PhD Yaroslav Kolesnikov
(on behalf of the Budker Institute of Nuclear Physics BNCT team)

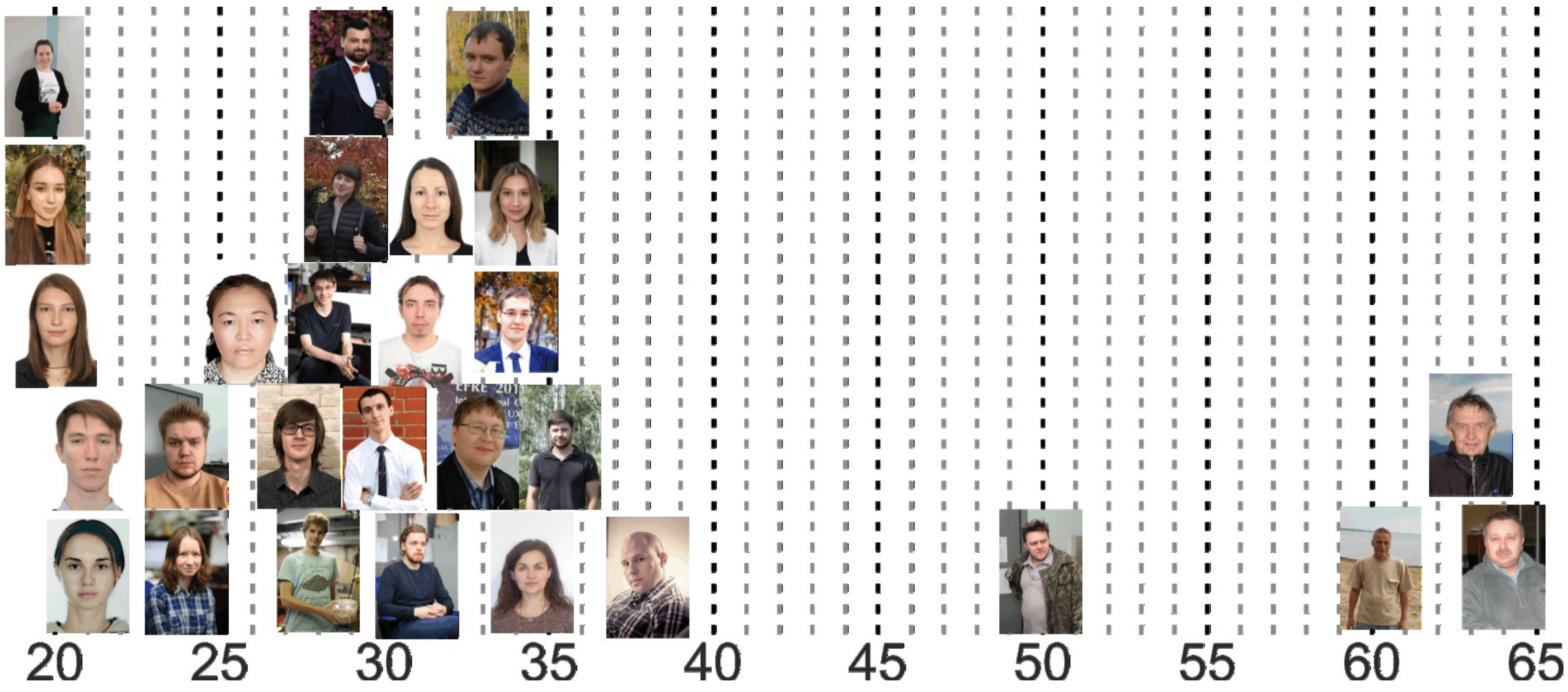
Accelerator based neutron source VITA for measuring nuclear reaction cross sections and for irradiating advanced materials

BNCT team + local users

32 members:

16 researchers (1 – head of lab, Prof. Sergey Taskaev, 6 – PhDs)
7 PhD students
5 students
4 physical facility laboratory assistants

Average age 32 years



What is the VITA?

Accelerator based neutron source VITA:

Vacuum-insulated tandem accelerator
Lithium target with controlled thickness
Set of beam shaping assemblies

High power **dc** proton/deuteron beam (up to 20 kW):

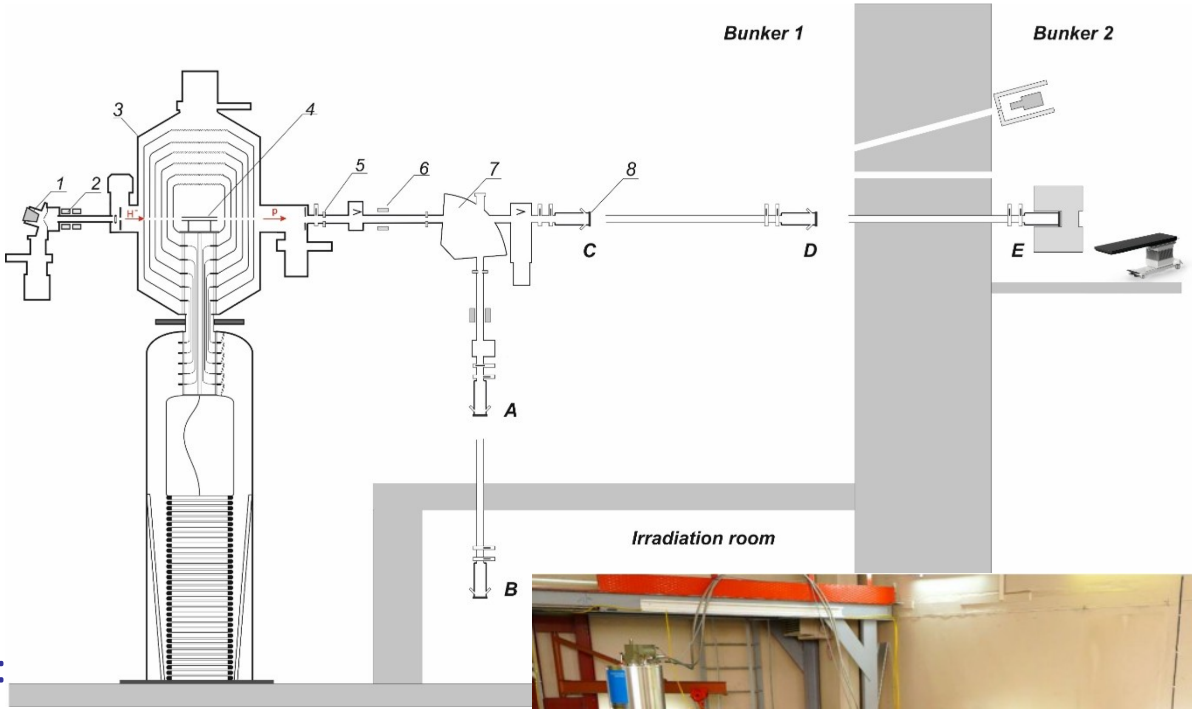
Energy in range from 0.3 to 2.3 MeV
Current in range from 1 nA to 10 mA

