IPAC'10 The 1st International Particle Accelerator Conference
The 1st International Particle Accelerator Conference
Kyoto, Japan / May 23-28, 2010

Accelerators Application for Basic and Applied Research at JINR

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JINR, Dubna

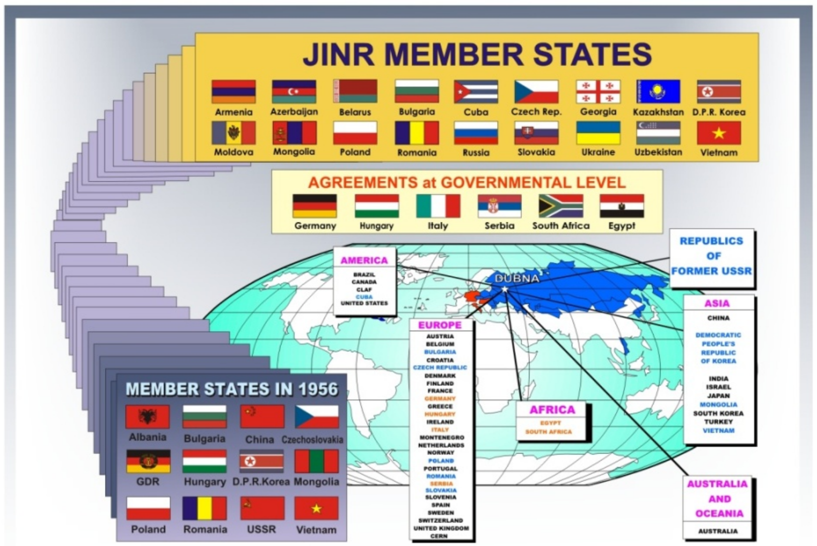
JOINT INSTITUTE FOR NUCLEAR RESEARCH
JINR

Contents

Introduction: JINR and Its Accelerator Facilities

JINR today :
International intergovernmental organization

- 18 Member States
- 6 Associated Members States
- about 700 research partners in 60 countries
- staff members ~ 5500



Three Pillars of JINR:

- ❑ Basic research in high energy and nuclear physics, condensed matter physics and radiobiology;
- ❑ Education programme;
- ❑ Applied research based on achievements in basic research.

Special Economic Zone in DUBNA

Introduction: JINR and Its Accelerator Facilities

JINR today

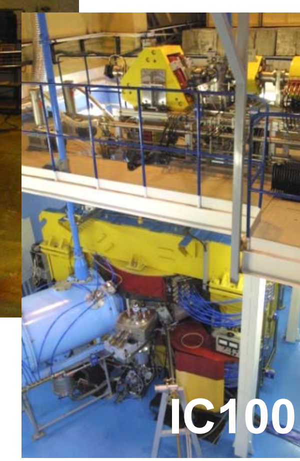
Special Economic Zone in DUBNA

Introduction: JINR and Its Accelerator Facilities

Synchrocyclotron

SC Proton Synchrotron

Heavy Ion Cyclotrons



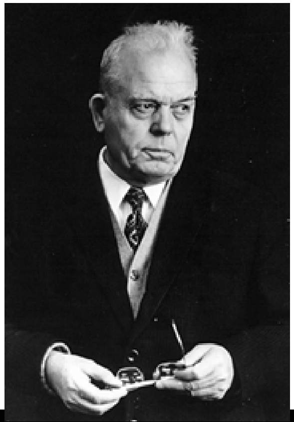
1. Phasotron and medical applications

I.V.Kurchatov and V.P. Dzhelepov

Synchrocyclotron “Phasotron”

The First Accelerator in Dubna

Constructed in frames of the Soviet Atomic Project, commissioned in 1949, still in operation



M. G.Meshcheryakov

Machine parameters:

- Protons
- 660 MeV
- 2.2 μA – slow extraction,
- 3 μA – fast extraction

Research program:

- ✓Muon-catalysis
- ✓Pion & muon physics
- ✓Nuclear physics

Main application:

Cancer therapy

1. Phasotron and medical applications

7 treatment cabins:

1, 2 – protons 100, 130, 200 MeV+ *proton tomograph*

3 – 660 MeV protons

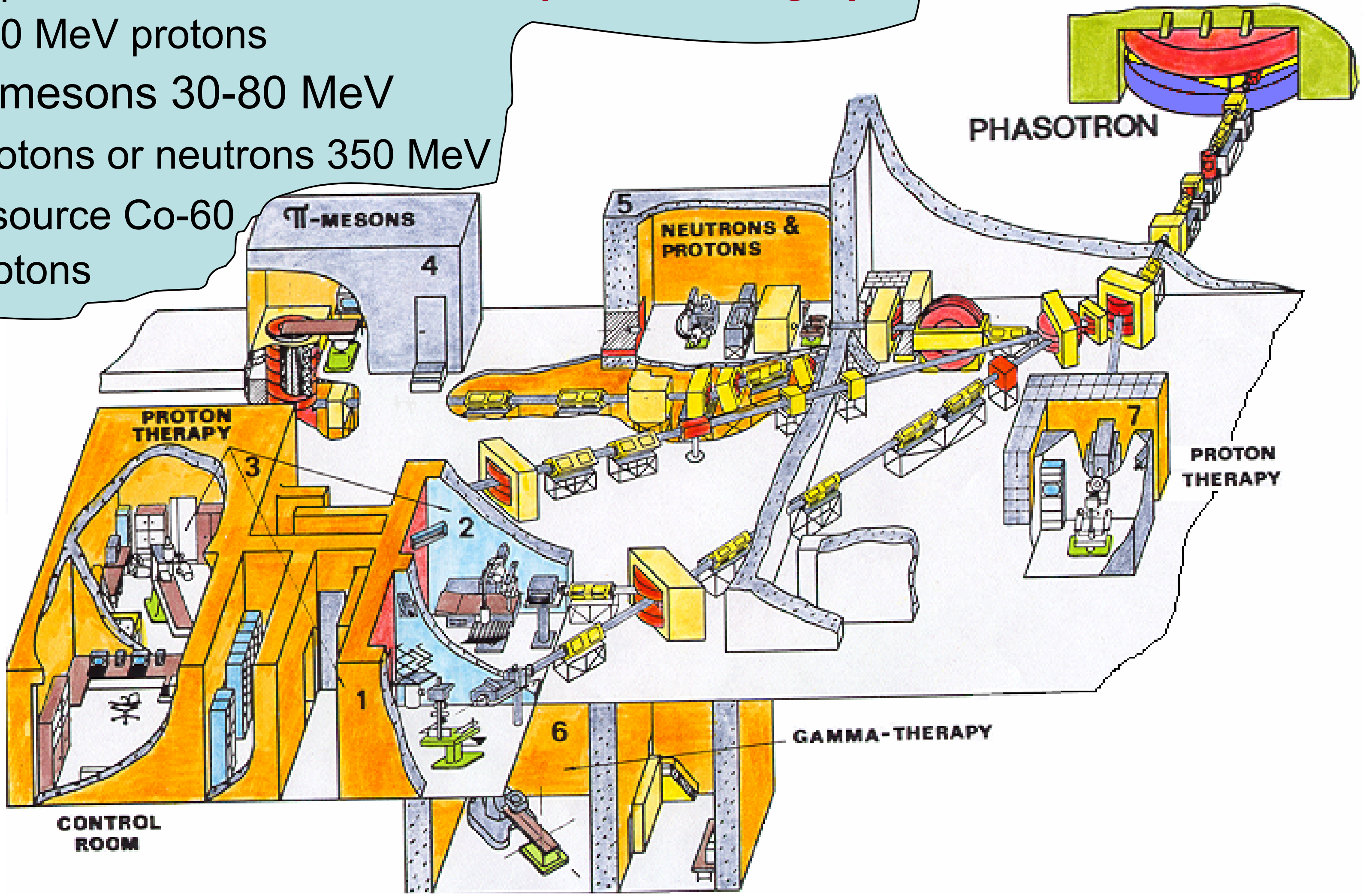
4 – π-mesons 30-80 MeV

5 – protons or neutrons 350 MeV

6 – γ-source Co-60

7 – protons

Cancer therapy at Phasotron



1. Phasotron and medical applications

7 treatment cabins:

1, 2 – protons 100, 130, 200 MeV+ *proton tomograph*

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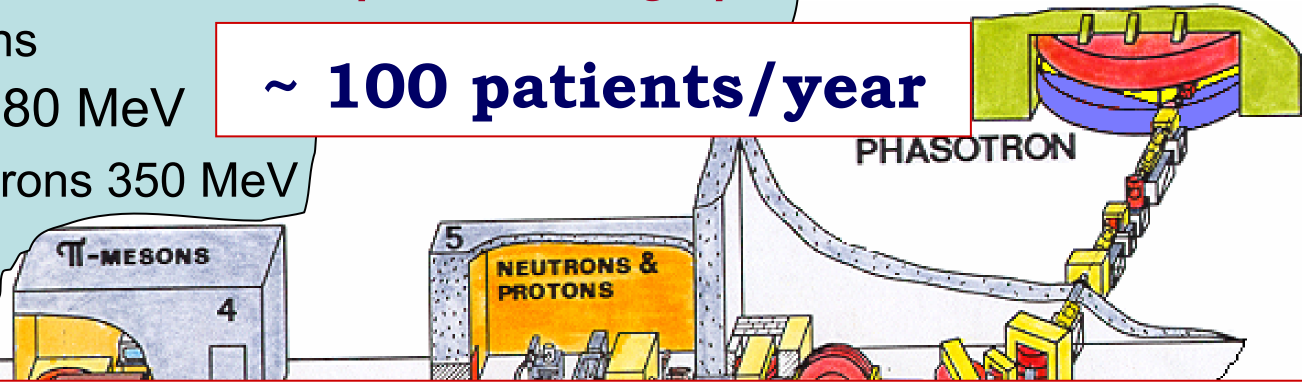
5 – protons or neutrons 350 MeV

6 – γ-source Co-60

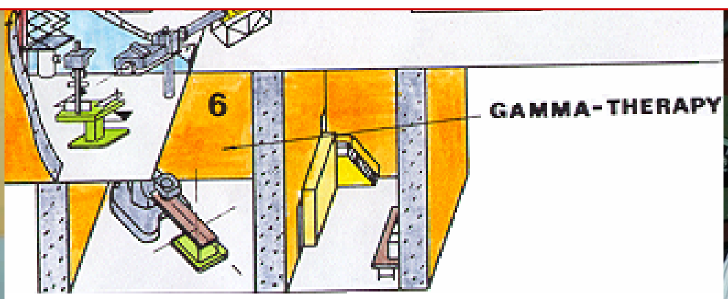
7 – protons

Cancer therapy at Phasotron

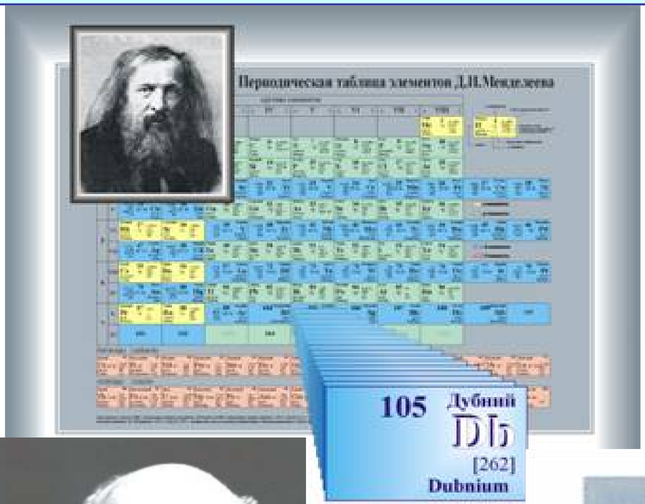
~ 100 patients/year



Presently design and construction of dedicated cyclotrons for cancer therapy is in progress in collaboration with IBA C° (Belgium)



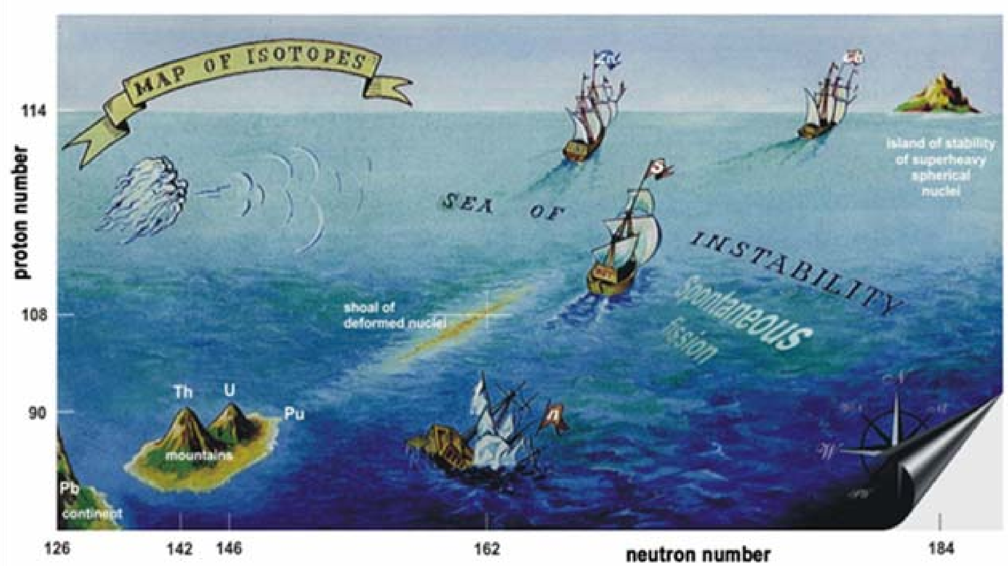
2. Cyclotrons at Flerov Laboratory of Nuclear Reactions



