Concept of the UCN Source at the WWR-K Reactor (AlSUN)

Kylyshbek Turlybekuly[1,3], Asset Shaimerdenov[1], Darkhan Sairanbayev[1], Avganbek Sabidolda[1], Zhanibek Kurmanaliyev[1,3], Akzhol Almukhametov[1], Ekaterina Korobkina[2], Egor Lychagin[3], Alexey Muzychka[3], Valery Nesvizhevsky[4], Cole Teander[5] and Pham Khac Tuyen[3,6]

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Presentation Plan

1. **Brief history of helium UCN converters**
   - *Initial UCN source concept based on helium*
   - *Other UCN source concept based on helium*
2. **Why WWR-K as a unique UCN source?**
   - *WWR type reactors*
   - *WWR-K reactor*
3. **Concept of the UCN source at the WWR-K reactor**
   - *Basic concept of UCN source*
   - *Estimates of the 8.9 Å neutron fluxes*
   - *Estimates of UCN production*
   - *Extraction and transport of UCNs*
4. **Investigations on improvement of UCN concept at WWR-K reactor**
   - *Investigation of the cooling system with a heat conducting wall*
   - *Investigation of wall coatings with high critical energy*
   - *Investigation of focusing neutron guides of UCN*
5. **Conclusion**

Brief history of helium UCN converters

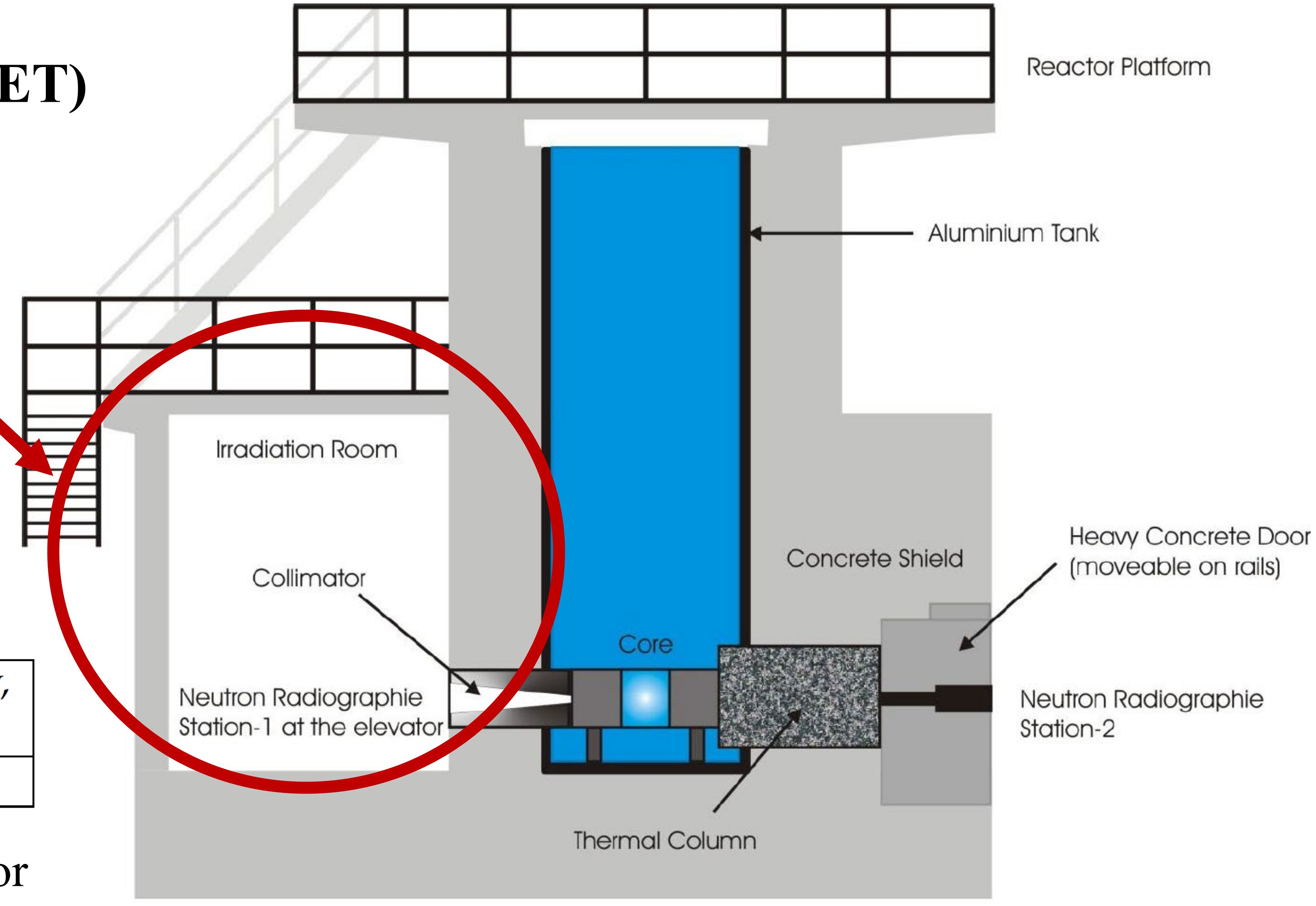
✓ Initial UCN source concept based on helium

Bulk Shielding Experimental Tank (BSET)

Concept of an UCN source:
- graphite moderator at room;
- SF^{4}He at a temperature below ~1 K;
- 12 cm thick bismuth gamma – screen;

Neutron source	TN flux, $n/cm^2/s$	Thermal load mW	UCN density, UCN/cm^3
TRIGA Mark II (250 kW)	$8 \cdot 10^{10}$	30	200

