Measurements of nuclear reaction cross-sections at VITA

Sokolova Evgeniia

BINP

Novosibirsk State University
*THE REAL SCIENCE

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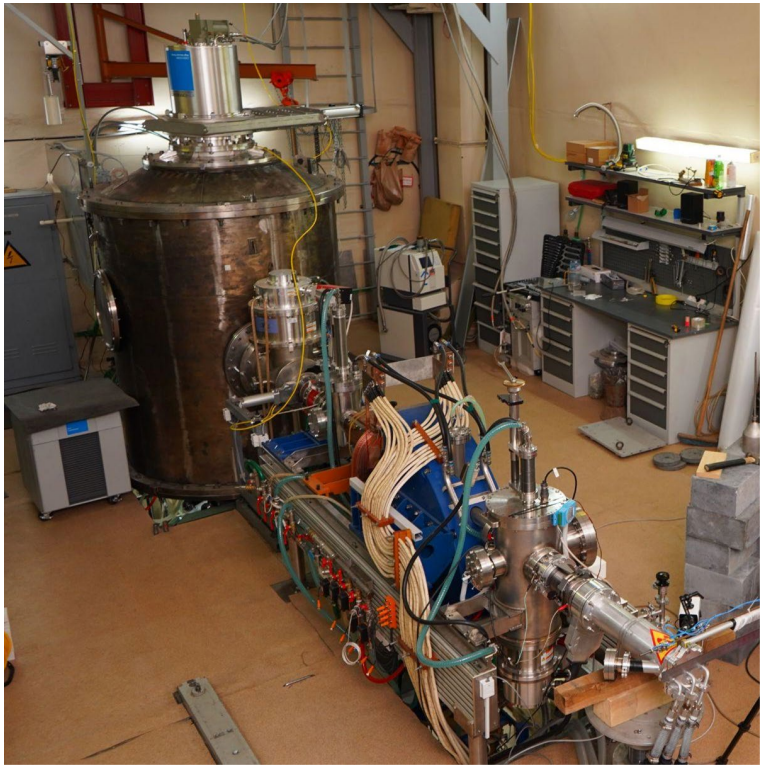
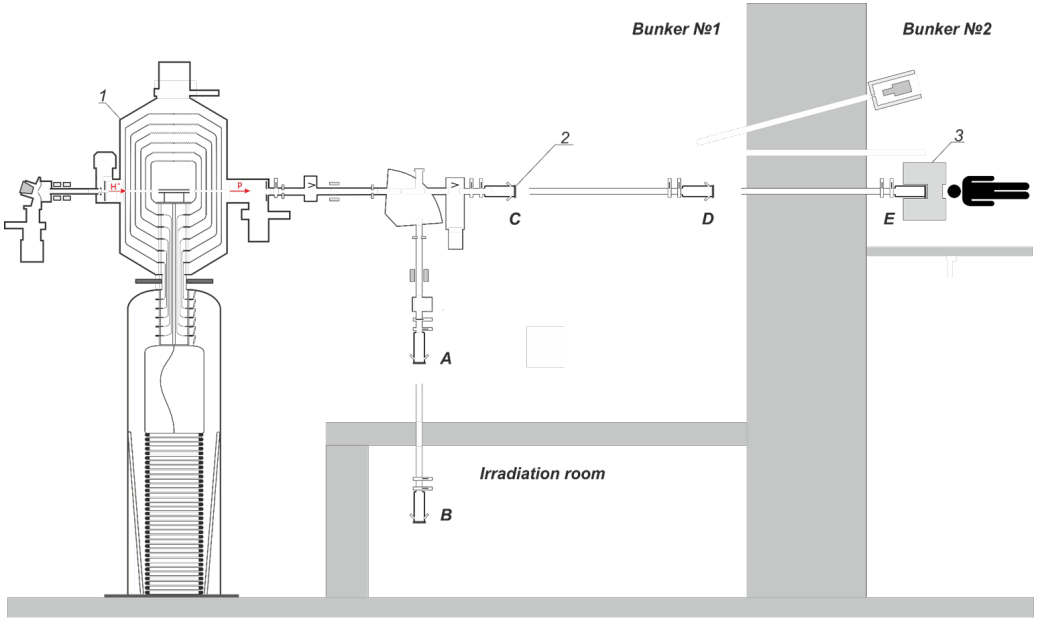
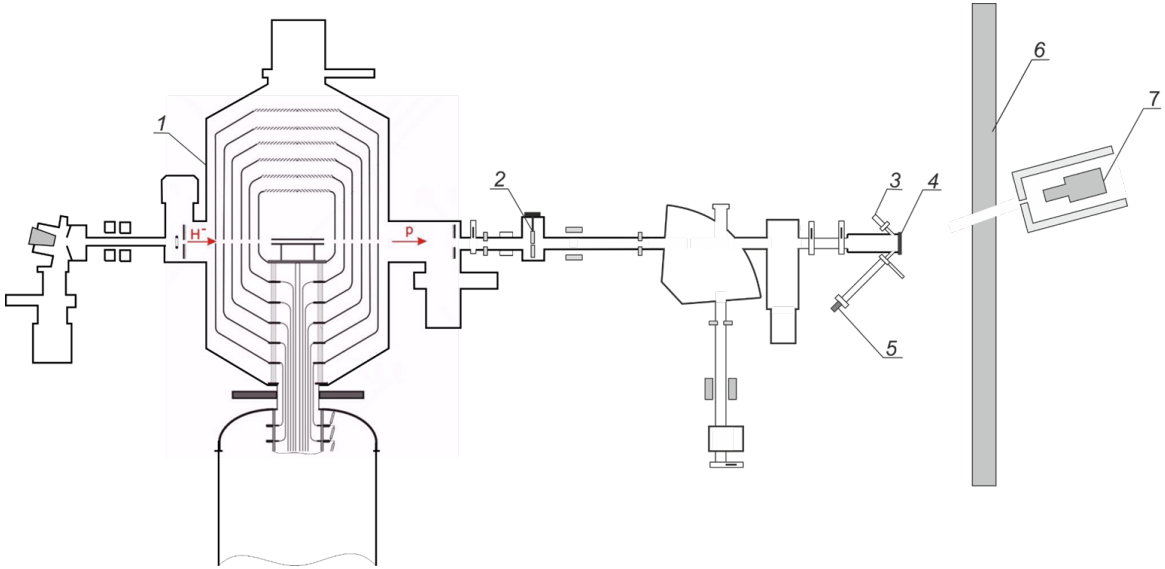
Accelerator based neutron source VITA