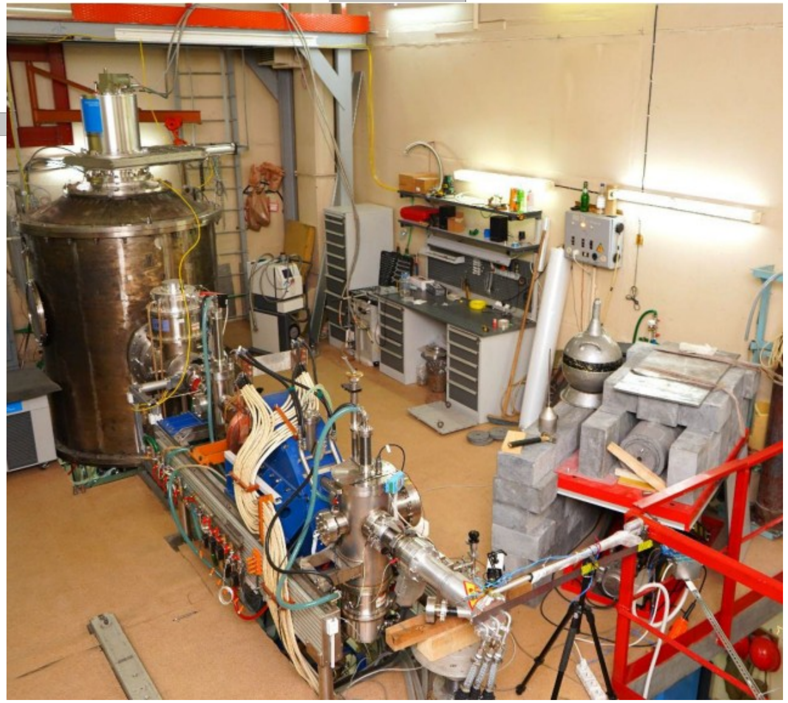
High power neutron source (up to $2\cdot10^{12}$ (d^+) and 10^9 (p) s^{-1}):

– cold neutrons (D_2O at cryo temp)
– thermal neutrons (D_2O/plexiglass)
– epithermal neutrons (MgF_2 moderator)
– fast neutrons (deuteron beam)

Intense photon source: 478 keV – $^{7}Li(p,p'\gamma)^{7}Li$
511 keV – $^{19}F(p,\alpha e^+e^-)^{16}O$

Intense α-particles source: $^{7}Li(p,\alpha)\alpha$, $^{11}B(p,\alpha)\alpha\alpha$
Intense positrons source: $^{19}F(p,\alpha e^+e^-)^{16}O$





For investigations in NCT

Development and testing of boron delivery agents

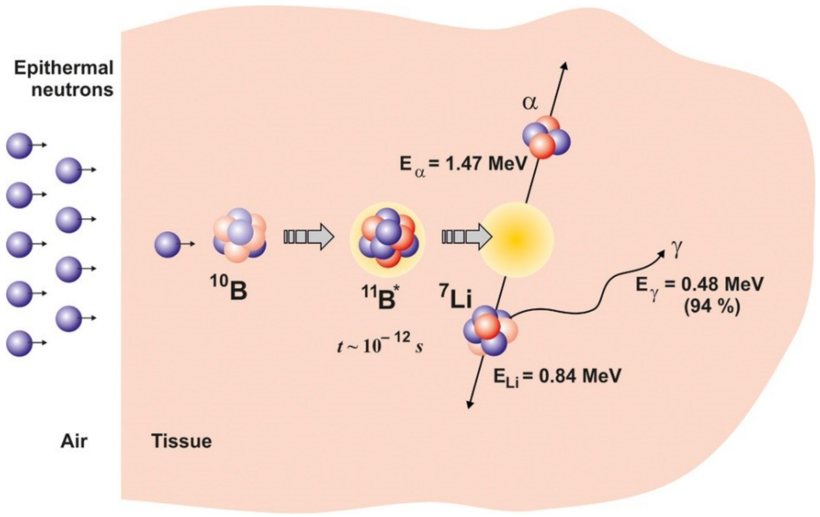
In vitro and *in vivo* tests with neutron generation

Treatment of pets

Dosimetry (neutron detectors, Ga-detector, PGA)

Development of LiNCT

…



Other applications

Testing materials for CERN, ITER… (NAA, radiation resistance under fast neutrons)

