WSG-5 on Condensed matter and neutron physics
for the Strategic Long-Term Plan of JINR

DNS-IV: a New Advanced Neutron Source at JINR

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I.T. Tretyakov (Russia) – N.A. Dollezhal Research and Development Institute of Power Engineering (NIKIET), Moscow

D. Chudoba (Poland) – Frank Laboratory of Neutron Physics JINR, Dubna (scientific secretary)

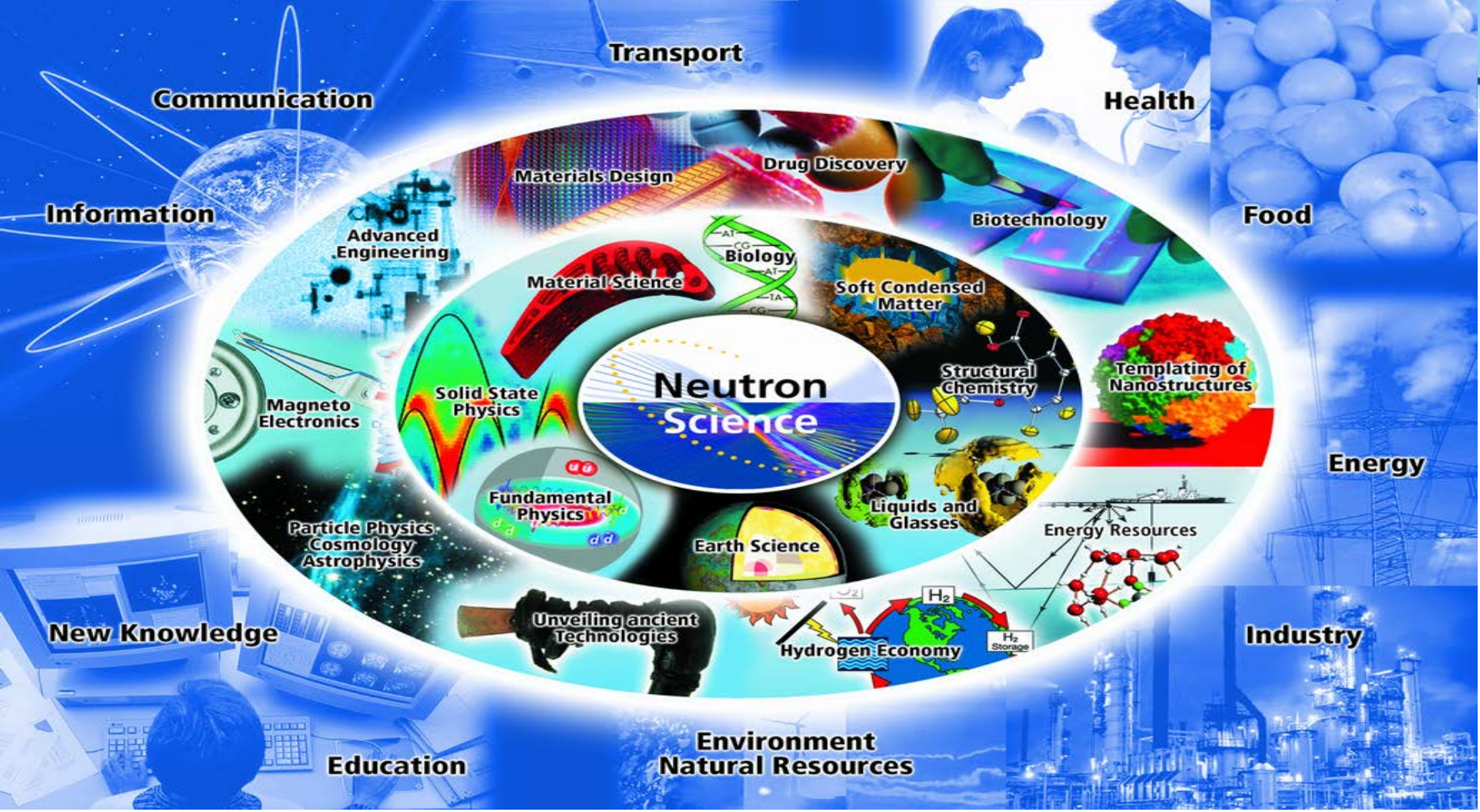
Meetings and workshop

- **Regular semiannual meetings of the WSG-5:**
  June 15, 2018; January 23,2019; June 18, 2019

- **International Workshop (December 6-7, 2018):**
  - **46 participants from Sweden, France, Germany, Hungary, Slovakia, Poland and Russia**
  - **leading European and Russian neutron centers were represented.**

A New Advanced Neutron Source at JINR: Dubna Neutron Source (DNS-IV)

- A long-term strategy aiming:
  - to construct a world leading neutron source **DNS-IV** at JINR
  - to open unprecedented possibilities for scientists from JINR member states and worldwide for research in condensed matter physics, fundamental physics, chemistry, material and life science.
- Project is extended over two strategic planning periods, till 2036.
- Estimated construction costs (incl. instrumentation) - about 500M€



Neutron Science – critical applications in:

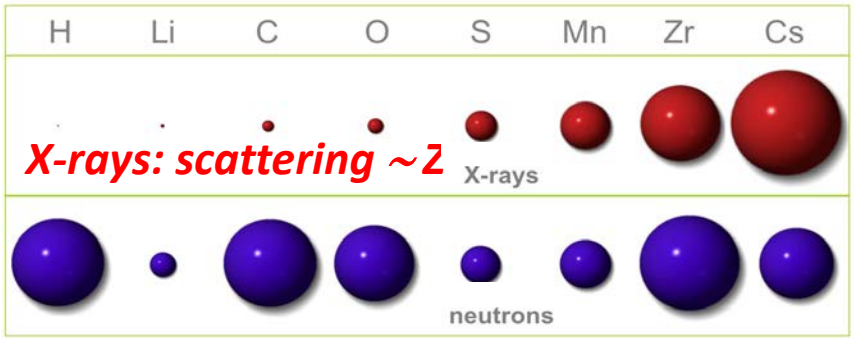
- Condensed matter physics (new materials, material design)
- Information technologies (spintronics)
- Fundamental physics
- Life science: Biophysics, Pharmacology and Medicine – drug design and delivery
- Engineering

Neutrons vs. X-rays

- **Neutron scattering - no systematic A(Z) dependence => light elements are not masked by heavy ones**

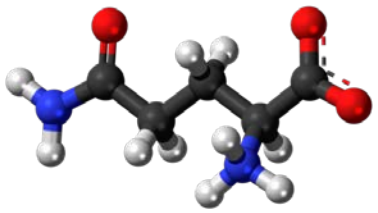
H^+ is not visible for X-rays at the background of heavier atoms, but very well visible for neutrons!