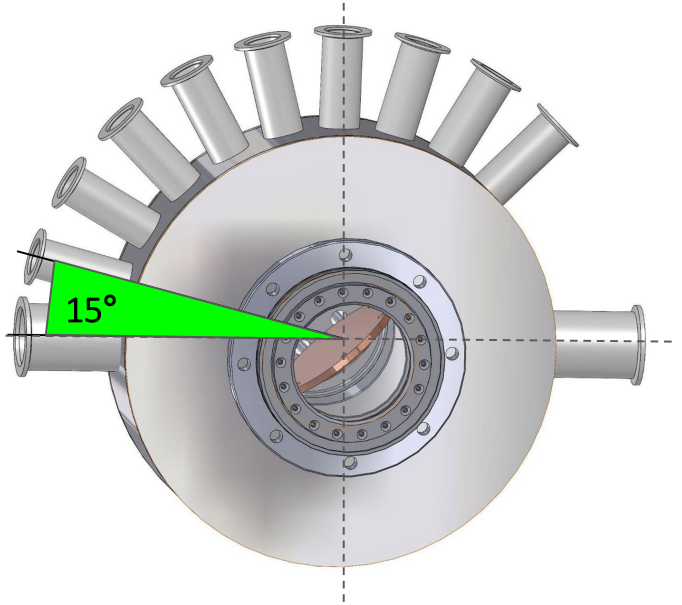


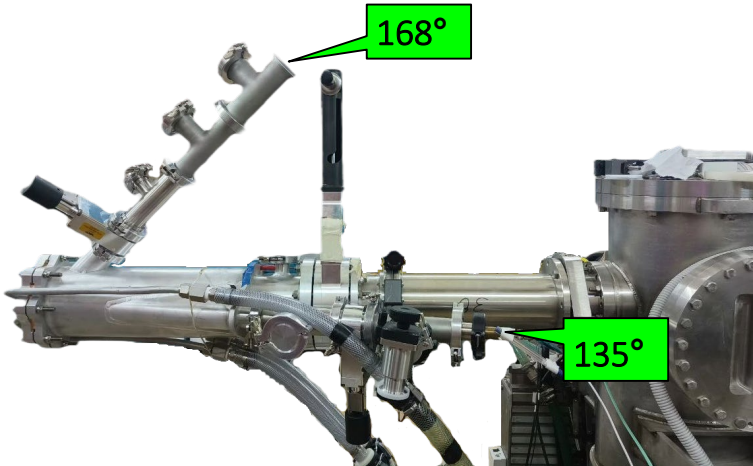
1 - vacuum insulated tandem accelerator
2 - target (*A, B, C, D, E* position*)*
3 - beam shaping assembly



Scheme of the cross-section measuring







1 - vacuum insulated tandem accelerator
2 - collimator
3, 5 - α-spectrometer PDPA-1K (IPTP, Dubna, Russia)
4 - target
6 - radiation shielding
7 - γ-ray spectrometer SEG1KP-IPTP (IPTP, Dubna, Russia)