Cross-section measurements (p^+ or d^+ beam on ^{6}Li, ^{7}Li, ^{10}B, ^{11}B, ^{19}F, … targets)

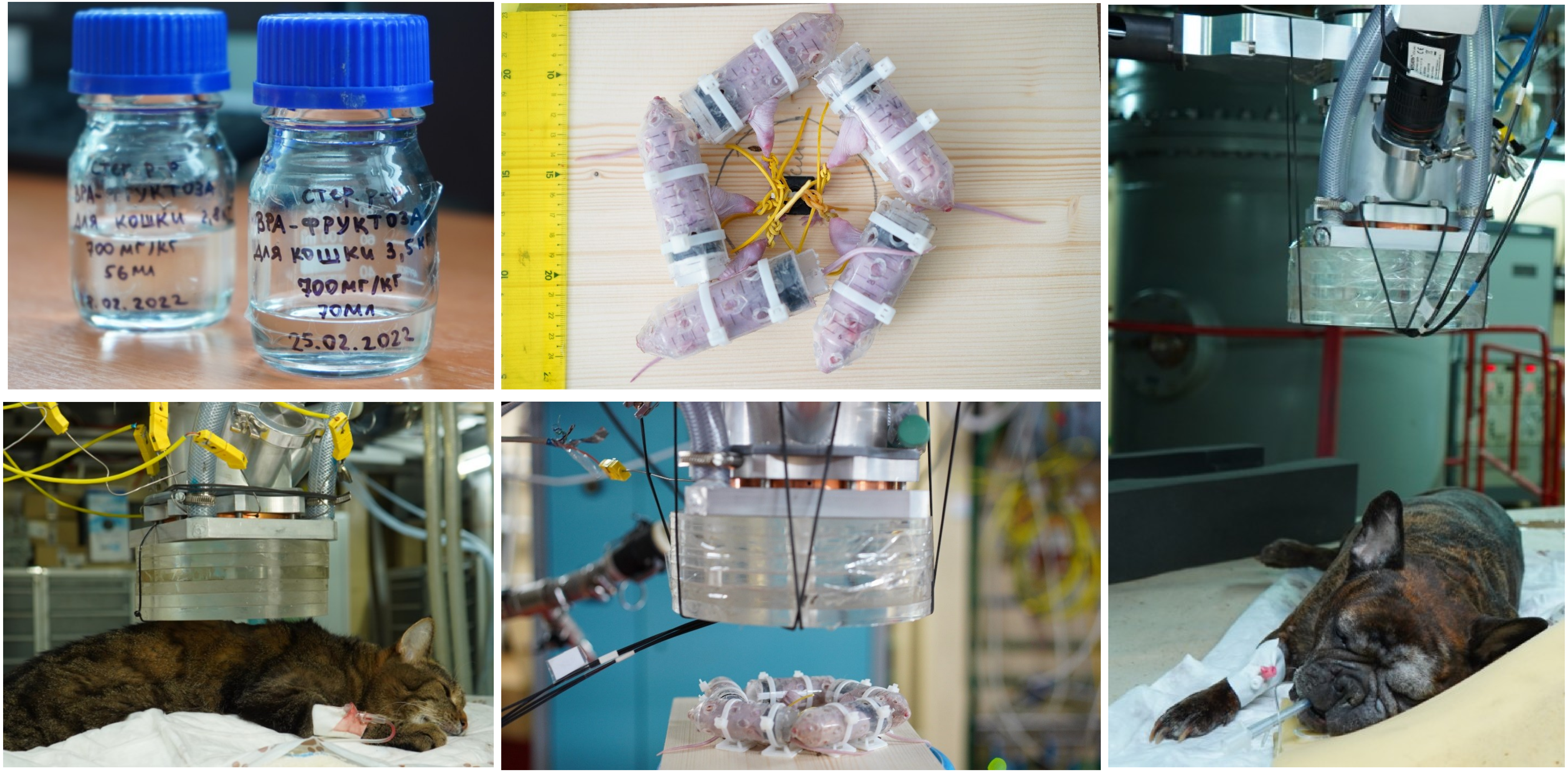
Spectrum measurements

Development of diagnostics for high power dc beam parameters – position, size, current, phase space

Proton microscopy – *in situ* measurements of alloys on the targets (down to 1 nm)

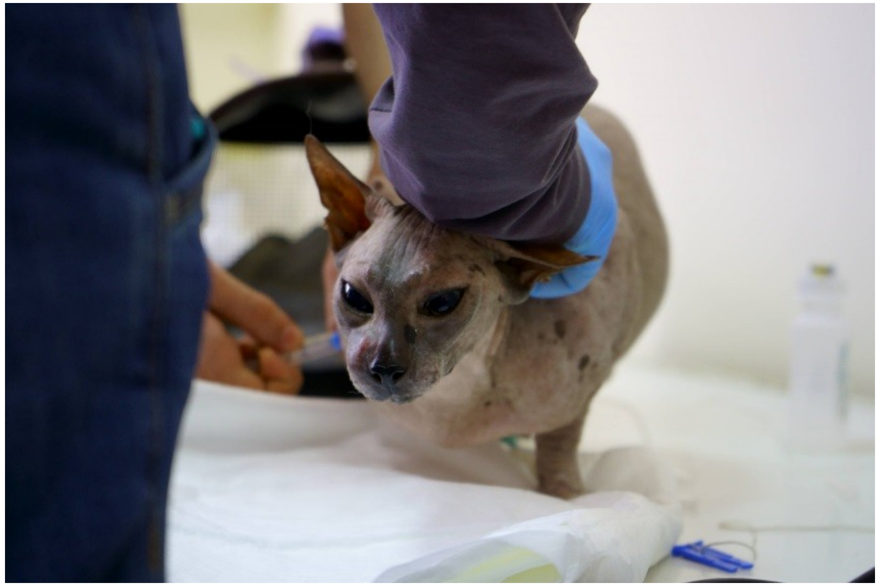
…

In vivo Accelerator-based Boron Neutron Capture Therapy for Spontaneous Tumors in Large Animals: Case Series / V. Kanygin [et al.] // Biology. – 2022. – Vol. 11, Iss. 1. – P. 138.



