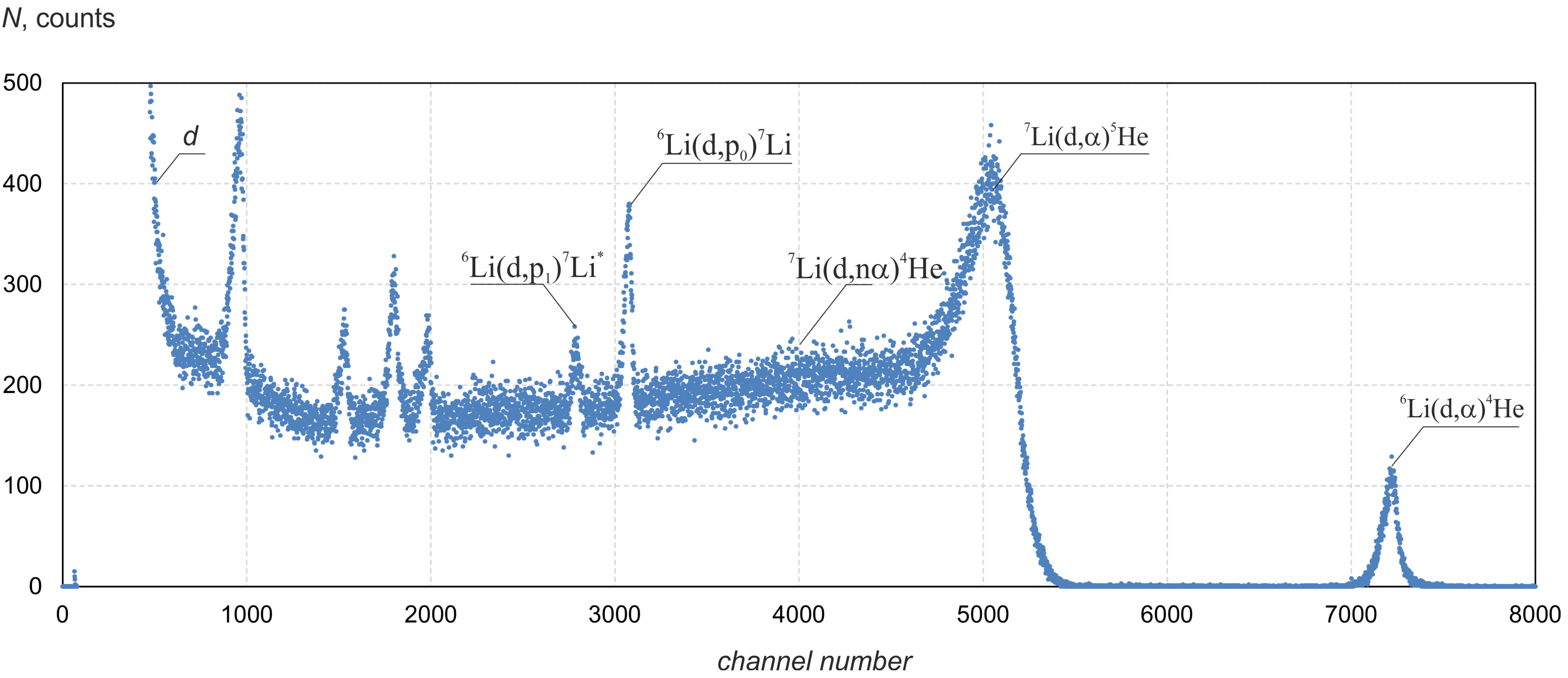
2-α reaction

Reliability – 6 methods for measuring lithium thickness!



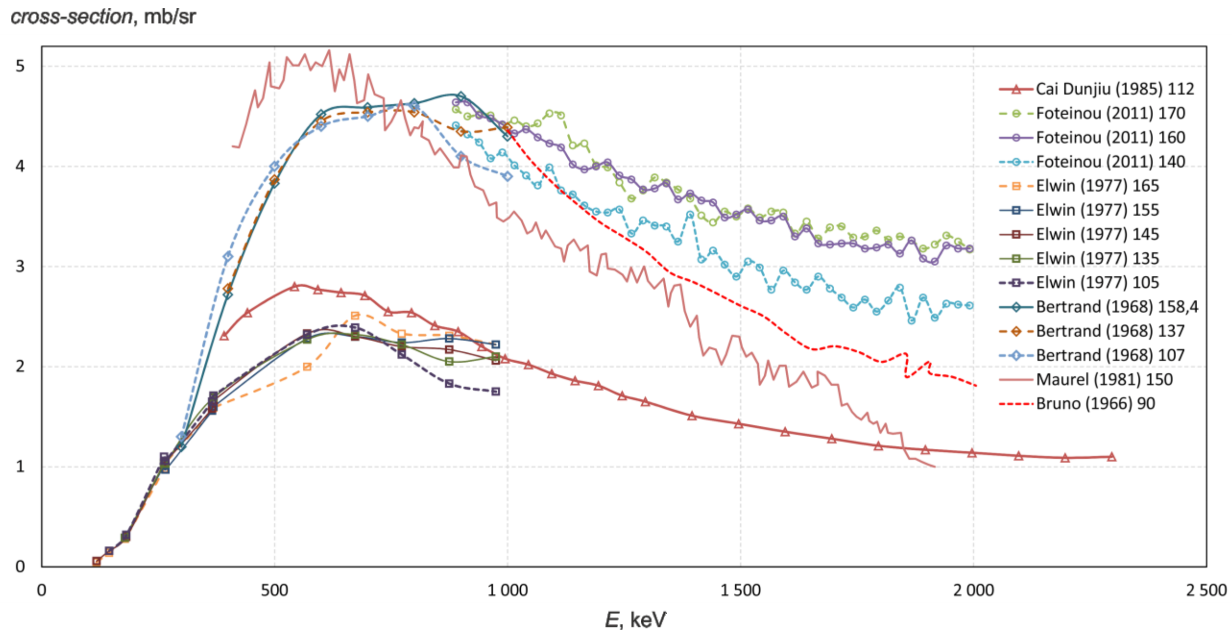
d + Li

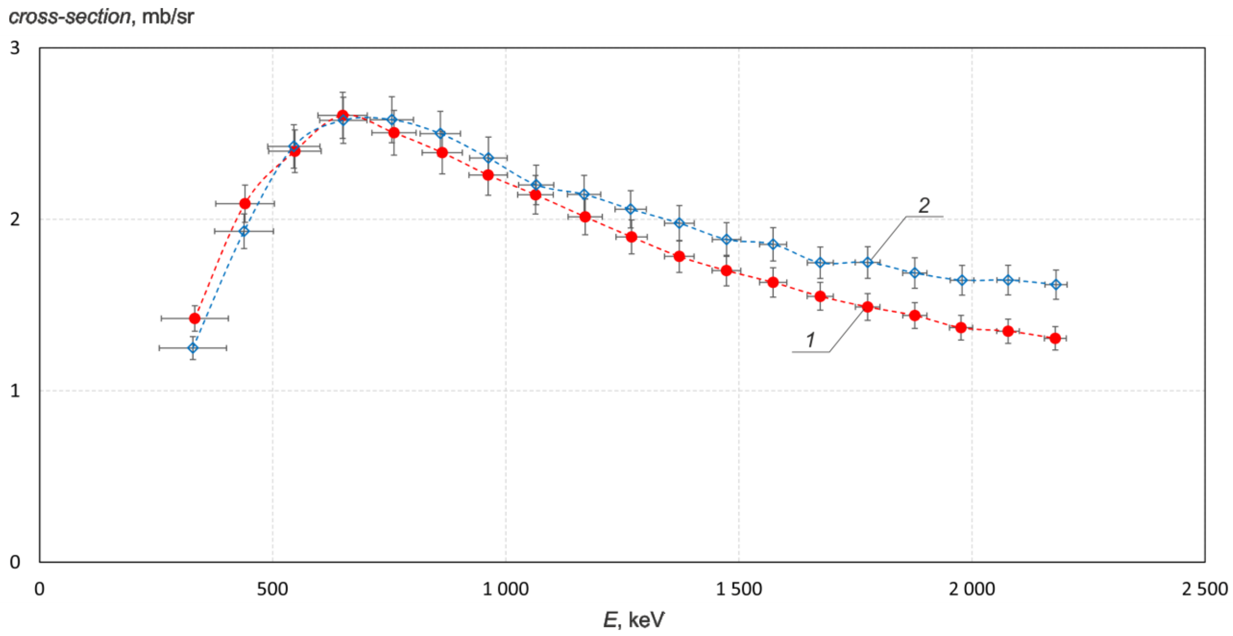
	Reaction	IBANDL dσ/dΩ	IBANDL σ	ENDF/B	TENDL	JENDL	our dσ/dΩ	our σ
1	$^{7}Li + d = n + {}^{8}Be + 15.028$ MeV $^{8}Be \rightarrow 2\,\alpha + 0.094$ MeV	-	-	-	-	-	☑	☑
2	$^{7}Li + d = n + \alpha + \alpha + 15.121$ MeV	-	-	-	-	-	☑	
3	$^{7}Li + d = \alpha + {}^{5}He + 14.162$ MeV $^{5}He \rightarrow n + \alpha + 0.957$ MeV	2	-	-	-	-	☑	☑
4	$^{6}Li + d = \alpha + \alpha + 22.38$ MeV	10	-	+	-	-	☑	☑
5	$^{6}Li + d = n + {}^{7}Be + 3.385$ MeV	-	-	-	-	-		
6	$^{6}Li + d = p + {}^{7}Li + 5.028$ MeV	4	-	+	-	-	☑	☑
7	$^{6}Li + d = p + {}^{7}Li^{*} + 4.550$ MeV	4	-	-	-	-	☑	☑
8	$^{6}Li + d = t + p + \alpha + 2.6$ MeV	-	-	-	-	-		
9	$^{6}Li + d = t + {}^{5}Li + 0.595$ MeV $^{5}Li \rightarrow \alpha + p + 1.965$ MeV	-	-	-	-	-		
10	$^{6}Li + d = {}^{3}He + {}^{5}He + 0.840$ MeV $^{5}He \rightarrow n + \alpha + 0.957$ MeV	-	-	-	-	-		