Parameters of the proposed UCN source at the TRIGA reactor

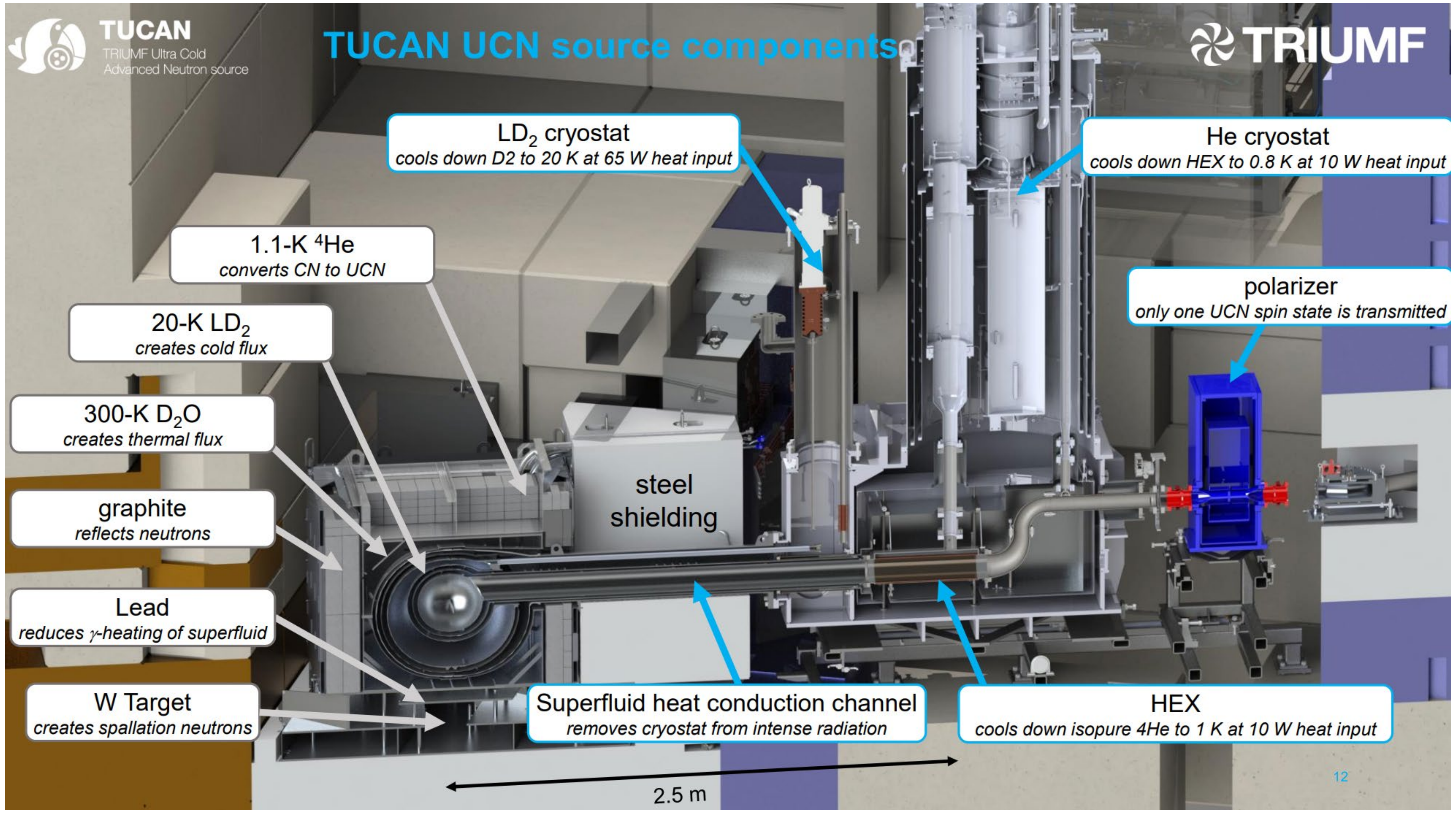


Vertical cross section TRIGA Mark II reactor in Vienna

Golub, R. Ultracold neutrons (UCN) at a Triga reactor. Nucl. Instrum. Methods Phys. Res. ***1984****, 226, 558–559.*

Other helium UCN source concepts

✓ TRIUMF TUCAN UCN source concept

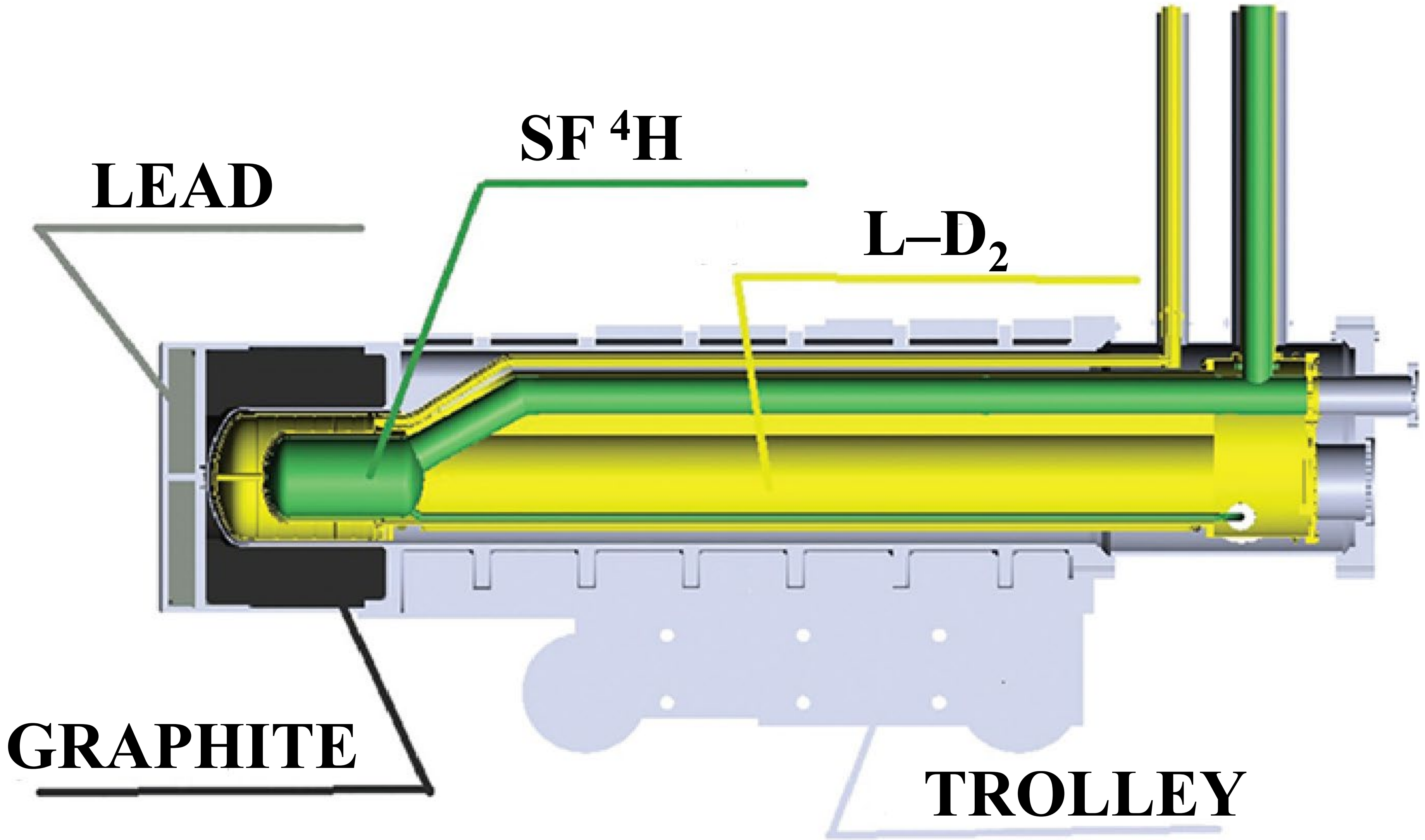


Accelerator power	**19.3 kW**
P_{UCN}	$(1.4\text{-}1.6)\cdot10^7$ UCN/s
ρ_{UCN} in exp. set.	220 UCN/cm^3

Schreyer,W.; Davis, C.A.; Kawasaki, S.; et al. Nucl. Instrum. Methods A **2020**, 959, 163525.