Li + proton/deuteron

$^{7}Li(p,n)^{7}Be$
$^{7}Li(p,p'g)^{7}Li$
$^{7}Li(p,a)^{4}He$

} Boron neutron capture therapy

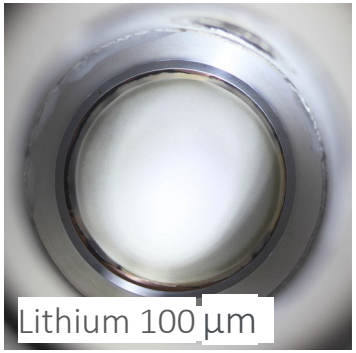
$^{6}Li(d,a)^{4}He$
$^{6}Li(d,p)^{7}Li$
$^{6}Li(d,p)^{7}Li^{*}$

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

} Powerful source of fast neutrons

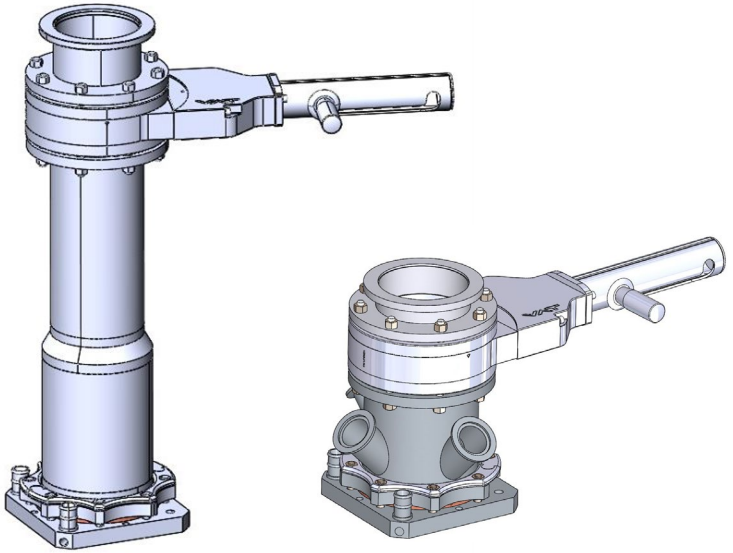
Lithium target manufacturing

System for thermal vacuum evaporation



Lithium 100 µm

Lithium on air

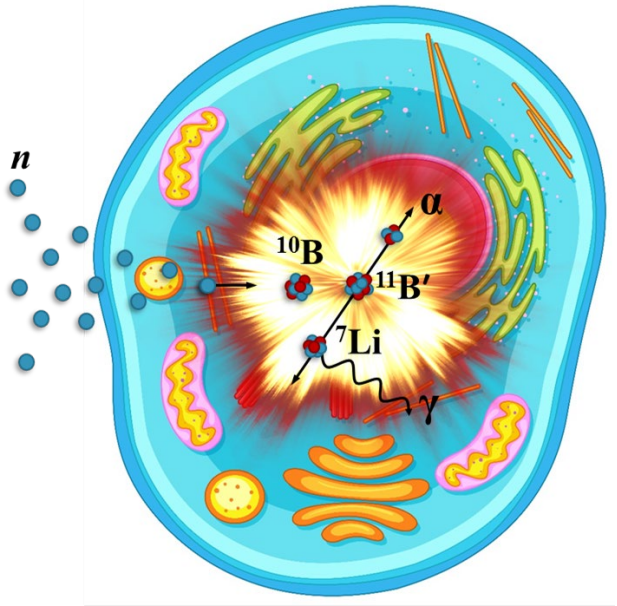


Glove box with argon 99,9998 %

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

Neutrons for BNCT (Boron neutron capture therapy)

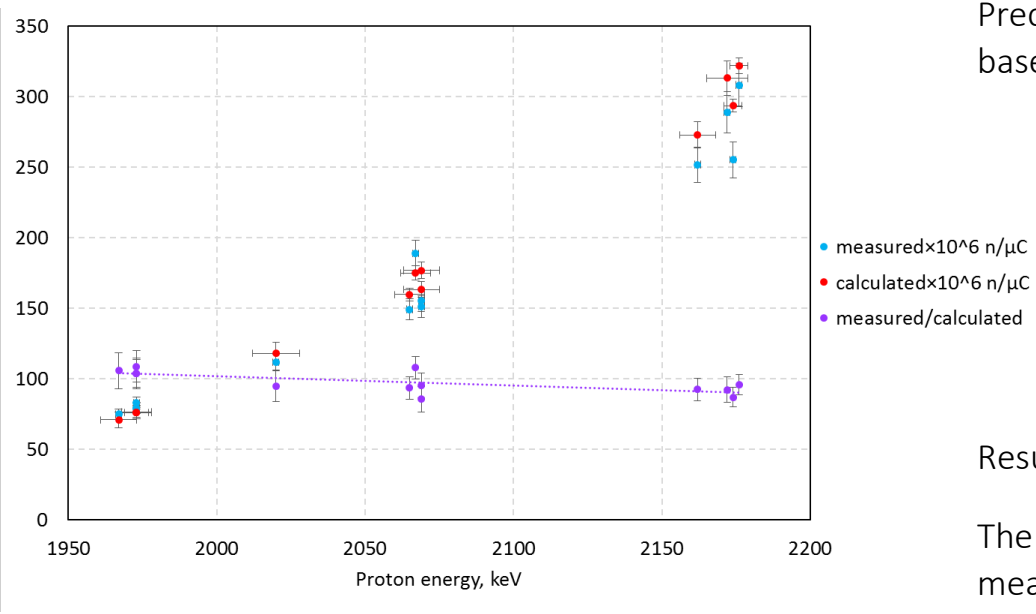
- $^{7}Li(p,n)^{7}Be$ - is the best reaction for BNCT
- only calculations of the neutron yield
- the calculations of different groups of scientists vary greatly



