Workshop "Advanced Ideas and Experiments for DNS-IV"
6 – 8 December, 2018, Dubna

DNS-IV Project.

Present Status and Trends

- superbooster
- accelerator
- research programme
- experimental stations

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FLNP Neutron Superboosters

1-st Generation
IBR, 1960
IBR + microtron, 1964

$e, 30\ MeV, 80\ mA$

$\overline{W}_r = 6\ kW, \Delta t = 40\ \mu s$

$\overline{W}_b = 0.5\ kW, \Delta t = 4\ \mu s$

$\hat{\Phi}_n = 10^{13} n/cm^2/s$

2-nd Generation
IBR30 +LUE40, 1969

$e, 40\ MeV, 200\ mA$

$\overline{W}_r = 25\ kW, \Delta t = 50\ \mu s$

$\overline{W}_b = 12\ kW, \Delta t = 4\ \mu s$

$\hat{\Phi}_n = 10^{14} n/cm^2/s$

3-d Generation

IBR2, 1982

$\overline{W} = 2\ MW$

$\hat{\Phi}_{th} < 6 \cdot 10^{15} \frac{n}{cm^2 s}$

$\bar{\Phi}_{th} < 8 \cdot 10^{12} \frac{n}{cm^2 s}$

$\nu = 5 \cdot s^{-1}$

$\Delta t_{th} = 350\ \mu s$

Resource:2035-2037

Ananiev V.D., Blokhintsev D.I., Shabalin E.P. et al. JINR 13-4392, Dubna 1969,

IBR-2 pulsed reactor with injector (LIU–30: e, 30 MeV, 200 A)

Dubna Neutron Source of the 4-th Generation

Neutron flux density: $\overline{\Phi}_{th} = 2 \cdot 10^{14}; \widehat{\Phi}_{th} = 10^{17} \mathrm{n/cm^2/s}$ (20 times higher IBR-2)

Neutron pulse duration:

A. Long pulse	$\Delta t_{\mathrm{therm}} = 150 \div 300\ \mu\mathrm{s}$	Reactor
B. Short pulse	$\Delta t_{\mathrm{therm}} = 20 \div 30\ \mu\mathrm{s}$	Superbooster
C. Very short	$\Delta t_{\mathrm{therm}} = 0.01 \div 1\ \mu\mathrm{s}$	Spallation

Proton accelerator for superbooster:

deeply subcritical state of the superbooster

superbooster gives multiplication $M = 50 \div 500$

short neutron pulse duration

Open question: the optimum balance between resolution and intensity

Aksenov V.L., Ananiev V.D., Komyshev G.G., Rogov A.D., Shabalin E.P.

JINR P3-2016-90, Dubna, 2016; Phys. Part. Nucl., Lett., 2017, V.14, N 5, P.788

On Limit of Neutron Flux from Pulsed Neutron Source Based on Fission

Road Map (Preliminary): 2015 - 2037

Activity	2015 – 18	2018 – 20	2021 – 24	2025 – 26	2027 – 35	2036 – 37
Conceptual research	2015 – 18					
Technical study		2018 – 20				
R & D			2021 – 24			
Engineering design				2025 – 26		
Construction					2027 – 35	
Commissioning						2036 – 37

Conceptual research: 2015 – 2018

I. Neutron Superbooster

Aksenov V., Balagurov A., Pepelyshev Yu., Rogov A. JINR P-13-2016-49 (2016); VANT: Physics of Nuclear Reactors (2017). **High-Flux Pulsed Neutron Source on the Base of Cascade Booster**

Ananiev V., Pepelyshev Yu., Rogov A. JINR P13-2017-43 (2017); VANT: Physics of Nuclear Reactors (2018) **Optimization Study of the IBR-2 Reactor**

Shabalin E., Aksenov V., Komyshev G., Rogov A. JINR P-13-2017-57 (2017); At. Energy (2018). **High-Flux Pulsed Reactor Based on Neptunium**

Vinogradov A., **Pepelyshev Yu.**, Rogov A. Sidorkin S. JINR P13-2018-40 (2018)
High-Flux Pulsed Neutron Source Driven by a Proton Accelerator for Beam Research

—— : **reports on this workshop**

Conceptual research: 2015 – 2018

II. An accelerator

- linear superconducting 0.8 ÷ 1.2 GeV
- synchrotron, storage ring 0.8 ÷ 1.2 GeV
- cyclotron 0.8 GeV