X-ray and neutron scattering power



Neutrons: irregular scattering

- **Neutron scattering clearly distinguish between neighboring atoms (for biology, particularly N, C and O)**
- **Refining structure of proteins => drug design**



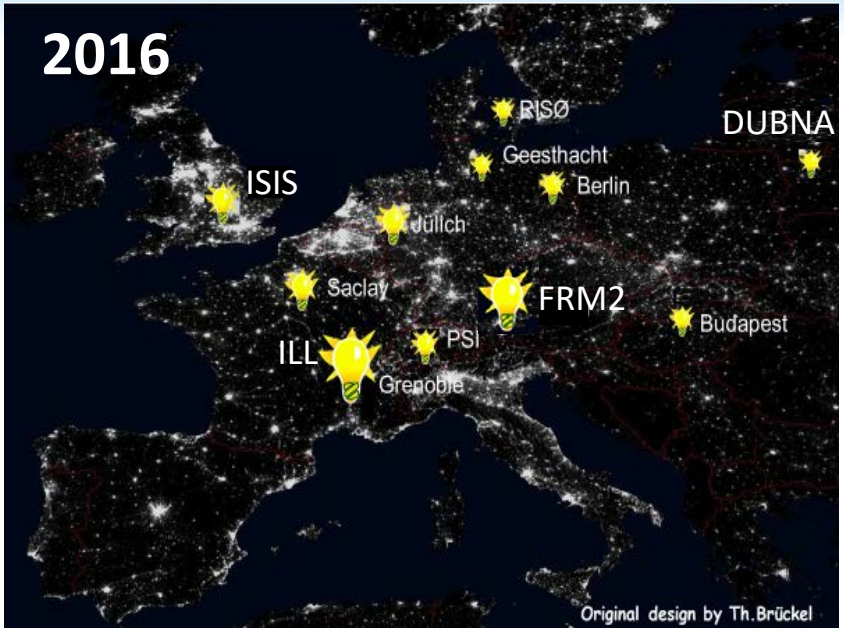
- **Neutron energies: $kT_{room} \approx 0.01$eV (cf. 10-100 keV for X-rays)**
  => non-disturbing and non-destructive probe;
  => much more sensitive to weak and slow atomic motions.
- **Neutrons: isotopic contrast! H/D difference – invaluable for biology**

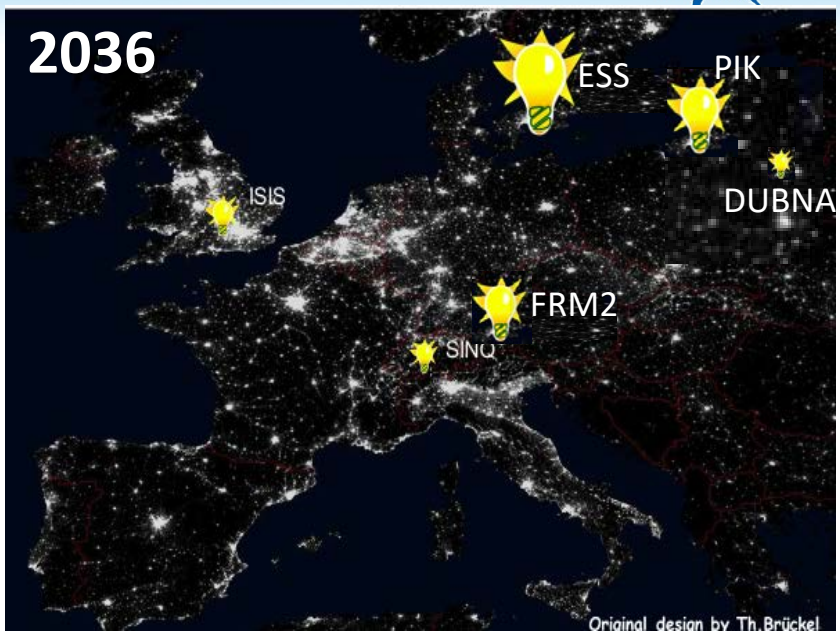
Fundamental physics at DNS-IV

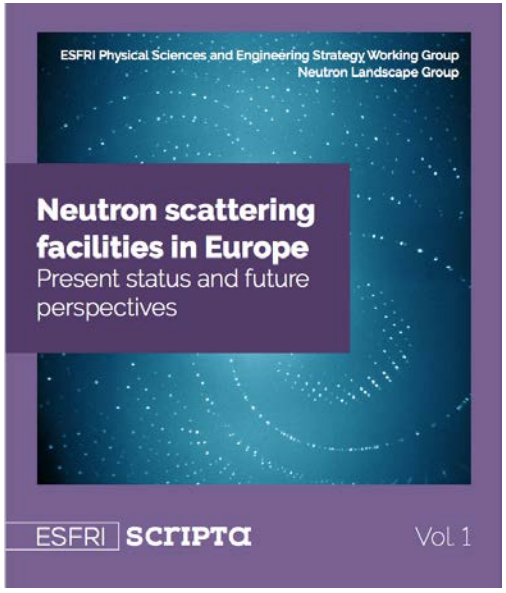
- **Very cold neutrons (VCN) - wavelengths 20Å to 100Å:**
  - **fundamental physics (search for neutron-antineutron oscillations; neutron lifetime measurements, search for extra-short-range interactions at neutron scattering, experiments with neutrons in a whispering gallery);**
  - **developing new techniques for condense/soft matter physics (high-resolution neutron spin-echo technique, reflectometry, high-resolution inelastic scattering, small angle scattering)**

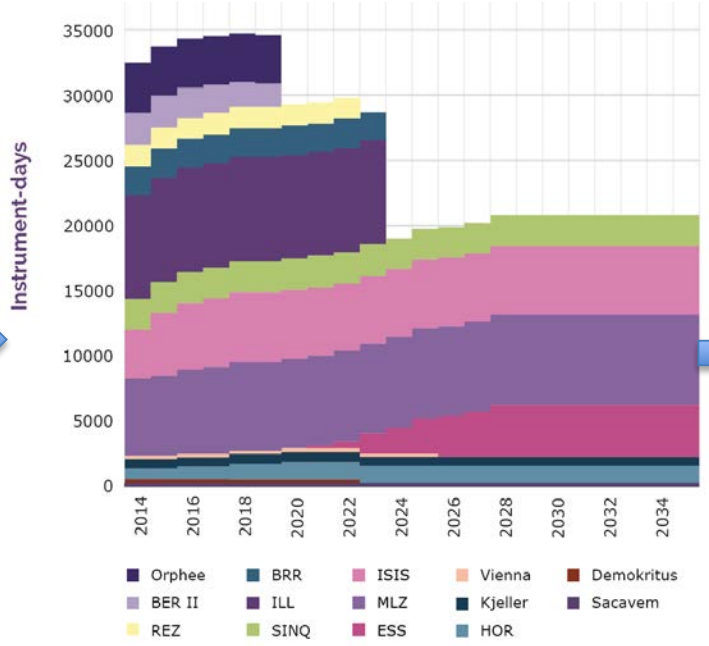
- **Ultra cold neutrons (UCN) - wavelengths > 600Å**
  - **traditional research with UCN (neutron lifetime measurement, neutron EDM search, precise measuring quantum states in gravitational field as tool for search new types of interaction, etc.);**
  - **new techniques for condense/soft matter and surface physics (high-resolution neutron microscopy, reflectometry);**