Fundamental Research in Nuclear Physics

Synthesis of Transfermium Elements

Georgy Flerov



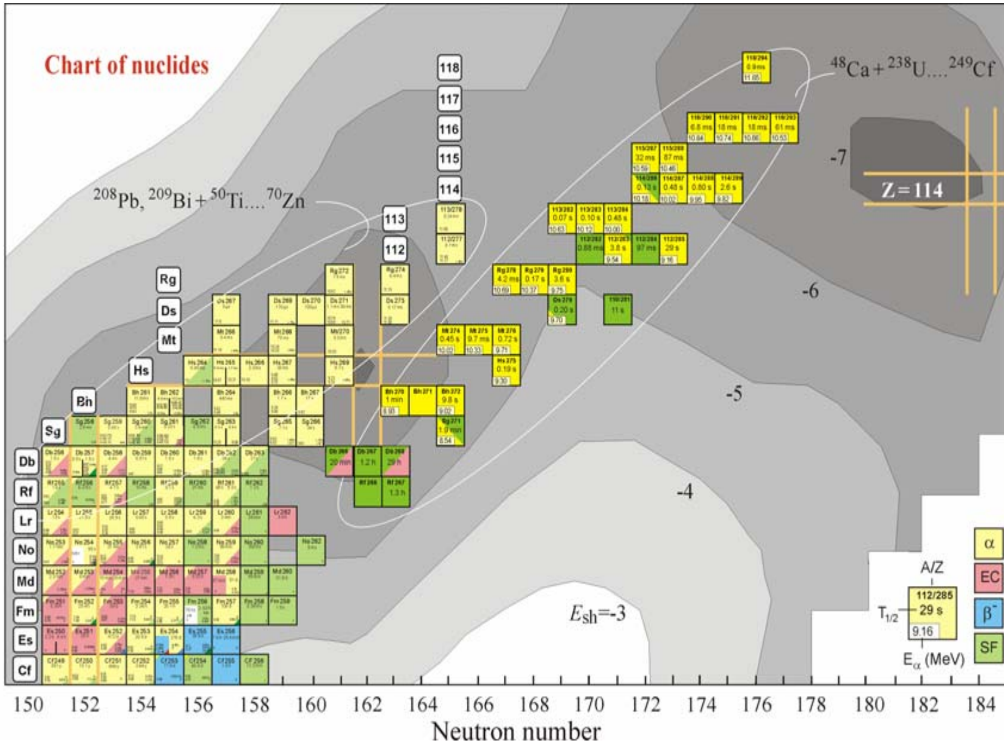
Yuri Oganessian

Fundamental Research in Nuclear Physics

For the last decade JINR has become one of the leading scientific centres in the world in low energy heavy-ion physics.

Synthesis of Transfermium Elements

(Contnd)



Fundamental Research in Nuclear Physics

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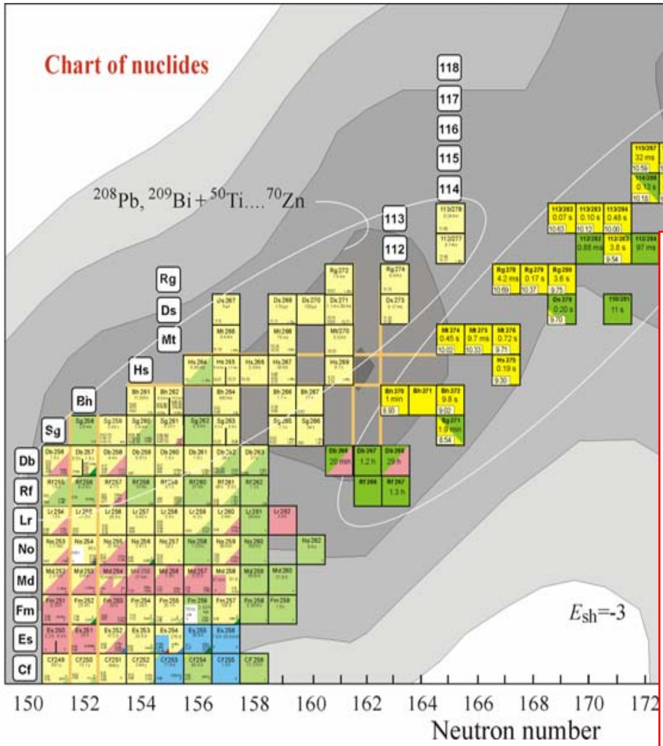

Number of observed decay chains of the elements ##	
118	3
116	26
115	4
114	43
113	2
112	8
117	3

Fundamental Research in Nuclear Physics

Synthesis of Transfermium Elements
(Contnd)

U400 Beam Parameters

Ion	Energy, MeV/amu	Current	
		mcA	10^{12} pps
$^{7}Li^{1+}$, $^{6}Li^{1+}$	16.6	30	60
$^{11}Li^{2+}$	16.6	33	40
$^{12}C^{2+}$, $^{13}C^{2+}$	14.4	35	30
$^{14}N^{2+}$	9.4	35	30
$^{14}N^{3+}$	20.3	35	30
$^{18}O^{3+}$	19.3	35	25
$^{20}Ne^{4+}$	20.9	35	20
$^{22}Ne^{4+}$	17.8	35	20
$^{36}S^{6+}$	15	25	9
$^{40}Ar^{8+}$	19.9	35	10
$^{48}Ca^{5+}$	5.3	22	7
$^{48}Ca^{9+}$	19	10	3
$^{86}Kr^{9+}$	5.1	10	2
$^{136}Xe^{14+}$	4.4	0.2	0.03

Fundamental Research in Nuclear Physics

Synthesis of Transfermium Elements (Contnd)

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$^{136}Xe^{14+}$	4.4	0.2	0.03

The projectile for synthesis of the elements 113-118

Synthesis of Super-Heavy Elements (Contnd)

Year	Discovered element	Laboratory
1963	102 No – Nobelium[1]	FLNR
1961/1965	103 Lr – Lawrencium[1]	LBNL/FLNR
1966/1969	104 Rf – Rutherfordium[1]	FLNR/LBNL
1970/1971	105 Db – Dubnium[1]	FLNR/LBNL
1974	106 Sg – Seaborgium[1]	LBNL/LLNL
1981	107 Bh – Bohrium[1]	GSI
1984	108 Hs – Hassium[1]	GSI/FLNR
1982	109 Mt – Meitnerium[1]	GSI
1994	110 Ds – Darmstadtium[2]	GSI