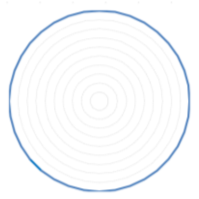

N, counts
500
400
300
200
100
0
0
1000
2000
3000
4000
5000
6000
7000
8000
channel number
d
^{6}Li(d,p$_1$)^{7}Li*
^{6}Li(d,p$_0$)^{7}Li
^{7}Li(d,nα)^{4}He
^{7}Li(d,α)^{5}He
^{6}Li(d,α)^{4}He

$^{6}Li(d,\alpha)\alpha$

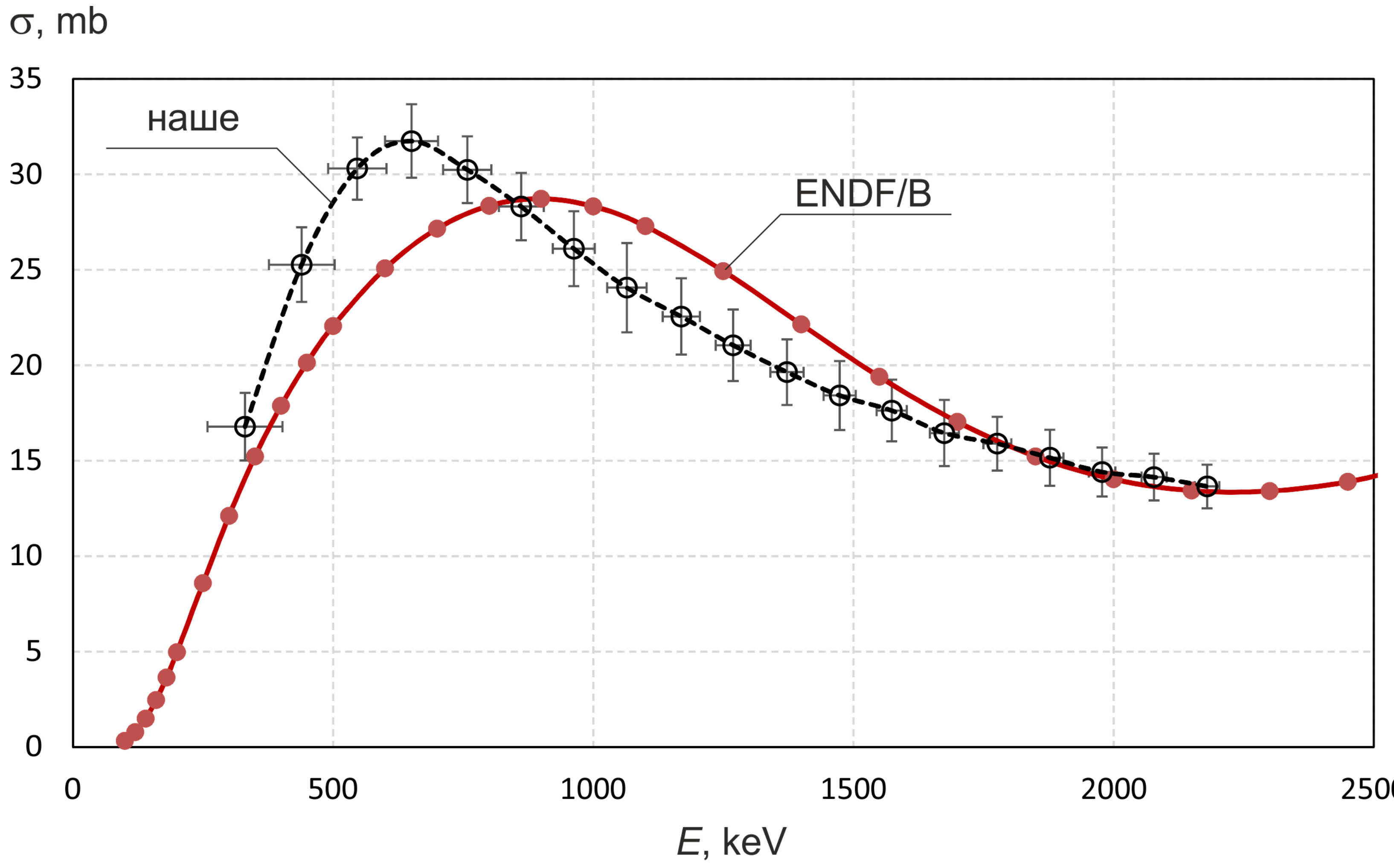
our result NIM B (2024)