Other helium UCN source concepts

✓ WWR-M PNPI UCN source concept



Reactor power	16 MW
P_{UCN}	$(6\text{-}8)\cdot10^7$ UCN/s
ρ_{UCN} in exp. set.	10^4 UCN/cm^3

A P Serebrov et al 2017 J. Phys.: Conf. Ser. 798 012147

WWR type reactors

WWR-SM (Uzbekistan, 1959-now) 10 MW

WWR-M (Gatchina, RF, 1959-2015) 15 MW

WWR-M (Ukraine, 1960-2015) 10 MW

WWR-Ts (Obninsk, RF, 1964) 15 MW

WWR-K (Kazakhstan, 1967-now), Conversion, 2016 6 MW

First UCN

Lushchikov V. I., Yu.N.Pokotilovskii, A.V.Strelkov, F.L.Shapiro. *JETP Lett.* **9** 23 (1969)

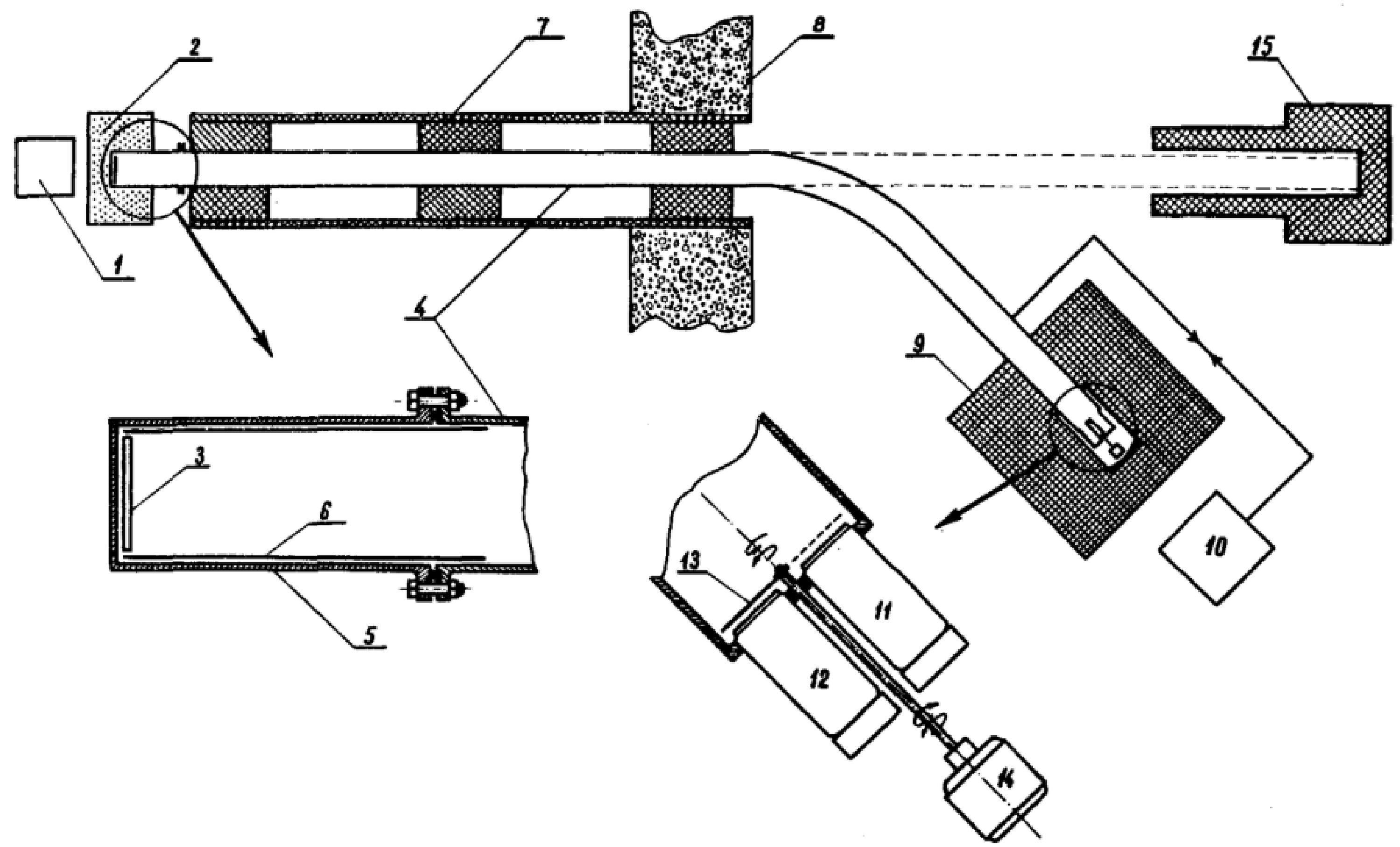

1968
IBR
6 кW

F. L. Shapiro **V. I. Lushikov**


A. V. Strelkov **Ye. N. Pokotilovsky**

OBSERVATION OF ULTRACOLD NEUTRONS

V. I. Lushchikov, Yu. N. Pokotilovskii, A. V. Strelkov, and F. L. Shapiro
Joint Institute for Nuclear Research
Submitted 18 November 1968
ZhETF Pis. Red. 9, No. 1, 40 - 45 (5 January 1969)



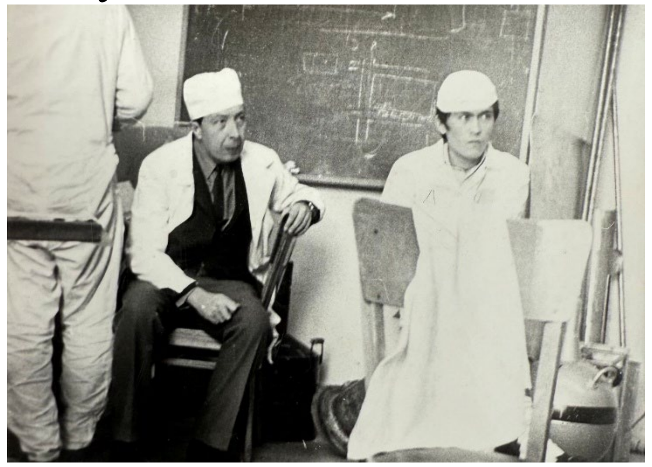
'ig. 1. Diagram of setup. 1- IBR reactor; 2, 3 - moderator (2 - paraffin, 3 - polyethylene .ayer 1 mm thick); 4 - copper tube, 9.4 cm i.d., total length 10.5 m; 5 - aluminum tube; 6 - :opper-foil cylinder; 7 - shield (paraffin with boron carbide); 8 - 2-m concrete wall of re- .ctor chamber; 9 - detector shield (paraffin); 10 - tube filling and evacuating system; 11, .2 - detectors (FEU-13 with layers of ZnS or ZnS + Li compound); 13 - copper shutter (gap ›etween shutter and detector < 1 mm); 14 - shutter mechanism; 15 - trap for direct beam.