Our patients

In vivo Accelerator-based Boron Neutron Capture Therapy for Spontaneous Tumors in Large Animals: Case Series / V. Kanygin [et al.] // Biology. – 2022. – Vol. 11, Iss. 1. – P. 138.



In vivo Accelerator-based Boron Neutron Capture Therapy for Spontaneous Tumors in Large Animals: Case Series / V. Kanygin [et al.] // Biology. – 2022. – Vol. 11, Iss. 1. – P. 138.

№	Дата	Пол	Кот/собака	Порода	Город	Кличка	Возраст	Вес	Тип онкологии	Препарат	Клиника	Флюенс пучка, мА·	Энергия, МэВ
1	11.12.2019	М	Собака	Мопс		Шон	11		Фибросаркома		Бэст (?)	4,4	2,05
2	26.02.2020	Ж	кошка			Сабрина			Опухоль в области слизистой левого носового хода.	BSH		4,4	2,05
3	26.02.2020	М	кот			Пушок			Опухоль мягких тканей области носа и верхней губы	BSH		4,4	2,05
4	18.09.2020	Ж	Собака			Каппа	10		Опухоль мягких тканей с тотальным поражением носовой поло	BSH		4,4	2,05
5	24.09.2020	Ж	кошка			Селедка	4		Опухоль мягких тканей левого бедра.			4,4	2,05
6	13.10.2020	Ж	Собака			Дая	12		Опухоль мягких тканей со смещением носовой перегородки и обструкцией носоглотки.			4,4	2,05
7	08.02.2021	Ж	Собака			Дая	12		Остеосаркома				2,05
8	08.02.2021	?	Кот			Перчик	4		Карцинома				2,05
9	08.02.2021	?	Кошка			Кира	6		Фибросаркома				2,05
10	05.03.2021		Кот										2,05
11	05.03.2021		Кот										2,05
12	05.03.2021		Кот										2,05
13	28.02.2022		Собака	Немецкий боксер		Прометей	7		Плоскоклеточный рак на слизистой оболочке ротовой полости		Пульс (Караульных Матвей	4,4	2,05
14	05.03.2022	Ж	Кошка			Лося	8		Фибросаркома холки		Бэст	4	2,05
15	05.03.2022	Ж	Кошка			Митца	13		Опухоль лицевого черепа		Бэст	4	2,05
16	23.06.2022	Ж	Кошка	Мейн-кун		Аюта	11	5,8	Огромная опухоль в носоглотке	Магневист	Бэст	4,4	2,05
17	29.09.2022	М	Собака	Беспородный	Нижний Новгород	Джон	14	32	Хондросаркома, рецидив. До этого 2 хирургические операции	Магневист	Бэст	4,4 (2х2,2)	2,05
18	29.09.2022	М	Кот	Британец	Бердск	Семен	6	6	Саркома правого бедра и подвздошной кости	Магневист	Бэст	4 (2х2)	2,05
19	30.09.2022	Ж	Кошка	Беспородная	Самара	Маруся	10	?	оскоклеточный рак верхней челюсти с ростом опухоли за глазное ябл	Магневист	МаксиВет	4 (2х2)	2,05
20	25.10.2022	М	Кот	Беспородная	зевка (Московская об	Лёва	11	7,4	плоскоклеточный рак верхней челюсти (справа)	Магневист	МаксиВет	4,4 (2х2,2)	2,05
21	25.10.2022	Ж	Собака	Йоркширский терьер	Москва	Лили	13	3,6	Метастазы в легких	Магневист	МаксиВет	3,4 (2,2 + 1,2)	2,05
22	25.10.2022	М	Кот	Мейн-кун	Санкт-Петербург	Колбаска	6	5,9	области носа слева с деструкцией кости, регионарная лимфаденопа	Магневист	МаксиВет	2,2	2,05
23	21.12.2022	Ж	Кошка	Мейн-кун		Аюта	11	6	Та же опухоль (в носоглотке)	BPA	Бэст	4,4 (2х2,2)	2,05
24	01.02.2023	Ж	Собака	Йоркширский терьер	Москва	Лили	13	3,7	Опухоль в правом легком, метастазы в левом	BPA+Gd (Магневист)	МаксиВет	4,4 (2х2,2)	2,05
25	02.02.2023	Ж	Собака	"Той-терьер"	Новосибирск	Боня	8	6	Опухоль слюнной железы	BPA+Gd (Магневист)	Бэст	4,4 (2х2,2)	2,05
26	02.02.2023	М	Кот	иканская короткошер	Новосибирск	Шерхан	12	6,1	Опухоль слюнной железы	BPA+Gd (Магневист)	Бэст	4,4 (2х2,2)	2,05
27	02.02.2023	Ж	Кошка	Метис	Новосибирск	Назира	8,5	4	Опухоль в носовой полоти	BPA+Gd (Магневист)	Бэст	4,4 (2х2,2)	2,05

Totally 27 pets by present time

VITA for China in the Budker INP

Going down in History: China Reaches a New Milestone to Develop an Advanced In-Hospital BNCT Solution for Clinical Use