Open questions

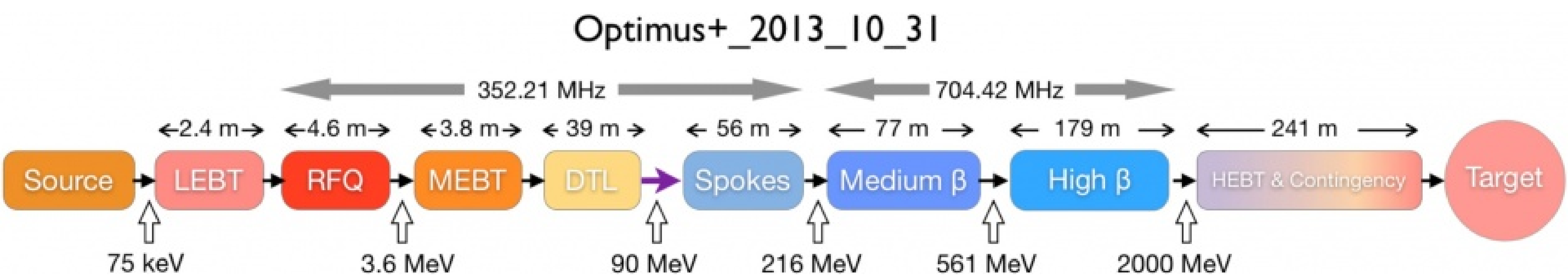
1) role of an accelerator stability
   (the problem of coupled dynamical systems)
2) matching of proton pulse length and moderating time of slow neutrons
3) cost

Aksenov V., Komyshev G., Rzyanin M., Shabalin E., **Accelerator-Driven Pulsed Reactors for Beam Research.** European Cyclotron Progress Meeting, Sept. 2018, Dubna.

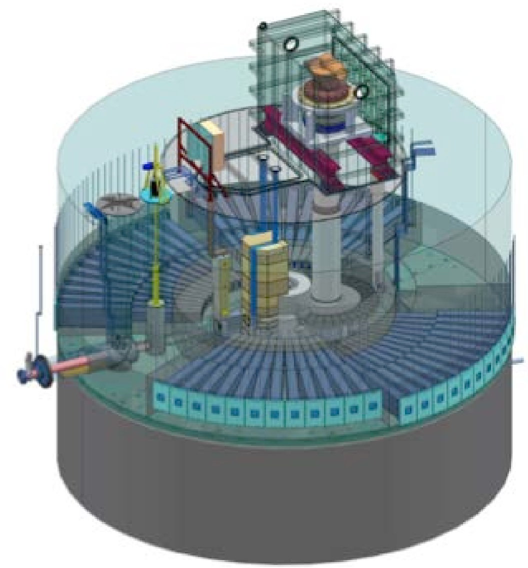
EUROPEAN SPALLATION SOURCE
Lund, Sweden

Plan: 2019 first beam on target, 2023 starts user program, 2025 construction complete

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.