First UCN in Kazakhstan

INSTITUTE OF NUCLEAR PHYSICS

INTERNATIONAL INTERGOVERNMENTAL ORGANIZATION JOINT INSTITUTE FOR NUCLEAR RESEARCH

Akhmetov, E.Z.; Kaipov, D.K.; Konks, V.A.; Lushchikov, V.I.; Pokotilovskii, Y.N.; Strelkov, A.V.; 474 Shapiro, F.L. Generation of ultracold neutrons at the stationary WWR-K reactor. At. Energy **1974**, 475 37(1), 35–38. (In Russ.)



Kaipov D.K. Akhmetov E.Z.

1973

Shapiro F.L **Lushchikov V.I**

Strelkov, A.V. **Pokotilovskii, Y.N**

«АТОМНАЯ ЭНЕРГИЯ», Т. 37, ВЫП. 1, ИЮЛЬ

Получение ультрахолодных нейтронов на стационарном реакторе ВВР-К

АХМЕТОВ Е. З., КАИПОВ Д. К., КОНКС В. А., ЛУЩИКОВ В. И., ПОКОТИЛОВСКИЙ Ю. Н., СТРЕЛКОВ А. В.,

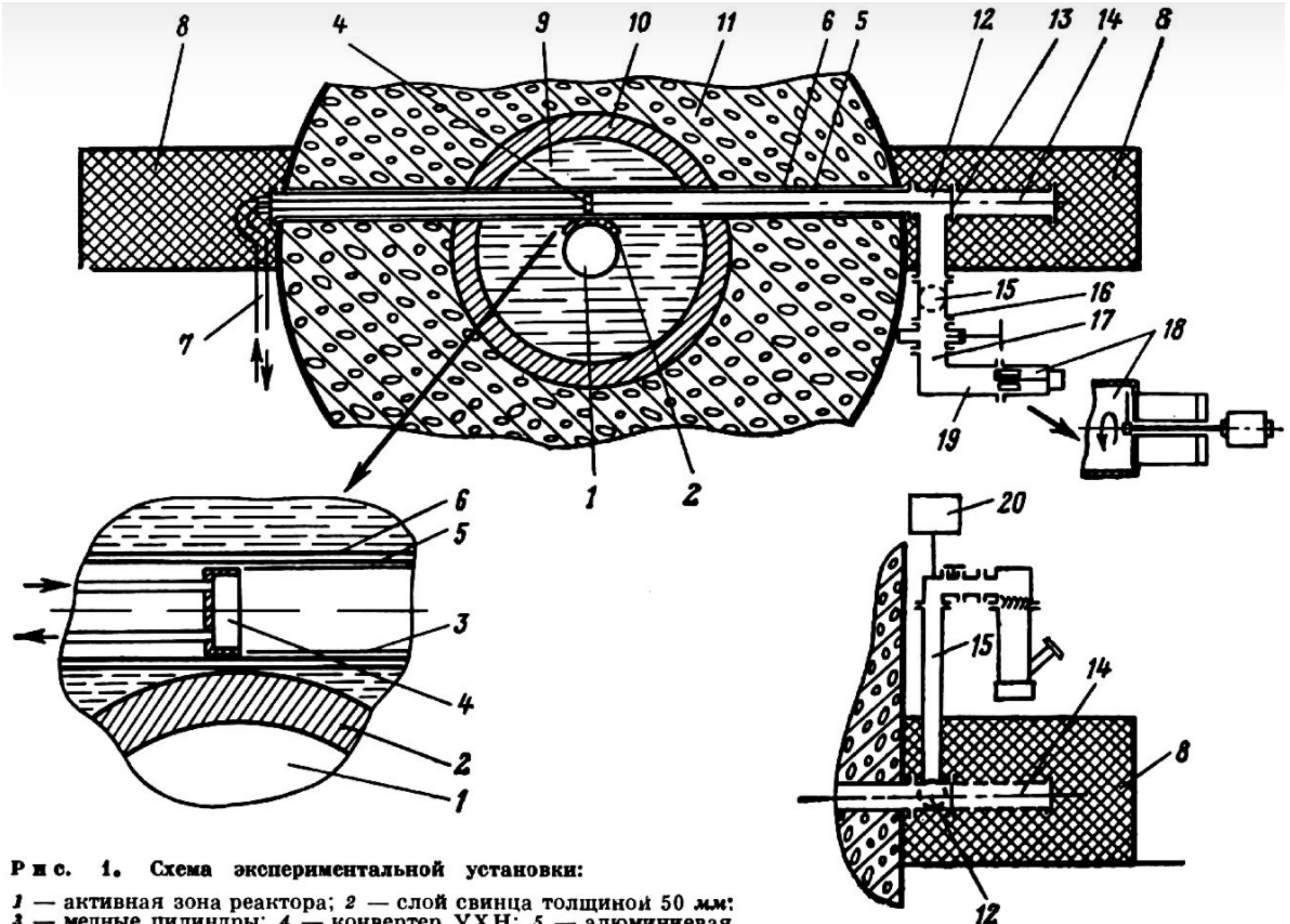
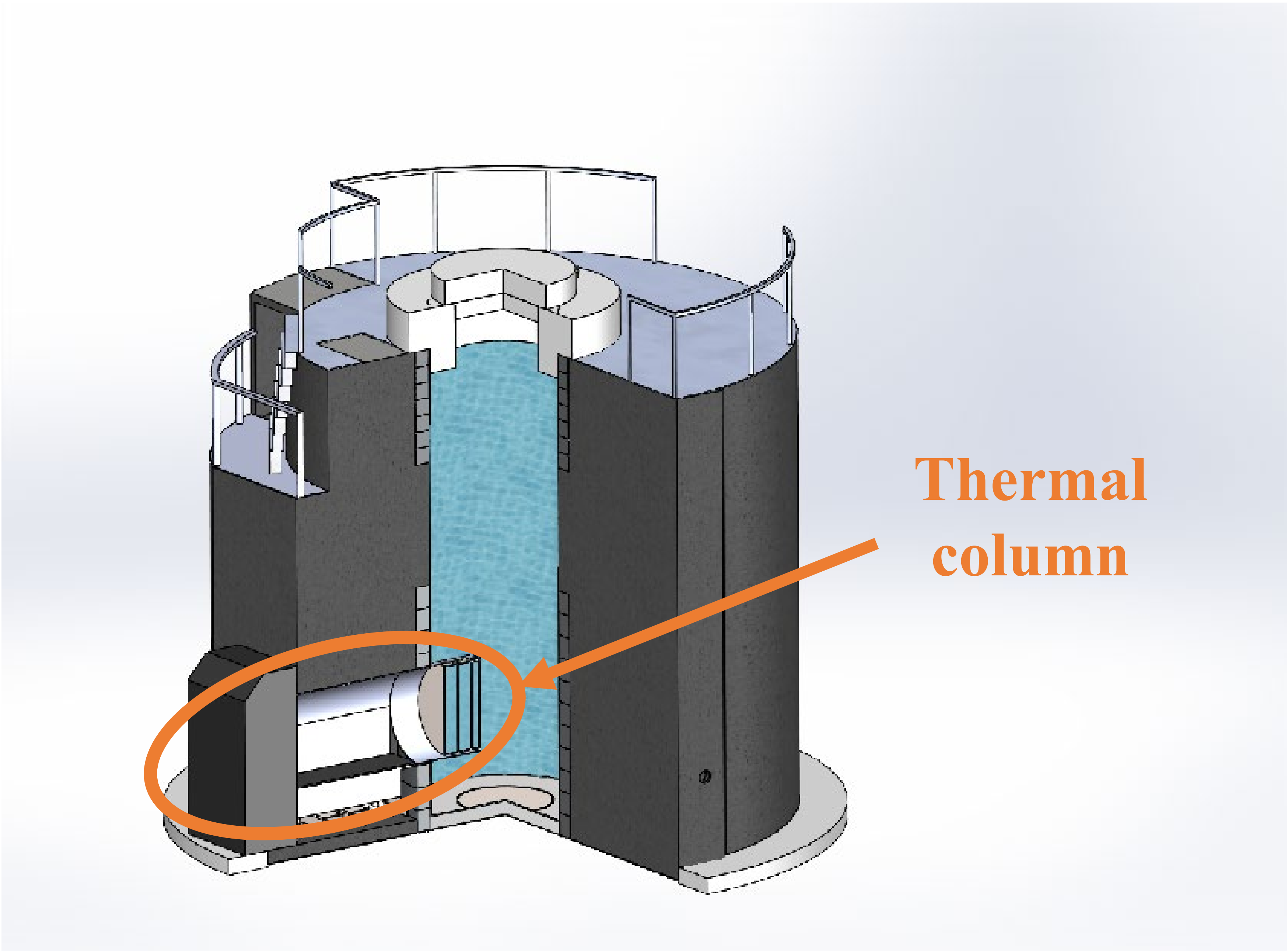


