NATIONAL RESEARCH CENTRE
«KURCHATOV INSTITUTE»

PETERSBURG NUCLEAR PHYSICS INSTITUTE
Russia, 188300, Leningrad District , Gatchina, Orlova Roscha

V. AKSENOV

REACTOR PIK AND EUROPEAN NEUTRON LANDSCAPE

1. Reactor PIK
2. Nuclear Physics Instrumentation
3. PIK, ESS, what's after?

ISINN-24, Dubna, May 24, 2016

REACTOR PIK

Petersburg Nuclear Physics Institute of the NRC "Kurchatov Institute"

Central part of the reactor complex PIK (2014)

Reactor Complex PIK

Start up complex №1.
Facilities of reactor complex PIK for the first criticality
(commissioned in 2009)

2011 a critical state of the fuel assembly was achieved and a complete test of the reactor systems was produced without coolant at W = 100 W

Reconstruction of the Laboratory Complex PIK

Buildings of the Laboratory Complex

Reconstruction of the Laboratory Complex PIK

Buildings of the Laboratory Complex

Bldg. 104
Neutron guide hall
and laboratories

Bldg. 100E
Cryogenic housing of UCN

Petersburg Nuclear Physics Institute of the NRC “Kurchatov Institute”

Technical engineering infrastructure

Building 100B – Equipment of primary cooling

Petersburg Nuclear Physics Institute of the NRC "Kurchatov Institute"

Building 100G – Equipment of secondary cooling

Petersburg Nuclear Physics Institute of the NRC "Kurchatov Institute"

Building 116 – backup diesel power station, backup control panel, training and modeling complex

Petersburg Nuclear Physics Institute of the NRC "Kurchatov Institute"






Building 122 – Emergency storage of liquid radioactive waste

Petersburg Nuclear Physics Institute of the NRC “Kurchatov Institute”

Building 104 – Neutron guide hall

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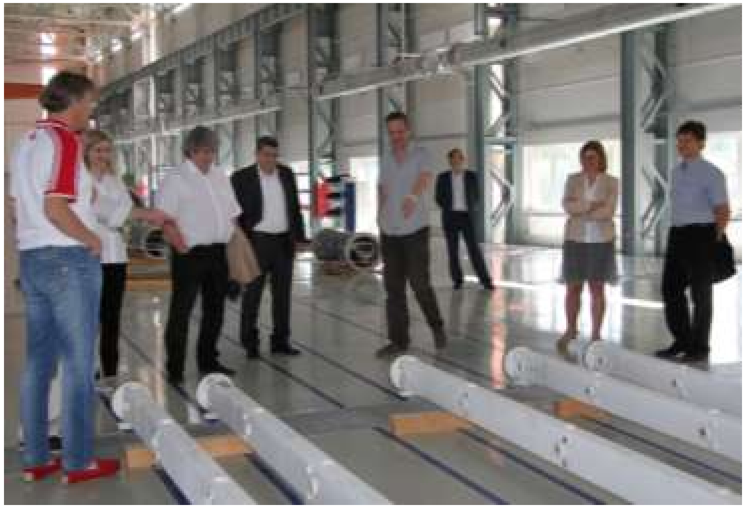
1st NSAC Meeting (10-11 March 2015) @ PNPI, Gatchina

Experimental Stations for Condensed Matter



NUCLEAR PHYSICS INSTRUMENTATION

Pulsed Neutron Sources for Nuclear Physics

Neutron source (laboratory)	$\langle I_n \rangle$, 10^{15} n/s	Δt, ns	Q, 10^{30} n/s³	Number of instruments for nuclear physics experiments
LANSCE (LANL, USA)	10	1-125	0.64*)	8 (total, partial cross sections) + ICE House test facility
n_TOF (CERN, Switzerland)	0.4	10	4	6 (total, capture, fission, scattering,(n,α))
ORELA (ORNL, USA)	0.13	2-30	0.14*)	5 (total, partial cross sections)
GELINA (IRMM, Belgium)	0.025	1	25	5 (total, partial cross sections)
GNEIS (PNPI, Gatchina)	0.3	10	3	3 (total, capture, fission) + ISNP/GNEIS test facility
IREN (JINR, Dubna, project)	1.0	400	0.0062	under construction

<In> - average intensity of neutrons emitted in 4π solid angle

Δt - neutron pulse width

$Q = \langle I_n \rangle / (\Delta t)^2$ - quality coefficient of the neutron source

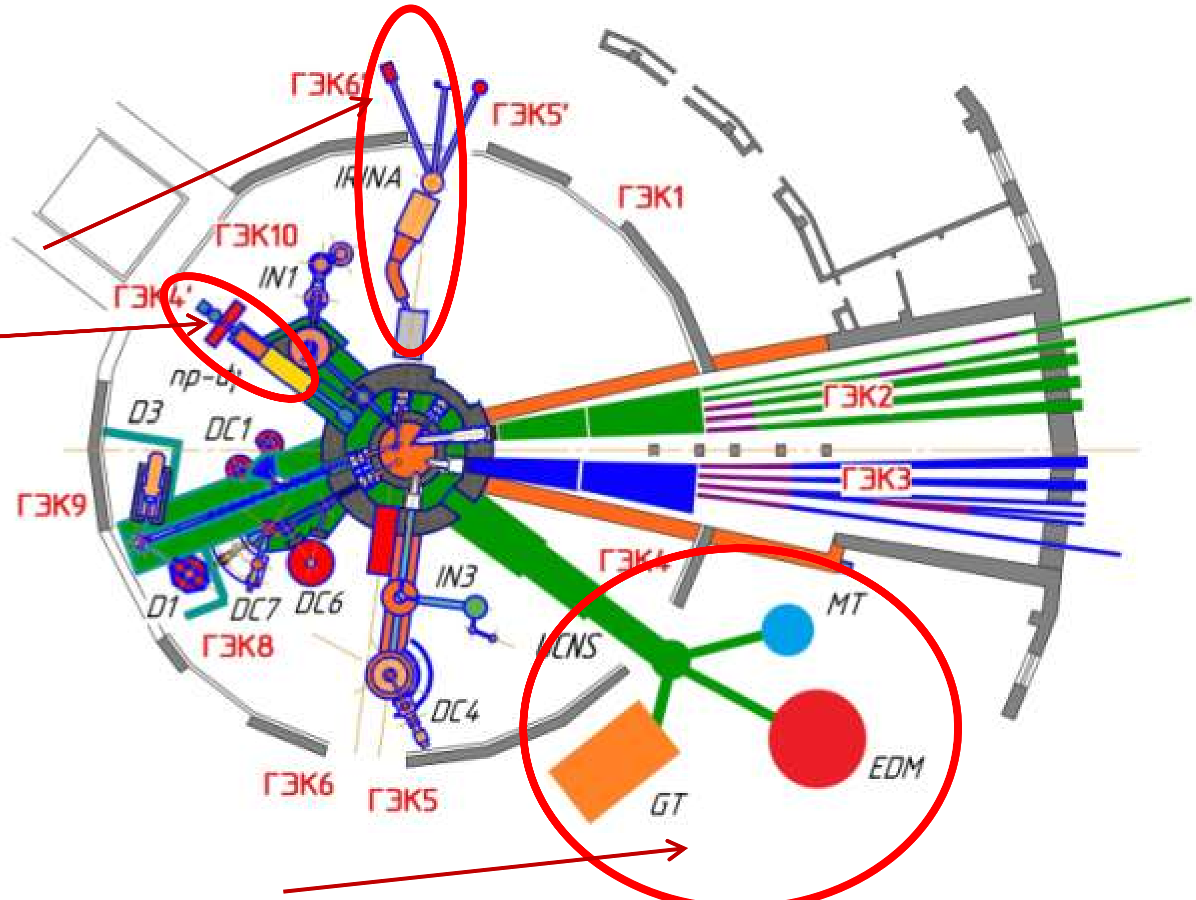
*) - present value corresponds to maximum pulse width

O.A. Sherbakov

Advanced High Flux Neutron Sources

	PIK	ILL	FRM-II	ISIS	SNS	J-Park	IBR-2
Diffraction	7	13	9	12	6	7	6
SANS	6	5	6	4	2	1	1
Spectroscopy	5	17+3	10	8	9	4	2
Reflectometry	4	3	2	5	2	2	3
Nuclear Physics	9	7	4	-	1	3	2
Sum	32	45+3	31	29	20	17	14

Hall of Horizontal Channels – Particle Physics



2nd phase

IRINA - Mass separator laser-nuclear complex

Neutron decay – Polarized cold neutron beam facility

n4 – Setup «Neutrino» (located in the under-reactor space)

1st phase

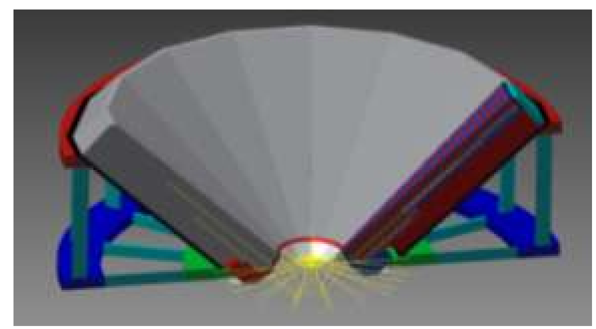
- **MT** - Installation for measurement of the neutron lifetime using a magnetic storage of ultracold neutrons
- **GT** - Large gravitational trap for measuring the neutron lifetime
- **EDM** - magnetic resonance spectrometer to measure the EDM using UCN