Experimental confirmation of neutron yield is needed!

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

Neutrons for BNCT (Boron neutron capture therapy)



Precise neutron yield measurements are carried out based on the number of ^{7}Be [1]

Result:

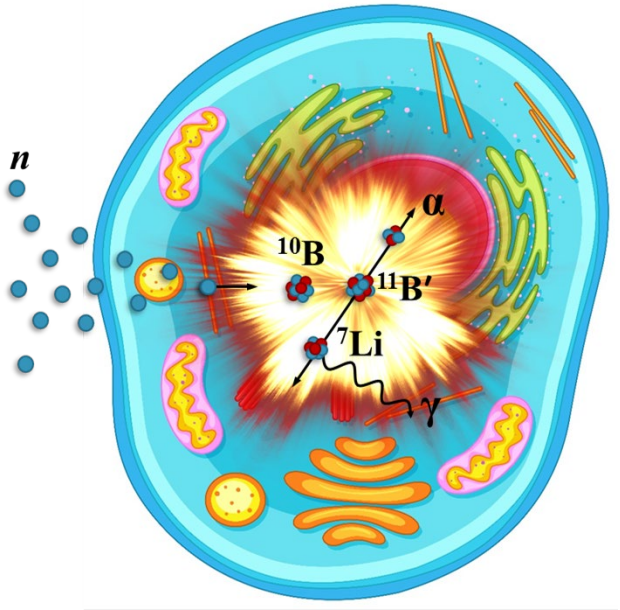
The neutron yield from the developed lithium target, measured at proton energies from 2 to 2.2 MeV, agrees with the calculated one with an accuracy of 5%.

[1] M. Bikchurina, et al. Biology 10 (2021) 824.

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

γ-quanta in BNCT (Boron neutron capture therapy)

- γ-quanta with an energy of 478 keV in the reaction $^{7}Li(p,p'\gamma)^{7}Li$ are generated from the lithium target
- The 478 keV γ-quanta yield is comparable to the neutron yield
- γ-quanta provide an undesirable dose of gamma-radiation and must be taken into account when planning therapy
- Data on γ-quanta yield are scarce and contradictory



The measurement of γ-quanta yield is needed!

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

γ-quanta yield

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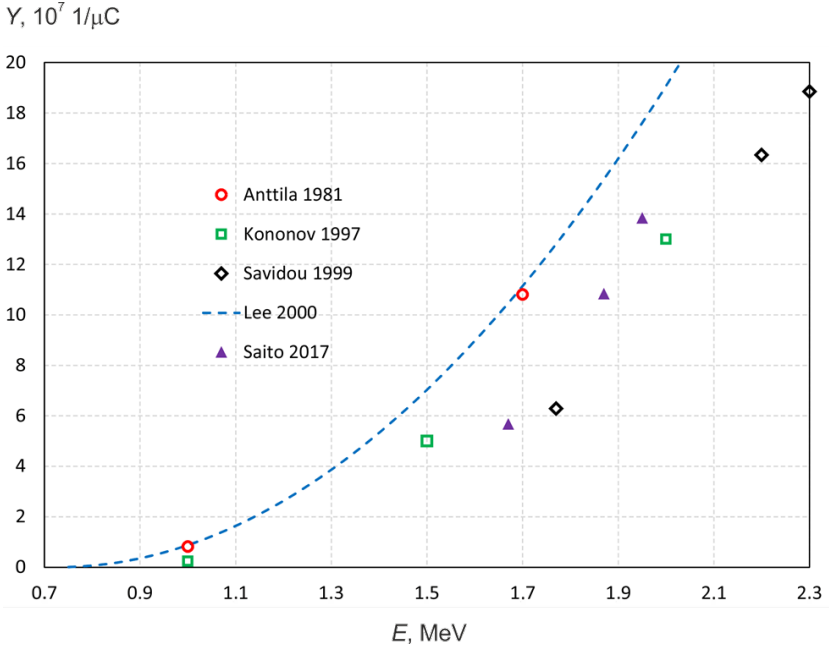
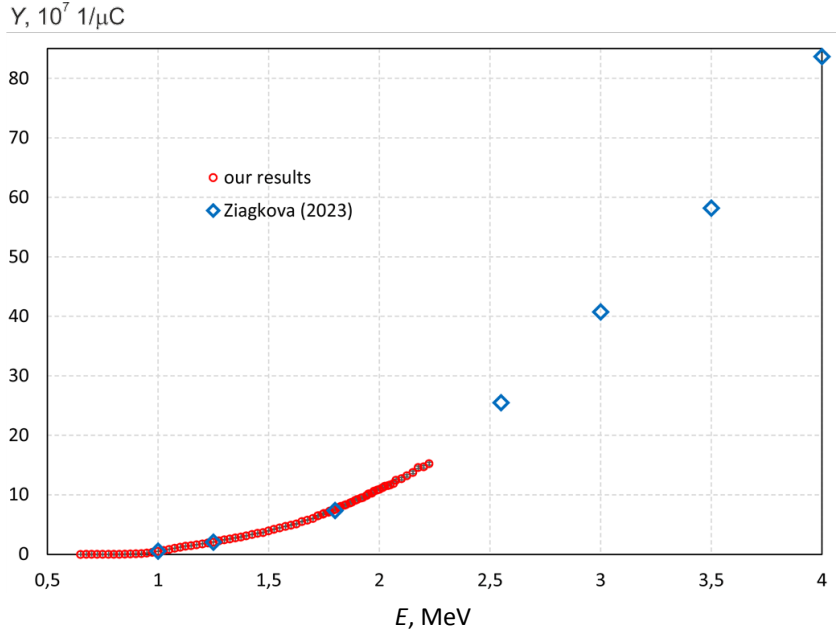
IBANDL