European neutron landscape



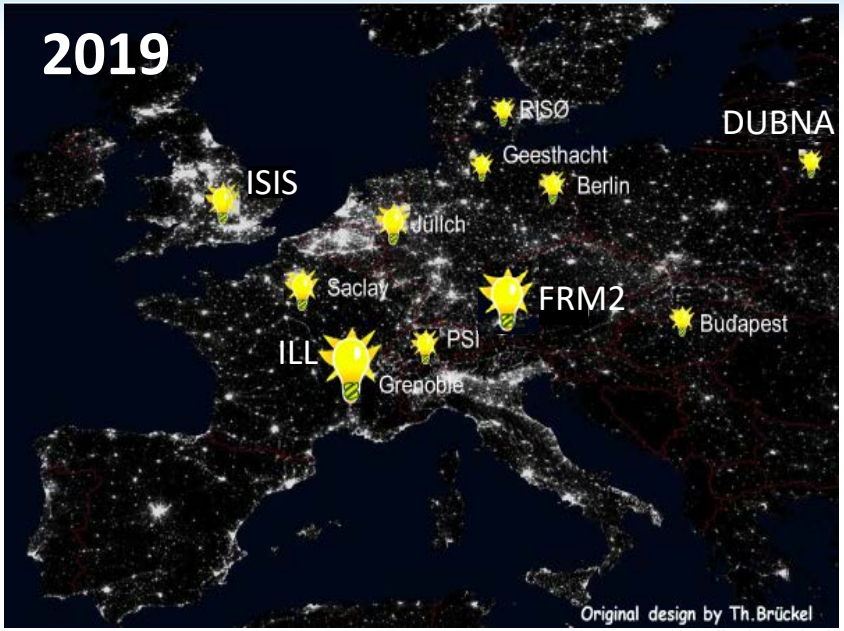


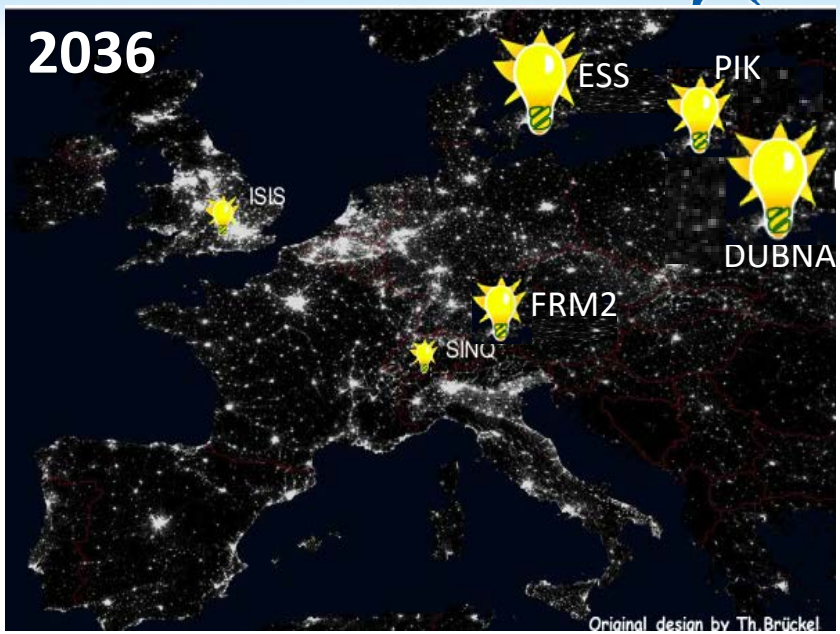


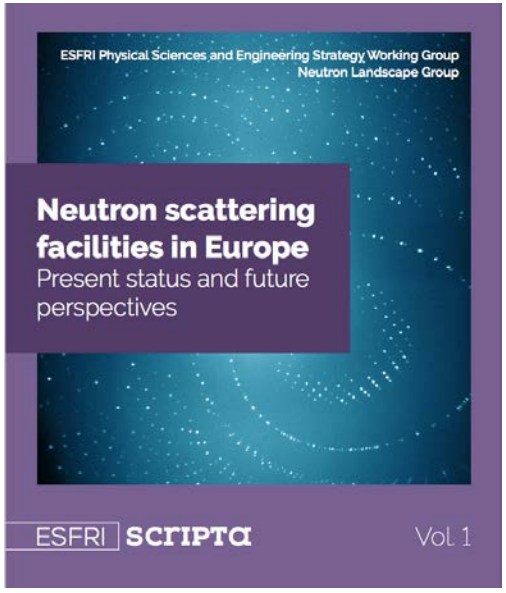


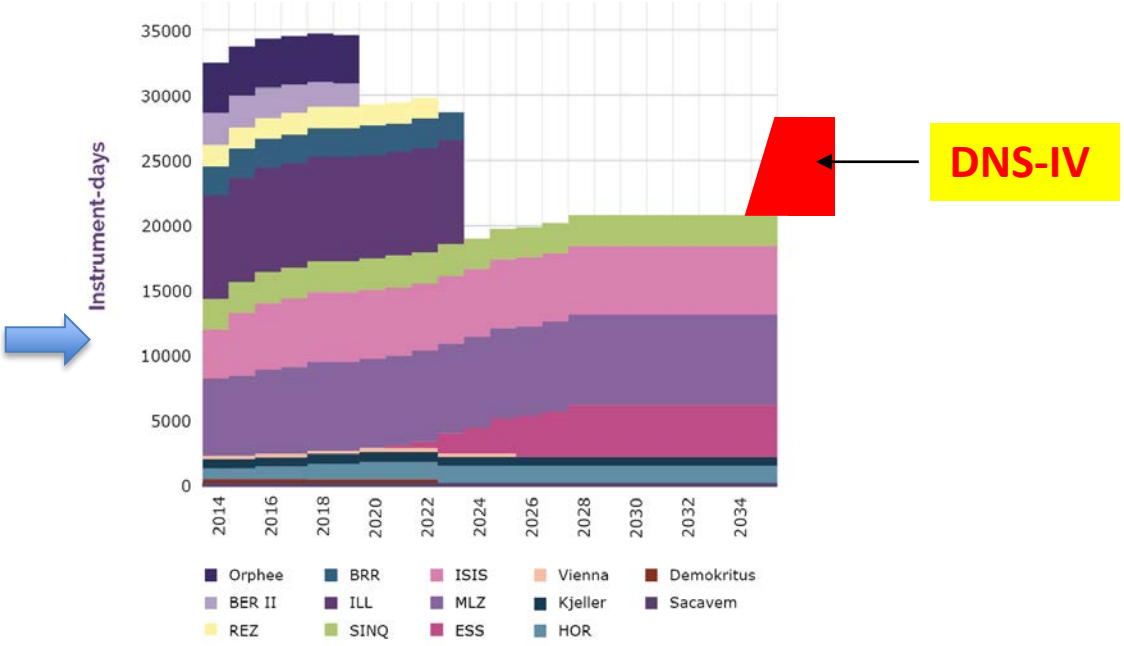
- Inevitable shortage of neutron access
- Clear need in a new neutron source