Рис. 1. Схема экспериментальной установки:

1 — активная зона реактора; *2* — слой свинца толщиной 50 *мм*; *3* — медные цилиндры; *4* — конвертер УХН; *5* — алюминиевая труба; *6* — сквозной касательный канал реактора; *7* — система охлаждения конвертера; *8* — защита прямого пучка; *9*, *10*, *11* — водяная, чугунная и бетонная защиты реактора соответственно; *12*, *16*, *17*, *19* — медные участки нейтроновода; *13* — медная фольга; *14* — алюминиевая труба; *15* — вертикальный участок нейтроновода для вакуумной откачки; *18* — детектор УХН; *20* — система наполнения и контроля давления гелия.

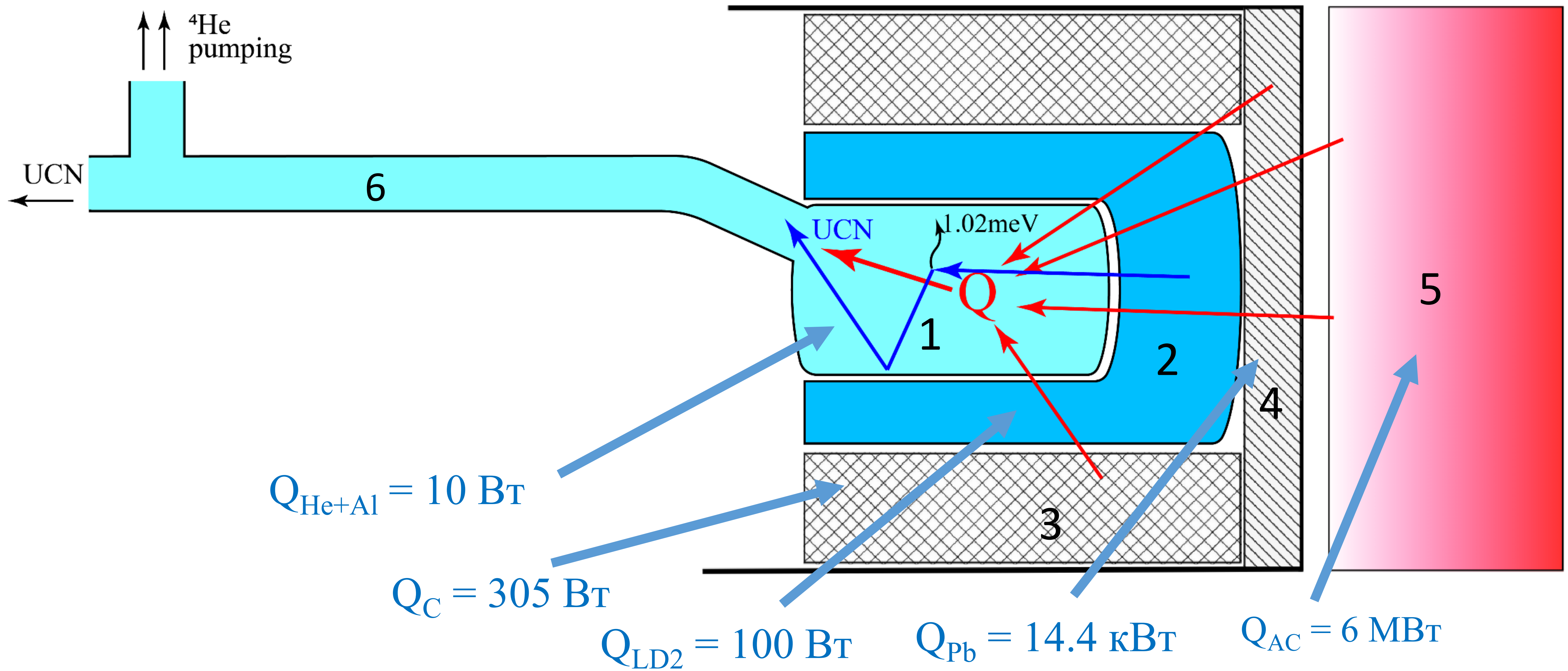
Reactor WWR-K



Reactor WWR-K
- Power 6 MW
- Flux density $2.2 \cdot 10^{14}\ \mathrm{n/cm^2 \cdot s}$
- Ideal for UCN source