New generation of neutron lifetime experiments

Big Gravitrap

Magnetic trap

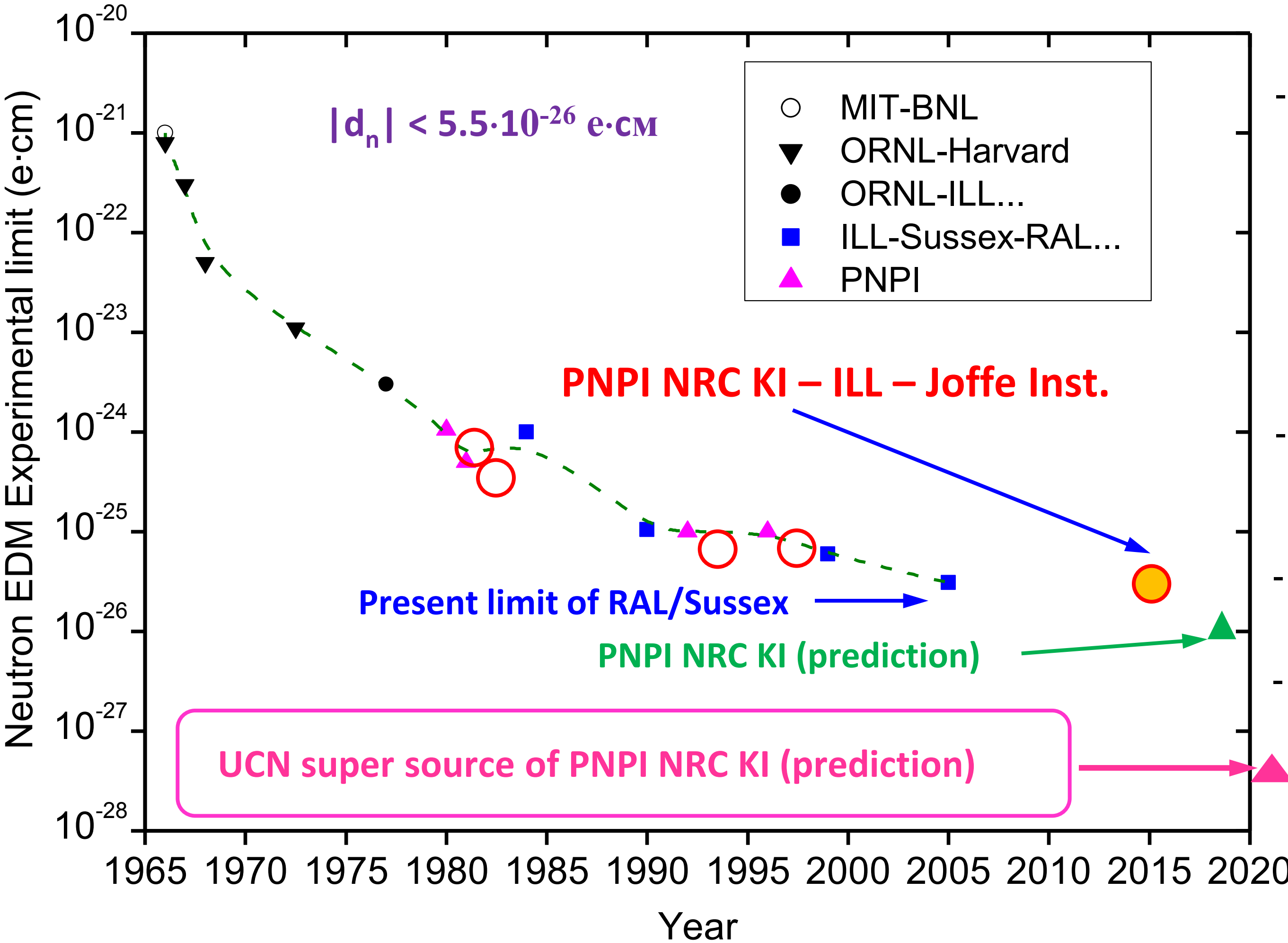
τ_{beam}-τ_{ucn}=8.4(2.2)s (3.8σ)



Goal: to reach accuracy **0.2 sec** by the **storage of neutron in material trap** *(A.P. Serebrov)*

Goal: to reach accuracy **0.2 sec by magnetic storage of neutron** *(V.F. Ezhov)*

Neutron electric dipole moment



- Weinberg Multi-Higgs
- Minimal SUSY

Cosmology

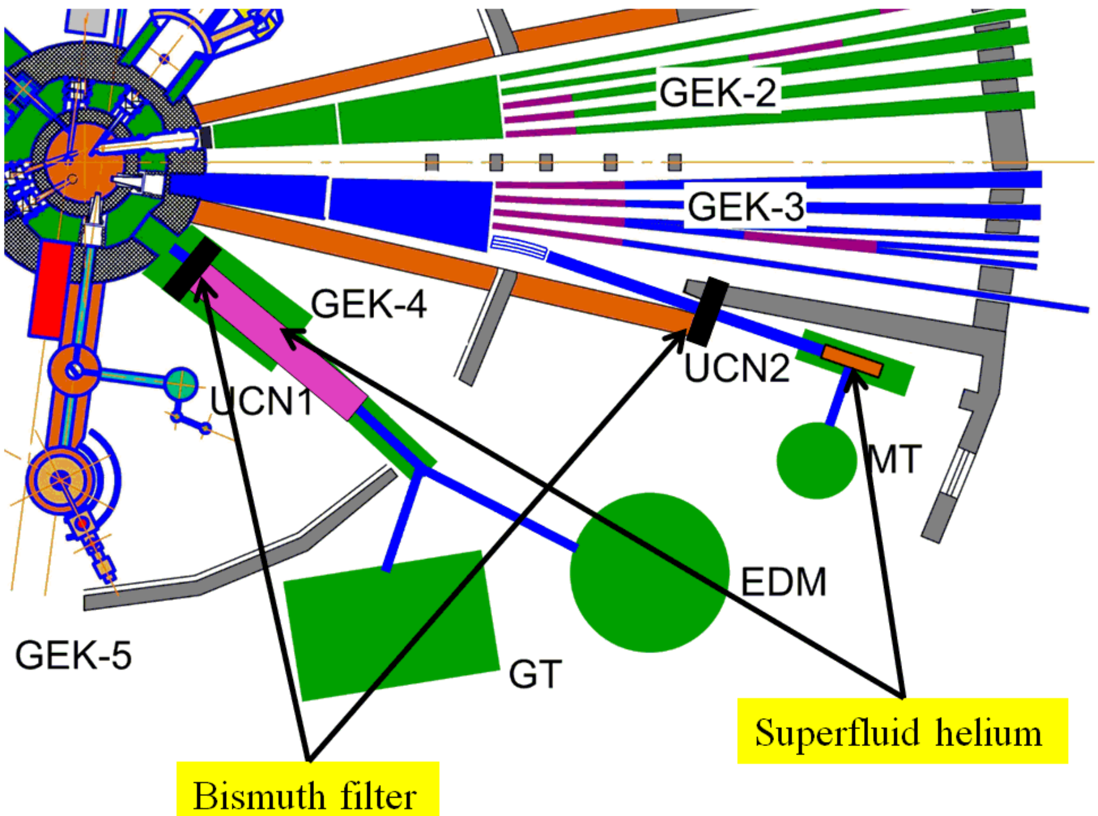
- Left-Right Symm.

Teoretical prediction

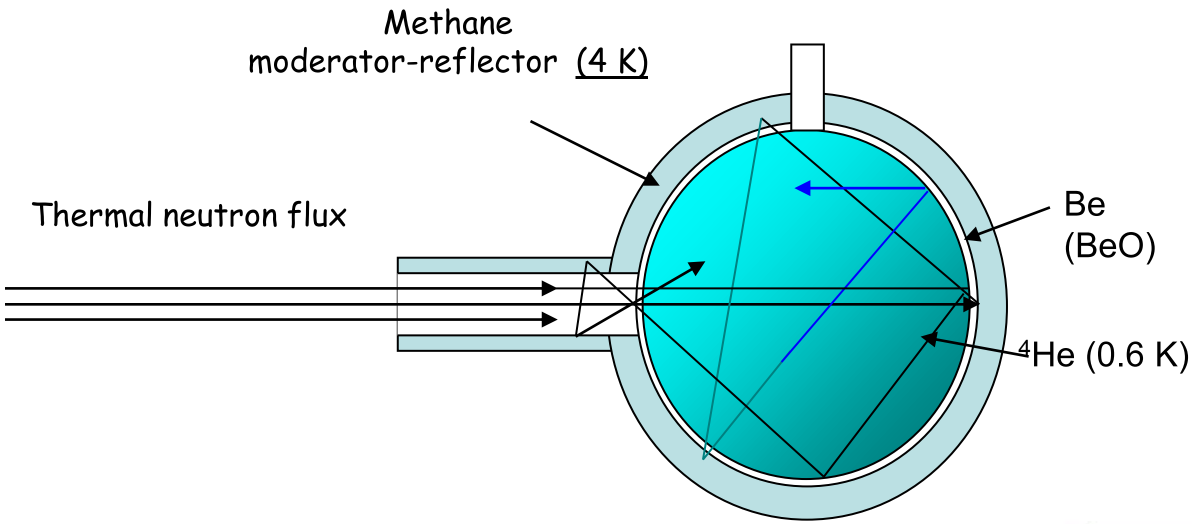
A.P. Serebrov, et al., JETP Letters, 99, pp. 4–8, (2014)

UCN beam positions at PIK reactor

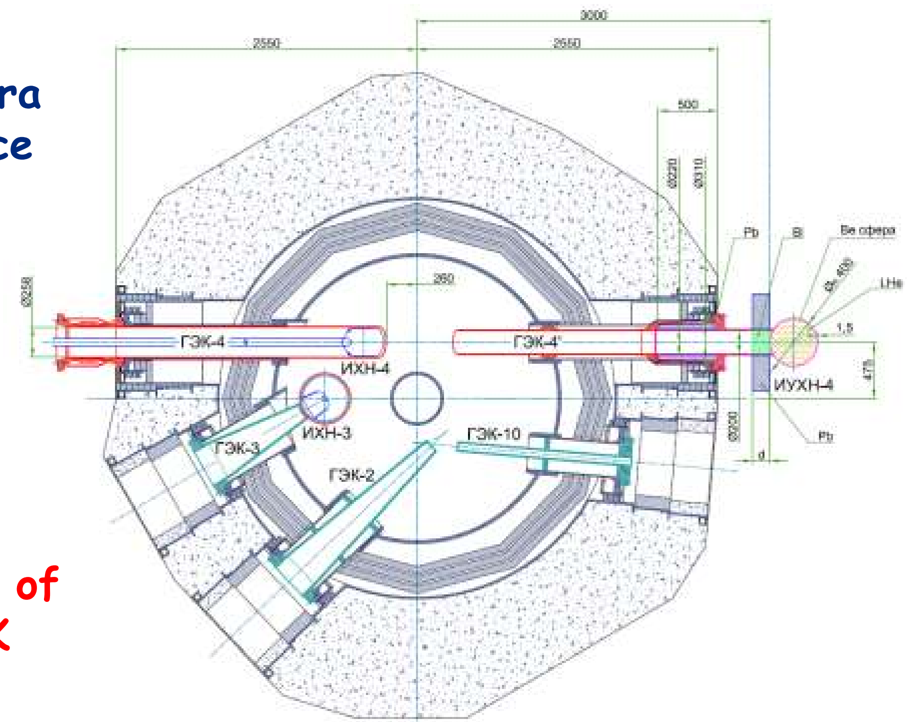
Ultracold neutron source with superfluid 4He converter.
The production rate of UCNs expected about **100 $cm^{-3} \cdot s^{-1}$**.
The expected UCN density **>10^3 cm^{-3}**, that **exceeds the available and planed density of the world UCN sources at one order of value**.