EXFOR





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

cross-section of the reaction

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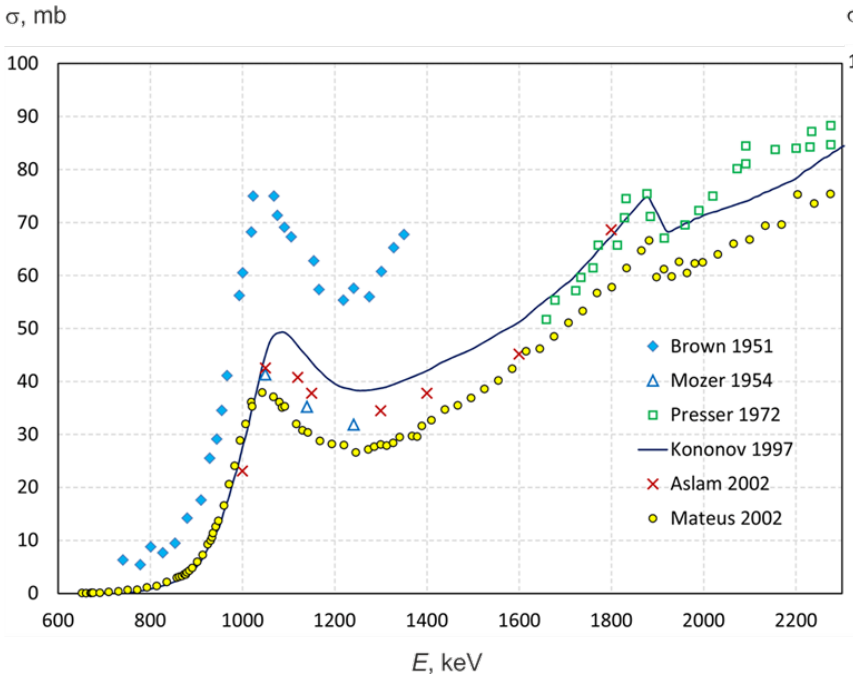
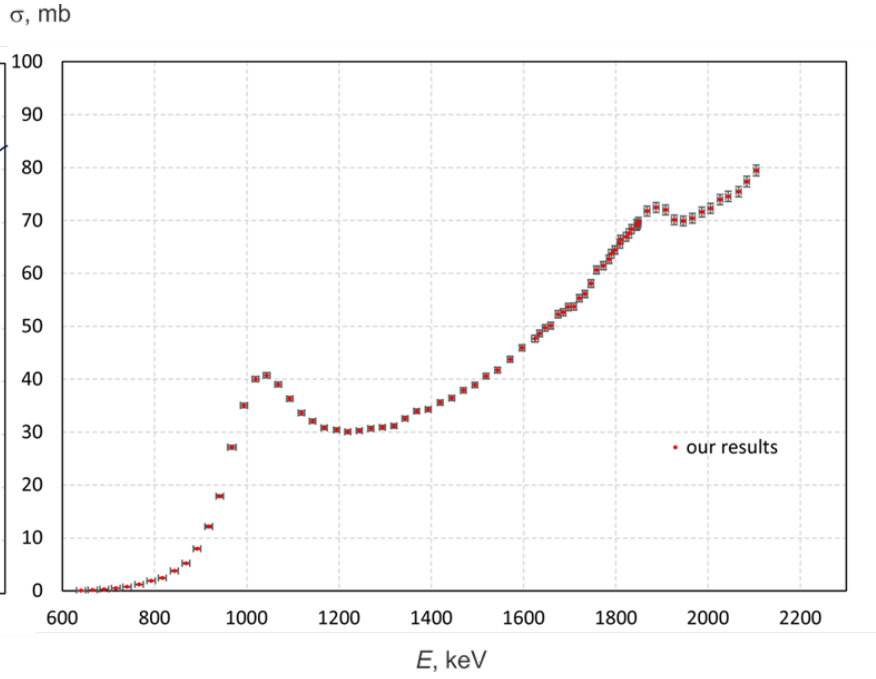
IBANDL