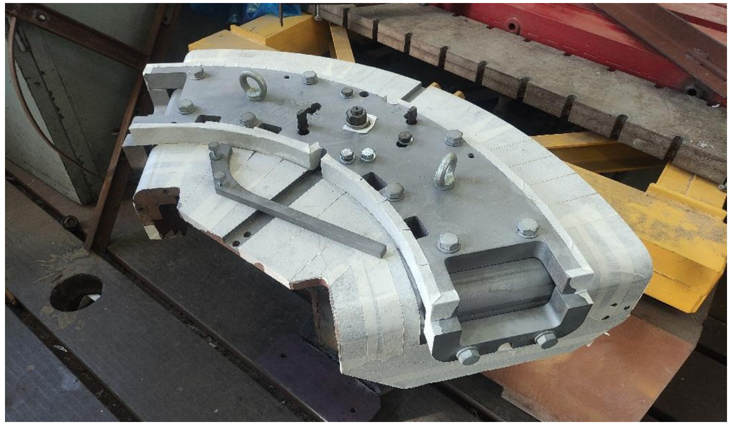
The current beam under the proton condition of 2.3 MeV and 8 mA already meets the clinical criteria powered by neutron beam control technology. That means China has become the second country to develop and implement AB-BNCT complete technology, and the country for the first time utilizes an electrostatics accelerator in human study.

Frebruary 2023.

Newsletter #19

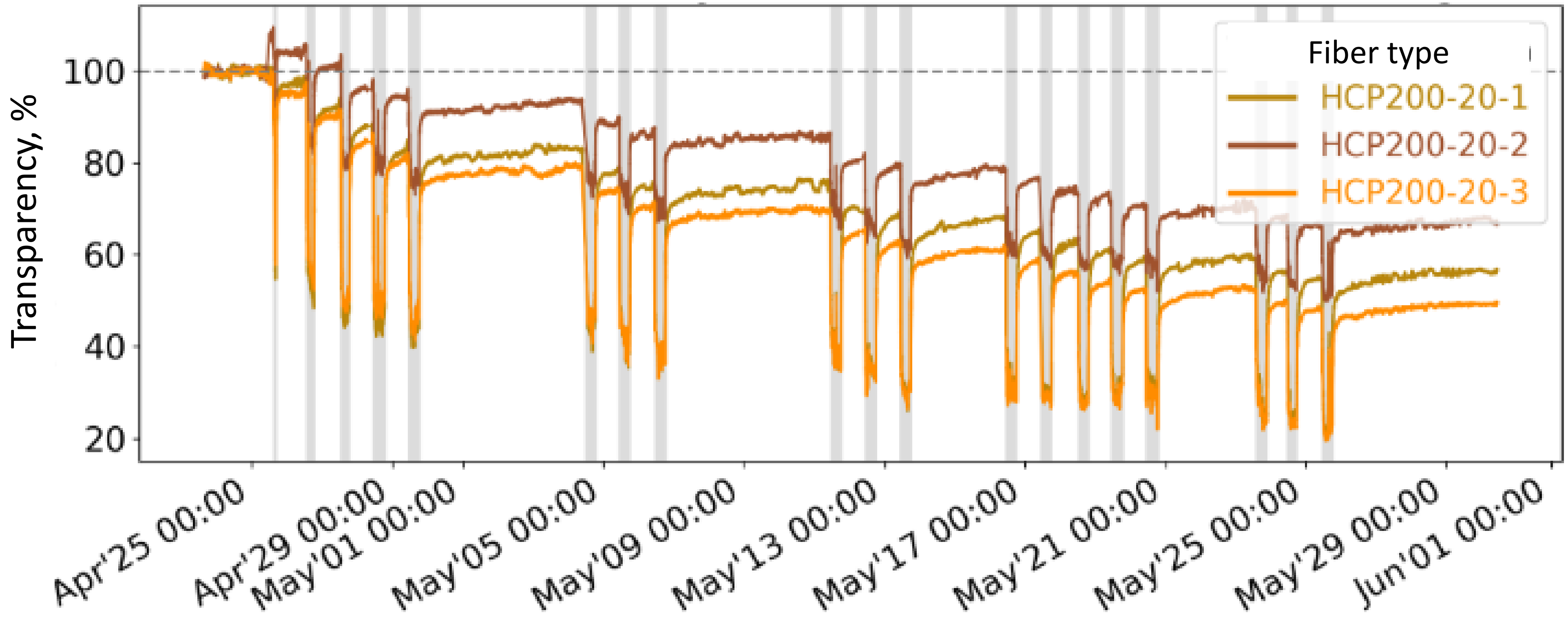
Until 12.2023 Assembling a neutron source in the Budker INP

Until 12.2024 Installing VITA in Moscow



Material testing

We measured the dependence of optical fiber transparency versus fast neutron fluence up to a value of $3 \cdot 10^{14}$ neutrons/cm^2



One month of stable neutron generation with 8 hours per day without degradation of neutron yield

VITA = powerful, stable, reliable fast neutron source

Simultaneously with the fiber optics irradiation at VITA were also irradiated:

– Semiconductor photomultiplier tubes and dc-dc converters for the ATLAS detector of the CERN Large Hadron Collider (Geneva, Switzerland);