Helium Ultra Cold Neutron Source



Schematic view of the idea of the helium ultra cold neutron source on thermal neutron source

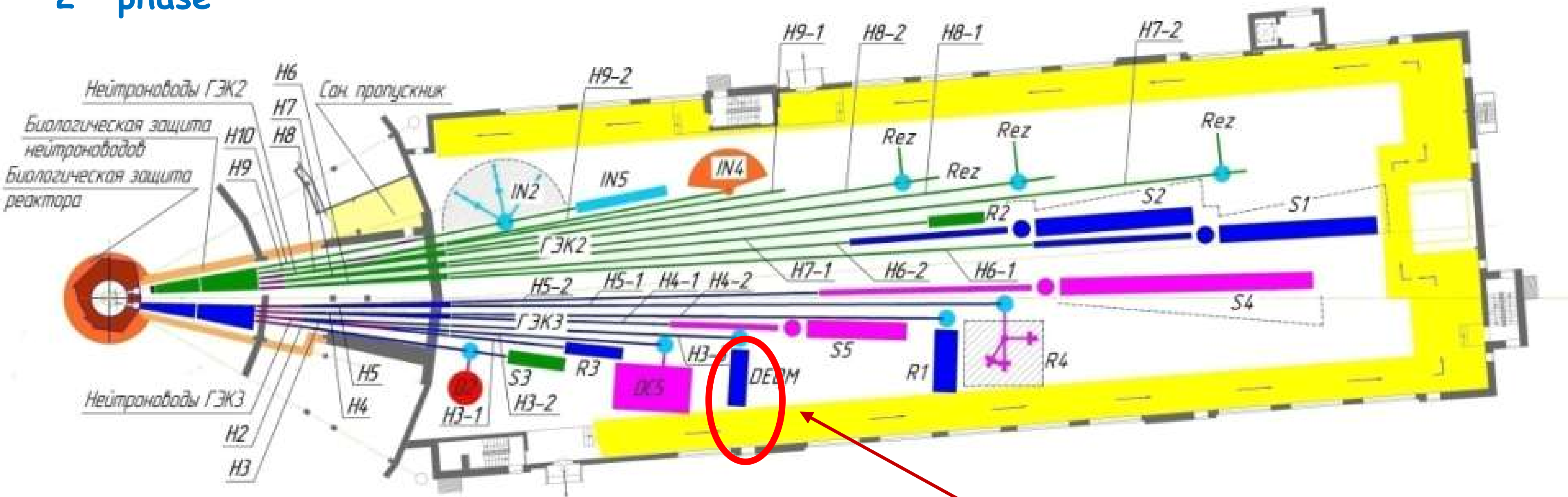


E.V. Lychagin, A.Yu. Muzychka,
G.V. Nekhaev, E.I. Sharapov,
A.V. Strelkov (JINR, Dubna),
V.V. Nesvizhevsky (ILL, Grenoble)

Placement option on extracted channel of thermal neutrons of the reactor PIK

Neutron Guide Hall – Particle Physics

2nd phase



DEDM – Position on cold neutron beam

<u>The first stage scientific program which can be realize here</u>

1. neutron EDM search using the diffraction in a noncentrosymmetric crystal

electric field value 10^8- 10^9 V/cm, which is 10000 higher than in UCN method.

Final goal is to reach (2-3) 10^{-27}e cm

Crystal-diffraction study of the fundamental neutron properties –

1. Equivalence of inertial and gravitational masses with 10^{-5} accuracy
2. Test of neutron electro neutrality with accuracy 10^{-22}e

Understanding of the nucleus

Nuclear Structure
(nuclear models)

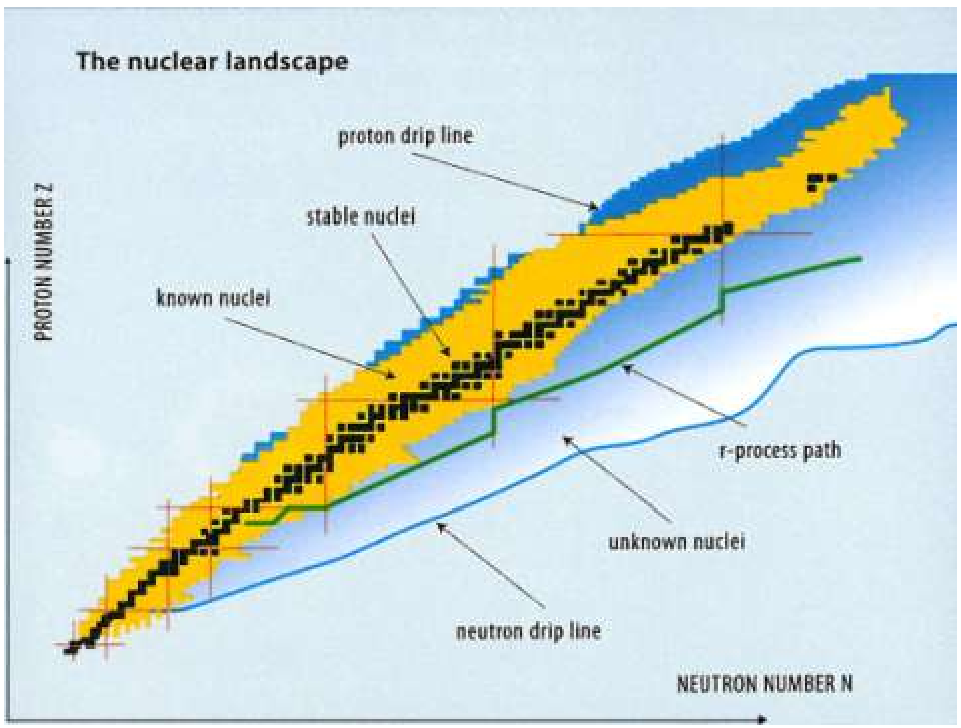
Fission Physics

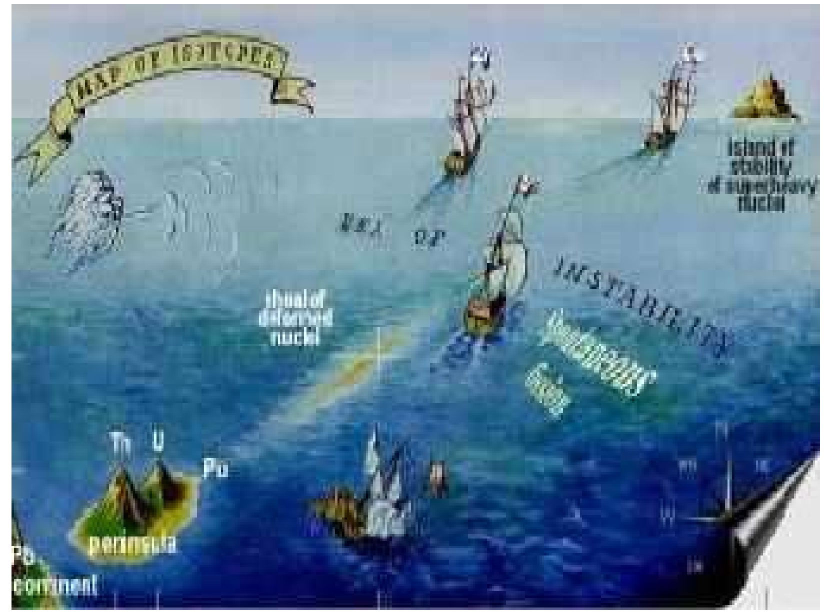
Nuclear Data

Superheavy elements
Gatchina-Dubna

Probing exotic
(n-rich) nucleus

Phase Transitions
in nuclei





Astrophysics
(where do the heavy
elements come from?)

red giant stars (s-process)

super nova (r-process)

Периодическая таблица элементов Д.И.Менделеева

группы элементов

период	ряд	I	II	III	IV	V	VI	VII	VIII		
1	I	H 1							He 2		
2	II	Li 3	Be 4	B 5	C 6	N 7	O 8	F 9	Ne 10		
3	III	Na 11	Mg 12	Al 13	Si 14	P 15	S 16	Cl 17	Ar 18		
4	IV	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28
4	V	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36		
5	VI	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46
5	VII	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54		
6	VIII	Cs 55	Ba 56	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78
6	IX	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86		
7	X	Fr 87	Ra 88	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	110
7	XI	111	112	(113)	114	(115)	116	(117)	(118)		

s-элементы

p-элементы

d-элементы

f-элементы

Лантаноиды Lanthanides

Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71

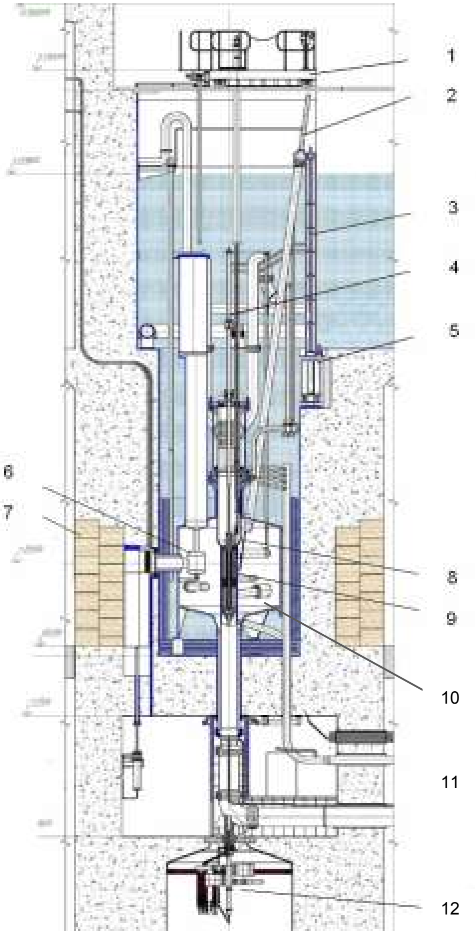
Актиноиды Actinides

Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

[illegible] IUPAC (Handbook of Chemistry and Physics. Ed. D.R.Lide, 74th edition, 1993-1994, CRC Press, and Eur.Phys.J. C 3, 1-794 (1998), Springer-Verlag 1998).
[illegible] IUPAC [illegible]

Petersburg Nuclear Physics Institute of the NRC "Kurchatov Institute"

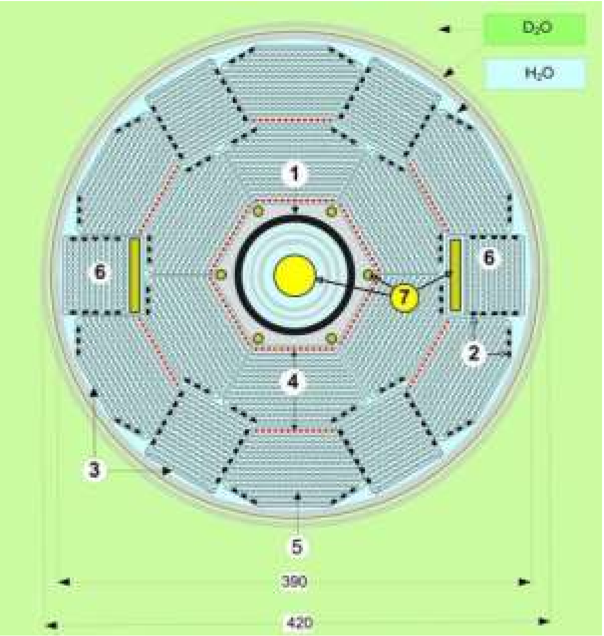
Drawing of the PIK reactor



1 – reloading machine
2 – rod drive
3 – hydro seal
4 – central experimental channel (CEC)
5 – reloading cylinder
6 – cold neutron source
7 – dismountable shielding
8 – absorber rod
9 – reactor vessel with the core
10 – heavy water reflector
11 – horizontal experimental channel (HEC)
12 - shutters drive