sent in January







$^{6}Li(d,\alpha)\alpha$



$^{6}Li(d,p_0)^{7}Li$, $^{6}Li(d,p_1)^{7}Li^*$

our result NIM B (2024)
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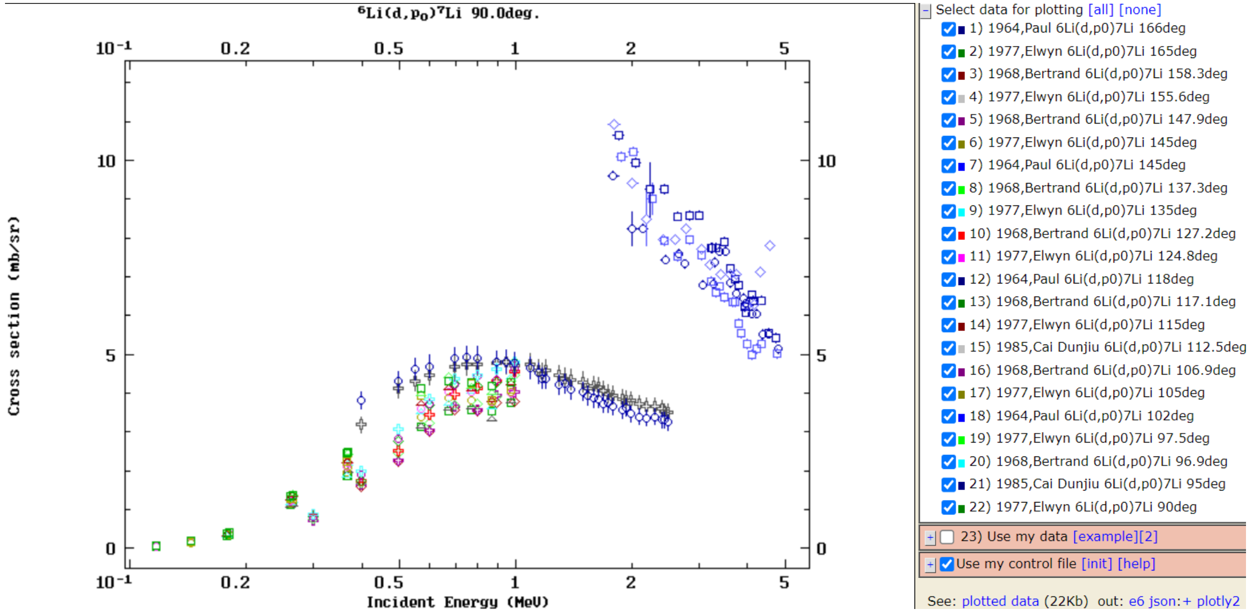
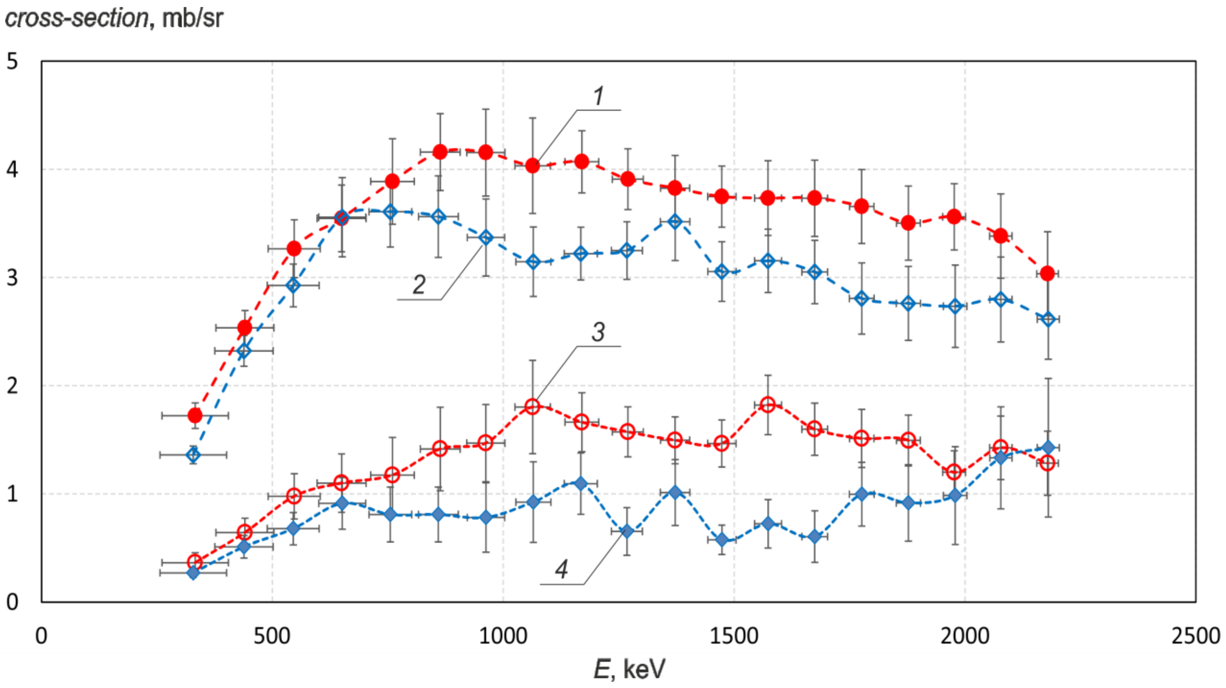
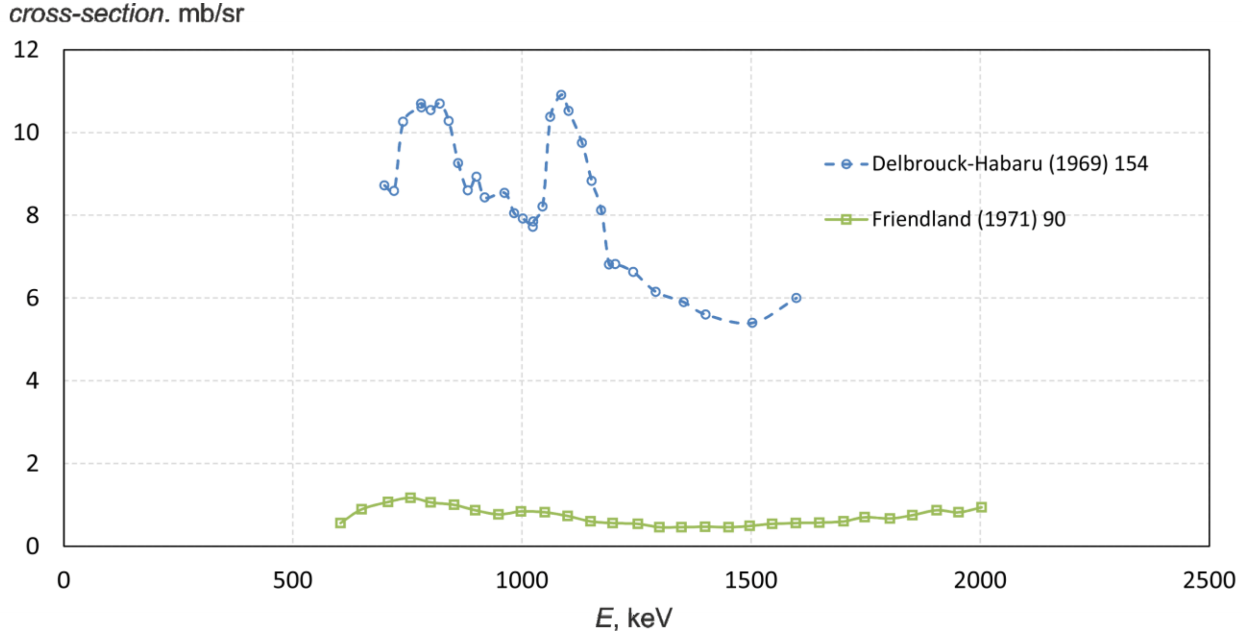
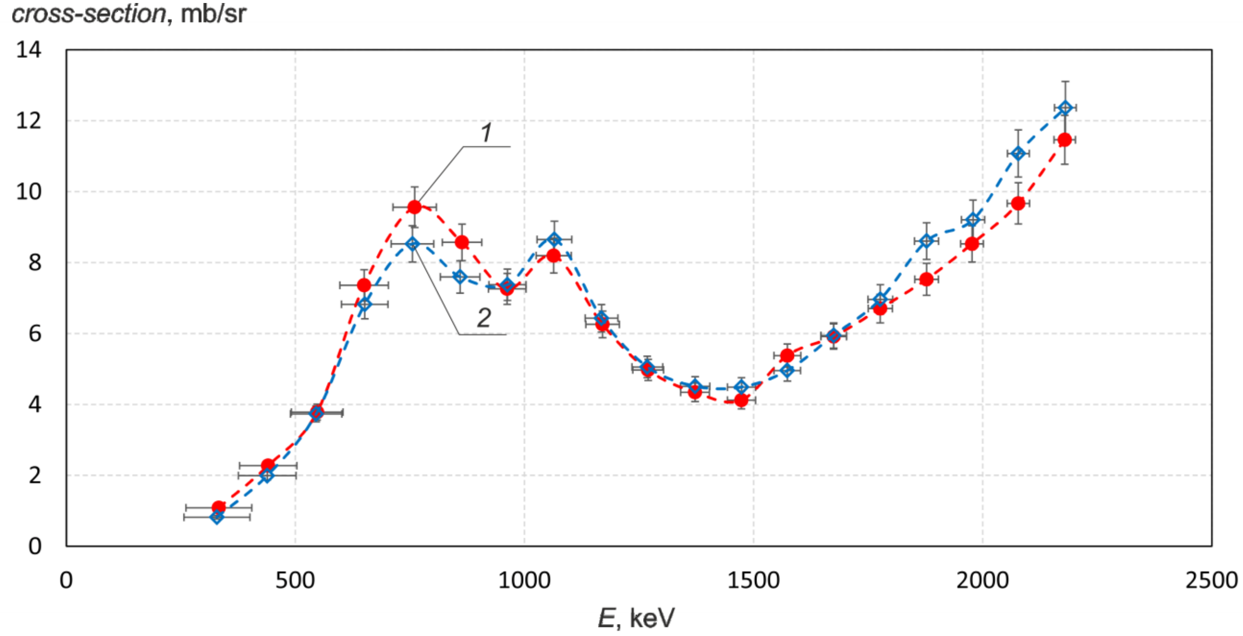