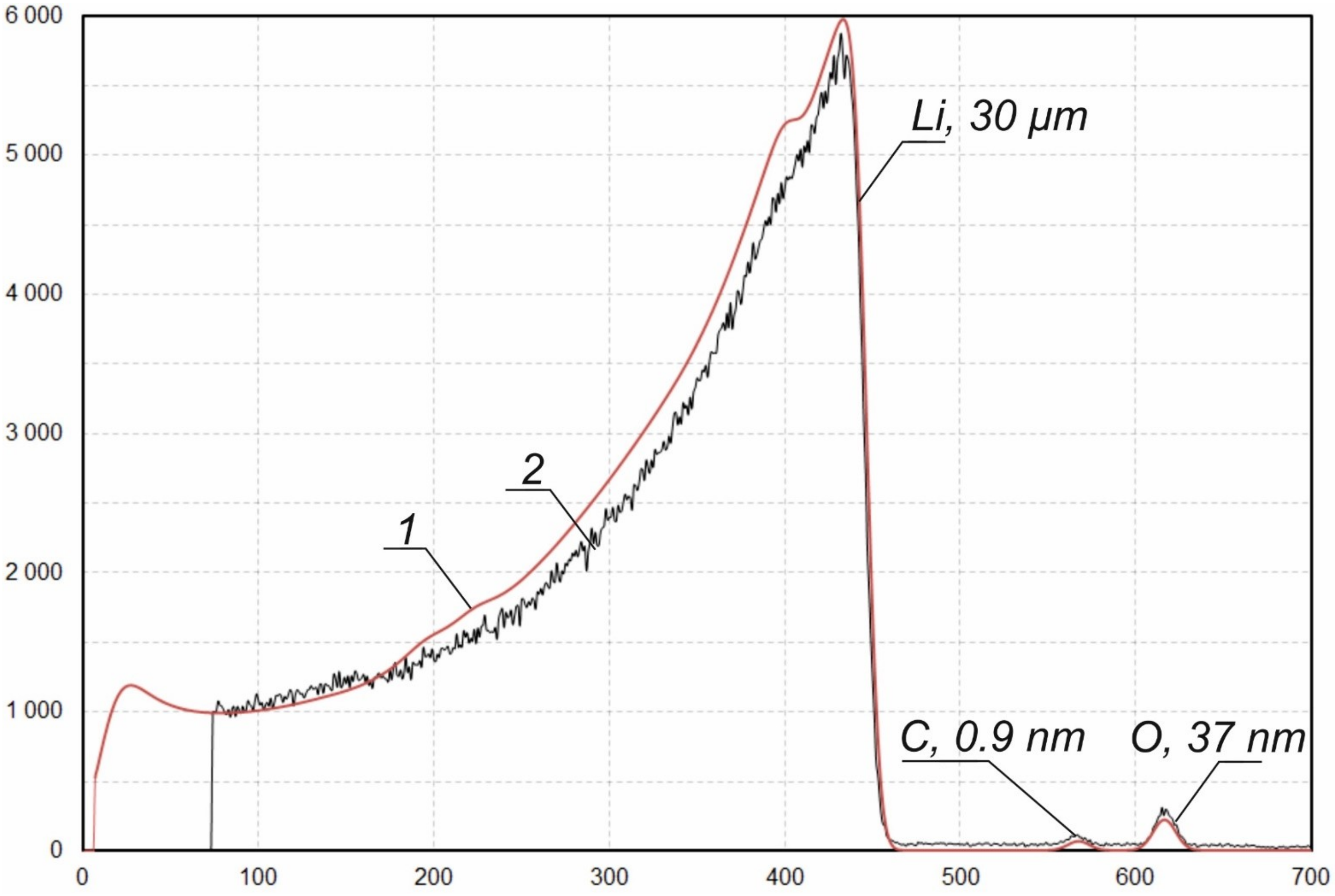
– A diamond detector for the International Thermonuclear Experimental Reactor (ITER, Cadarache, France);

– Boron carbide plates for ITER;

– Neodymium magnets for the hybrid quadrupole lens of the high-power linac at the Institute of Theoretical and Experimental Physics (Moscow, Russia);

– Natural and synthetic diamonds for the Nikolaev Institute of Inorganic Chemistry (Novosibirsk, Russia);

– Gas sensors based on titanium phthalocyanines for Novosibirsk State University (Russia).



Spectrum of back-scattered protons (2) and SIMNRA [1] simulation (1)

Useful method for:

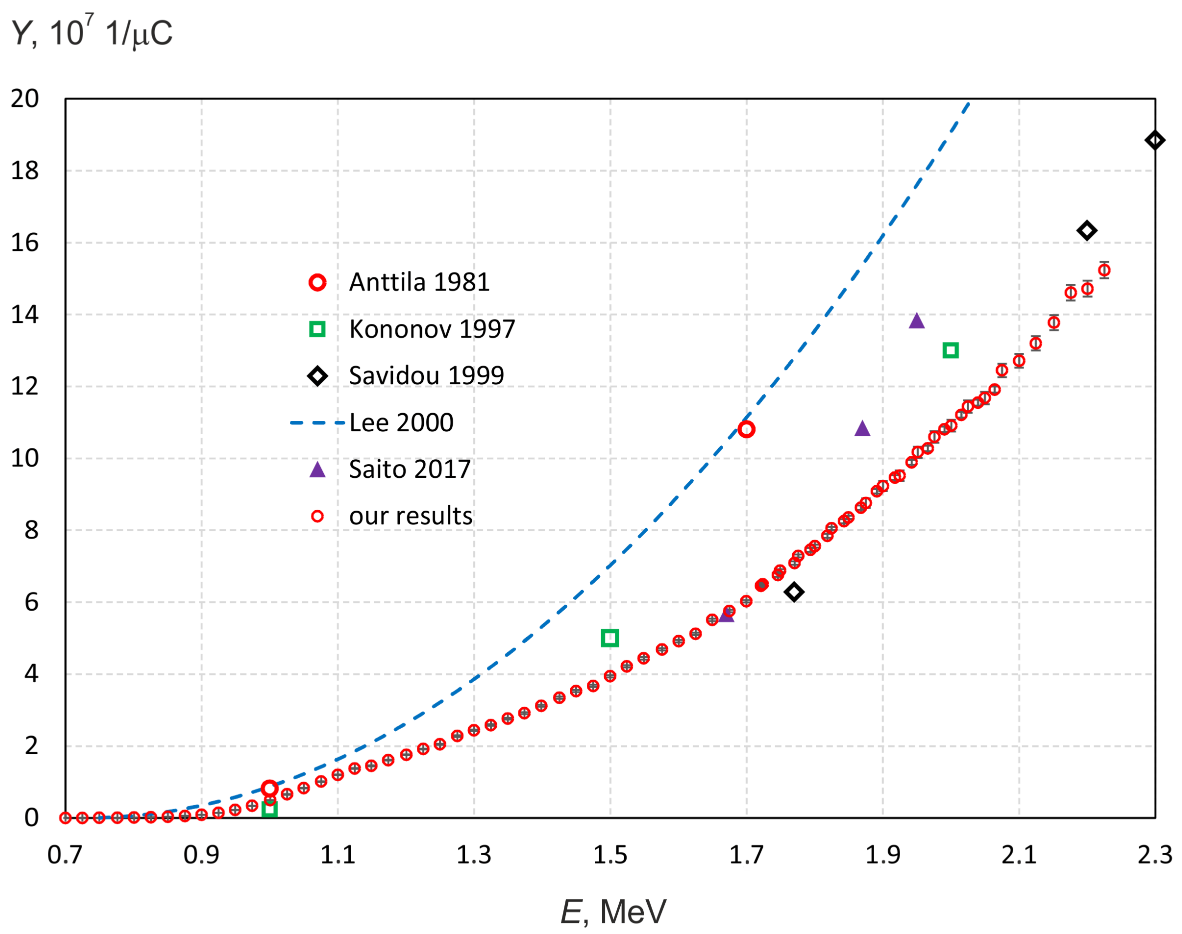
in situ measuring thickness of the target's surface composition