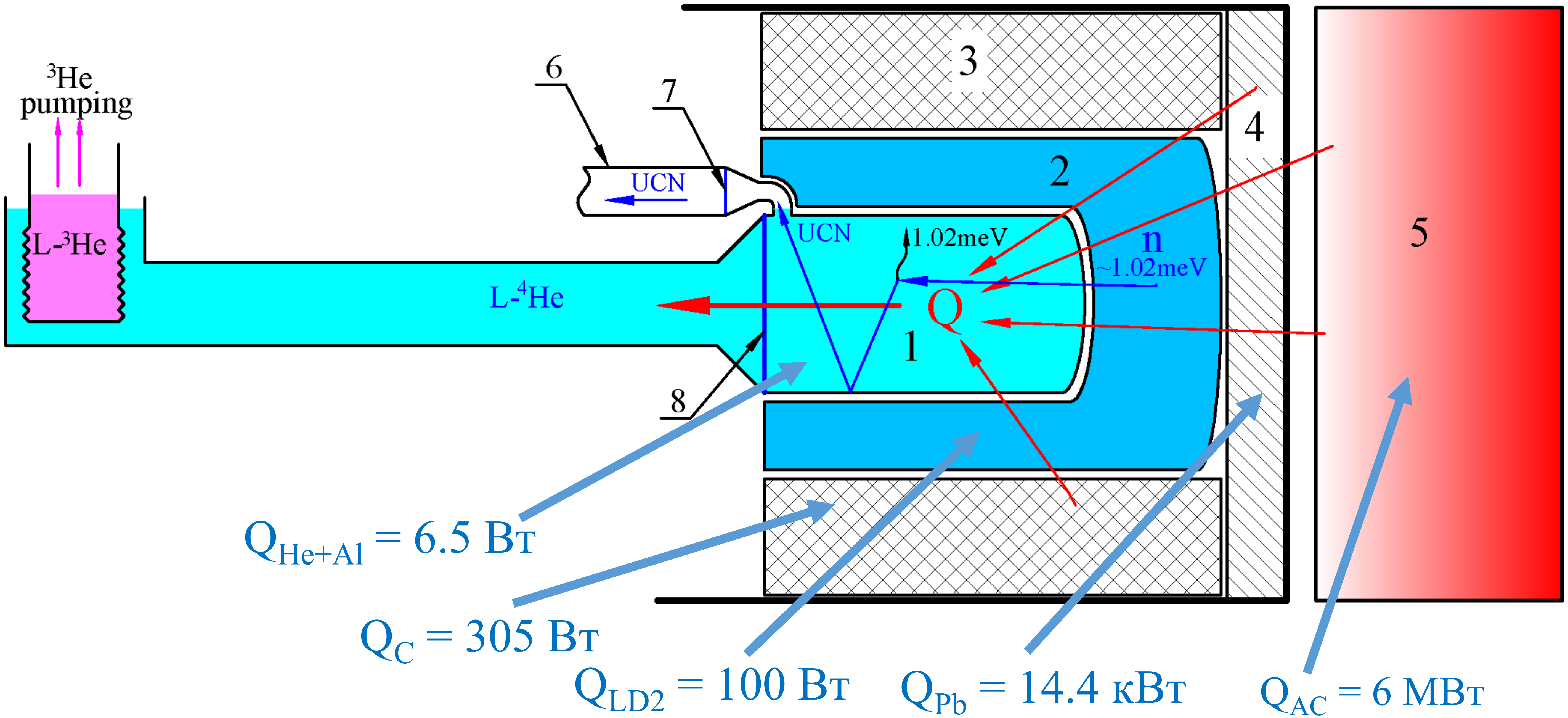
Thermal column
- Diameter: 1 m
- Close to active core

Basic concept of UCN source



1 - tank with liquid 4He, temperature T > 1 K; 2 - liquid deuterium, T ~20 K; 3 - graphite, T ~300 K; 4 - lead; 5 - reactor core; 6 - pipe for transportation of UCN and heat;

Concept of the UCN source at the WWR-K reactor



1 – trap with SF ^4He at a temperature T<1 K; 2 – LD_2, T~20 K; 3 – graphite, T~300 K; 4 – Pb; 5 – reactor active zone; 6 – neutron guide; 7 – separating foil; 8 – heat-conducting wall.

Article

Concept of the UCN Source at the WWR-K Reactor (AlSUN)

Kylyshbek Turlybekuly [1,3]*, Asset Shaimerdenov [1], Darkhan Sairanbayev[1], Avganbek Sabidolda[1], Zhanibek Kurmanaliyev[1], Akzhol Almukhametov[1], Ekaterina Korobkina[2], Egor Valeryevich Lychagin[3], Alexey Yurievich Muzychka[3], Valery Viktorovich Nesvizhevsky[4] and Cole Teander[5]

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2 Department of Nuclear Engineering, North Carolina State University, Raleigh, NC 27695, USA
3 Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, 6 Joliot Curie, Ru-141980 Dubna, Russia
4 Institut Max von Laue—Paul Langevin, 71 Av. des Martyrs, F-38042 Grenoble, France
5 Department of Physics, North Carolina State University, Raleigh, NC 27695, USA