World neutron landscape







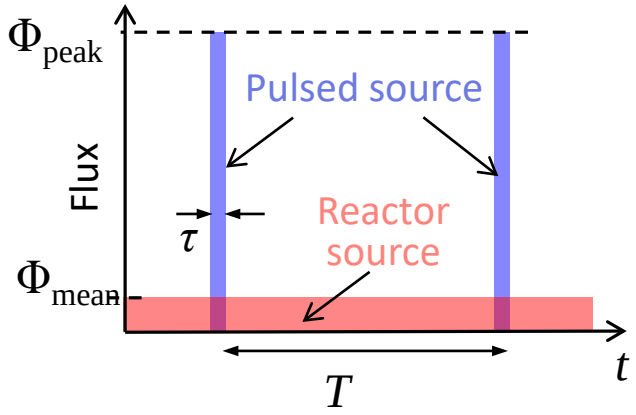


New Dubna neutron source

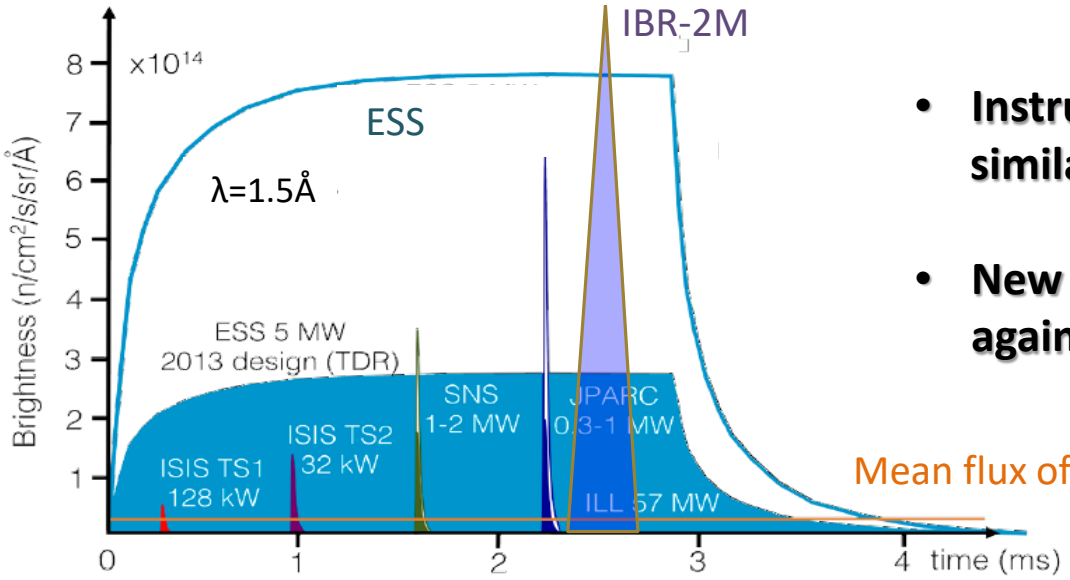
DNS-IV - not just another neutron source, but one of the best in the world!

Pulsed neutron source: peak neutron flux instead of mean neutron flux.

- ⇒ significant gain in the instrument performance
- ⇒ All neutron sources built during last two decades are pulsed sources (ISIS-2 (UK), J-PARC (Japan), SNS (USA).
- ⇒ European Spallation Source (ESS) – the most advanced neutron source (to be operational in 2024)



Neutron pulses at different facilities

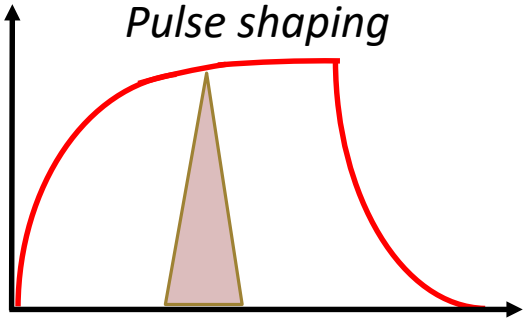


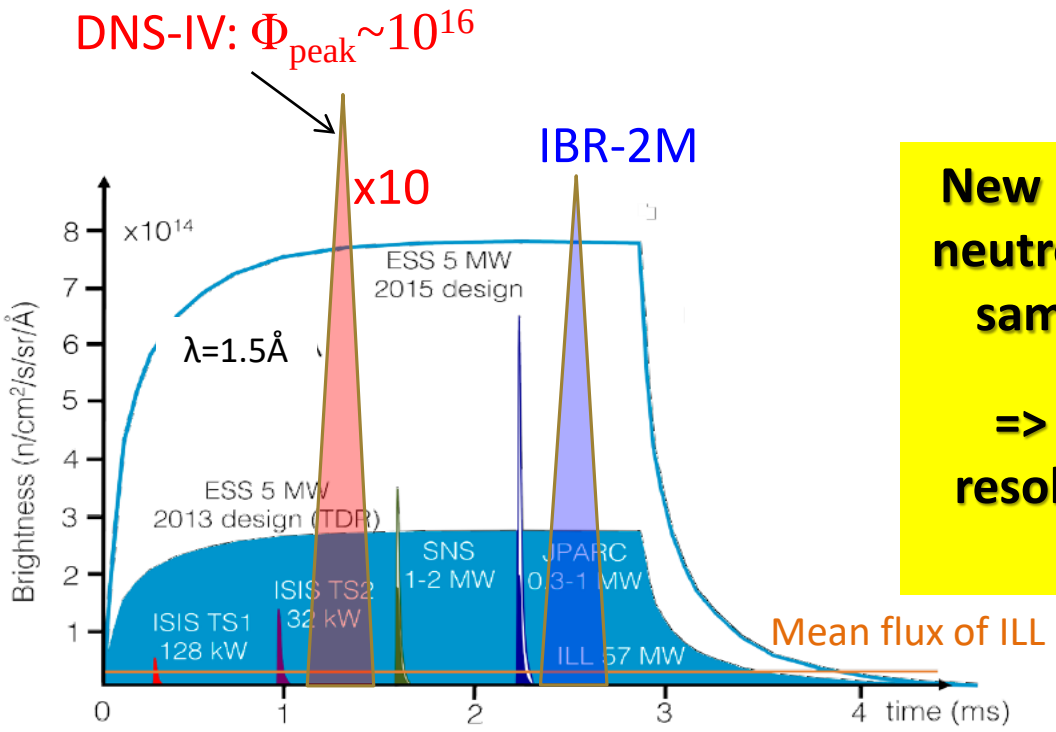
- **Instruments at ESS will outperform similar instruments at ILL by 20-100 times!**
- **New Dubna source will be benchmarked against the ESS.**

New Dubna Neutron Source: DNS-IV

DNS-IV - not just another neutron source, but one of the best in the world!