$^{7}Li(d,\alpha)^{5}He$

our result NIM B (2024)
sent in January

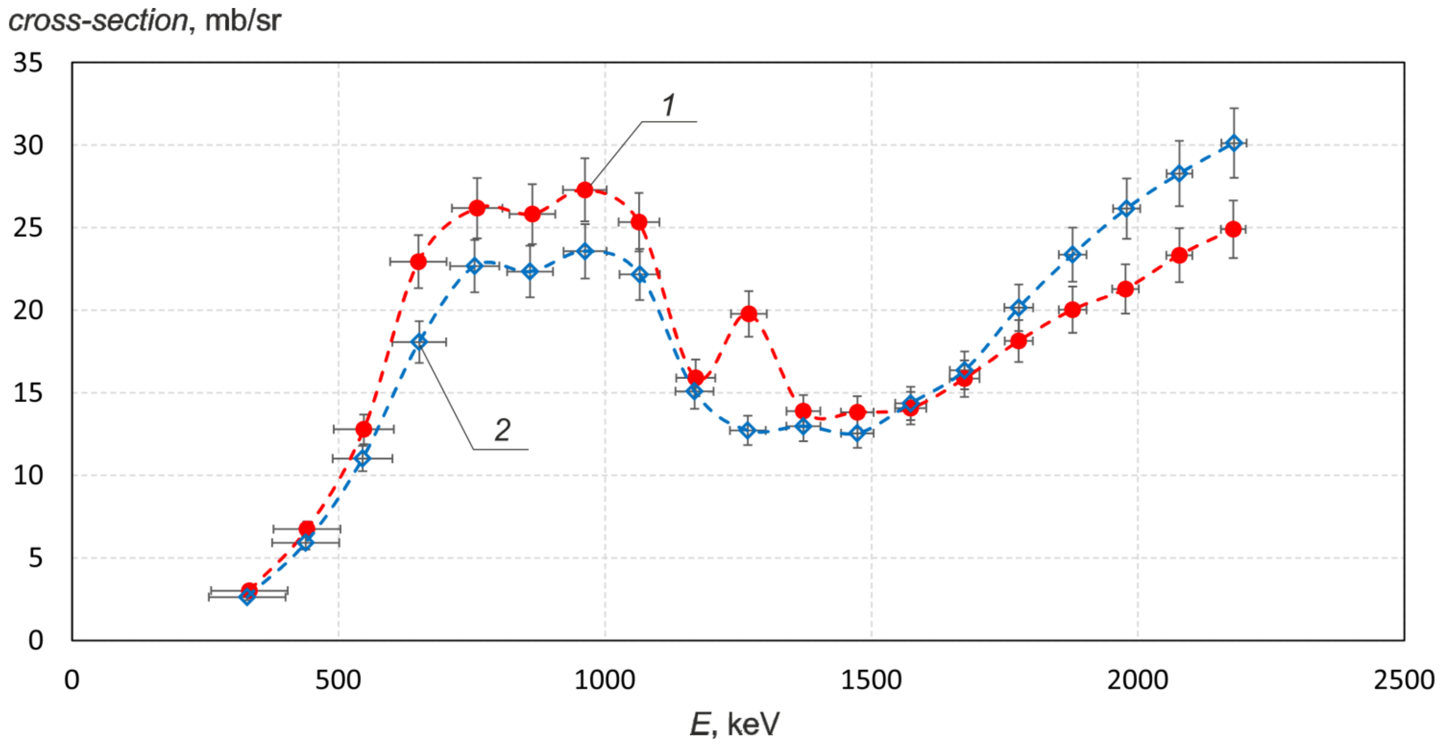




$^{7}Li(d,n\alpha)\alpha$

our result NIM B (2024)
sent in January

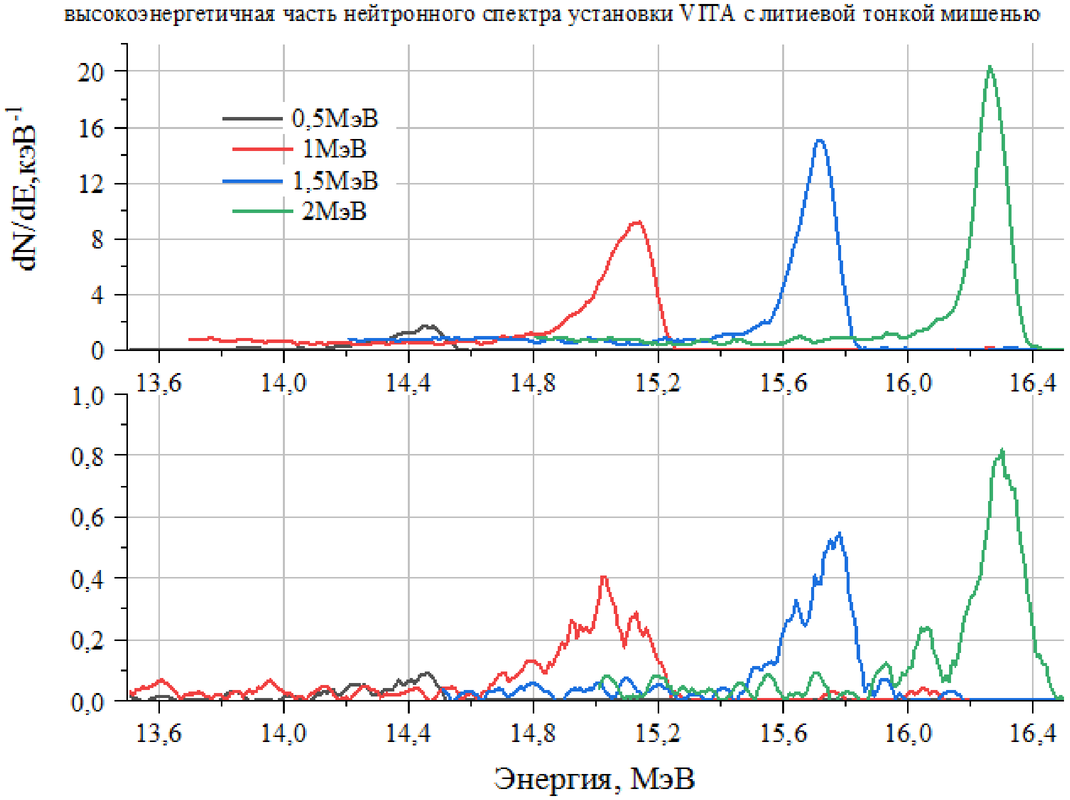
There are no data on the $^{7}Li(d,n\alpha)^{4}He$ reaction in the literature or databases