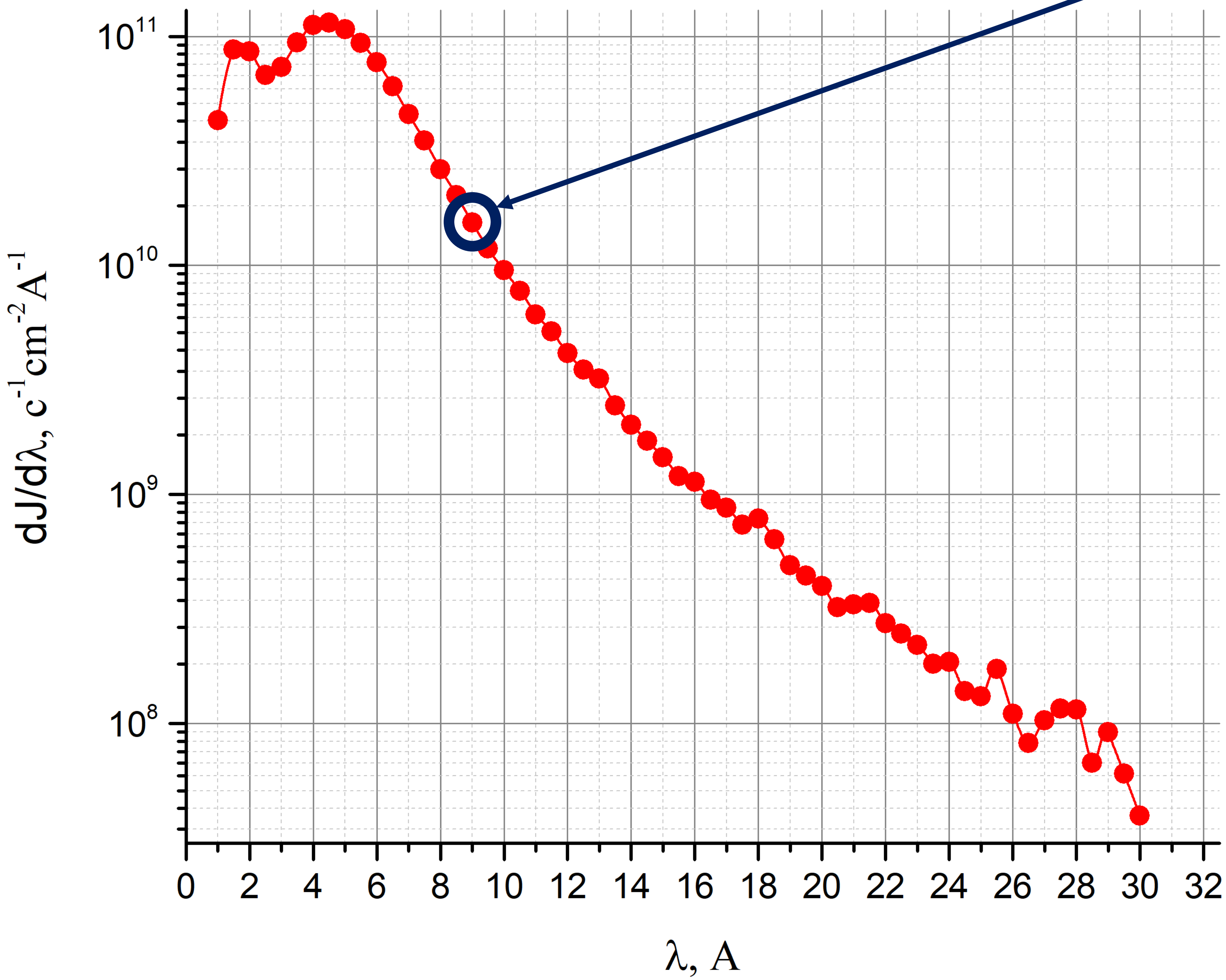
Abstract: We present the concept of the ultracold neutron (UCN) source with a superfluid helium-4 converter located in the thermal column of the WWR-K research reactor in Almaty, Kazakhstan. The conceptual design is based on the idea of an efficient system for accumulating UCNs in the source and transporting them to experimental setups. We propose to achieve an increase in the UCN density in the source by separating the heat flow and the UCN flow from the source, lowering the temperature of the SF 4He converter below ∼1 K and the coefficient of UCN loss in the walls of the accumulation trap. The temperature decrease is expected to be achieved by increasing the efficiency of the helium cooling system, as well as by reducing the thermal load on the UCN accumulation trap walls. A large total number of accumulated UCNs is expected to be achieved due to the high critical velocity of the wall material of the accumulation trap. The implementation of such a design critically depends on the availability of materials with specific UCN and cryogenic properties. This paper describes the conceptual design of the source, discusses its implementation methods and material requirements, and plans for material testing studies.

Special issue in Materials, MDPI, devoted to Workshop in Kazakhstan (2024):
New Materials for Neutron Sources and Instruments
https://www.mdpi.com/journal/materials/special_issues/1XF70W3M3M
https://indico.inp.kz/event/3/

Estimates of the 8.9 Å neutron fluxes

Goorley, J.T.; et al. Initial MCNP6 Release Overview - MCNP6 version 1.0. LA-UR-13-229342013.

dJ/dλ (8.9 A) = 1.62·10^{10} ***cm^{-2} s^{-1} Å^{-1}***



Differential neutron flux density averaged over the volume of SF ^{4}He trap.

Estimates of UCN production

$^{Be}R = 4.55\cdot10^{-8} \cdot dJ/d\lambda\ (8.9\ A)\ cm^{-3}s^{-1}$

Let UCNs are produced in a trap with Be-coated walls

Spectrum will be as follows

$dR(E)/dE \sim \sqrt{E}$

The rate of production of UCNs

$R(E_{lim}) \sim (E_{lim} - E_{He})^{3/2}$

The production rate of the UCN source

$P_{UCN} = RV \rightarrow {}^{Be}P_{UCN} = 2.6\cdot 10^{7}\ UCN/s$

$$\rho_{UCN} = \tau^0_{stor}\cdot R = \tau^0_{stor}\cdot P_{UCN} / V$$

$$\frac{1}{\tau^0_{stor}} = \frac{1}{\tau_{He}} + \frac{1}{\tau_{wall}} + \frac{1}{\tau_\beta}$$

He temperature, K	τ_{He}, s	τ^0_{stor}, s
1.2	35	27
1.1	70	44
1.0	130	62
0.9	260	82
0.8	610	100

$$\boxed{\rho_{UCN}\ (0.9\ K) = 6.1\cdot 10^{4}\ UCN/\ cm^{3}}$$

Extraction and transport of UCNs

Estimation of the density of UCNs in the experimental setup

The experimental setup has the same volume as the source and has the same storage time $\boldsymbol{\tau^0_{stor}}$ as it is in the source

$$\boldsymbol{\rho_{exp}} = \boldsymbol{\rho_{max}}/8$$

Lost factor in the source: 2
Lost factor in the neutron guide: 2
Lost factor in the experimental setup with same volume and no SF ^{4}He: 1.65

$$\boldsymbol{\rho_{exp}} = \boldsymbol{\rho_{max}}/6.6 = 9.2 \cdot 10^3 \text{ UCN/cm}^3$$

Corrections

Factor 1: cutoff of the UCN spectrum on the side of high energies, $k_1 = 0.81$
Factor 2: decrease in the exit flux from the source, $k_2 = 0.88$
Factor 3: 0.1 mm thick separating Al foil, $k_3 = 0.74$

$$\boxed{\boldsymbol{\rho_{exp} = k_1\, k_2\, k_3\, \rho^0_{exp} = 4.9 \cdot 10^3\ \text{UCN/cm}^3}}$$

Parameters of different concepts

Improved concept of the UCN source

Flux density (8.9 Å)**:**

$\mathbf{dJ/d\lambda = 1.62 \cdot 10^{10}}$ ***cm*** $^{-2}$ ***s*** $^{-1}$ ***Å*** $^{-1}$

SF ^{4}He vessel wall material:

AlBeMet

SF ^{4}He vessel volume:

V=35 л

SF ^{4}He temperature:

T = 0.9 K

UCN density in the source:

$\boldsymbol{\rho \sim 6.1 \cdot 10^4}$ ***см*** $^{-3}$

UCN density in the exp. setup :