EXFOR





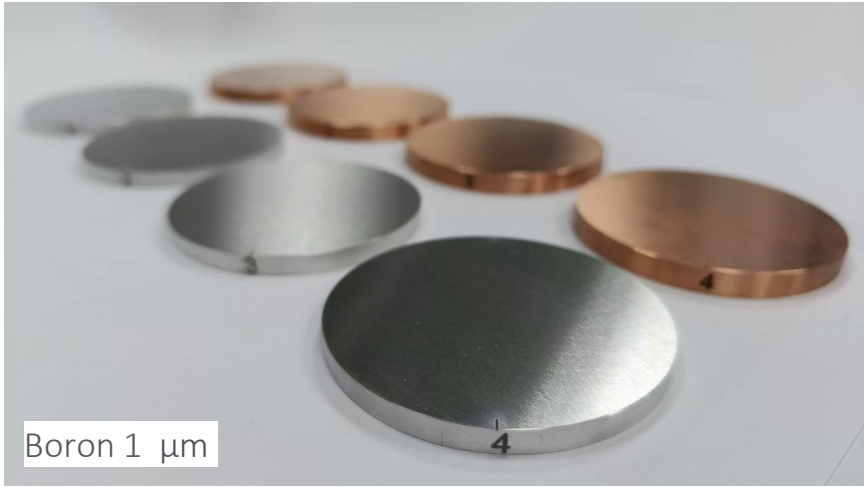
B + proton/deuteron

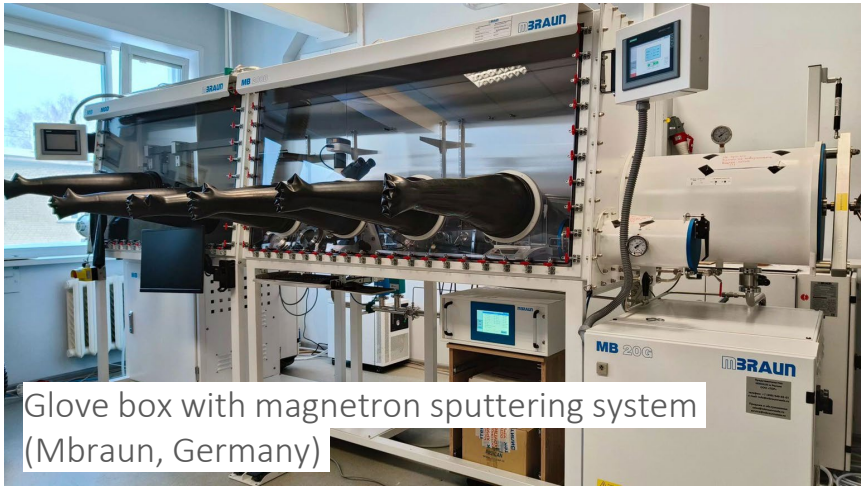
$^{11}B(p,a_0)^{8}Be$
$^{11}B(p,a_1)^{8}Be^{*}$
} 3*a* Aneutronic fusion reaction

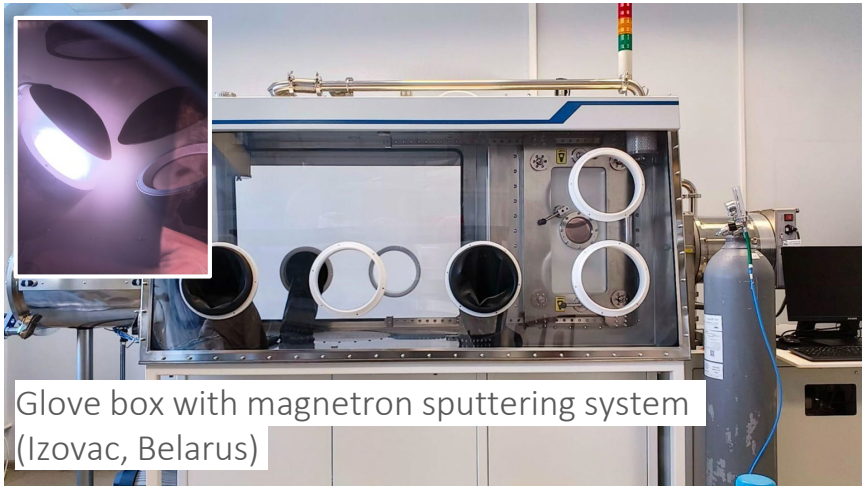
$^{10}B(d,a\ )^{8}Be$
$^{10}B(d,p)^{11}B$
$^{11}B(d,a)^{9}Be$
$^{11}B(d,p)^{12}B$
} Technological applications

Boron target manufacturing

Laboratory of Plasma Sources HCEI SB RAS
(thanks to Oks E.M., Nikolaev A.G., Yushkov G.Yu.)