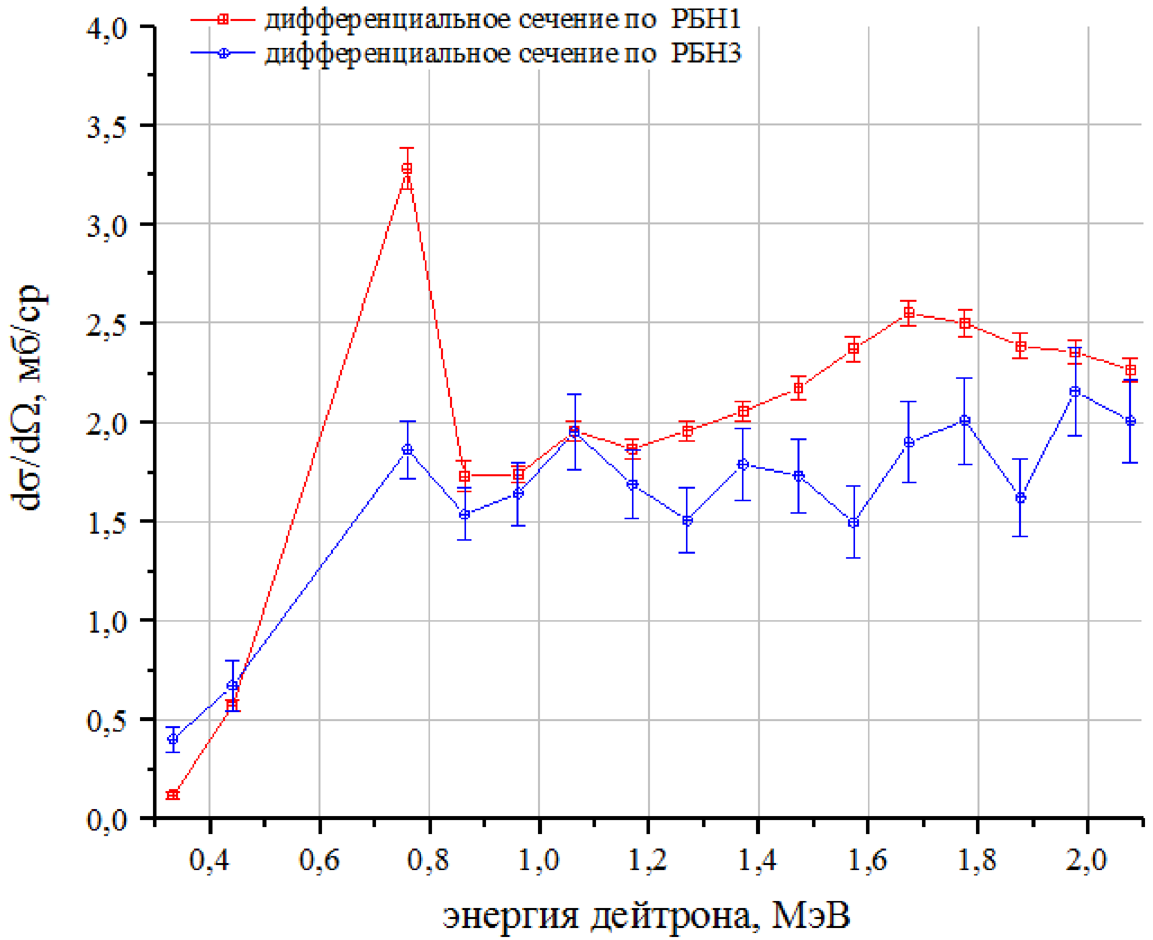


$^{7}Li(d,n)^{8}Be$

our result NIM B (2024) soon

There are no data on the $^{7}Li(d,n)^{8}Be$ reaction in the literature or databases





$$p + {}^{11}B$$

$$3\alpha$$

$${}^{11}B + p \rightarrow {}^{12}C \rightarrow \alpha + \alpha + \alpha + 8.681\ \text{MeV}$$

$${}^{11}B + p \rightarrow \alpha_0 + {}^{8}Be + 8.587\ \text{MeV}$$

$${}^{8}Be \rightarrow \alpha_{01} + \alpha_{02} + 0.094\ \text{MeV}$$

$${}^{11}B + p \rightarrow \alpha_1 + {}^{8}Be^{*} + 5.557\ \text{MeV}$$

$${}^{8}Be \rightarrow \alpha_{11} + \alpha_{12} + 3.124\ \text{MeV}$$