Chief designer: JSC "NIKIET"

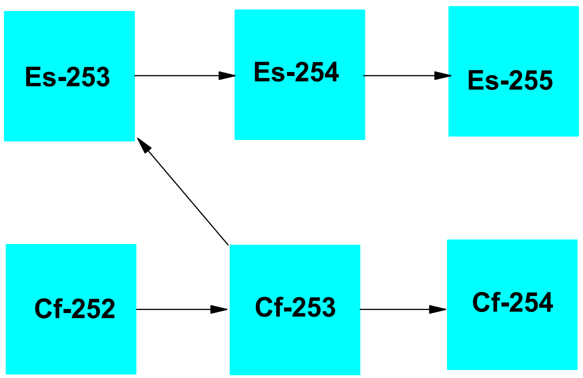
The core of the PIK reactor

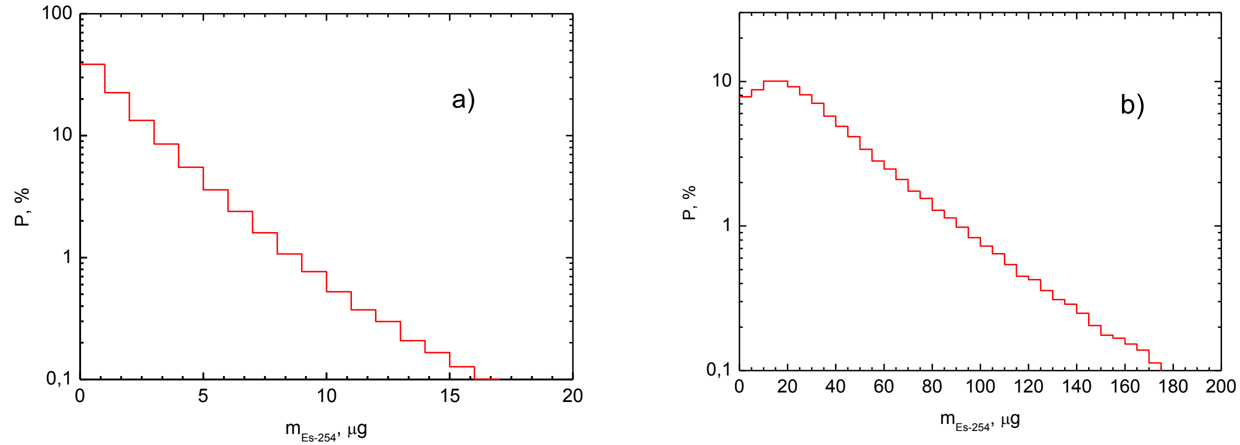


1– Hf absorbing shutters
2 – burnable absorber rods $Gd_2O_3 + ZrO_2$
3 – Zr fuel assembly cover;
4 – fuel elements with reduced fuel contents (0,48 of nominal content)
5 – fuel elements with nominal fuel contents
6 – fuel assemblies with witness-specimen of vessel material
7 – irradiated samples

Isotope ^{254}Es in the central channel of PIK

$$^{254}Es + {}^{48}Ca \rightarrow {}^{302-x}119 + xn$$ $t_{1/2}$ = 256 days, goal is 1 mg





Probabilities of ^{254}Es production in a) central channel; b) core

Target: ^{252}Cf, 100mg

Central channel: $\Phi_n = 8.6 \times 10^5$ n ·sm^{-2} · s^{-1}, $\Phi^{th} = 6 \times 10^5$ n ·sm^{-2} · s^{-1}

Core: $\Phi_n = 3 \times 10^5$ n ·sm^{-2} · s^{-1}, $\Phi^{th} = 2 \times 10^5$ n ·sm^{-2} · s^{-1}

Error of cross section 60%, ^{253}Es (n, f) no data, we need more nuclear data

Onegin M.S. "Investigation of the possibilities of heavy actinide isotopes production in high-flux reactor PIK". Report on Super Heavy Elements Symposium. Texas, USA, 2015.

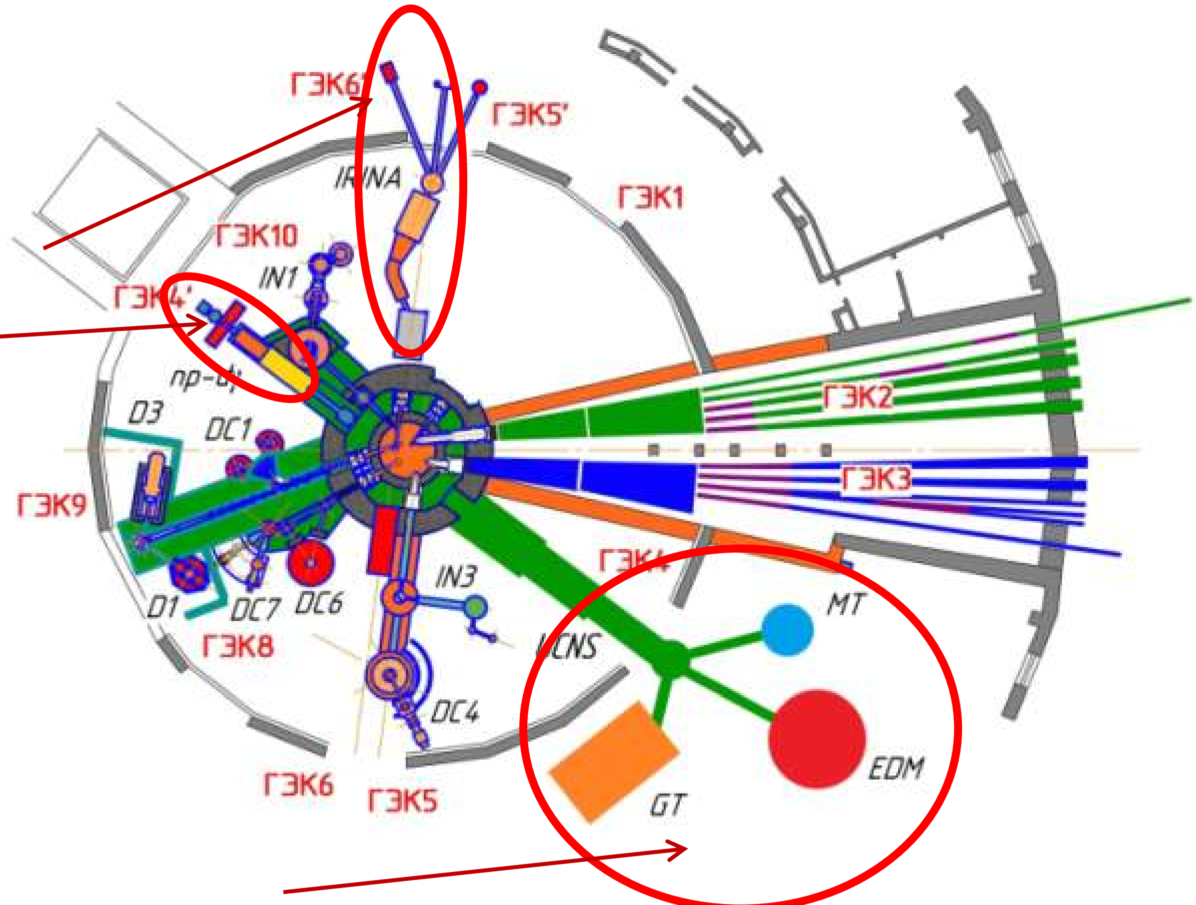
Horizontal Channels Hall – Nuclear Physics

2nd phase

IRINA - Mass separator laser-nuclear complex

Neutron decay – Polarized cold neutron beam facility

n4 – Setup «Neutrino» (located in the under-reactor space)



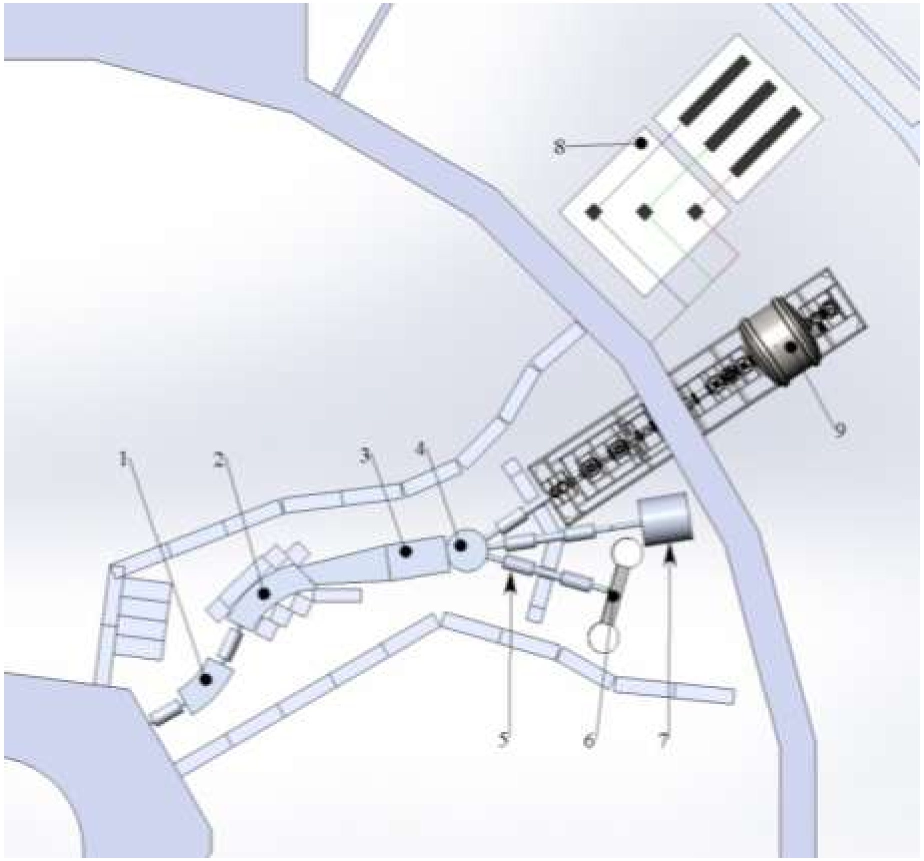
1st phase

- **MT** - Installation for measurement of the neutron lifetime using a magnetic storage of ultracold neutrons
- **GT** - Large gravitational trap for measuring the neutron lifetime
- **EDM** - magnetic resonance spectrometer to measure the EDM using UCN

Horizontal Channels Hall (2nd phase)

1. Mass separator laser-nuclear complex IRINA (studies on radioactive isotopes with neutrons). It is **ISOL type** machine (Isotope Separator On-Line) equipped with ISOLTRAP.