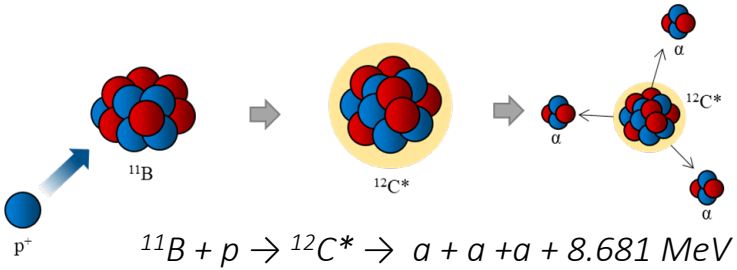




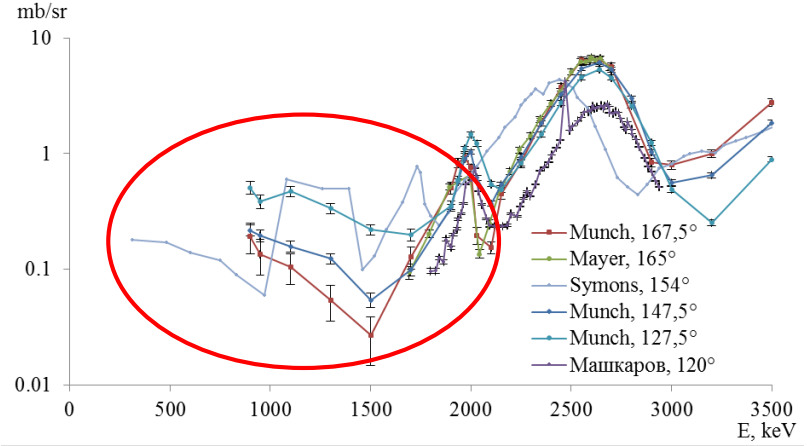


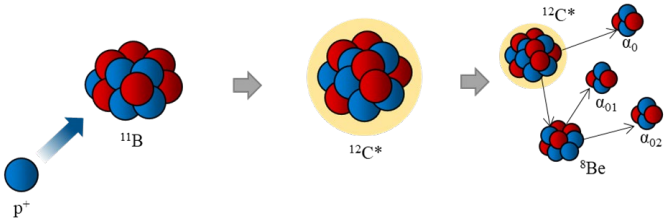
^{11}B(p,a)aa

Reaction mechanism and cross-section



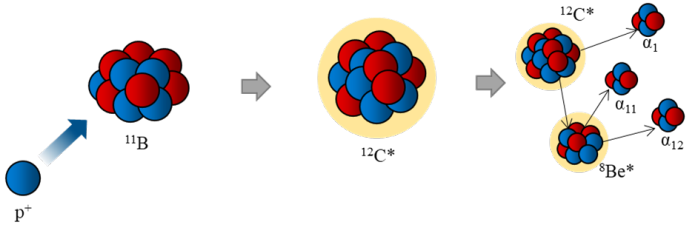
$^{11}B + p \rightarrow {}^{12}C^* \rightarrow a + a + a + 8.681\ MeV$





$^{11}B + p \rightarrow {}^{12}C^* \rightarrow a_0 + {}^{8}Be + 8.587\ MeV$

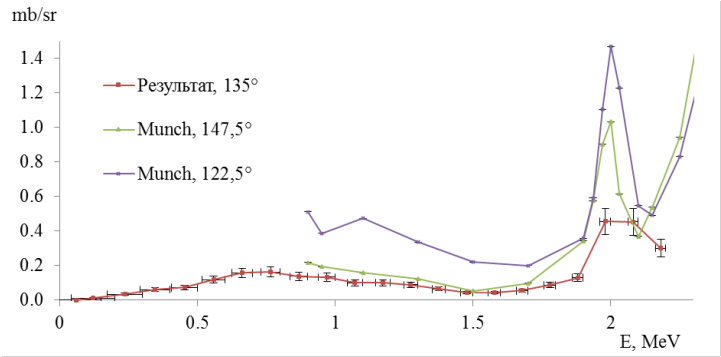
$^{8}Be \rightarrow a_{01} + a_{02} + 0.094\ MeV$