[1] Priority has been defined in 1993 (*Pure & Appl. Chem.*, Vol. 65, No. 8, p. 1757,1993)

[2] Priority has been defined in 2003 (*Pure & Appl. Chem.*, Vol. 75, No. 10, p. 1613, 2003)

Synthesis of Super-Heavy Elements (Contnd)

Year	Discovered element	Laboratory
1994	111 Rg – Roentgenium[3]	GSI
1996	112 Cn – Copernicium[4]	GSI
2004	113 no name[5]	FLNR / RIKEN
1998	114 no name[5]	Collaboration: FLNR & RIAR (Dmitrovgrad) & ORNL & LLNL & Vanderbilt University
2004	115 no name[5]	
2000	116 no name[5]	
2010	117 no name[5]	
2002	118 no name[5]	

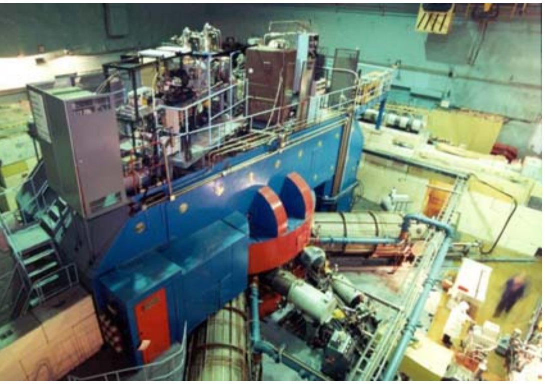
[3] Priority has been defined in 2004 (*Pure & Appl. Chem.*, Vol. 76, No. 12, p. 2101, 2004)

[4] Priority has been defined in 2009 (*Pure & Appl. Chem.*, Vol. 81, No. 7, p. 1331, 2009)

[5] Priority is not defined yet

U400M and Light Radioactive Nuclei Studies

U400M cyclotron parameters



Ion	Energy, MeV/amu	Current	
		mcA	10^{12} pps
$^{7}Li^{2+}$	35	30	60
$^{11}B^{3+}$	32	30	40
$^{12}C^{4+}$	47	35	40
$^{14}N^{4+}$	35	35	30
$^{14}N^{5+}$	54	15	15
$^{18}O^{5+}$	33	30	25
$^{22}Ne^{6+}$	32	15	10
$^{22}Ne^{7+}$	43	15	10
$^{36}S^{10+}$	33	1.7	0.6
$^{40}Ar^{12+}$	40	2	0.7
$^{48}Ca^{10+}$	20	1.7	0.5

U400M and Exotic Nuclei Studies

ACCULINNA fragment separator

G. Ter-Akopian et al.

2002 – 2003: search for ^{5}H and ^{7}H resonances with RIB's of ^{6}He & ^{8}He, cryogenic ^{2}H & ^{3}H targets, reactions :

$^{6}He + {}^{2}H \Rightarrow {}^{5}H + {}^{3}He$ $^{3}H + {}^{3}H \Rightarrow {}^{5}H + p$ $^{8}He + {}^{2}H \Rightarrow {}^{7}H + {}^{3}He$

2009 - 2010: RIB's generation and R-nuclei structure studies of ^{10}He, ^{12}He & ^{13}Li

Primary beams: ^{18}O and ^{15}N, 48 MeV/amu, 1 pmA ($6 \cdot 10^{12}$ pps) Beryllium target (2 mm), Secondary beams:

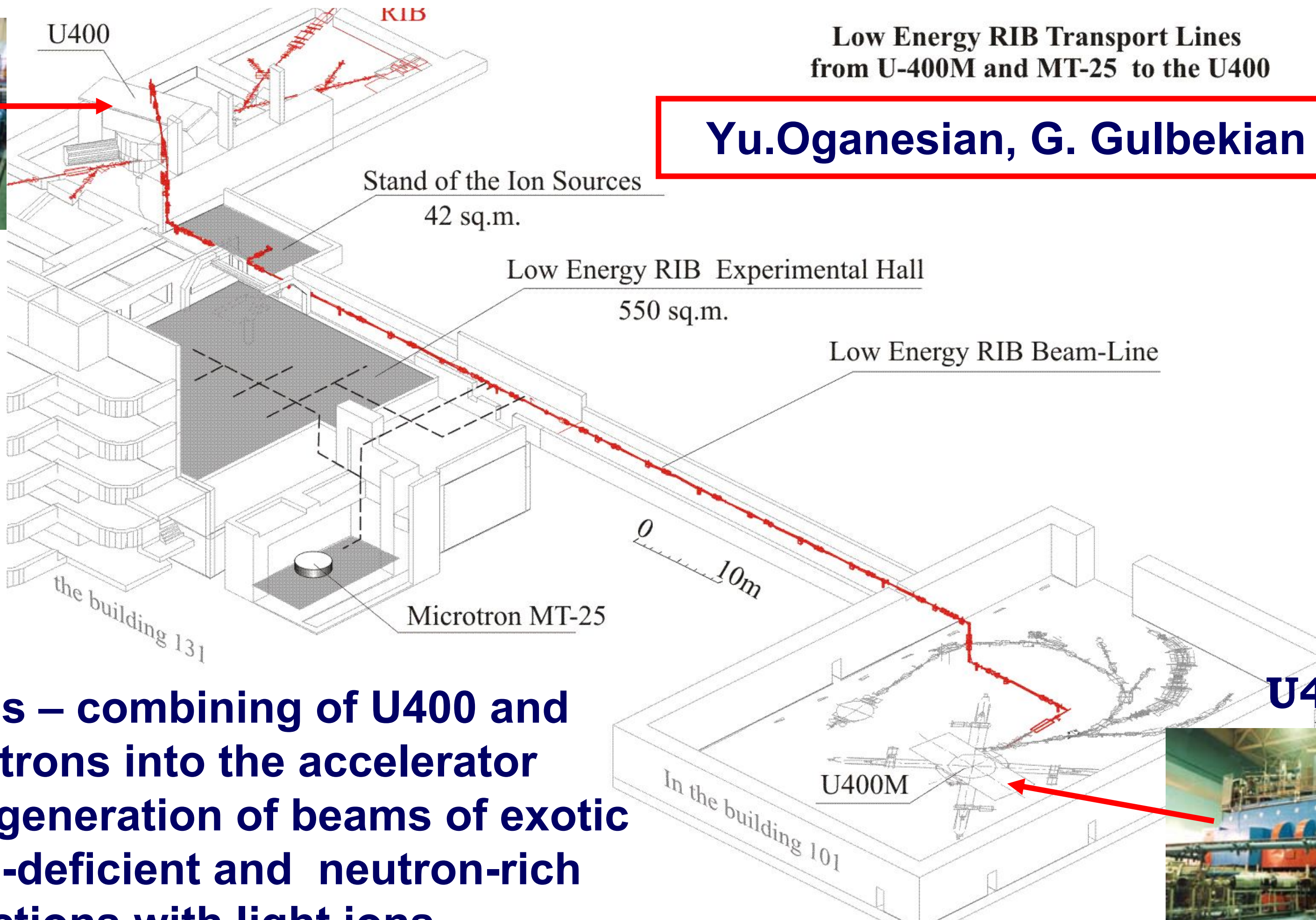
^{11}Li ($2 \cdot 10^{3}$), ^{12}Be ($6 \cdot 10^{4}$), ^{14}Be ($1 \cdot 10^{3}$), ^{15}B ($5 \cdot 10^{4}$), 35 MeV/u