$${}^{10}B + p = \alpha + {}^{7}Be + 1.148\ \text{MeV}$$

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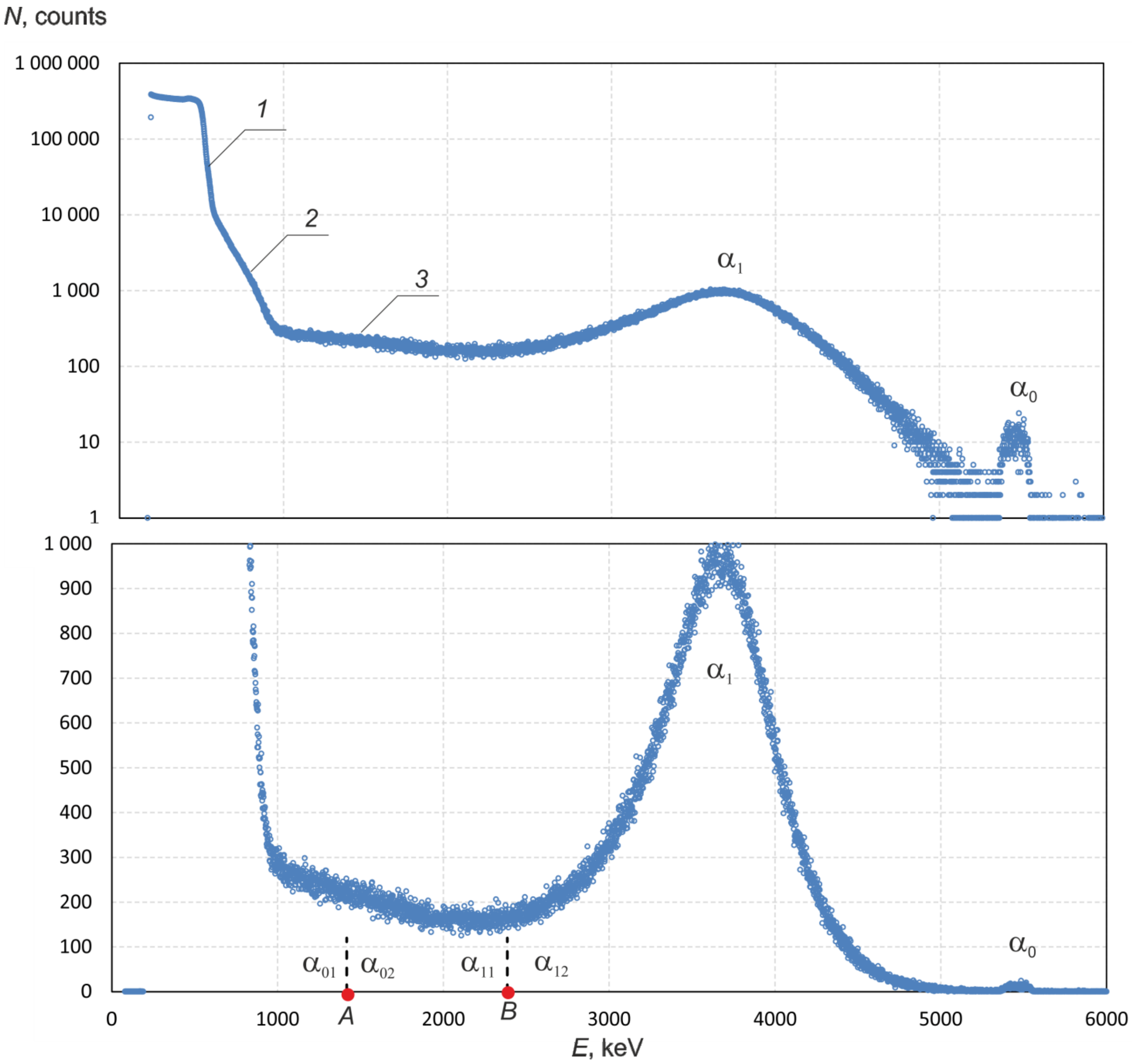
N, counts
1 000 000
100 000
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10
1
1
2
3
α1
α0
1 000
900
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700
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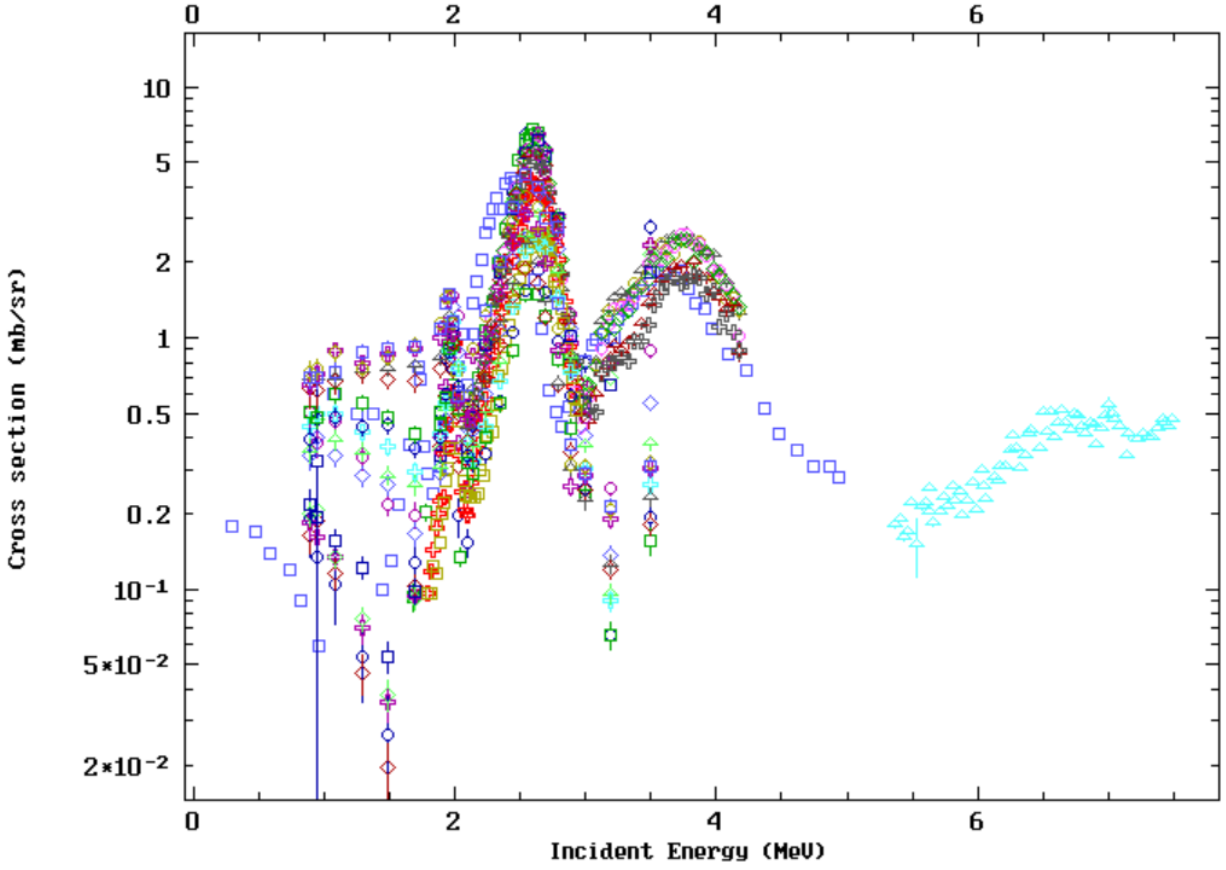
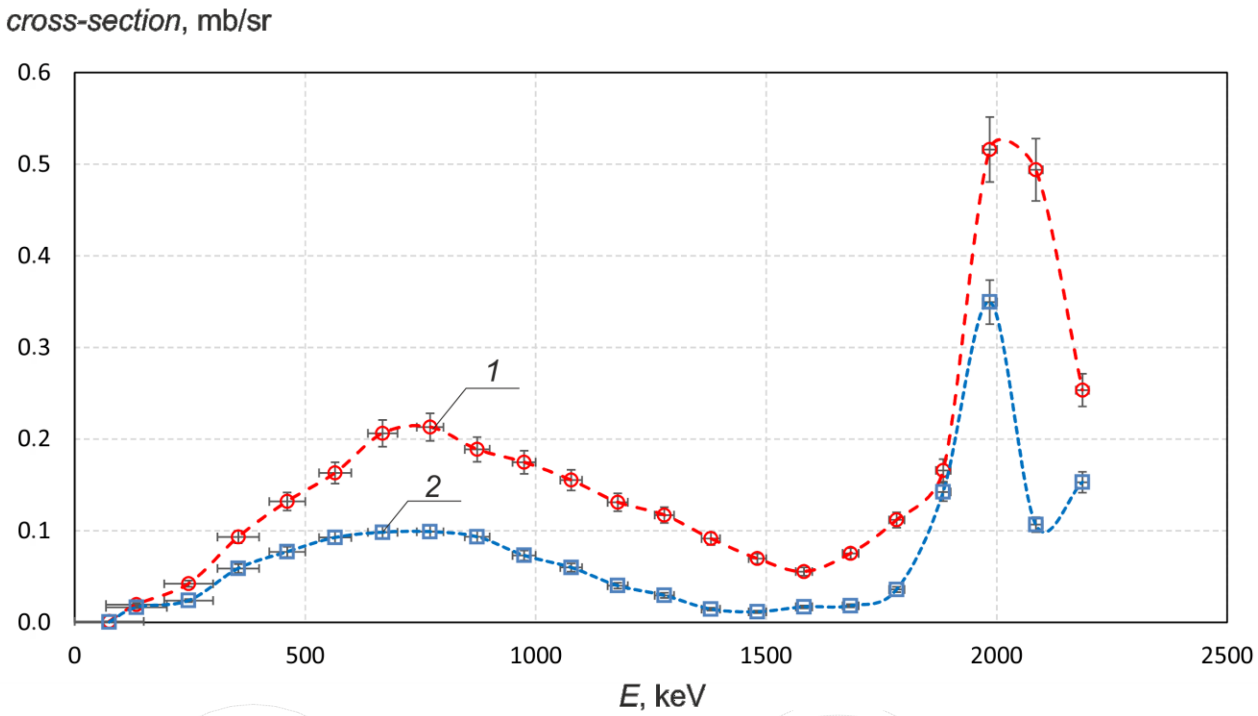
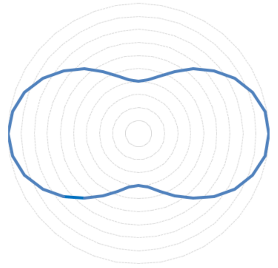
500
400
300
200
100
0
α01
α02
α11
α12
A
B
0
1000
2000
3000
4000
5000
6000
E, keV