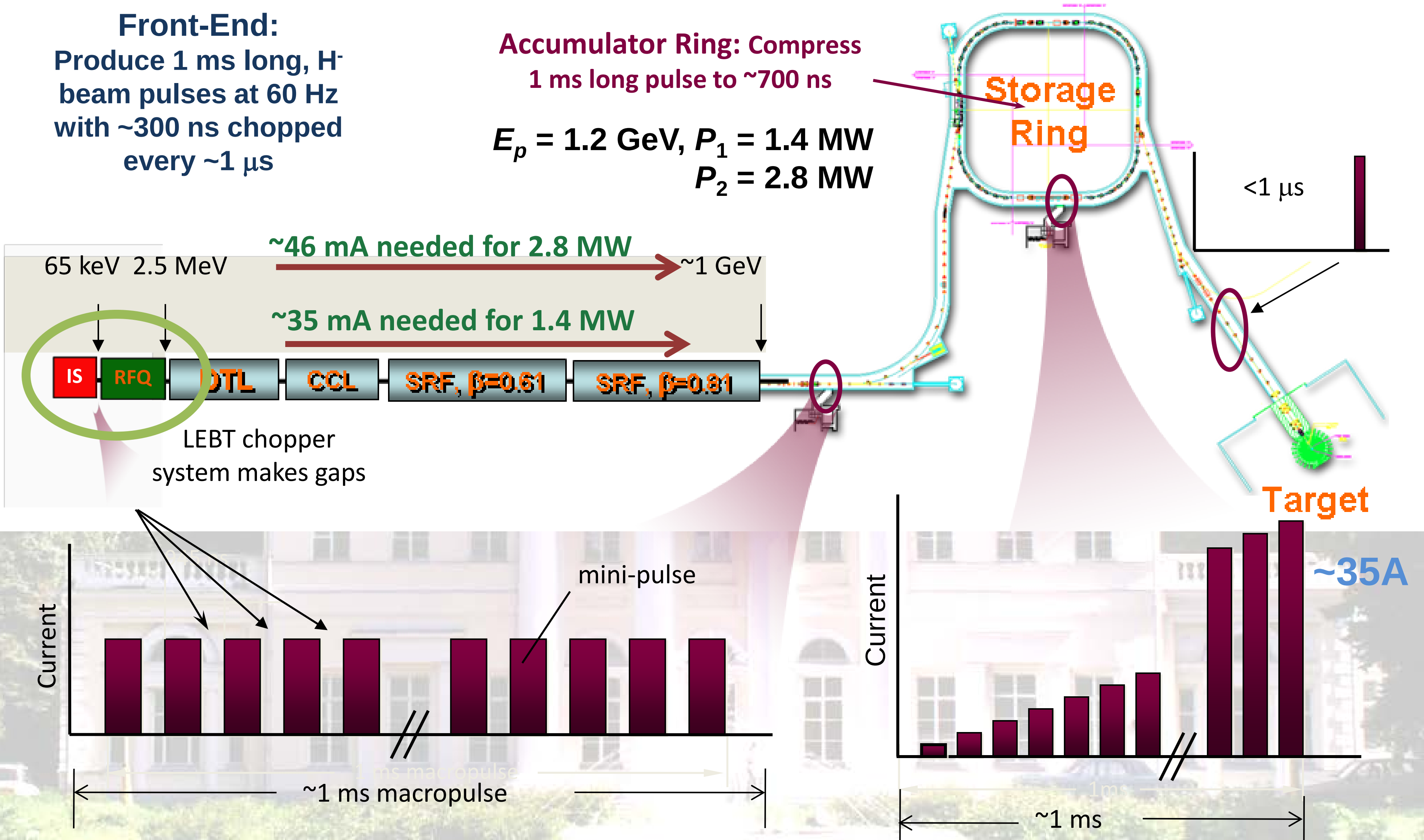


SNS, Oak Ridge, USA (since 2009)

Front-End:
Produce 1 ms long, H^- beam pulses at 60 Hz with ~300 ns chopped every ~1 μs

Accumulator Ring: Compress 1 ms long pulse to ~700 ns

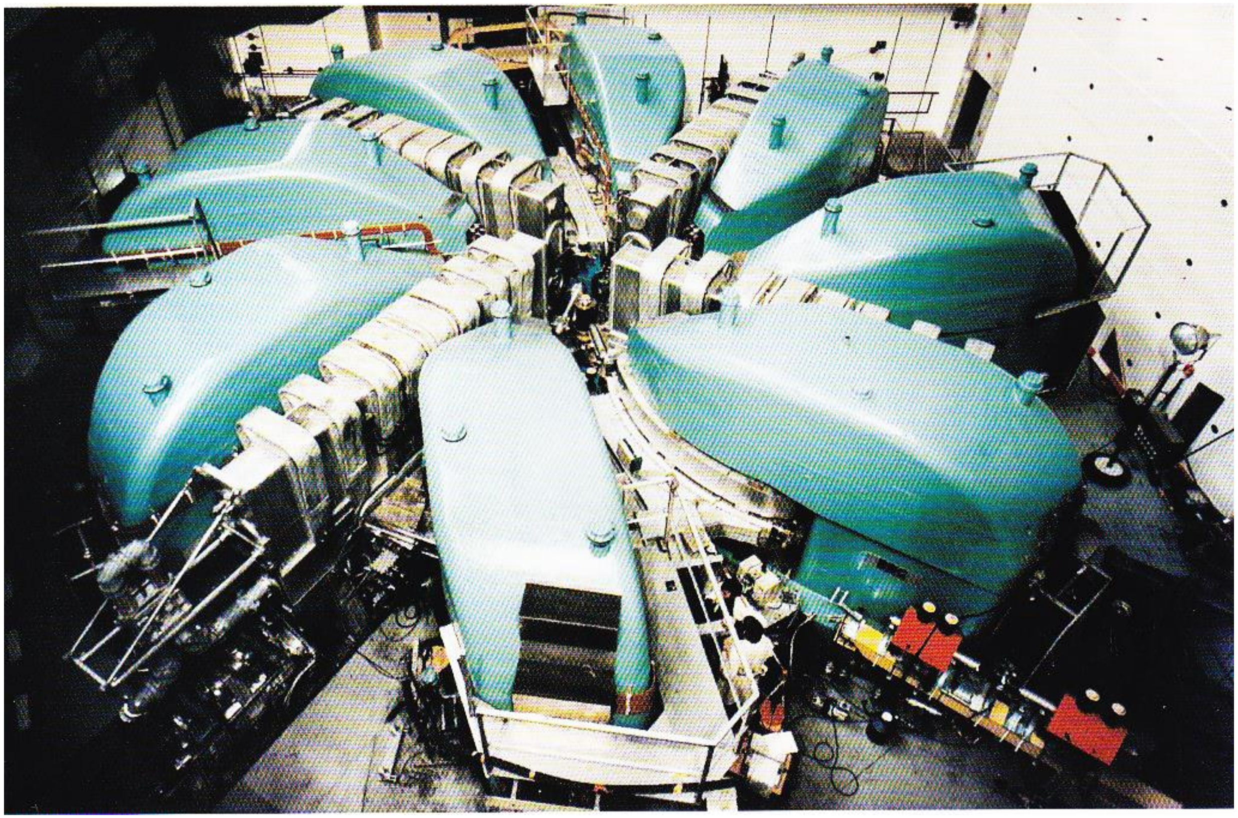
E_p = 1.2 GeV, P_1 = 1.4 MW
P_2 = 2.8 MW



The multi-turn charge exchange injection and clean extraction of the accumulator ring requires chopped H^- beam from the linac.