Unique ISOL facility will be installed on the horizontal channel of the PIK reactor with the neutron **flux on the target up to 5x10^{13} n/sec cm^{2}**, **that gives the best yield of nuclei enriched by neutron.**

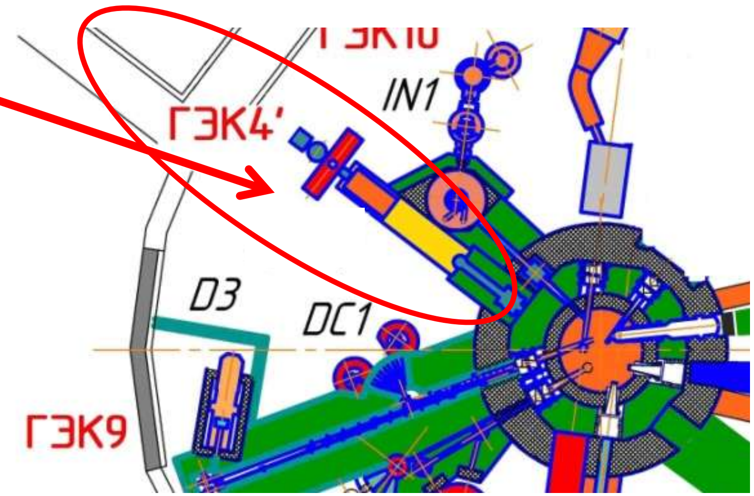


Goal is to study the

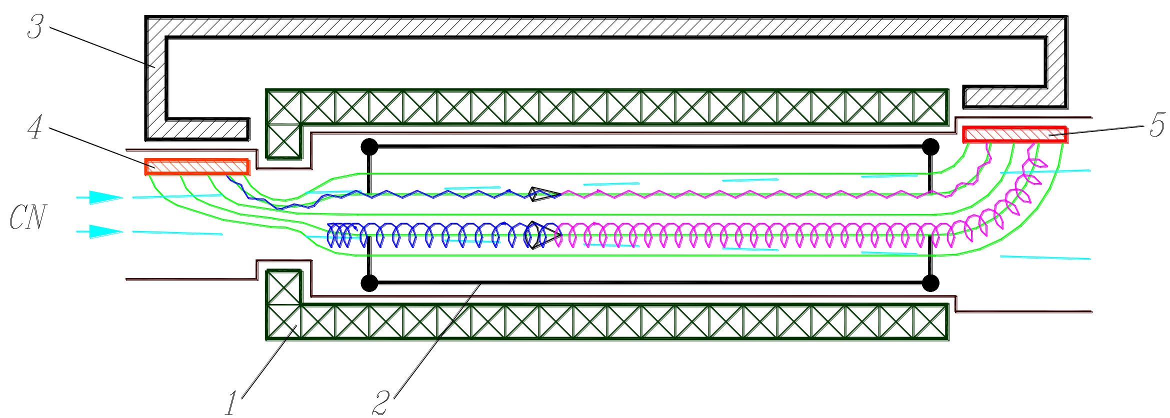
- **properties of nuclei enriched by neutron**
- **shape the nuclei** near the boundary of neutron stability.
- Precision measurements of **masses of nuclei far from the line of beta-stability** (ISOLTRAP).
- **Production of high purity radioisotopes for nuclear medicine.**

Horizontal Channels Hall

2. Polarized cold neutron beam position

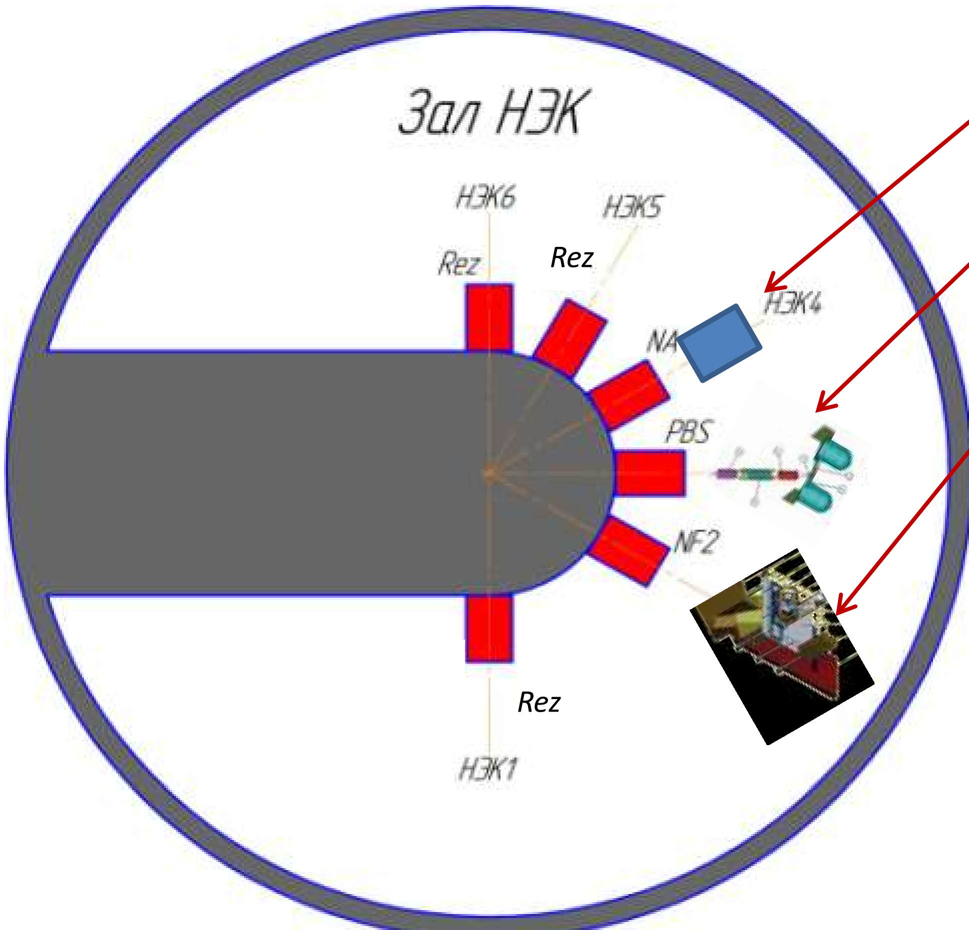


Goal is to organize the beam **position with the world highest flux of polarized cold neutrons** and install the setup for neutron **life time measurement in beam** and **decay asymmetry** measurement with accuracy **10^{-3}**



1 is the superconducting solenoid, 2 is the cylindrical electrode, 3 is the iron magnet frame, 4 is the electron detector, 5 is the proton detector

Hall of Inclined Channels (3)

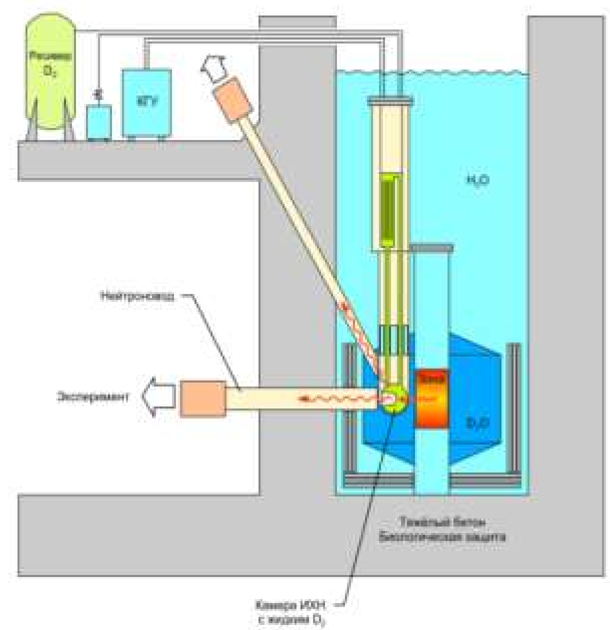


2nd phase

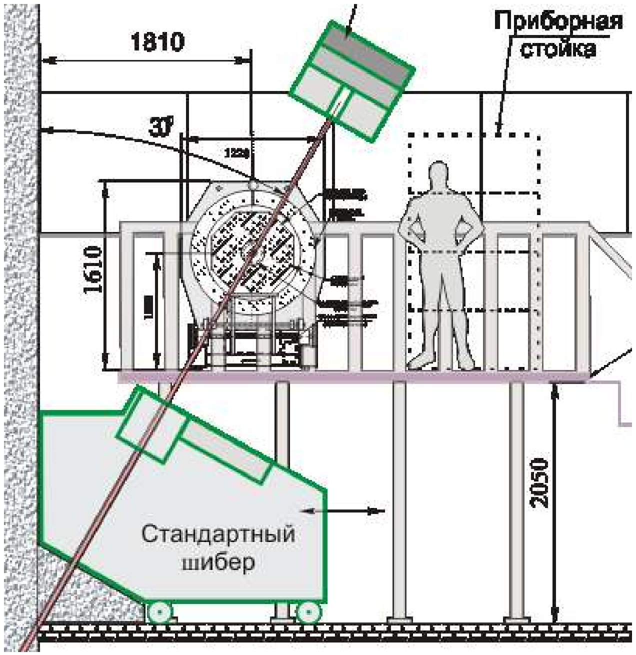
NA - Neutron Activation Analysis.

PBS - Nuclear spectroscopy in the capture of thermal neutrons

NF2 - Correlation investigations in fission



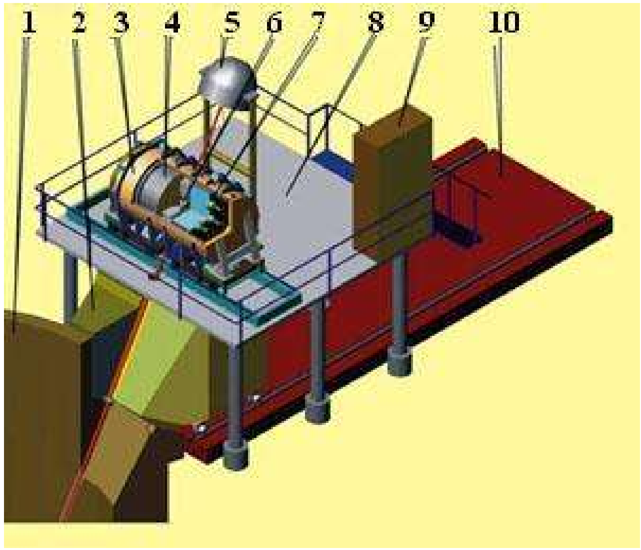
Inclined Experimental Channels Hall



1. NF2 Thermal neutron beam position for nuclear fission physics (hall of IEC) and install the setup for fission fragments study.