$\boldsymbol{\rho \sim 5 \cdot 10^3}$ ***см*** $^{-3}$**.**

Basic concept of UCN source

Flux density (8.9 Å)**:**

$\mathbf{dJ/d\lambda = 1.62 \cdot 10^{10}}$ ***cm*** $^{-2}$ ***s*** $^{-1}$ ***Å*** $^{-1}$

SF ^{4}He vessel wall material:

Al

SF ^{4}He vessel volume:

V=35 l

SF ^{4}He temperature :

T = 1.25 K

UCN density in the source :

$\boldsymbol{\rho \sim 2.1 \cdot 10^4}$ ***cm*** $^{-3}$

UCN density in the exp. setup:

$\boldsymbol{\rho \sim 1.7 \cdot 10^3}$ ***см*** $^{-3}$**.**

Investigations on improvement of UCN concept at WWR-K reactor

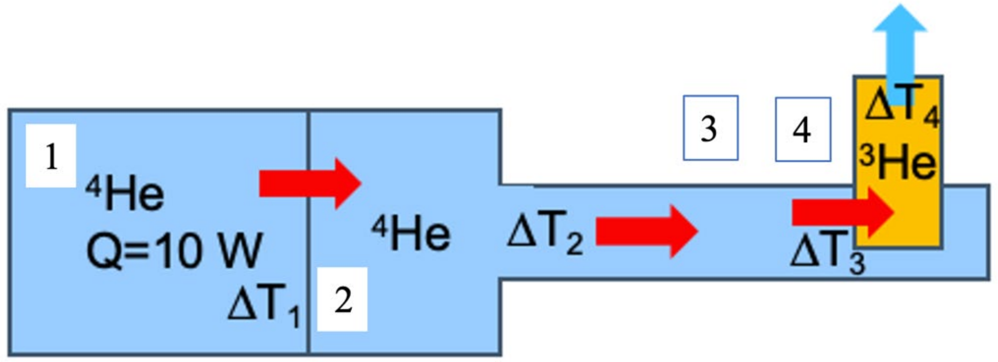
- Investigation of the cooling system with a heat conducting wall

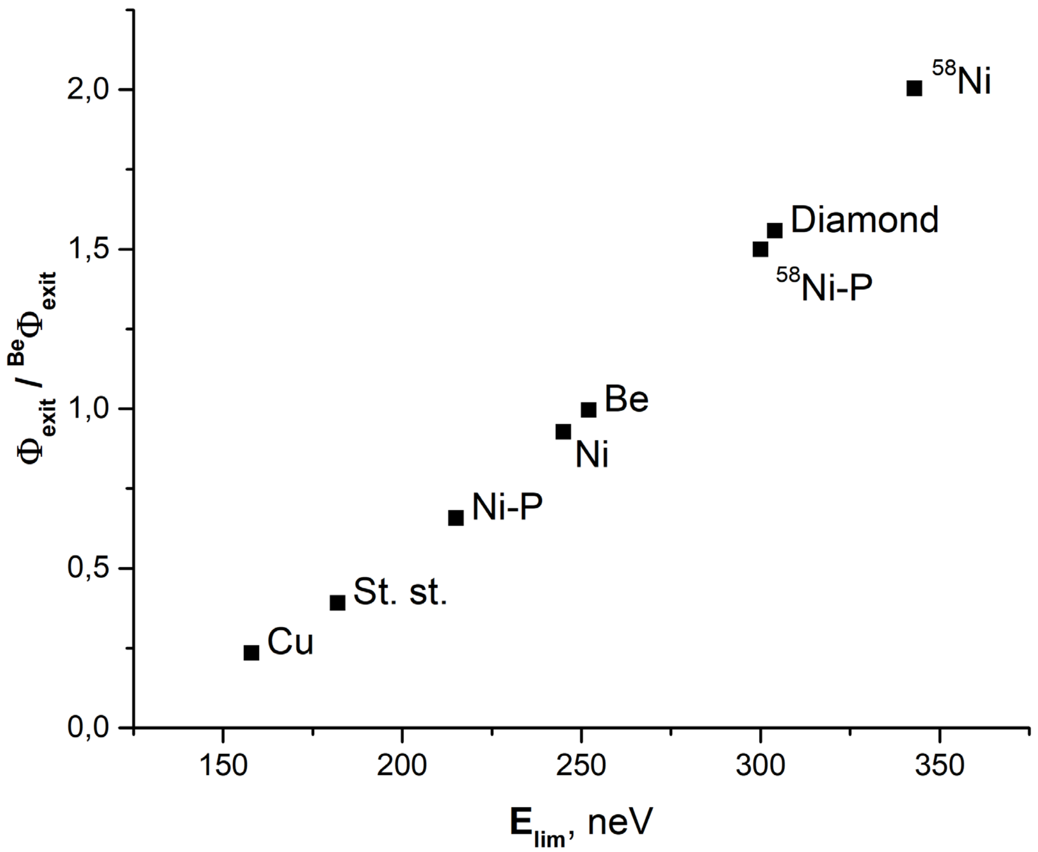
- Investigation of wall coatings with high critical energy

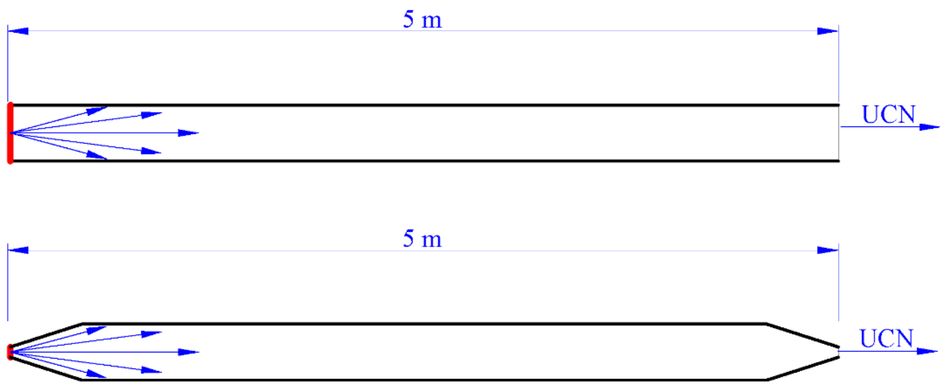
Modeling and Optimization of Experimental Setup Geometry for Measuring Ultracold Neutron Loss Factors Using Gravitational Spectroscopy *Speaker: Zhanibek Kurmanaliyev*

- Investigation of focusing neutron guides of UCN

Calculation for Improving the Efficiency of Ultracold Neutron Transport Using Monte Carlo Method *Speaker: Khac Tuyen Pham*







Conclusion

- The basic concept of UCN source based on helium is well developed and studied
- The WWR-K reactor is ideal place for helium UCN source
- The improved concept of UCN source based in helium is developed
- Additional investigations should be done to achieve an increase in the UCN density

Thank you for your attention!