Swiss Spallation Neutron Source (since 1974)

beam power 1.4 MW



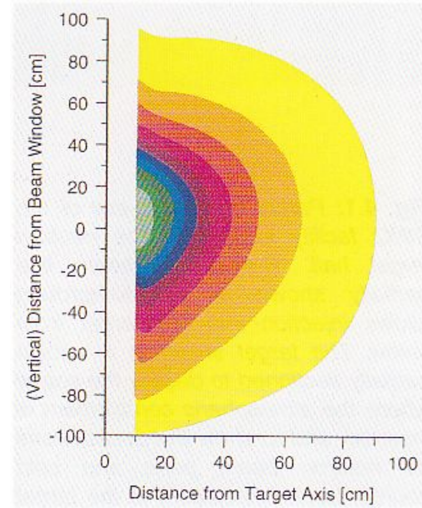


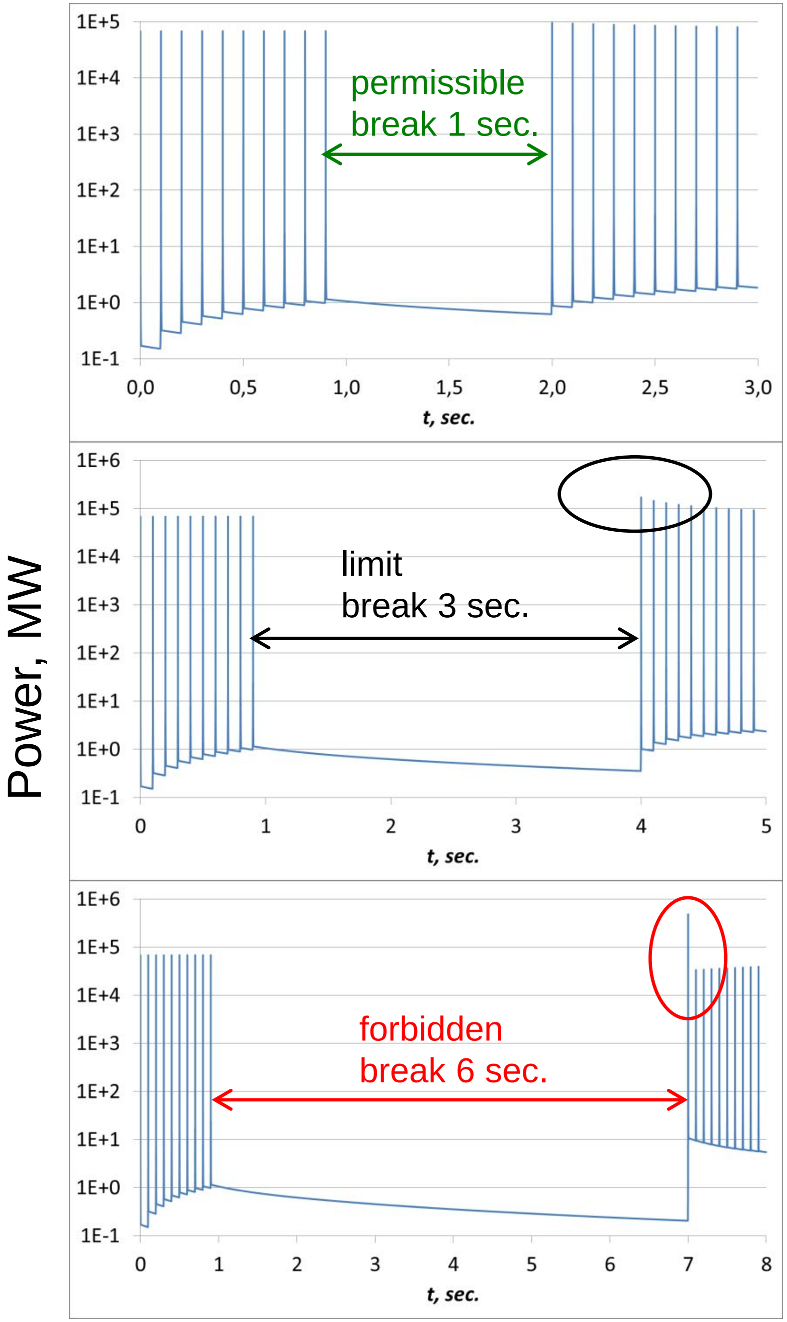
Fig. 4.3: Contours of the unperturbed thermal neutron flux in the SINQ-moderator tank at 1 mA proton current, for a massive lead target with low absorption container: the highest flux is in the centre near the beam window with 1.9 x 10^{14} n/cm² s (light green), decreasing in steps of 0.2 x 10^{14} n/cm² s for each consecutive coloured zone to 1 x 10^{13} n/cm² s (yellow) at the edge.

- beam current 2.4 mA DC
- energy spread ca. 1.5%
- accelerator frequency 50.63 MHz
- time between pulses 19.75 ns
- bunch width ca. 1 ns

PSI Ring Cyclotron	
Type:	Isochronous-Cyclotron
Magnets:	8
Total Magnet mass:	2000 t
Accelerating elements:	4 (5) Cavities(50 MHz)
Kinetic Energy:[4]	590 MeV

Injektor-2	
Type:	Isochronous-Cyclotron
Magnets:	4
Total Magnet mass:	760 t
Accelerating elements:	4 Resonators(50 MHz)
Energy:	72 MeV

Superbooster NEPTUN power deviation due to proton beam breakdown



$$E_p = 1.2\ GeV, \hat{I}_p = 50\ mA, \Delta t_p = 20\ \mu s$$

Multiplication factor $M = 500$

- It is permissible to triple the prompt power exceeding to the nominal value.
- A tenfold excess lead to damage of fuel elements.
- The reason is negative temperature reactivity feedback. When power is down, coolant decreases temperature of fuel that arises reactivity of the reactor core.