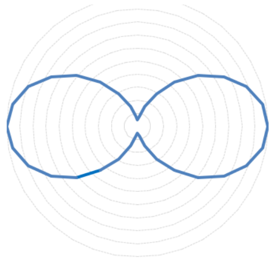
${}^{11}B(p,\alpha_0){}^{8}Be$

our result NIM B (2024)
sent in February



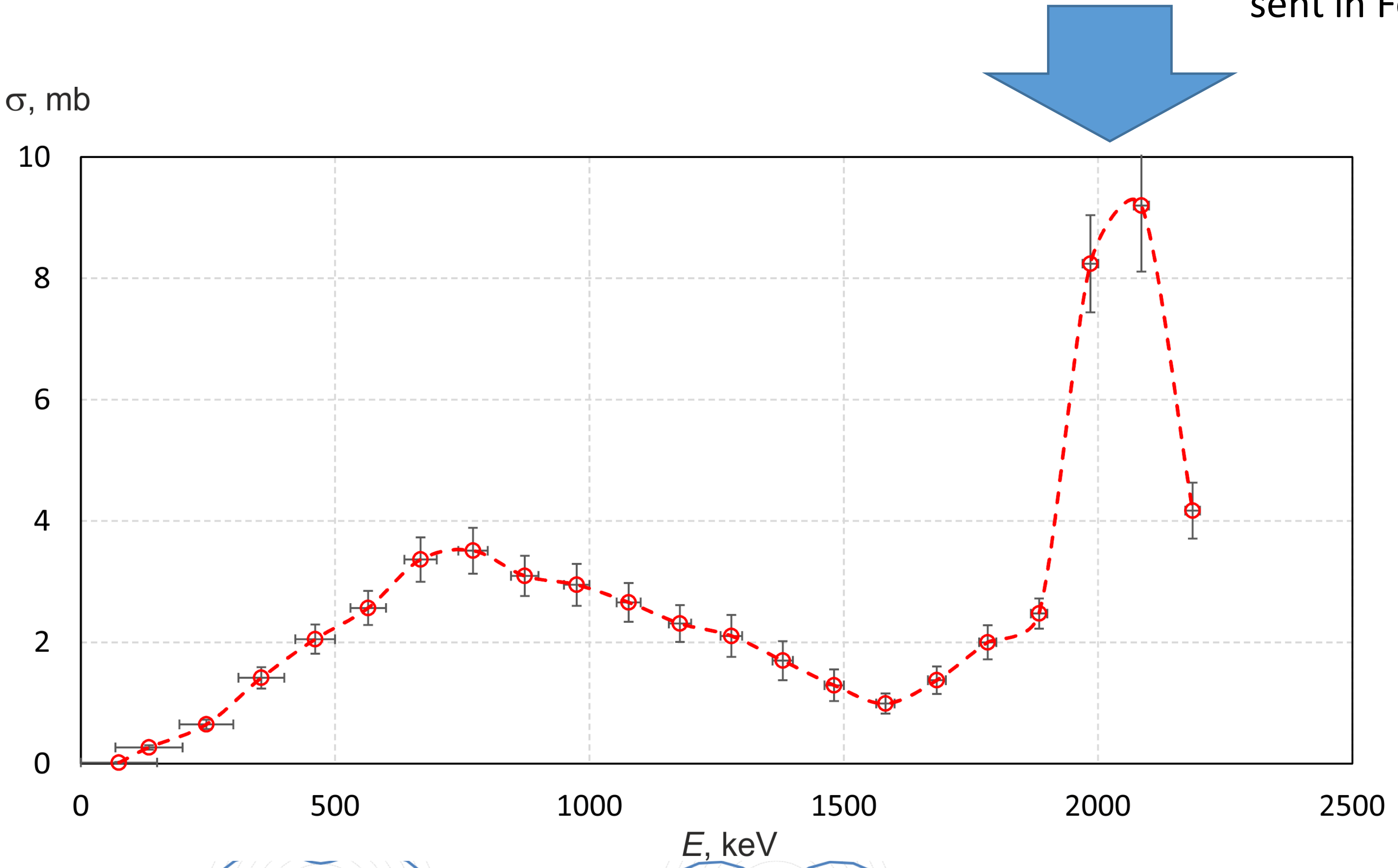


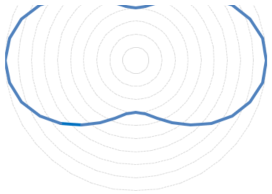


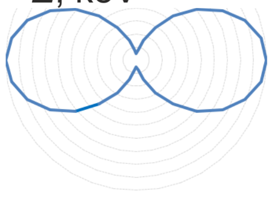


$^{11}B(p,\alpha_0)^8Be$

our result NIM B (2024) sent in February

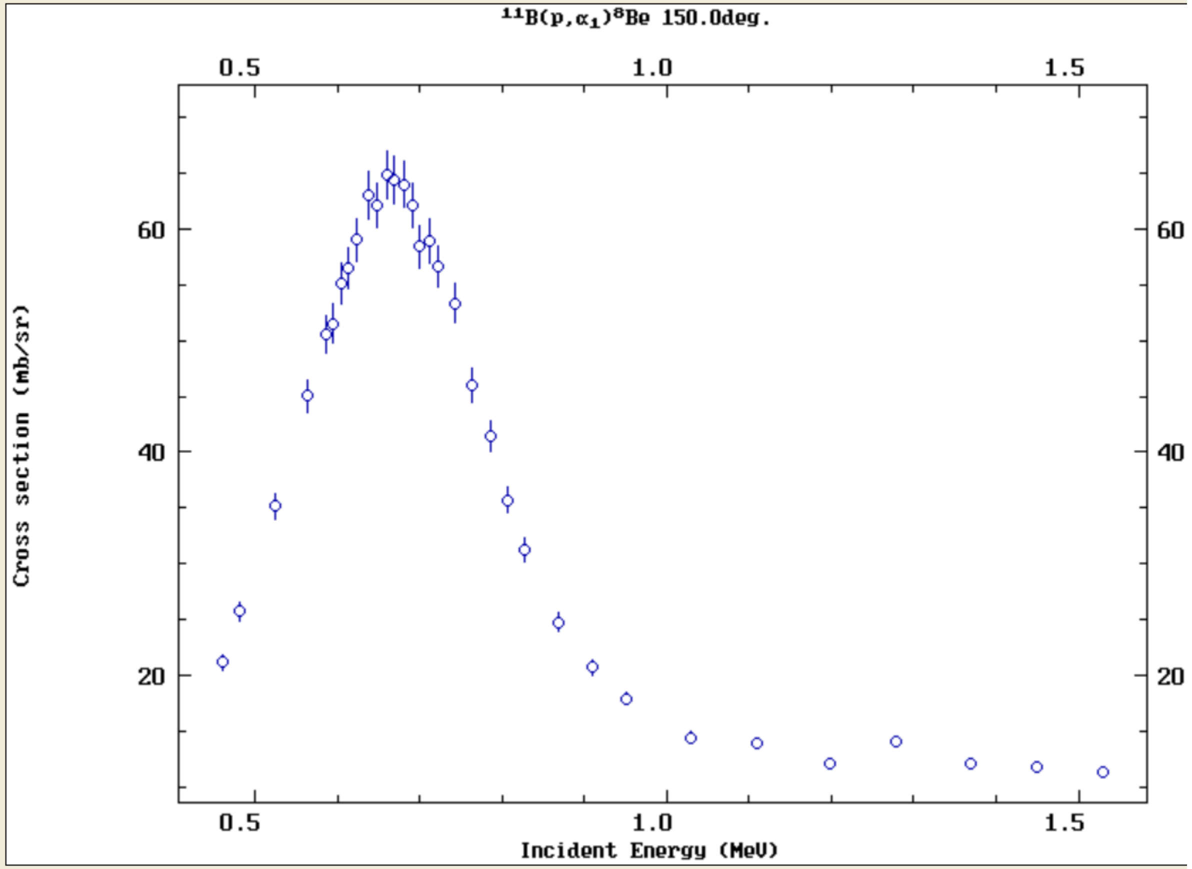






$^{11}B(p,\alpha_1)^8Be^*$

1) θ=150° E_1=0.5-1.5MeV Source: J.Liu+(2002), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.190, p.107



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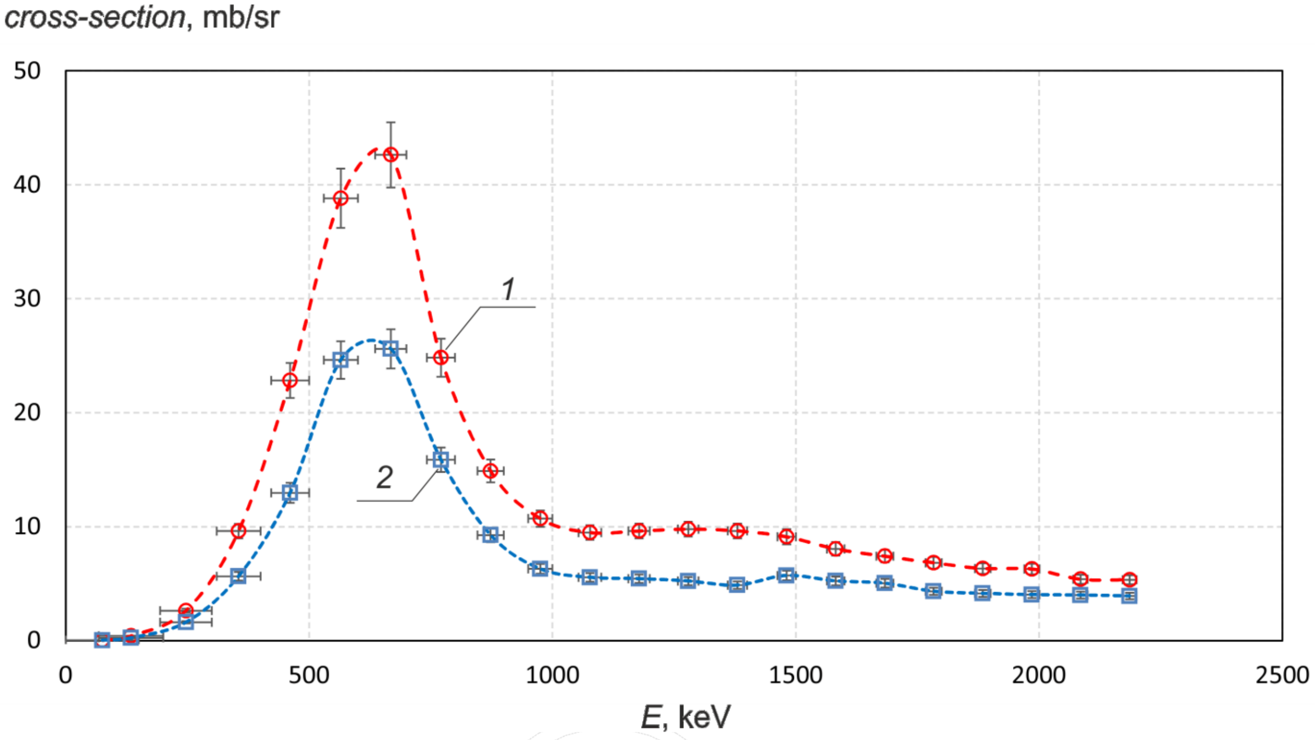

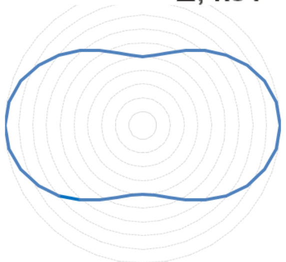

$^{11}B(p,\alpha_1)^8Be^*$

our result NIM B (2024)
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J Fusion Energ (2016) 35:538–543