$^{11}Li + {}^{2}H \Rightarrow {}^{10}He + {}^{3}He$ (200/month) $^{12}Be + {}^{12}C \Rightarrow {}^{10}He + {}^{14}O$ (50/month)

$^{11}Li + {}^{3}H \Rightarrow {}^{13}Li + p$ $^{14}Be + {}^{12}C \Rightarrow {}^{12}He + {}^{14}O$

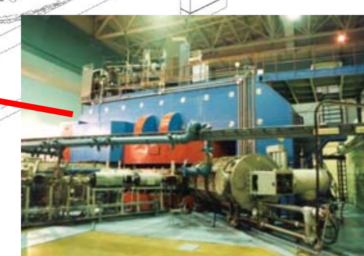
The Project DRIBS: Dubna Radioactive Ion BeamS

U400



Yu.Oganesian, G. Gulbekian et al.

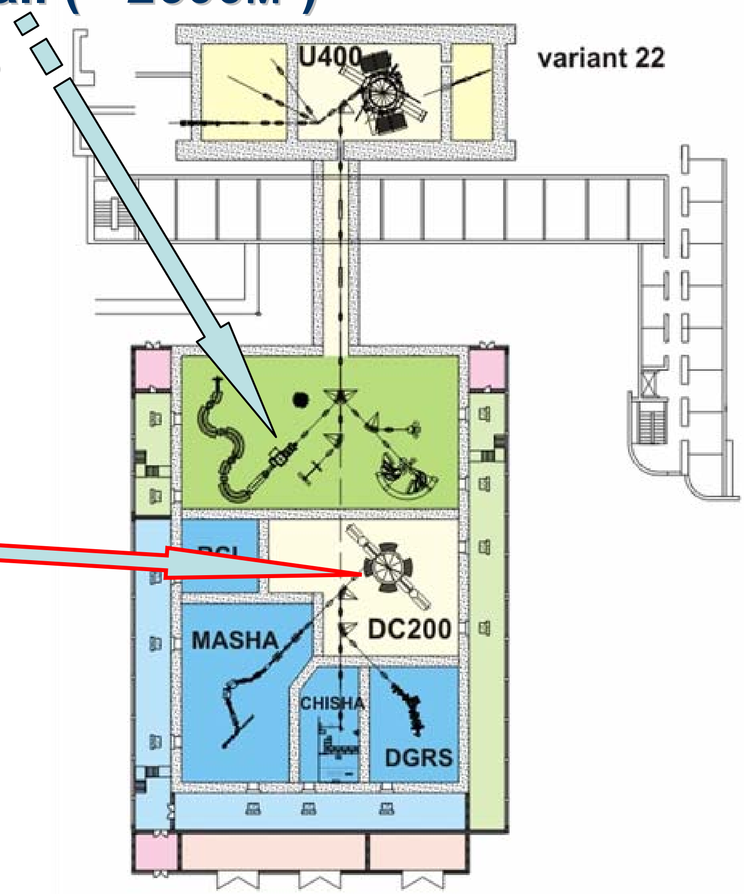
U400M



Project DRIBs – combining of U400 and U400M cyclotrons into the accelerator complex for generation of beams of exotic light neutron-deficient and neutron-rich nuclei in reactions with light ions.

DRIBs-III (2015)

- Modernization of U400M & U400 cyclotrons
- Construction of the new experimental hall (≈ 2600м²)
- Construction of next generation set-ups



- Construction of high current heavy ion cyclotron

DC200:

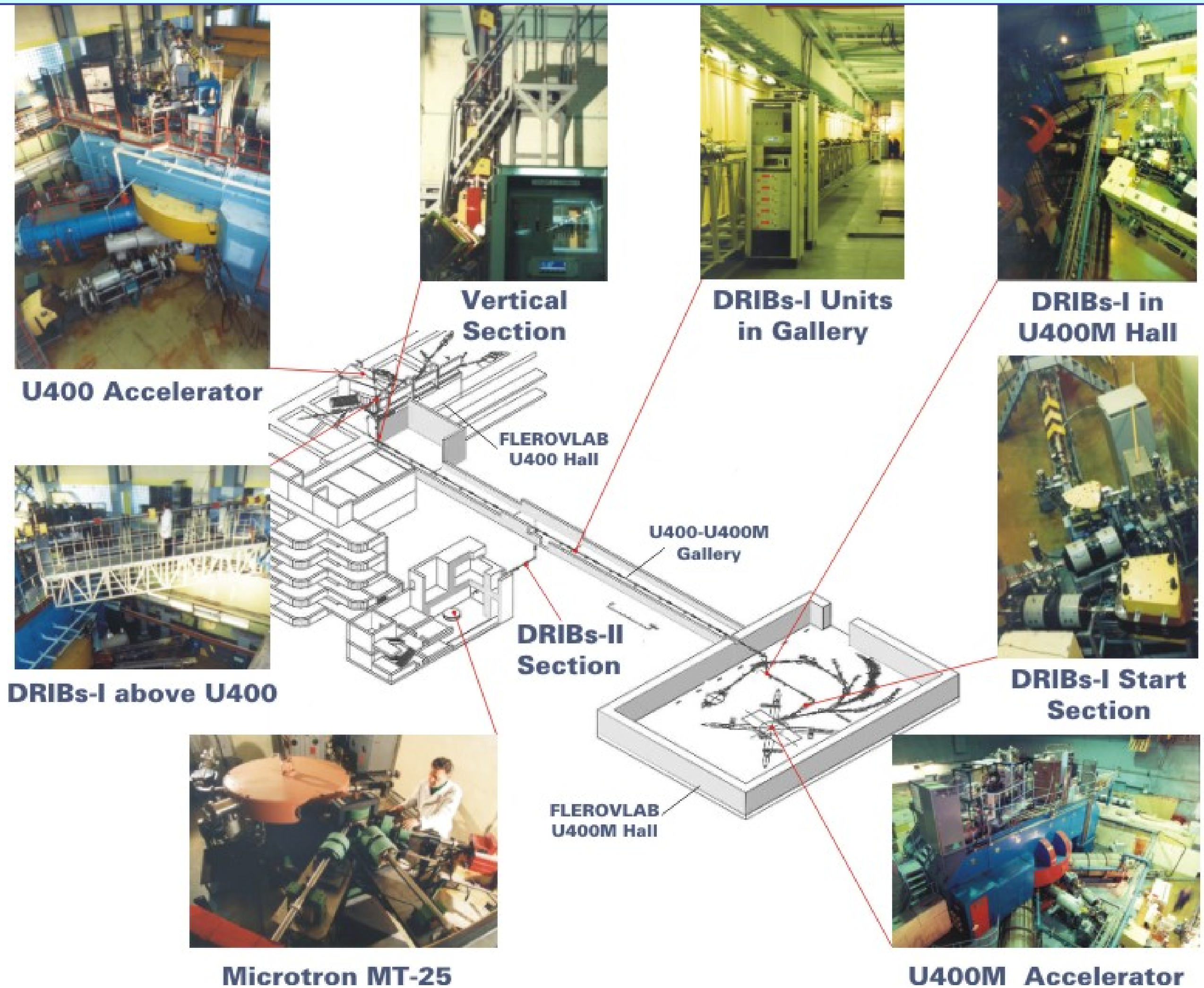
A≤ 100, E ≤ 10 MeV/u, I ≥ 10 pμA

2. Cyclotrons at FLNR

Fundamental Research in Nuclear Physics

DRIBS-I parameters (2008):

^{7}Li ($1.9 \cdot 10^{13}$ pps) $\Rightarrow$ ^{6}He ($5 \cdot 10^{7}$ pps)



IC-100 Cyclotron Beam Application

Production of:

- **track membranes with cylindrical pores of the diameter of 5 mcm – 0.05 mcm at the pore density of 10^6 - $3 \cdot 10^9$ per cm^2 ;**

- **track membranes of the new types corresponding to the requirements of the Life Science applied to the production of new medications and biologicals;**

- **metal nano-structures (e.g. nano-wires and submicron pipes) on the basis of pattern technology;**

- **ion-implantation synthesis of nano-size cluster structures in the solids.**

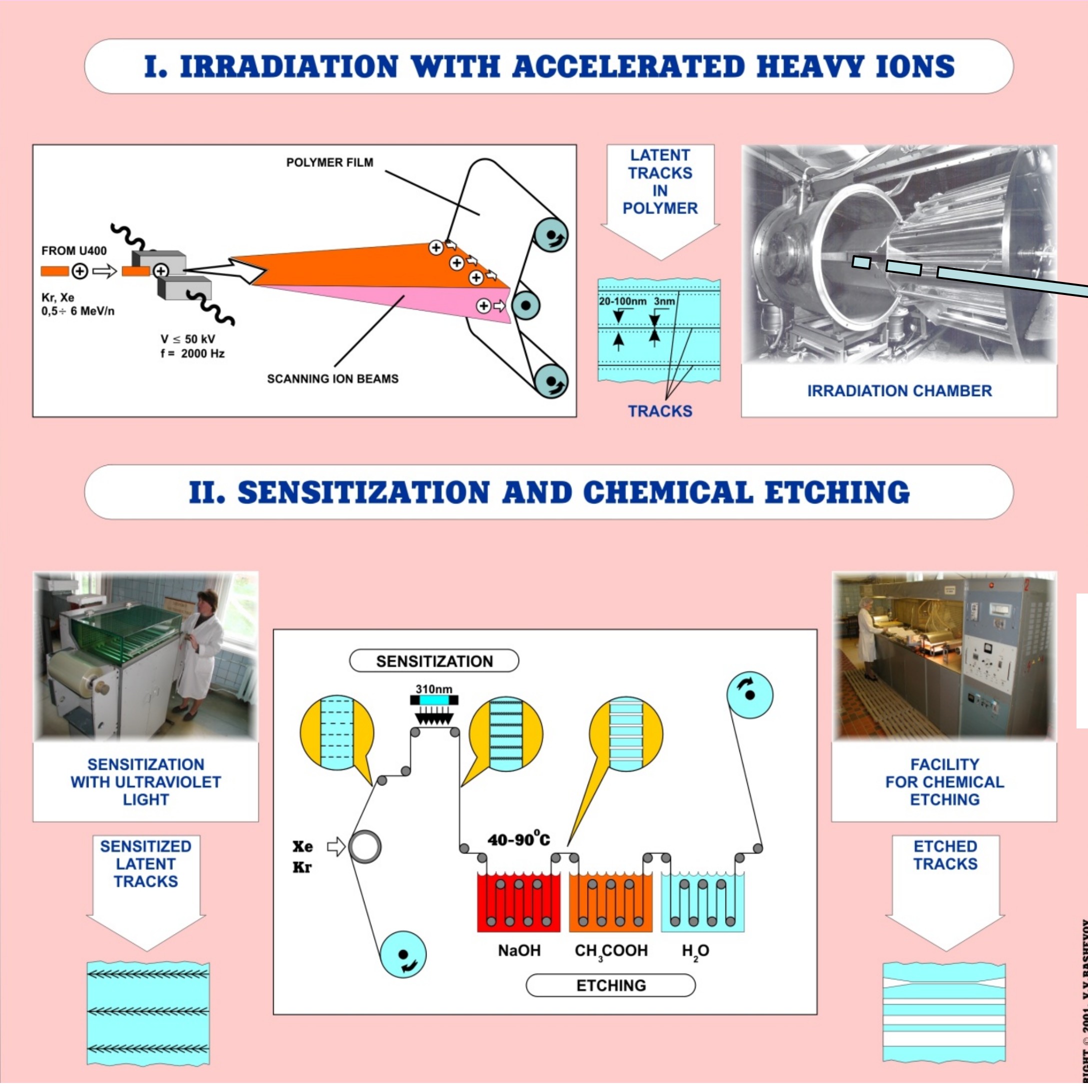
Accelerator Based Applied Research and Technology

Cyclotron IC-100

Ions	Energy [MeV/amu]	Intensity [pps]
$^{22}Ne^{4+}$	1.0 - 1.2	1.1E12
$^{40}Ar^{7+}$		2.23E12
$^{86}Kr^{15+}$		1.46E12
$^{127}I^{22+}$		0.71E11
$^{132}Xe^{23+}$		1.0E12
$^{182}W^{32+}$		2.9E9
$^{184}W^{31+}$		0.7E10