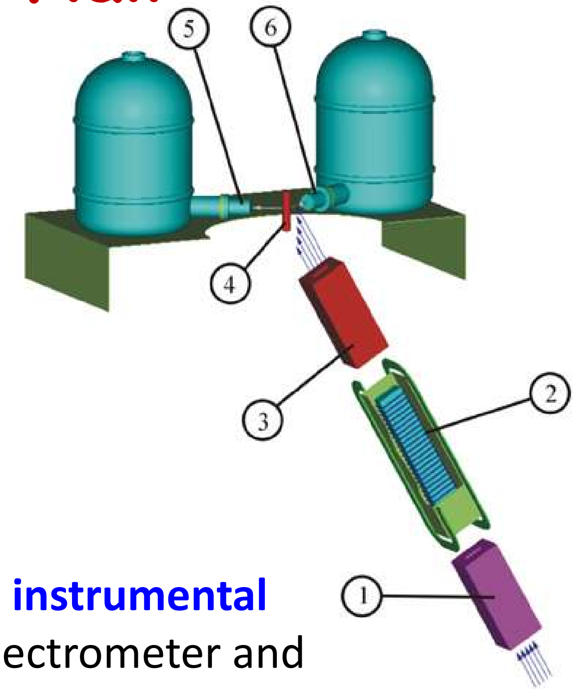
Correlation studies in nuclear fission:

- distributions of **number of fission neutron** depending on the parameters of the fission fragments and fissile systems.
- **angle and energy correlations** of neutrons, gamma-quanta and third particles in fission.



1 – reactor PIK vessel,
2 – standard shutter (additional placement of polarizer is possible),
3 – protection of the detector,
4 –scintillation detectors,
5 – beam-stop,
6 –detector of the charged fission products,
7 –photomultiplier,
8 – platform,
9 –instrument rack,
10 –shutter platform.

Inclined Experimental Channels Hall



2. PBS Nuclear radiation spectrometer

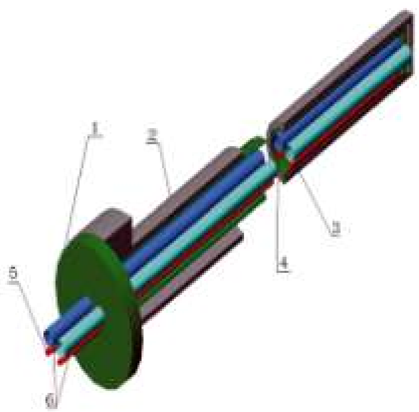
Goal is the measurement of emissions from neutron capture reaction cores for the study of nuclear structure.

3. NA Neutron activation analysis

INAA - Instrumental Neutron Activation Analysis.

NRA - Neutron Radiation Analysis

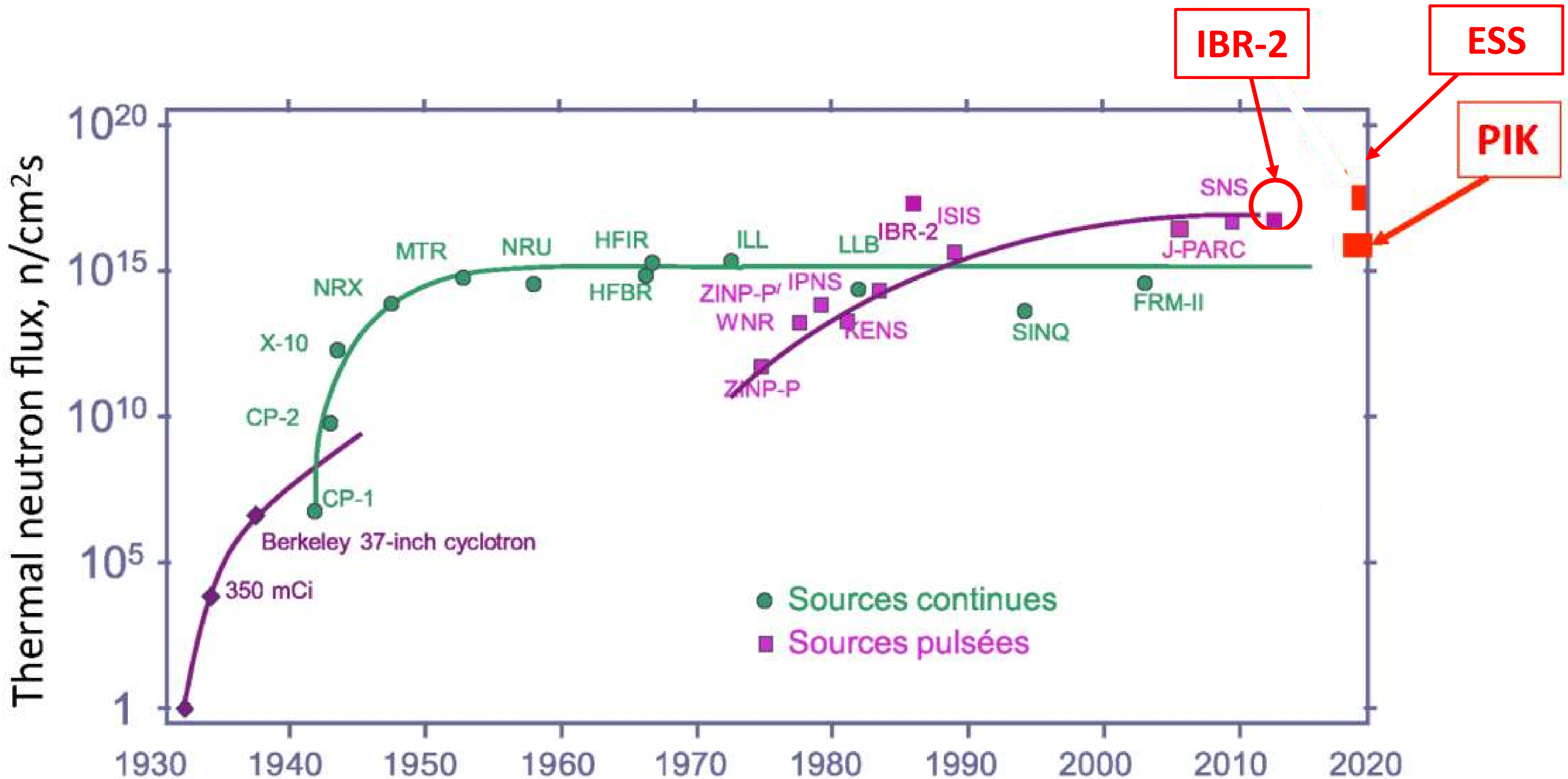
Goal is the creation of a measuring complex for conducting the **instrumental neutron activation analysis (INAA)** based on the gamma-ray spectrometer and **pneumatic transport installation (PTI)**.



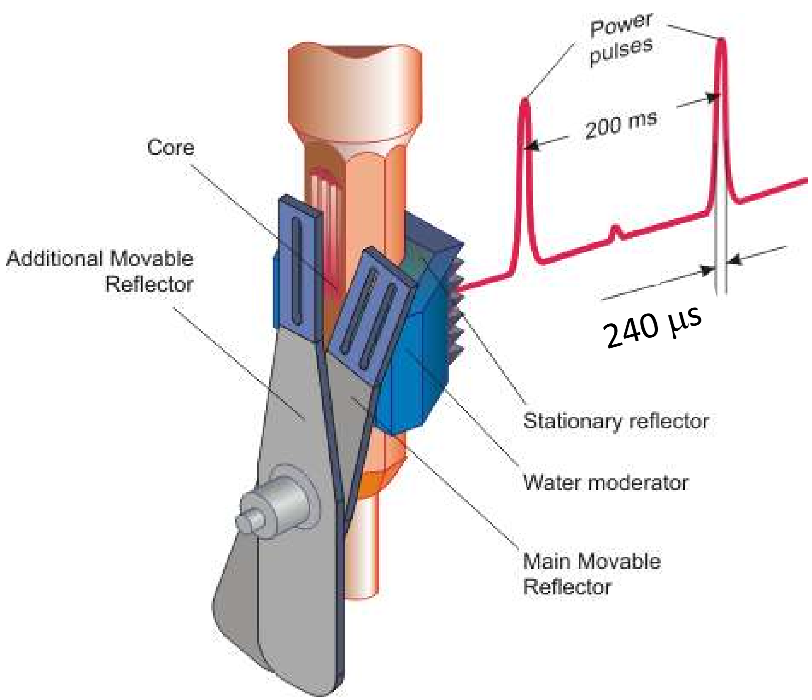
PIK, ESS

What's after?

ADVANCED NEUTRON SOURCES



Modernized IBR-2 High Flux Pulsed Reactor (FLNP JINR)



Information: http://flnp.jinr.ru/34/

Virtual excursion: http://uc2.jinr.ru/pano/lnf/

Operational since 1984

2007- 2010: modernization shutdown

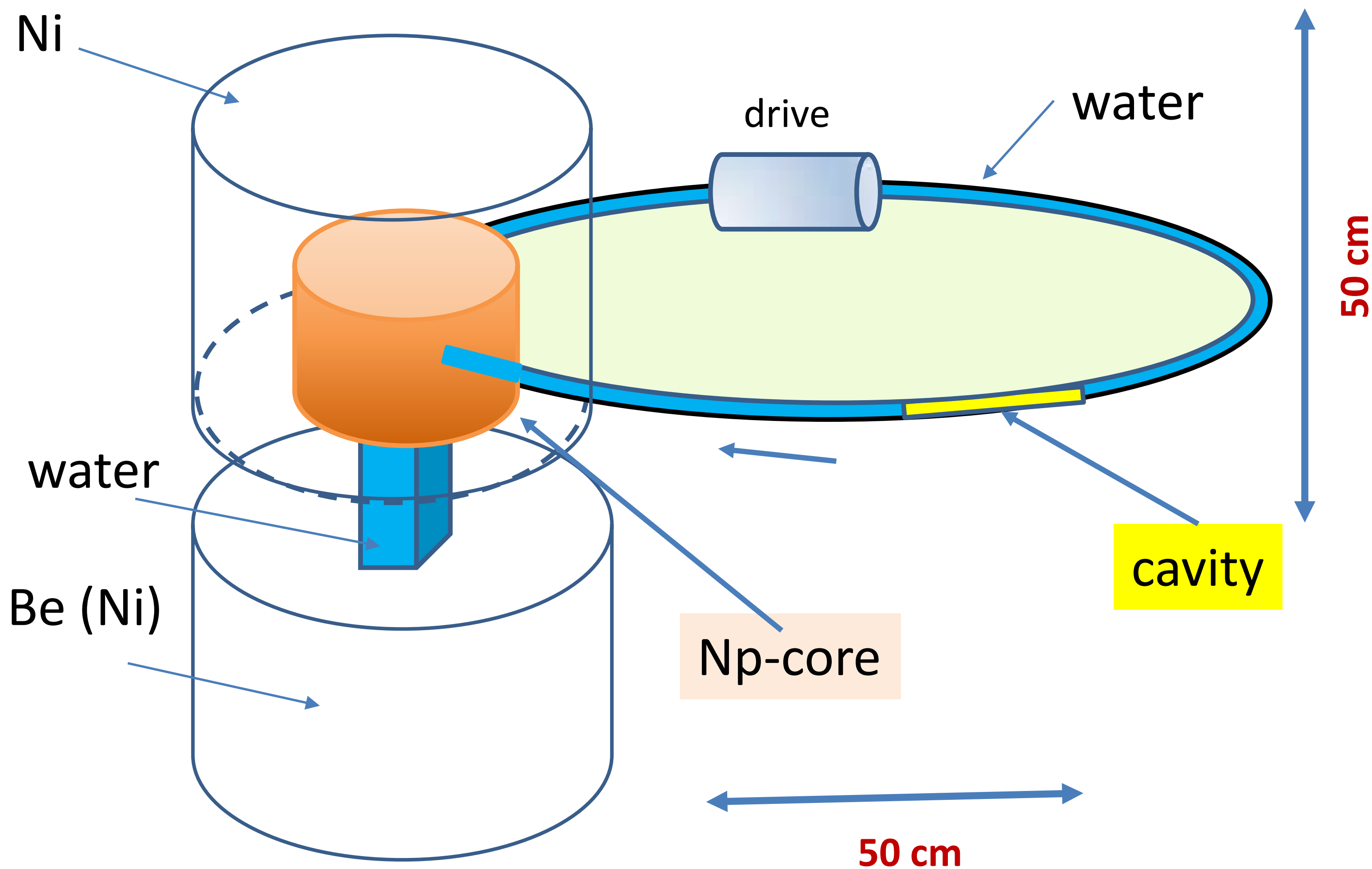
2010 – 2011 Physical and power start-up completed