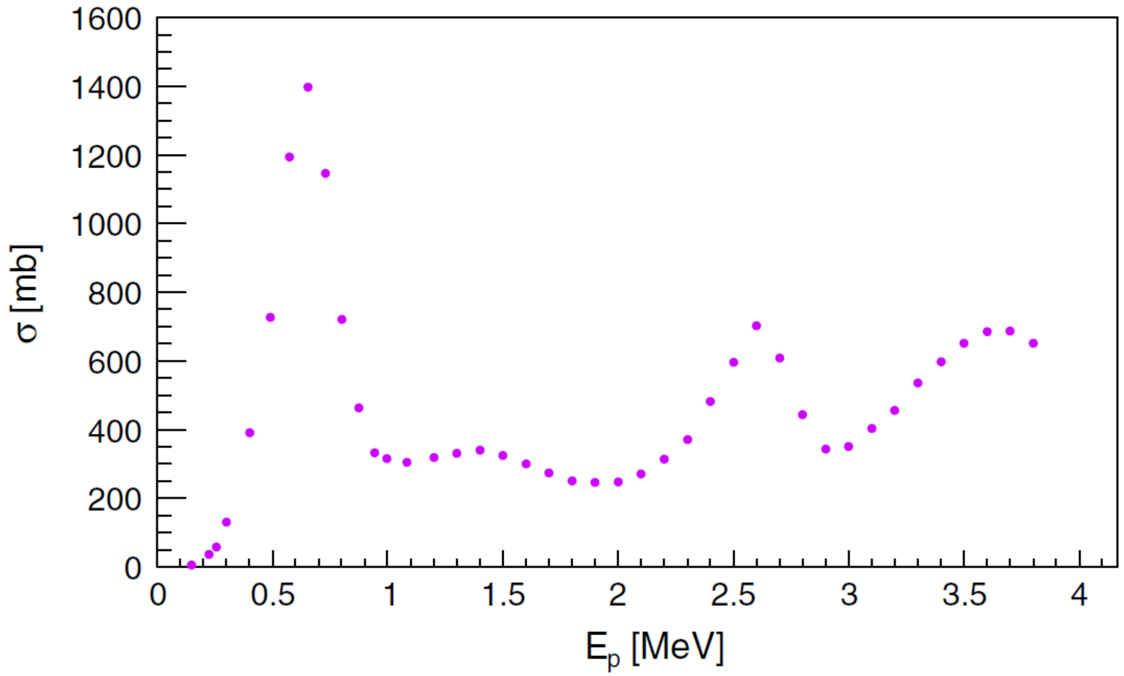
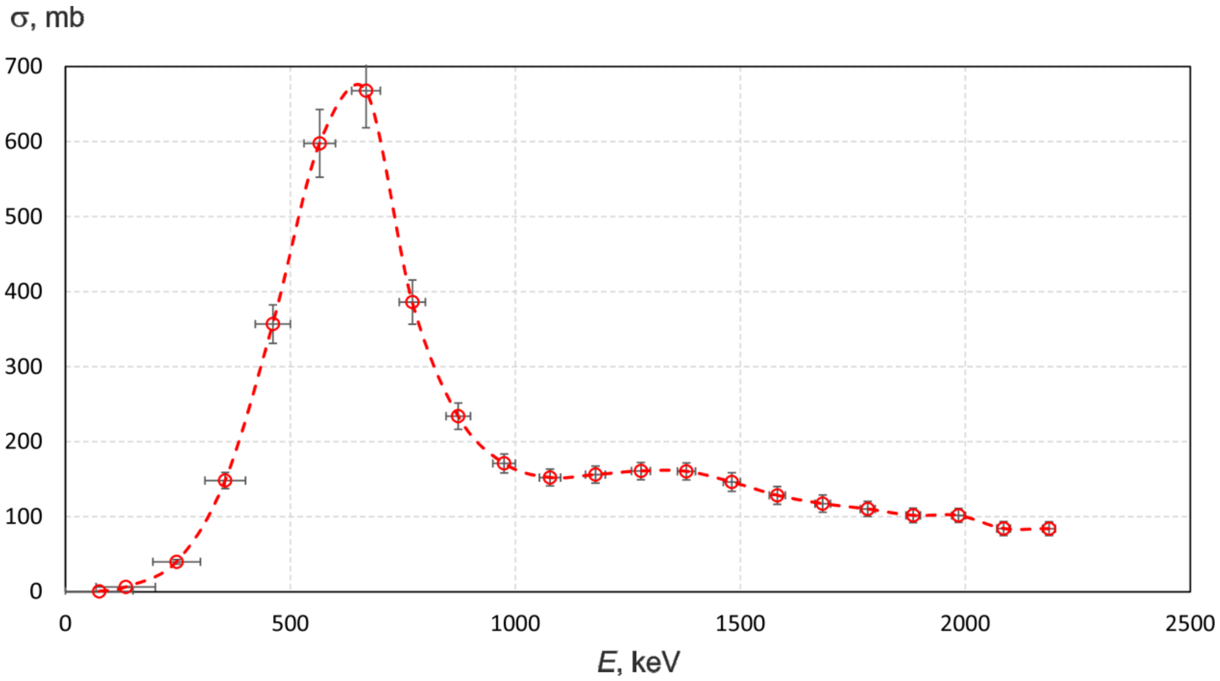
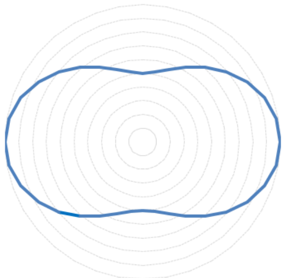


Fig. 4 The total cross section of the $^{11}B(p,\alpha)\alpha\alpha$ as a function of E_p. The *error bars* are smaller than the size of the points





d + B

$^{10}B(d,\alpha)^{8}Be$, $^{10}B(d,p)^{11}B$, $^{11}B(d,\alpha)^{9}Be$, $^{11}B(d,p)^{12}B$

We will submit the article to NIM B soon

The BINP proposed and created the accelerator based neutron source VITA, which is in demand for boron-neutron capture therapy, radiation testing of promising materials, etc.

A number of nuclear reaction parameters were measured at the accelerator based neutron source VITA

$^{7}Li(p,n)^{7}Be$, $^{7}Li(p,p'\gamma)^{7}Li$, $^{7}Li(p,\alpha)^{4}He$

$^{6}Li(d,\alpha)^{4}He$, $^{6}Li(d,p)^{7}Li$, $^{6}Li(d,p)^{7}Li^{*}$

$^{7}Li(d,\alpha)^{5}He$, $^{7}Li(d,n\alpha)^{4}He$, $^{7}Li(d,n)^{8}Be$

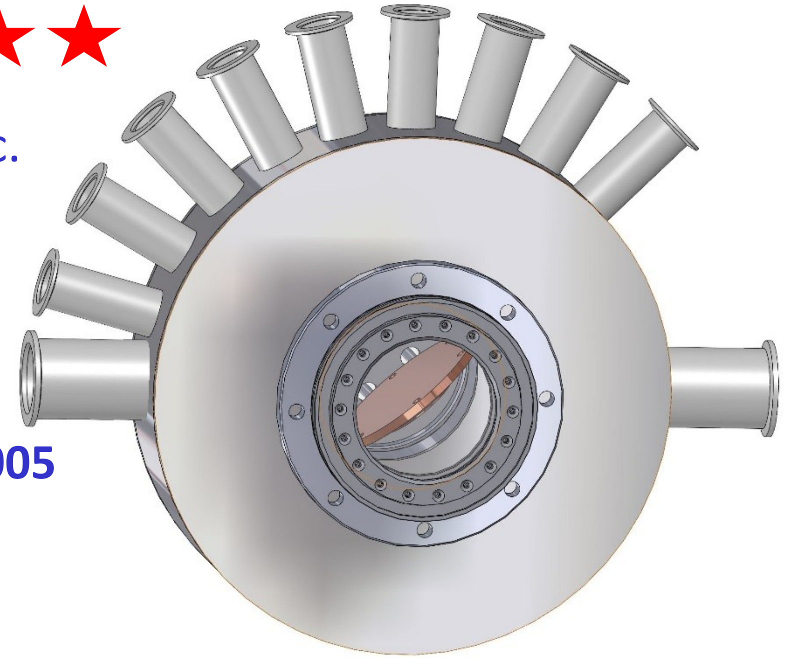
$^{11}B(p,\alpha_{0})^{8}Be$, $^{11}B(p,\alpha_{1})^{8}Be^{*}$

$^{10}B(d,\alpha)^{8}Be$, $^{10}B(d,p)^{11}B$, $^{11}B(d,\alpha)^{9}Be$, $^{11}B(d,p)^{12}B$

★★★★★★★★★★★★★★★

There are plans to measure the cross section of the $^{19}F(p,\alpha e^{+}e^{-})^{16}O$ reaction, etc.

We are open for cooperation.



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Thank you for your attention!