Track membrane production technology

P. Apel et al.



Chamber for polymer films irradiation

Maximum film width: 60 cm

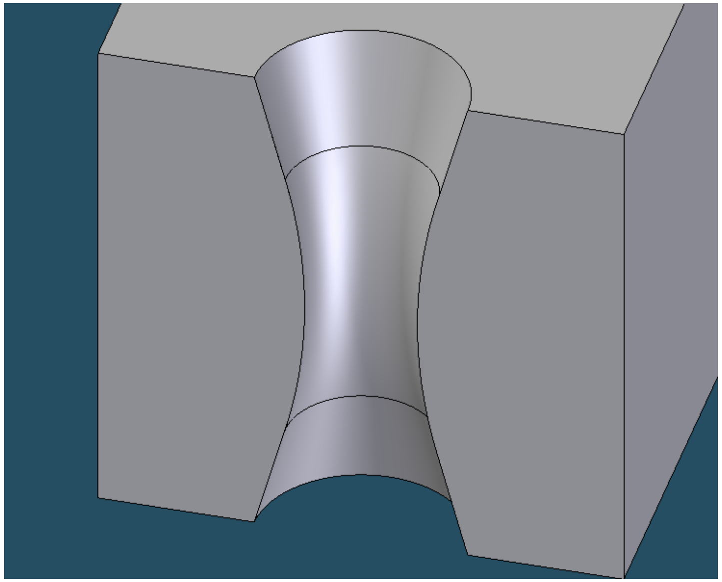
Film transport speed: 1- 100 cm/s

Typical productivity: 700 m/h

i.e. ~ 40 m^2/h

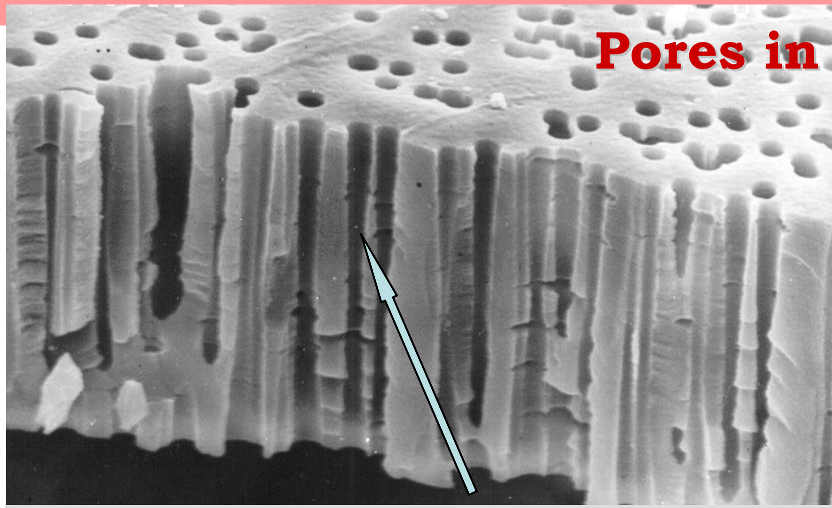
Track membrane production technology

Evolution of an heavy ion track in polimer film at chemical etching

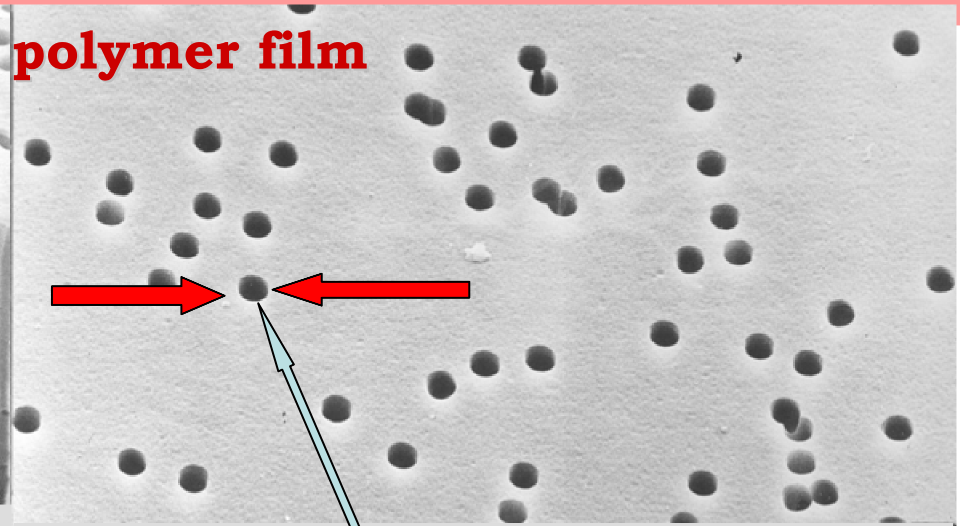


Track membrane production technology

Pores in polymer film

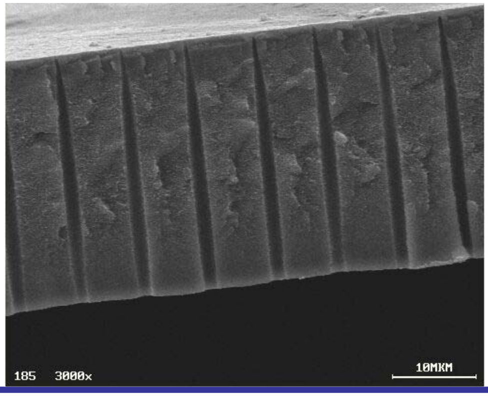


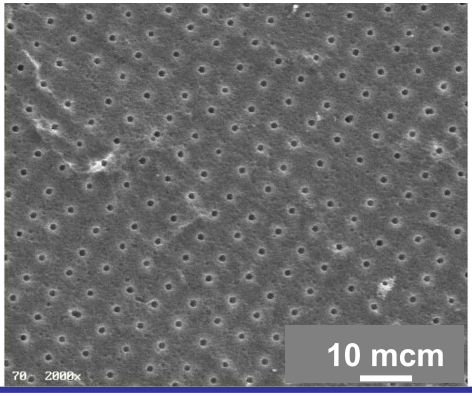
Membrane channel length is by a few thousand times larger of pore diameter



Pore diameter is of 5μ – 0.05μ

Asymmetric track membranes with regular structure → → modeling of biological ion channels