Conclusions: (1) The operation of the accelerator must be stable in the sense of temporal lack of proton pulses.

(2) Decreasing of M up to 200. Increasing of E_p up to 2.5 GeV.

M.V.Rzyanin, E.P.Shabalin (2018)

I have received from John Galambos at SNS, information on accelerator trips that we found when you and I discussed the NEPTUN plan. I have forwarded it to you. It shows that **accelerators simply don't operate without occasional outages, ranging from seconds up to hours.** It would be expensive, even if it is possible, to build an accelerator of interesting size that would not be subject to outages. It will be much better if the booster designers can design-in a reactivity temperature feedback feature that will allow operation through accelerator outages. This, if only to provide a long-enough safe interval during which to introduce negative reactivity when accelerator outages occur.

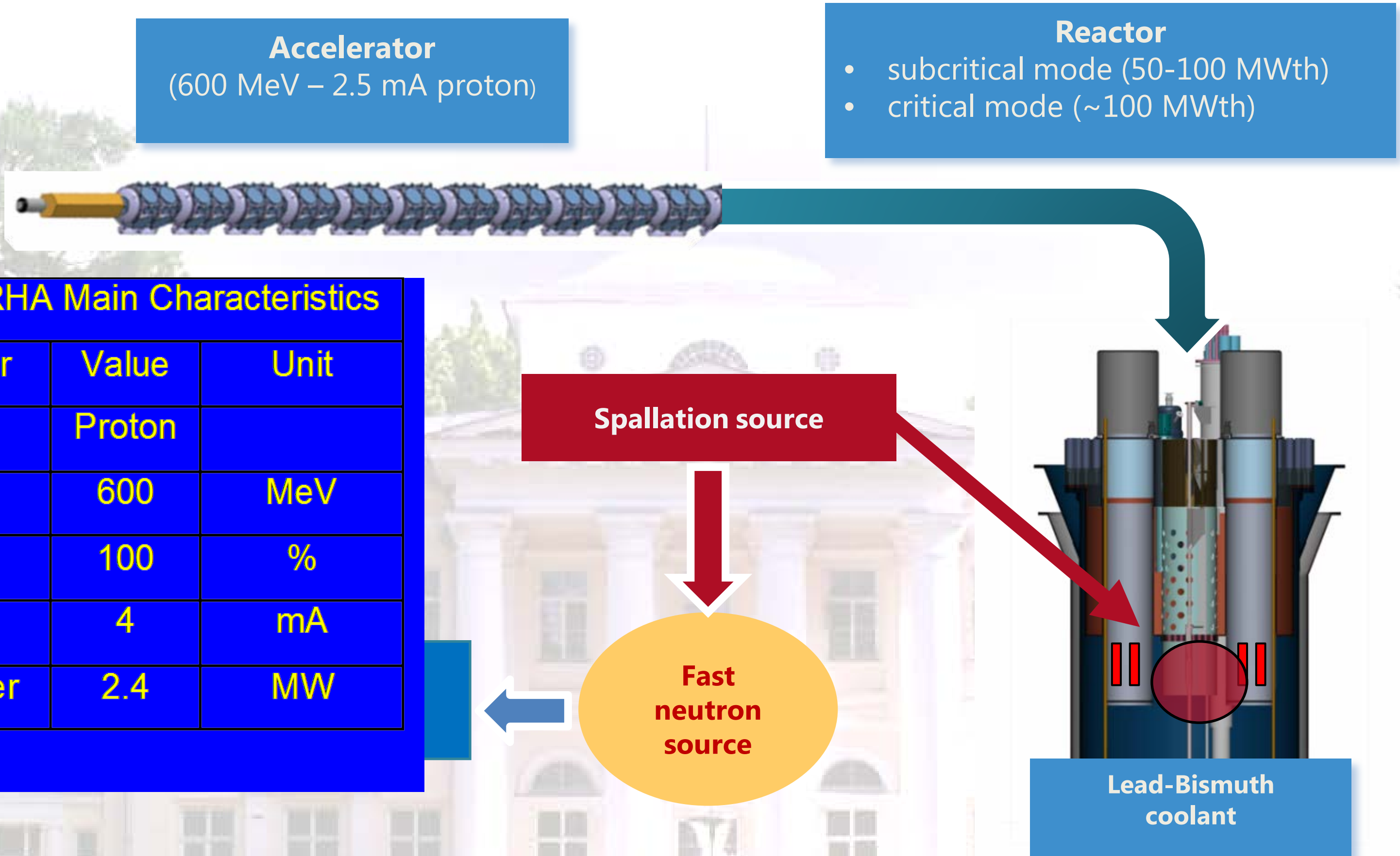
John M. Carpenter, 07.11.2018
Argonne National Laboratory, USA

COMMISSIONING STRATEGIES, OPERATIONS AND PERFORMANCE, BEAM LOSS MANAGEMENT, ACTIVATION, MACHINE PROTECTION

J. Galambos, SNS*, Oak Ridge TN, USA, T. Koseki, KEK, Tsukuba Japan, M. Seidel, PSI Villigen Switzerland. Proceeding of Hadron Beam 2008, Nashville, Tennessee, USA