2012 – Regular operation renewed

By D.P. Kozlenko, FLNP, Dubna

PULSED Np-REACTOR

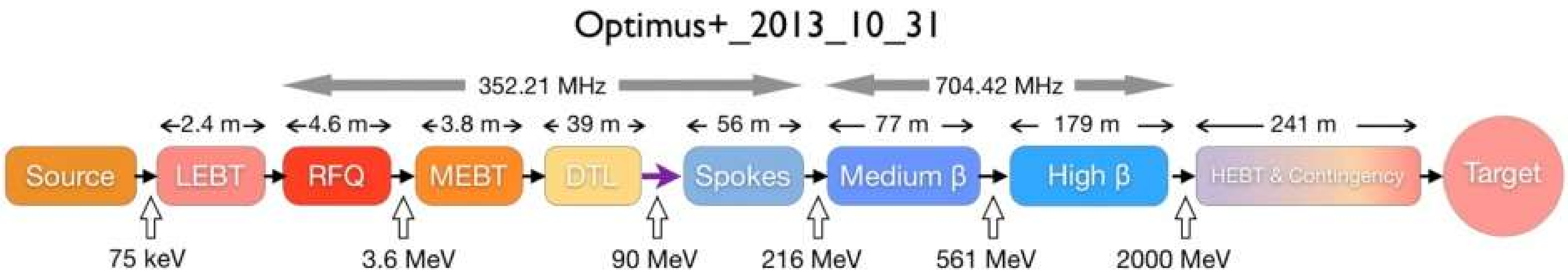
E.P.Shabalin, G.G.Kamyshev, A.D. Rogov (JINR, Dubna)



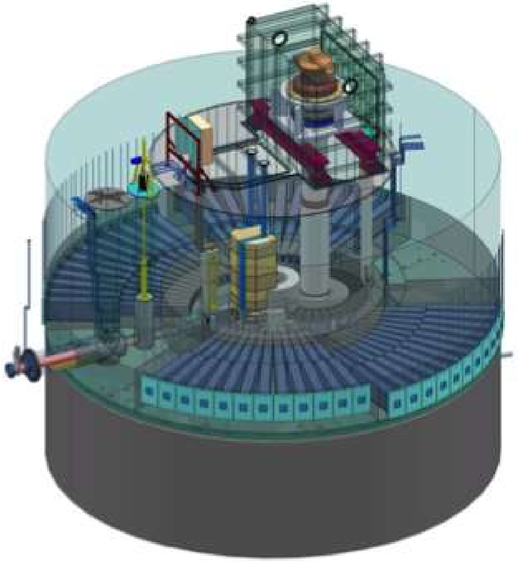
EUROPEAN SPALLATION SOURCE

February 2016

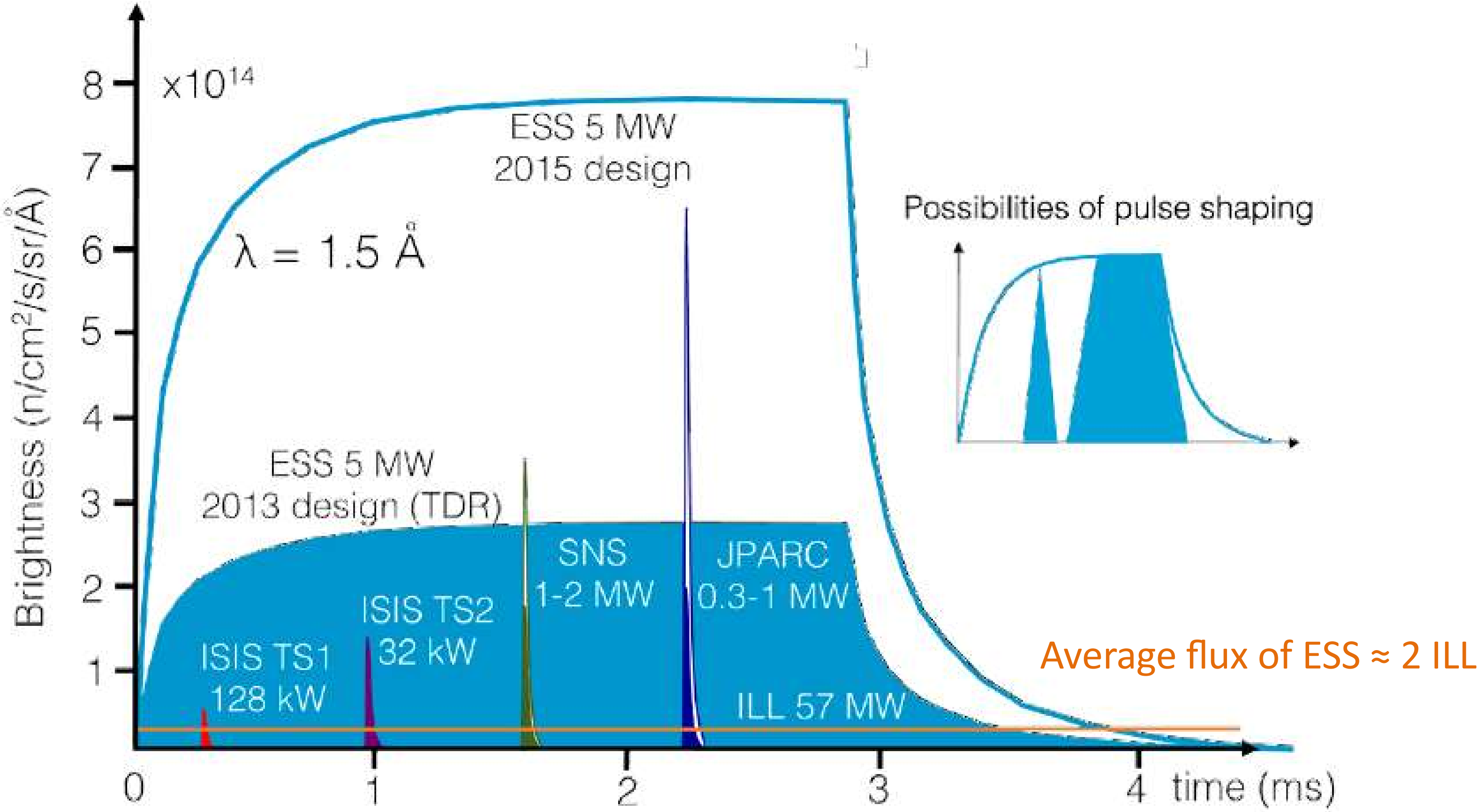
The ESS accelerator high level requirements are to provide a 2.86 ms long proton pulse at 2 GeV at repetition rate of 14 Hz. This represents 5 MW of average beam power with a 4% duty cycle on target.



The target station is a 4-tonne helium-cooled tungsten wheel. The design of the target has a direct impact on the number of neutrons that can be generated, and is therefore of utmost importance for the future scientific capabilities of the ESS facility.



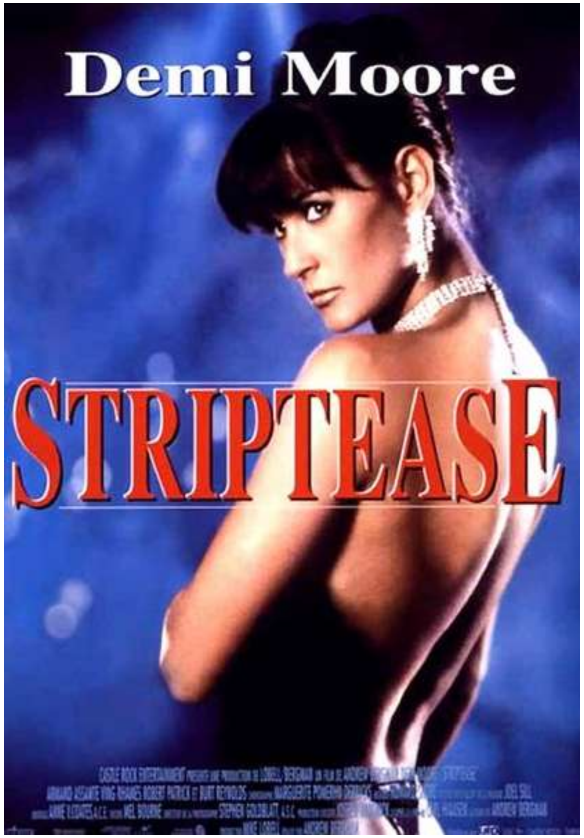
ESS vs. other spallation sources



Single-pulse source brightness as a function of time at a wavelength of 1.5 A at ESS, ILL, SNS, J-PARC and ISIS Target Stations 1 and 2. In each case, the thermal moderator with the highest peak brightness is shown.

Source: ESS

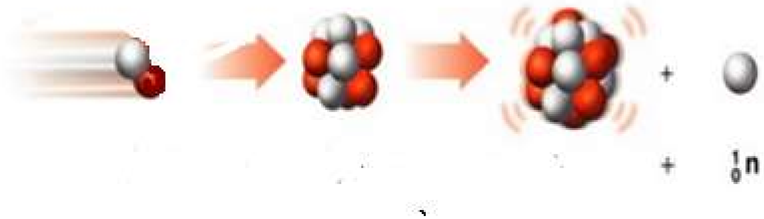
Stripping Neutron Source



The **Oppenheimer–Phillips process** (1935) or **strip reaction** is

$$^{2}D + {}^{A}X \rightarrow {}^{A+1}X + {}^{1}H$$

deuteron-induced nuclear reaction.