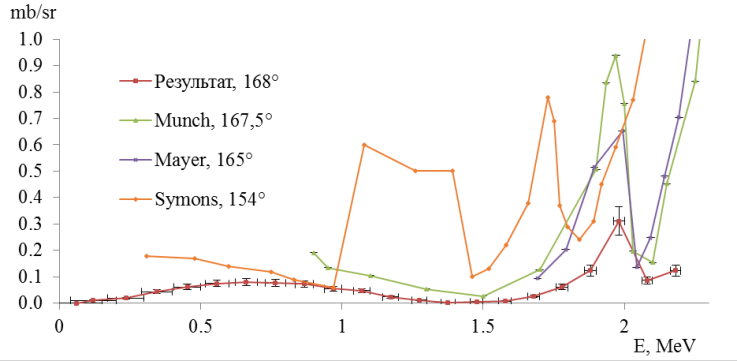


$^{11}B + p \rightarrow {}^{12}C^* \rightarrow a_1 + {}^{8}Be^* + 5.557\ MeV$

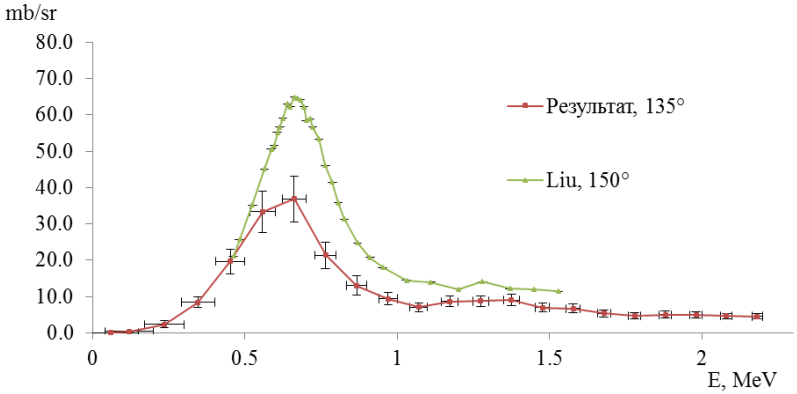
$^{8}Be \rightarrow a_{11} + a_{12} + 3.124\ MeV$

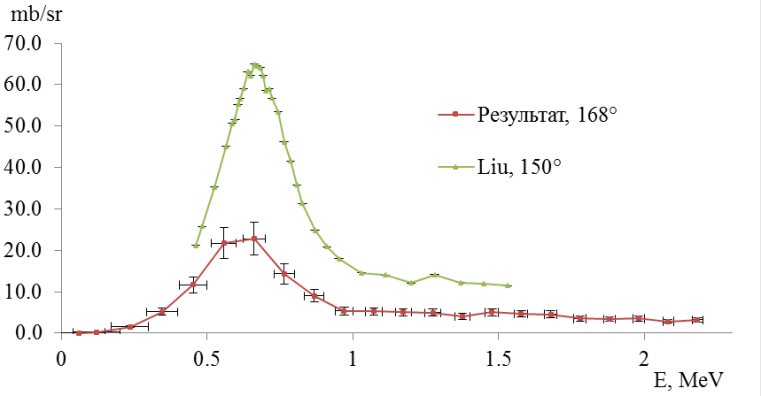
$^{11}B(p,\alpha_0)^8Be$





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





Conclusion

- The cross-sections of 19 nuclear reactions were measured with high accuracy at VITA:

  ^{7}Li(p,n)^{7}Be, ^{7}Li(p,p'g)^{7}Li, ^{7}Li(p,a)^{4}He, ^{6}Li(d,a)^{4}He, ^{6}Li(d,p)^{7}Li, ^{6}Li(d,p)^{7}Li*, ^{7}Li(d,a)^{5}He, ^{7}Li(d,na)^{4}He, ^{7}Li(d,n)^{8}Be [1, 2];
  ^{11}B(p,a_0)^{8}Be, ^{11}B(p,a_1)^{8}Be* [3]; ^{10}B(d,a)^{8}Be, ^{10}B(d,p)^{11}B, ^{11}B(d,a)^{9}Be, ^{11}B(d,p)^{12}B.

- Cross-sections of the reactions ^{7}Li(p,p'g)^{7}Li [4] and ^{7}Li(p,a)^{4}He [5] are included in the IBANDL and EXFOR nuclear reaction databases maintained by the IAEA.

[1] Taskaev et al. NIM B (2024) - sent for publication 02.24, after corrections and responses to comments 05.24
[2] Meshchaninov et al. Physics of Atomic Nuclei (2024) - sent for publication 02.24
[3] Taskaev et al. Physics of Atomic Nuclei (2024) - sent for publication 02.24
[4] Taskaev et al. NIM B 502 (2021) 85-94
[5] Taskaev et al. NIM B 525 (2022) 55-61

Thank you for attention!