European Project ADS - MYRRHA

(Multi-purpose hYbrid Research Reactor for High-tech Applications)



The MYRRHA Main Characteristics		
Parameter	Value	Unit
Particle	Proton	
Energy	600	MeV
Duty factor	100	%
Current	4	mA
Beam power	2.4	MW

7.09.2018 Belgian federal government announced:
558 MEu for 2019 – 2038, phase 1

- **the construction of MYRRHA accelerator up to 100 MeV**
- **proton target facility**
- **the preparatory phases of design and R & D for 600 MeV and the reactor**

European Cyclotron Progress Meeting
(3 – 5 Sept. 2018, Dubna)

I made a simple comparison between the expected neutron flux produced by a proton Linear accelerator of 1.2 GeV and 50 mA of current and the solution of 4 independent Superconducting Ring Cyclotron able to deliver 80 mA of proton at 800 MeV. 4 SRC will produce just 6% more neutrons that the Linac solution, moreover the solution with 4 SRC has much more redundancy and is more reliable in particular respect to the beam failure.

This is the Key point to clarify if we like to continue to evaluate the cyclotron option that I quoted around 640 M€, the 4 SRC option, and around 300 M€, the three cyclotrons option.

Luciano Calabretta, 16.09.2018
Lab. Nazionali del Sud, Instituto Nazionale di Fisica Nucleare (INFN)
Catania, Italy

Conclusions in-between: Accelerator?

1. The problem of an accelerator stability for Superbooster is open.
2. The cost of a research and a construction?
3. Advantage for physicists?

We need more arguments to an accelerator
(additional capabilities from protons)

Reports during this workshop

Nuclear physics (A.Popeko, FLNR; V.Panteleev, PNPI)

Transmutation physics (W.Furman, FLNP)

Isotope productions (N.Aksenov, FLNR)

Radiation physics (V.Skuratov, FLNR)

Muon physics (V.Duginov, DLNP)

Environment and biology (M.Frontasyeva, FLNP)

Conceptual research: 2015 – 2018

III. Research Programme and Instrumentation

V.Aksenov. **A 15-Year Forward Look at Neutron Facilities in JINR**. JINR Communications E3-2017-12 Dubna (2017)

V.Aksenov, E.Shabalin, Editors. **Dubna Neutron Source of the Fourth Generation. Superbooster NEPTUN.** JINR, Dubna (2018)

Oct.-Nov., 2018. Final open discussions on Condensed Matter Research.

Presentations: A.Balagurov, M.Avdeev, V.Bodnarchuk, E,Goremychkin, S.Kichanov

* **Condensed Matter Research** programme is prepared for long pulse reactor
* **UCN-Factory:** in progress (report by E.Lychagin)
* **Nuclear Physics:** No proposals

Invited speakers on Nuclear Physics Problems:

A.Popeko (Flerov Lab. of Nucl. Reactions, JINR) and

V.Panteleev (Petersburg Nucl. Phys. Inst., NRC KI)

Understanding the nucleus

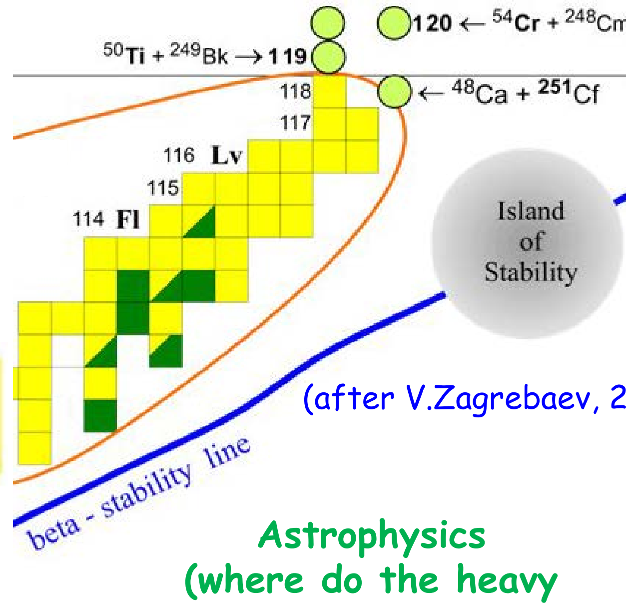
Probing exotic
(n-rich) nuclei

Fission Physics

Nuclear Data

Nuclear Structure
(nuclear models)