- Long pulse neutron source, however shorter pulse than at ESS (0.3ms vs. 3ms)
- 10 times higher magnitude
- ESS long pulse is good for low resolution experiments
- High resolution requires pulse shaping => intensity losses



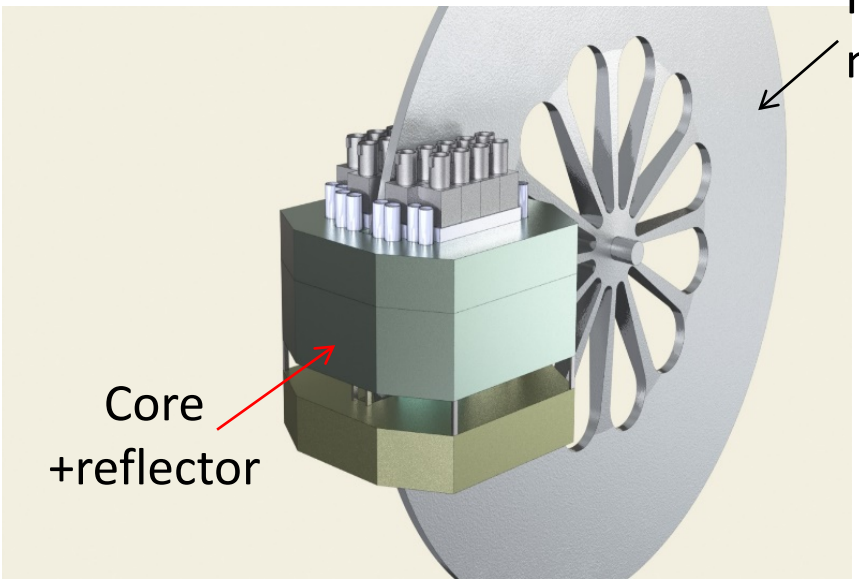


New Dubna source will provide shorter neutron pulses, however containing the same number of neutrons as at ESS.

=> it will be as good as ESS for low resolution experiments and better for high resolution experiments.

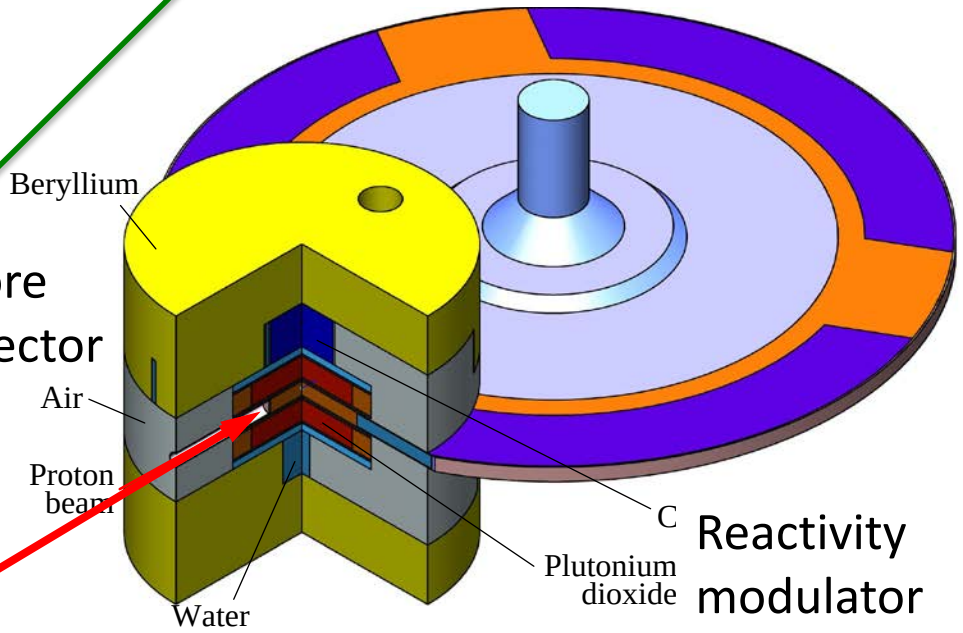
DNS-IV: two alternative concepts

1. Pulsed reactor IBR-3



E. Shabalin et al.

2. Accelerator-driven neutron source: spallation + multiplier



A. Vinogradov et al.

DNS-IV: two alternative concepts

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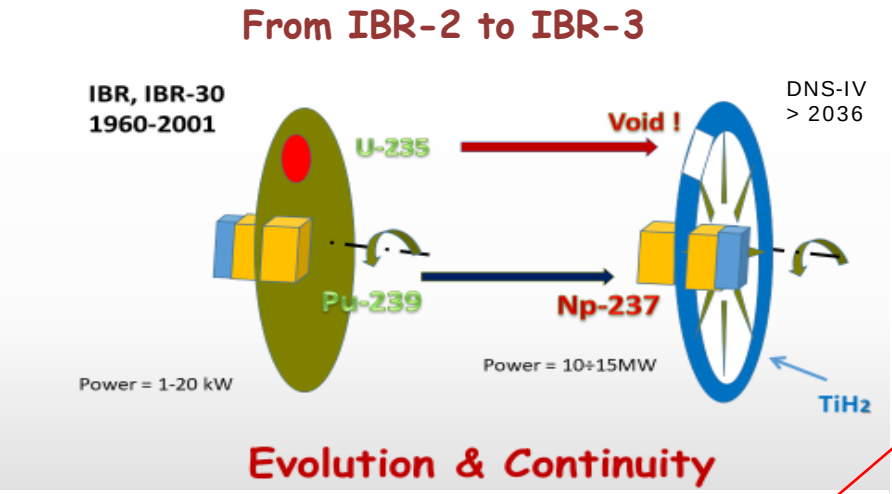
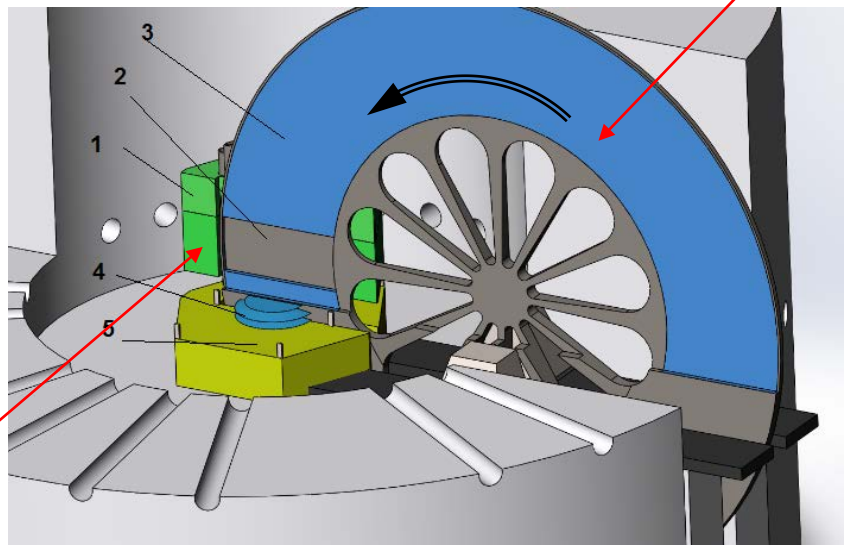
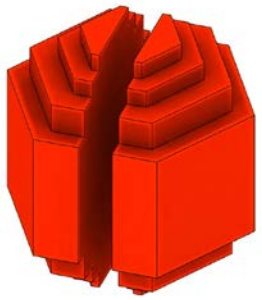