Measuring cross-sections of the nuclear reactions

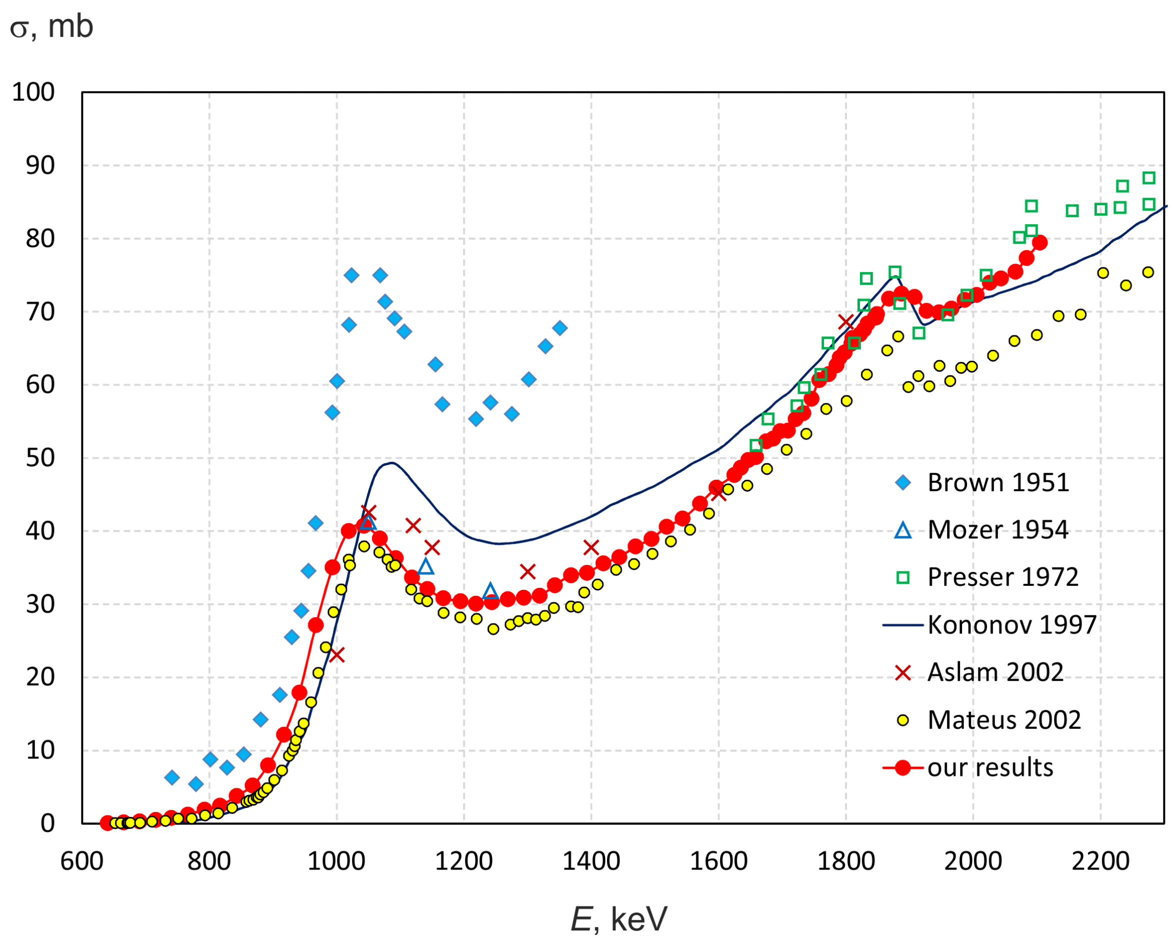
Additional tool for the measuring of the beam energy

1) SIMNRA v. 7.03 with SigmaCalc 2.0 for single user. License No. 1801-4848-WT-WA, Sept. 22, 2021