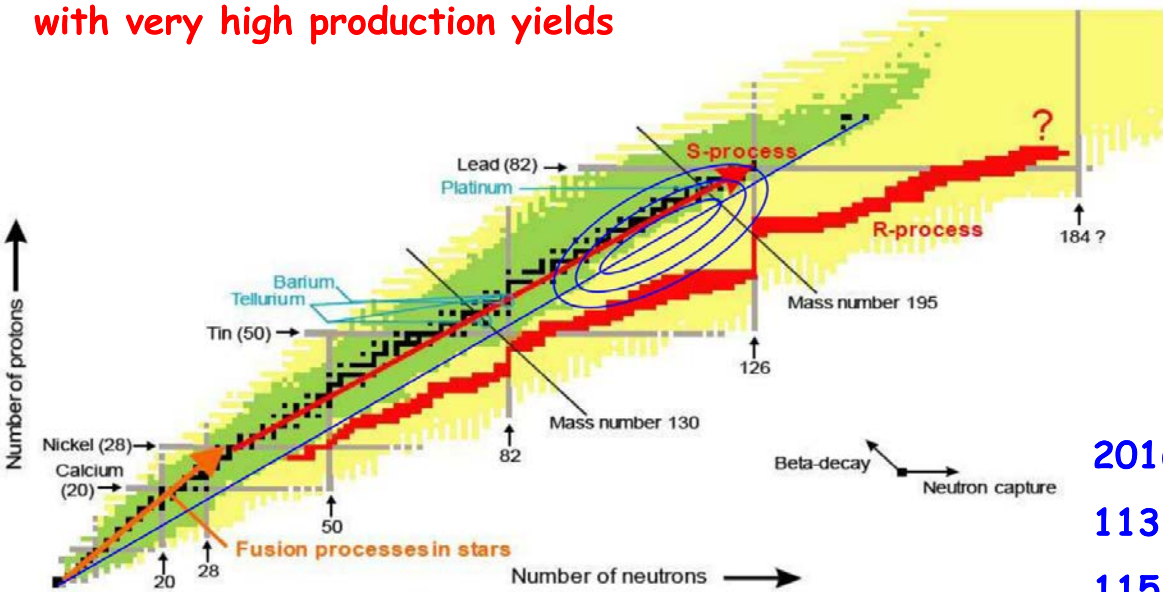
Phase Transitions
in nuclei



(after V.Zagrebaev, 2012)

Astrophysics
(where do the heavy
elements come from?)

DNS-IV will be able to provide for exotic nuclides
with very high production yields



Path ways by which elements in nature and in stars
are synthesized (after D.Habs et al., 2010)

2016:

113 – Nihonium (Nh),

115 – Moscovium (Mc),

117 – Tennessine (Ts),

118 – Oganesson (Og)

Mass-spectroscopy of radioactive nuclides

A high-flux Dubna Neutron Source of the 4-th generation will be able to provide exotic neutron-rich nuclides with very high production yields

The success of experiments depends both on the beam intensity and the accuracy of the measurements

mass-spectroscopy: **Isotope Separator On-Line (ISOL) Facilities, Penning traps (ion traps)**

Accelerators

ISOLTRAP/CERN
SHIPTRAP/GSI
JYELTRAP/JYEL
TITAN/TRIUMF

Reactors

TRIGATRAP/Mainz
PITRAP/PIK,
Gatchina (Project)

Factory of n-rich nuclides at DNS-IV

- nucleogenesis in nature and energy production in stars (path way of r, s-process, β-stability line)
- neutrino physics (on-line measurements of long-lived nuclides, ν-mass, ν-Majorano)
- fission physics

Pulse Fast Reactor IBR-3: Layout of Moderators

$\Delta t_n^{\text{fast}} = 150 \div 200\ \mu\text{s},\ \ 10\ \text{Hz},\ \ \widehat{\Phi}_{th} = 10^{17}\ ;\ \ \overline{\Phi}_{th} = 2 \cdot 10^{14}\ \text{n/cm}^2/\text{s}$ (2035/37), 200 MEu

Moderator $T_m = 30$ K

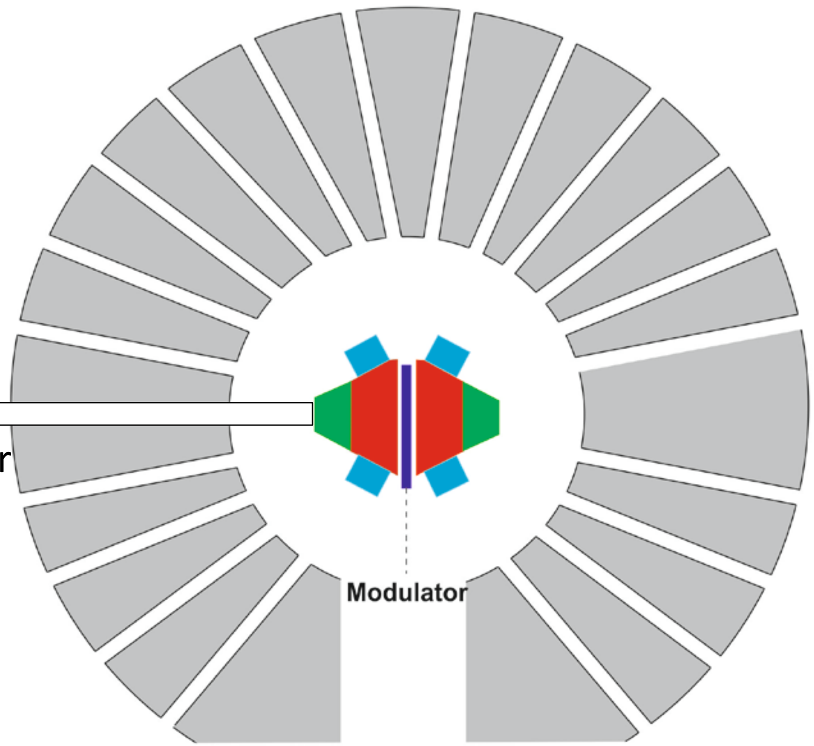
$\Delta t_n = 300 \div 350\ \mu\text{s}$