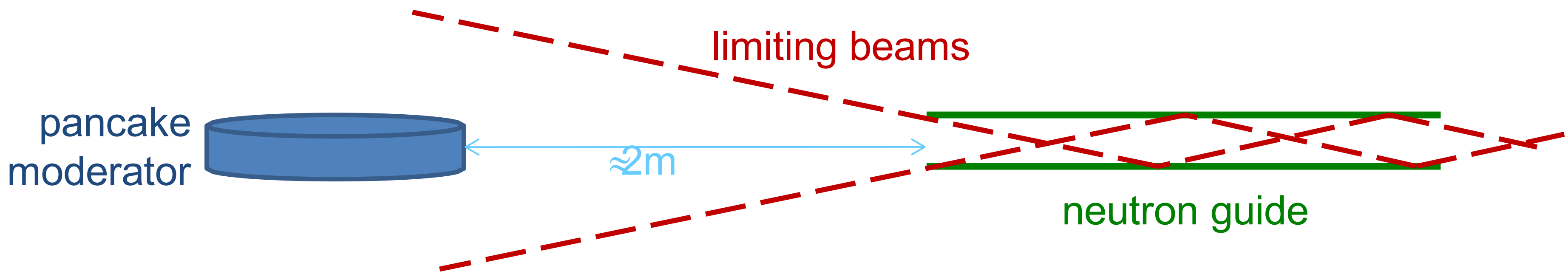


Compact Acceleratordriven Neutron Source (CANS) in Saclay (IRFU-LLB) 2030 20 MeV protons 100 mA + Be

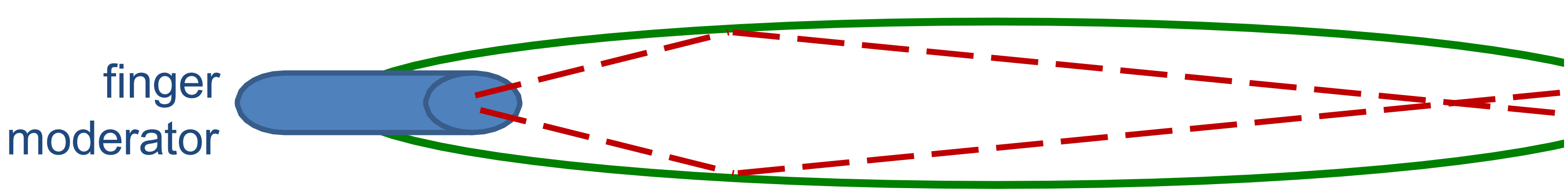
(A. Gukasov)

Beam Extraction

- spallation sources:
  problem to "fill" the neutron guide, if larger divergence is allowed:



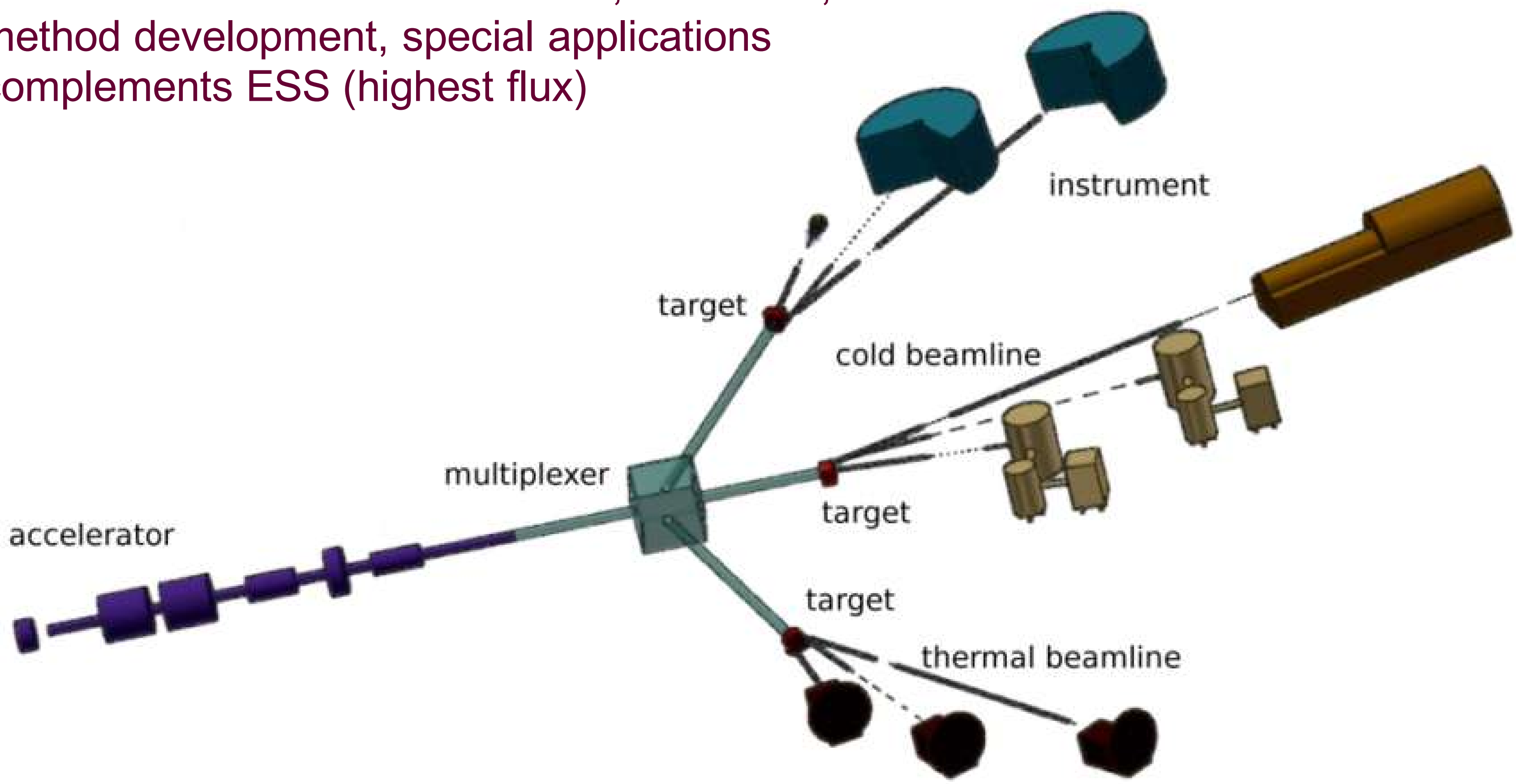
- HBS – relatively low radiation level → guides can start very close to moderator:



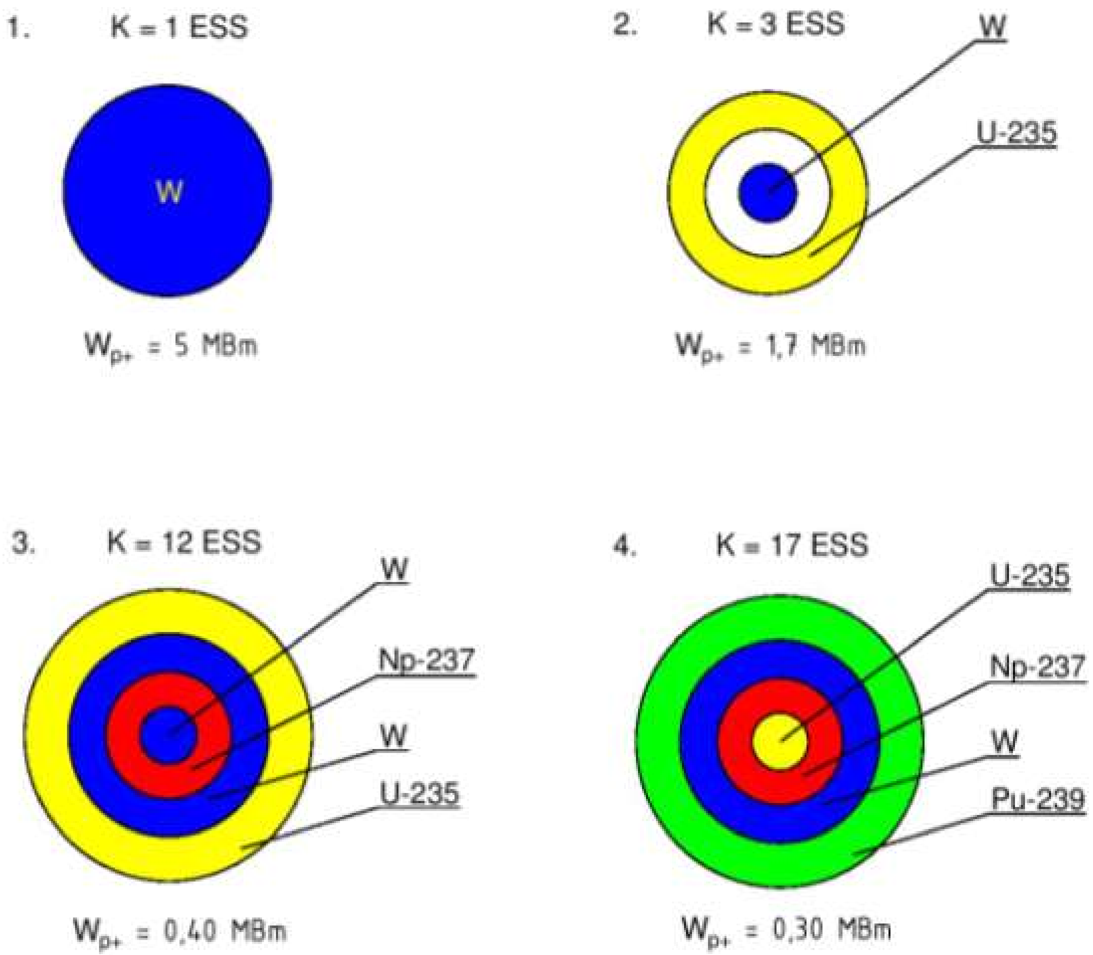
⇒ efficient beam extraction in combination
with modern beam transport system

Possible Facility Layout

- innovative approach for a novel type of neutron facility
- dedicated target stations with pulse structures adapted to specific instruments
- possible approach for a new network of smaller to medium sized sources in Europe
- low nuclear inventory and relatively low cost
- addresses needs in user demand, education, method development, special applications
- complements ESS (highest flux)



ADCSR (Accelerator Driven Cascade Subcritical Reactor)



V.F.Kolesov
Aperiodic Pulsed
Reactors (Sarov, 2007)

1 – ESS
2-booster W-U
3-two cascade booster W-Np-U
4-two cascade booster U-Nb-Pu

Variants of Cascade Subcritical Systems (2-4) in comparison with ESS (1)

V. Aksenov, A. Balagurov, Yu. Pepelyshev, A. Rogov (2016)

CONCLUSIONS

1. Nuclear Physics Instrumentation for reactor PIK needs more attantion
2. GNEIS, IR-8, IREN, IBR-2 are available for nuclear physics
3. Accelerator Driven Subcritical Systems are under consideration both for science and energetics
4. Compact (University) Neutron Sources is actual task for Neutron Society