Reactivity modulator TiH_2



1- Np-237 reactor core, 2 - empty sector of reactivity modulator, 3 - reactivity modulator coated with TiH_2 , 4 - moderator, 5 – Be reflector.



Spherical core
to reduce the amount of Np-237.

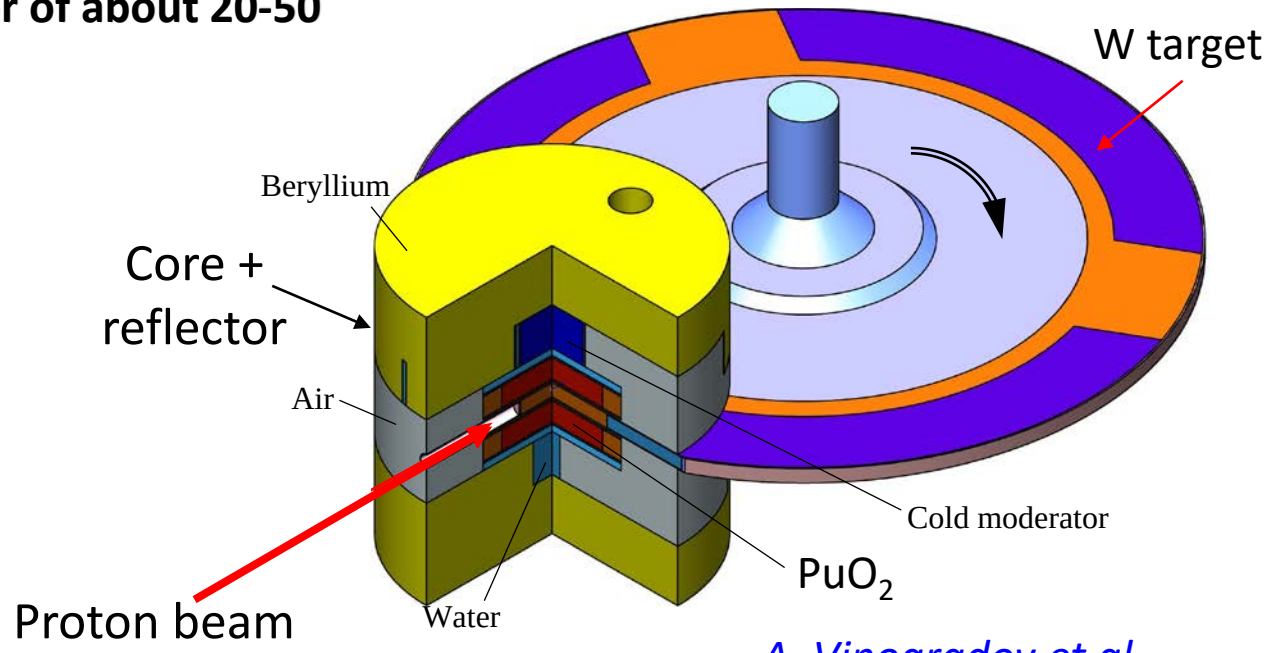
- **thermal power of 10-12 MW**
- **modified moderator placement geometry**

=> neutron flux density 10^{14} n/cm^2/s

DNS-IV: two alternative concepts

2. Accelerator-driven neutron source: spallation + multiplier

- **PuO_2 core operating in the deep under-critical mode**
- **neutron multiplication factor of about 20-50**