Cross-sections. $^7Li(p,p'\gamma)^7Li$

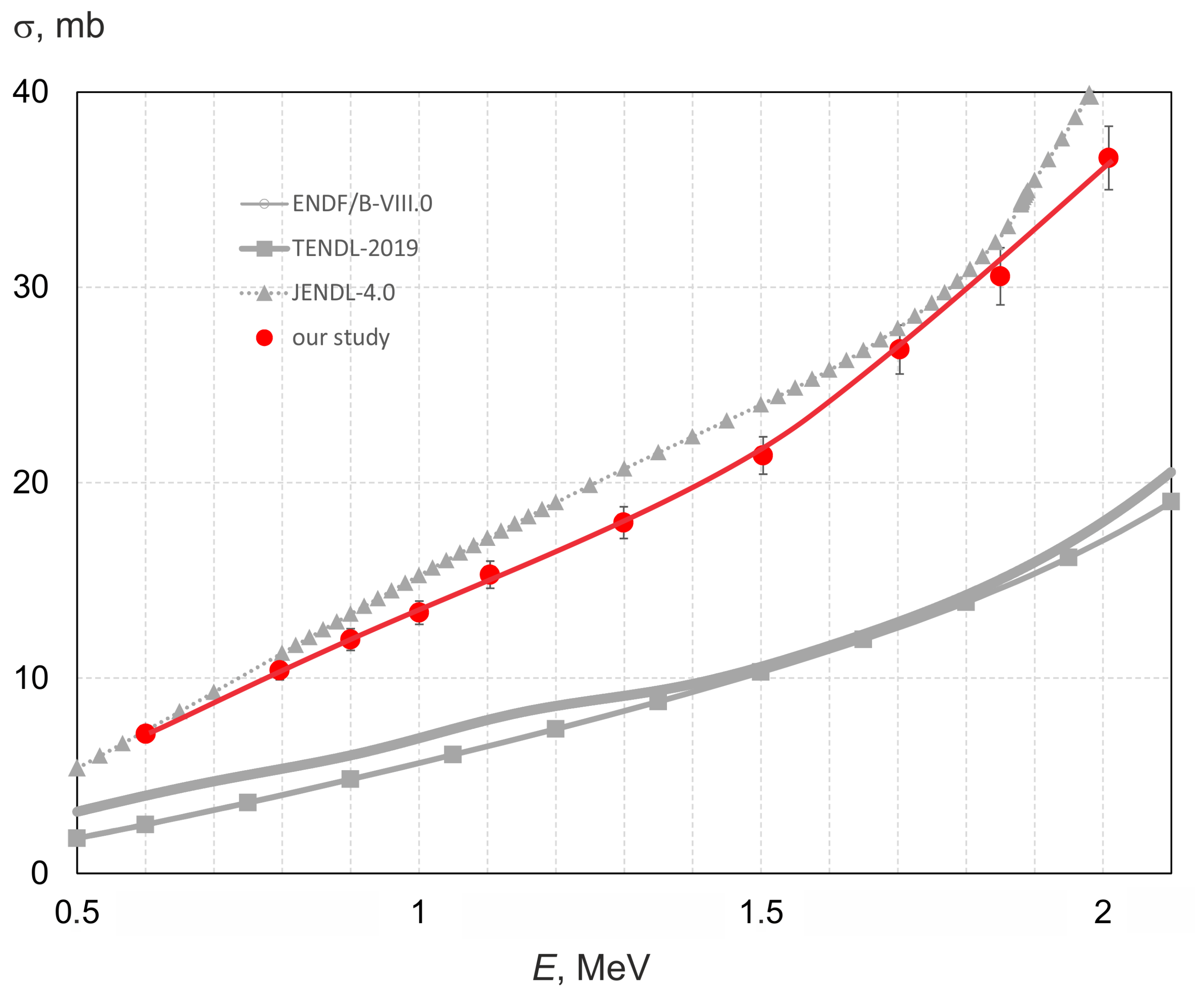


478 keV photon yield from a thick lithium target



$^7Li(p,p'\gamma)^7Li$ reaction cross-section

Cross-sections. $^7Li(p,\alpha)^4He$



+ IBANDL + Exfor

- Measurements error 3 %
- Lithium layer thickness = 422 ± 13 nm [Kasatov et. al. JINST 15 (2020) P10006]
- + 4 methods of approving thickness of the lithium target

Summary

VITA applications

Industrial

Cross-sections of nuclear reactions

Proton beam:

- $^{7}Li(p,p'\gamma)^{7}Li$ [1]
- $^{7}Li(p,\alpha)^{4}He$ [2]
- …

Deuteron beam [3]:

- $^{7}Li(d,n\alpha)\alpha$
- $^{7}Li(d,\alpha)^{5}He \rightarrow \alpha+n$
- $^{6}Li(d,\alpha)\alpha$
- $^{6}Li(d,p)^{7}Li$
- $^{6}Li(d,p)^{7}Li^{*} \rightarrow \gamma$ (478 keV)
- …

Material investigations

- Blistering investigations [4]
- Qualification and testing materials for ITER and CERN [5]
- …

Medical

BNCT investigations

- *In vitro* & *in vivo studies* [6]
- **Dosimetry studies [7]**
- **Drug delivery systems [8]**
- …

BNCT trials

- Pets [9]
- VITA in Xiamen
- **VITA in Moscow**
- VITA in Pavia
- …

1. S. Taskaev et al. NIMB 502 (2021)
2. S. Taskaev et al. NIMB 525 (2022)
3. To be published
4. S. Taskaev et al. NIMB 481 (2020)
5. A. Shoshin et al. Fusion Eng. Des. 178 (2022)
6. A. Zaboronok et al. Biology 10 (2021) 1124
7. S. Taskaev et al. Front. Nucl. Eng. publishing
8. A. Zaboronok et al. Pharmaceutics 13(9) (2021)
9. A. Zaboronok et al. Biology 11 (2022) 138

Thanks for the attention

We are open for collaboration!

Taskaev@inp.nsk.su Team leader, Professor Sergey Taskaev