Moderator $T_m = 60$ K

$\Delta t_n = 250 \div 300\ \mu\text{s}$

Channel for Proton beam

reserve area for Superbooster



Moderator poisoned

$\Delta t_{th} \approx 30\ \mu\text{s}$

$\overline{\Phi}_{th} = 4 \cdot 10^{13}\ \text{n/cm}^2/\text{s}$

$\widehat{\Phi}_{th} = 2 \cdot 10^{16}\ \text{n/cm}^2/\text{s}$

Moderator $T_m = 300$ K

Factory of

n-rich nuclides

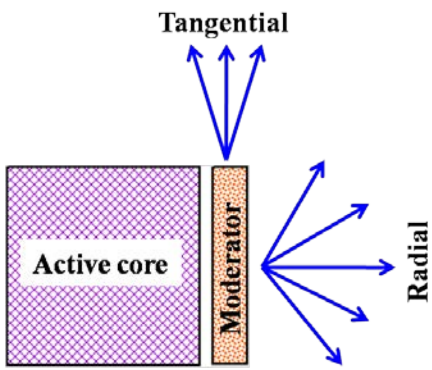
UCN – Factory

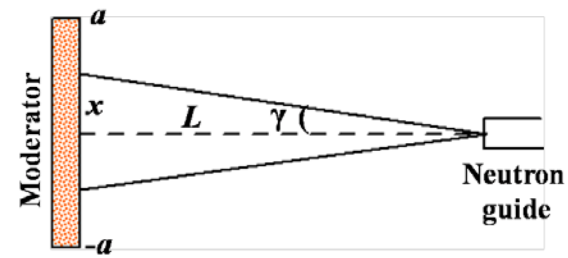
Background 3.2 ÷ 3.5 %, Choppers 5 ÷ 7 m from the core, 20 – 30 beamlines

Phase 1: diffr., inel., SANS, Reflectometry, Radiography

Phase 2: diffr., inel., SANS, SpinEcho, Reflectometry

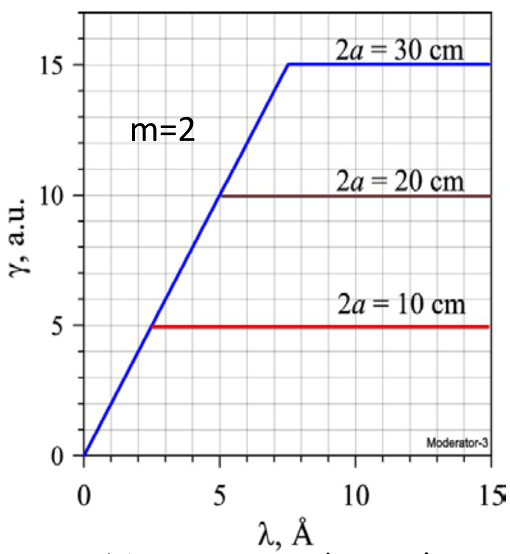
2019: conceptual research of moderators



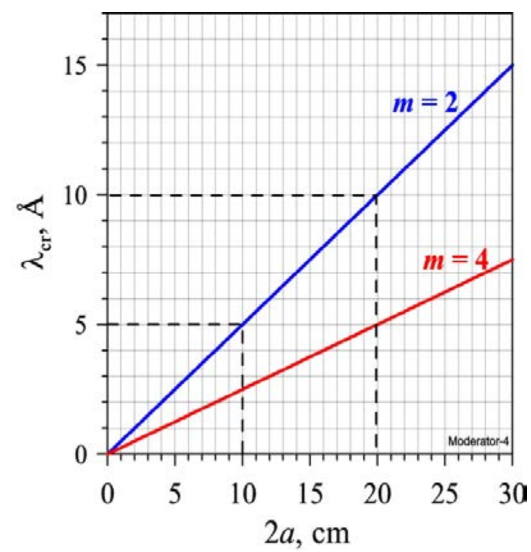


- Tangential: more thermal and no fast neutrons
- Radial: more moderating square

$$\gamma = x/L \leq \gamma_{cr} \rightarrow x \leq \gamma_{cr} \cdot L \quad (\text{Ni: } \gamma_{cr} = 1.22 \cdot 10^{-3} \cdot \lambda, \ m = 1.5 \div 5)$$



Neutron guide angle



At $\lambda > \lambda_{cr}$ no increasing in n-guide

Conclusions final

1. IBR-2 shut down 2035/36; not so much time;

2. Two proposals for the conceptual design:
   - Long Pulsed Reactor IBR-3 (200 MEu);
   - Accelerator Based Neutron Source (900÷1200 MEu).

3. Open questions:
   - nuclear data for Np-237;
   - more arguments for an accelerator;
   - accelerator cost.

4. 2019: main task is the moderators study.

Acknowledgments

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