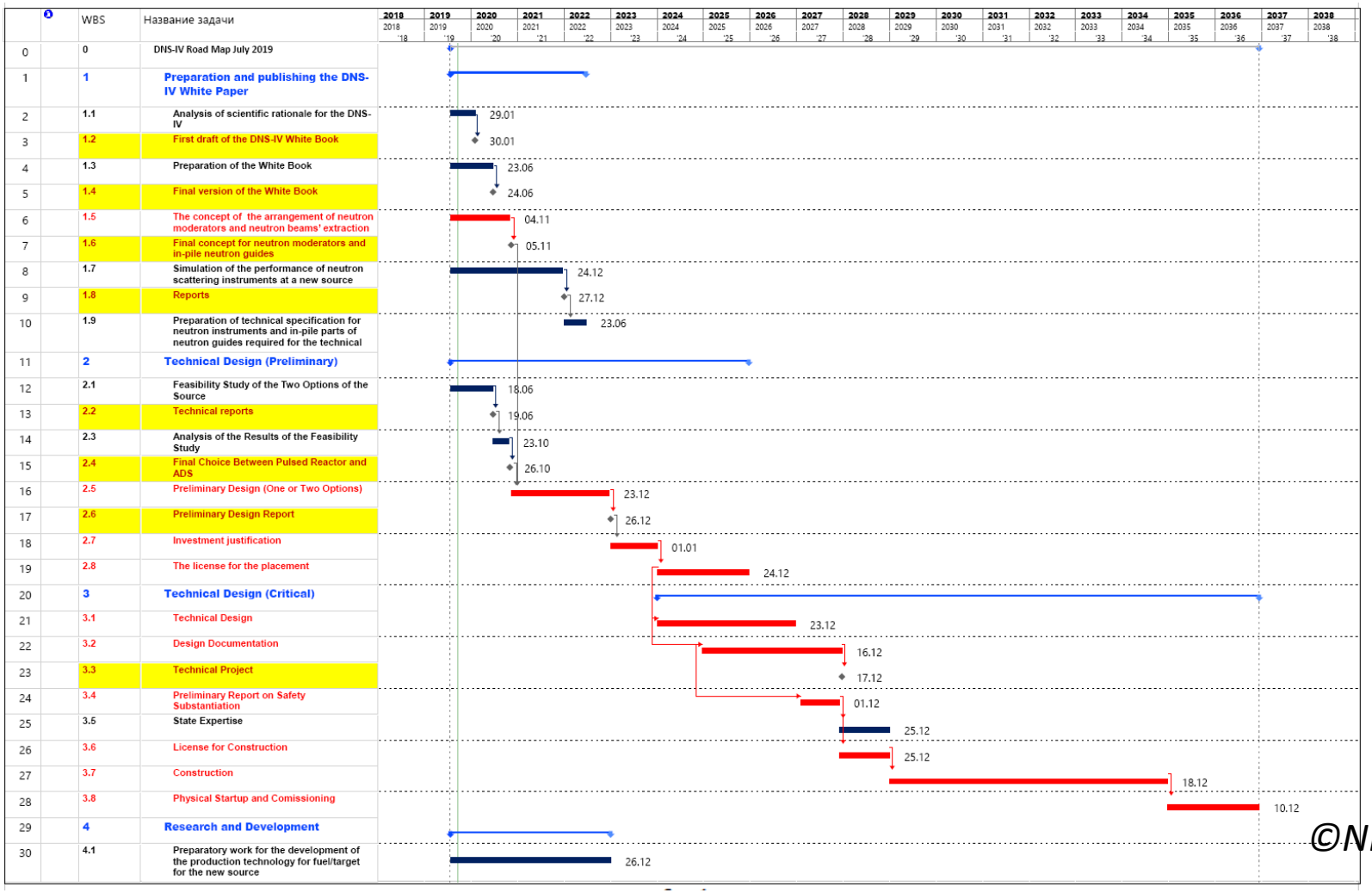


A. Vinogradov et al.

⇒ **the same neutron flux as at ESS can be achieved by a 1.2GeV proton accelerator with the (20-50) times less beam power (0.1 MW vs. 5MW@ESS).**

⇒ **technical problems to be solved - the influence of instability of the accelerator's operation on the stability of the operation of the booster.**

- **Both options are under the feasibility study in N.A. Dollezhal Research and Development Institute of Power Engineering (NIKIET), Moscow**
- **A positive feedback was already obtained for the IBR-3 project**
- **Roadmap for design and construction of DNS-IV:**



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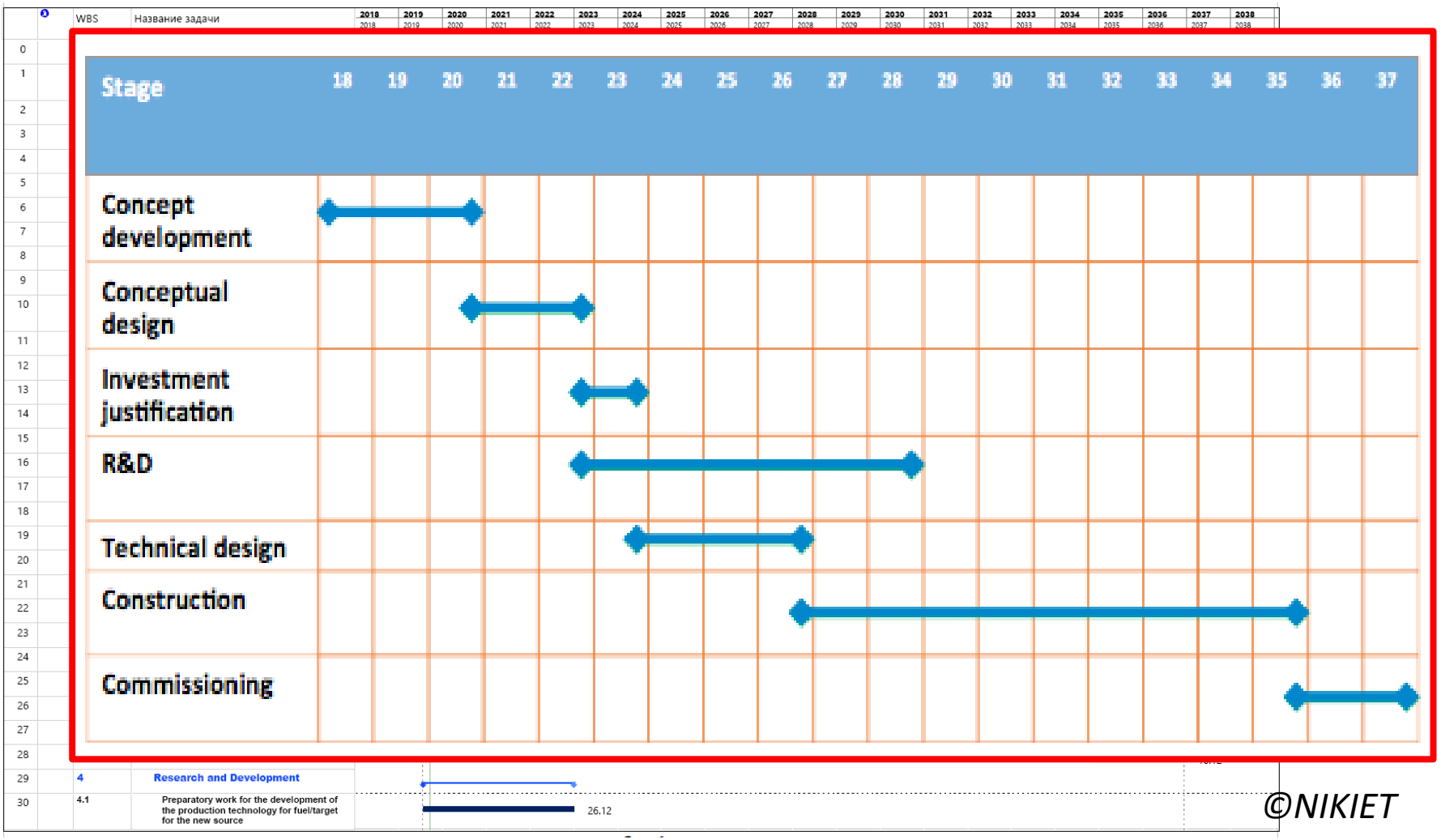

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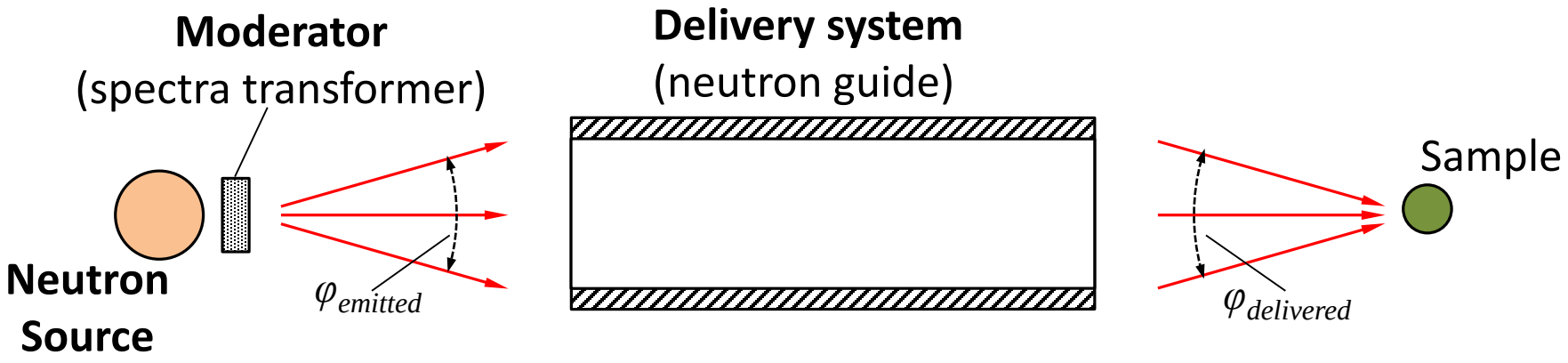
Highly efficient neutron source: maximal use of the emitted neutrons and neutrons delivered to instruments



Expected gain vs. IBR-2:

Flux	10
Moderators	2-3
Delivery system	5-7
Instruments	3-5
Total	**300-1000**

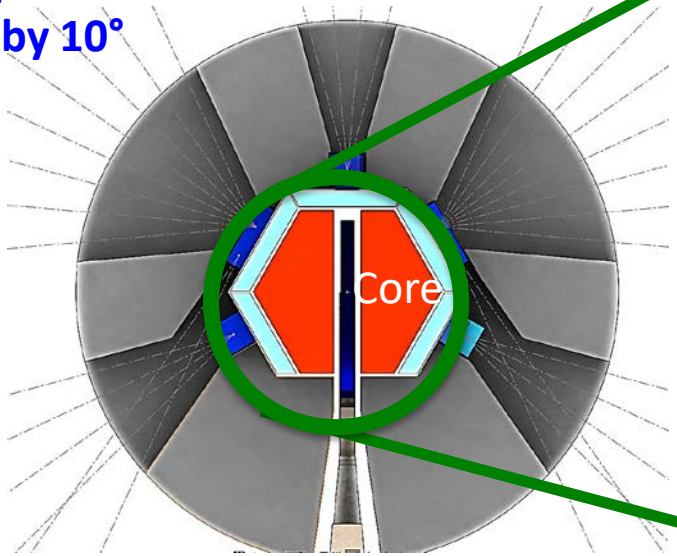
Neutron source will be built in combination with proper moderators, neutron delivery system and instruments.

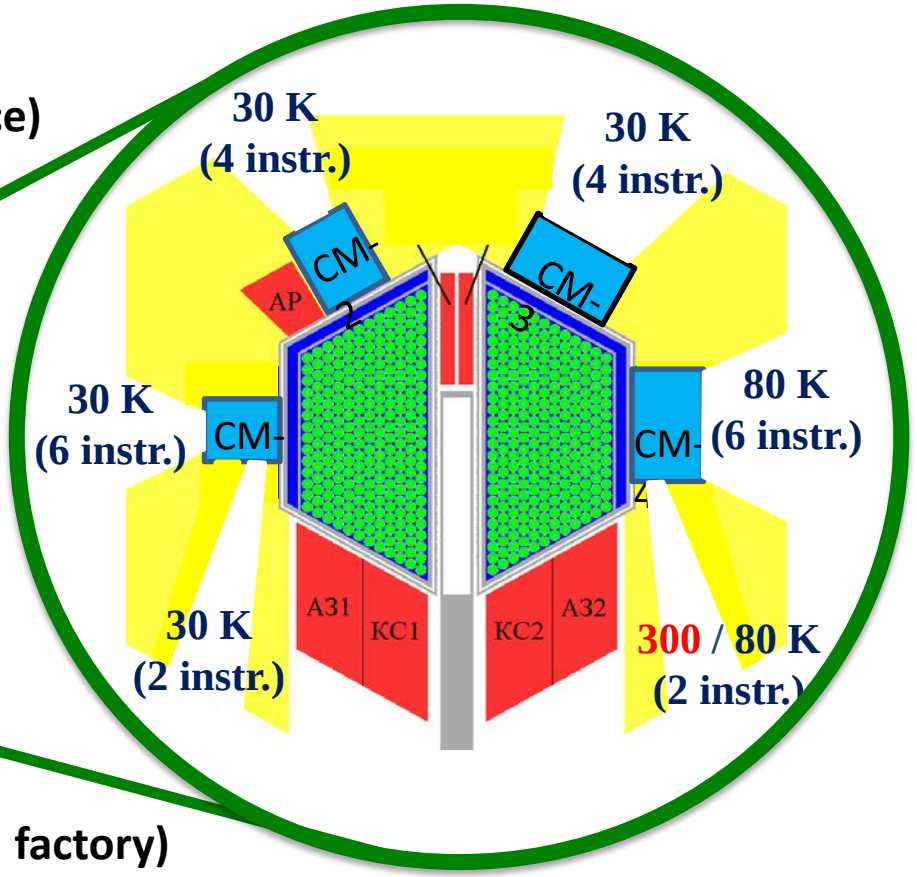
Plans for 2023-2030

1. Development of the final concept of modern thermal and cold moderators

- Grooved moderators (high intensity)
- Low-dimensional moderators (high brilliance)

32 beamports separated by 10°





- Converters for very cold neutrons (VCN/UCN factory)

  - time focusing of UCN at pulsed neutron beam.
  - construction of the VCN source prototype with directed extraction of neutron beam.
  - optimization of various moderators and UCN extraction systems for DNS-IV

Plans for 2023-2030

2. Design of modern neutron instruments

- **Monte-Carlo simulations and optimization of neutron delivery system – maximal use of the emitted neutrons.**
- **Monte-Carlo simulations and optimization of neutron scattering instruments – maximal use of the delivered neutrons.**
- **Development of dedicated Monte-Carlo simulation procedures**

3. Design of the high-efficient neutron delivery system

- **Ballistic, elliptic and parabolic neutron guides**

4. IBR-2 Instrumentation Development

- **Construction, installation and commissioning of two inelastic neutron scattering spectrometers in inverted and direct geometry at the beamline #2;**
- **Upgrade of the all IBR-2 instruments;**
- **Design of the instruments for DNS-IV, testing the key technologies prototypes at the IBR-2;**

Conclusions

- Systematic shortage of the neutron beamtime in Europe and worldwide raises demand in construction the new neutron sources;
- We propose the new advanced neutron source at JINR (DNS-IV) (the combination with modern moderators, neutron guides and instruments), which promises to be one of the best in the world;
- DNS-IV will open unprecedented possibilities for scientists from JINR member states and worldwide for research in condensed matter physics, fundamental physics, chemistry, material and life science;
- FLNP possesses the high-level competence in construction and operation of pulsed neutron sources, cold and ultra-cold neutron sources and neutron instrumentation;
- FLNP is also staffed by a large number of motivated young scientists and engineers eager to work on this new exciting project;
- The planned start of the DNS-IV operation is 2036-2037;

Thank you for your attention!