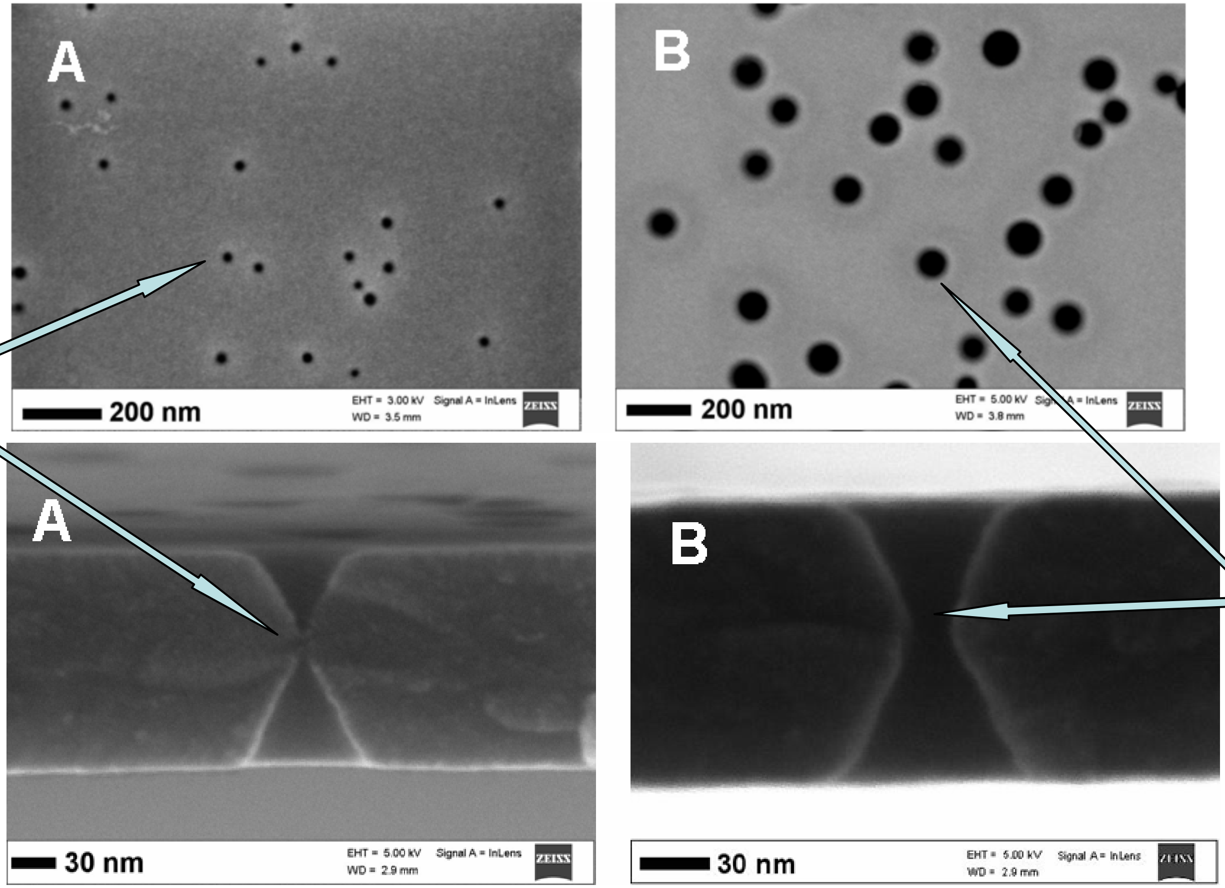
An example: film irradiated at GSI with "microbeam" ahs been etched at JINR with a special technology.

[P.Yu. Apel, I.V. Blonskaya, O.L.Orelovitch, S.N. Dmitriev. NIM in Phys. Res., 2009]

Track membrane production technology

Nanopore track membranes fabricated from thin Si_3N_4 films for nanofluidics

Channel diameter: A ~ 20 nm



Channel diameter: B ~ 100 nm

I.Vlassiuk, P.Yu.Apel, S.N.Dmitriev et al. Proc. Nat. Acad Sci.,106 (2009) 21039

Track membrane production technology

Nanopore track membranes fabricated from thin Si_3N_4 films for nanofluidics

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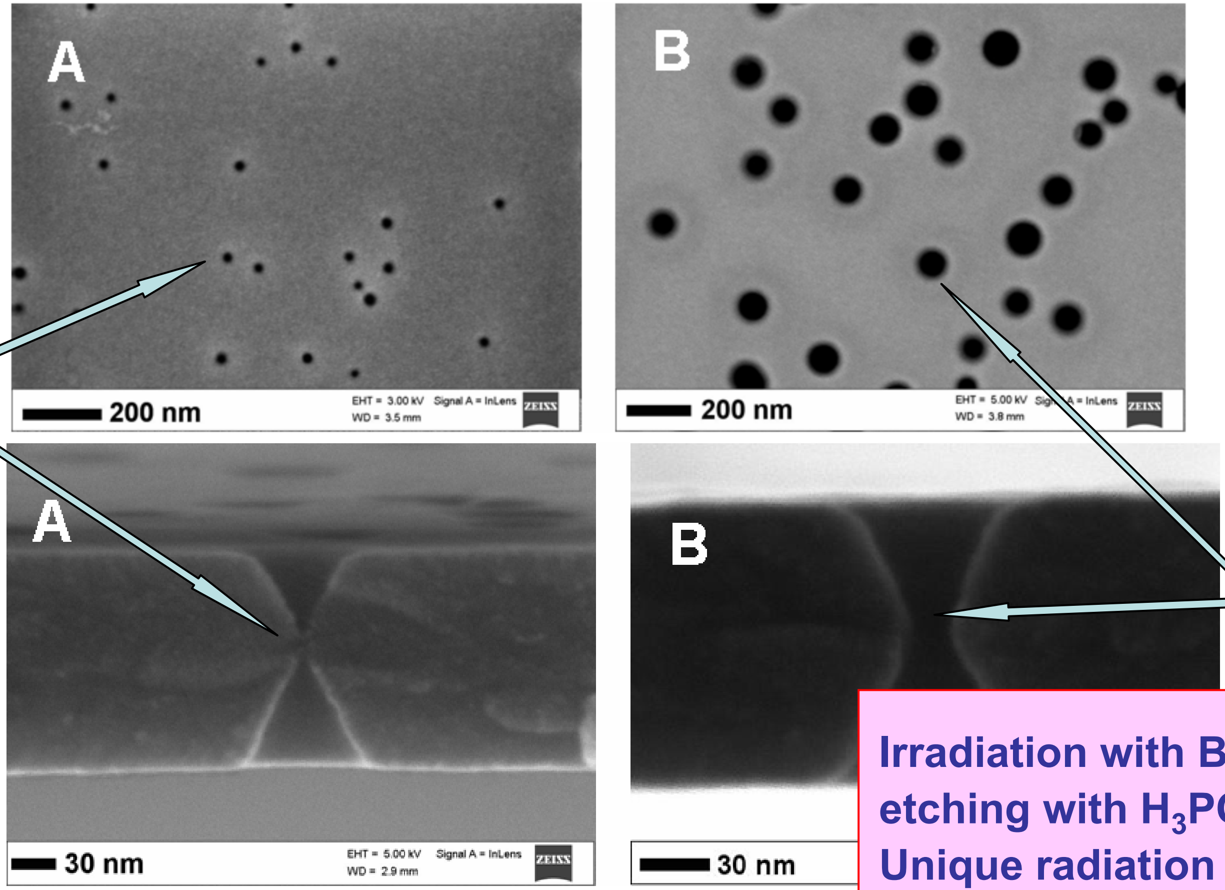


Channel diameter: B ~ 100 nm

I.Vlassiuk, P.Yu.Apel, S.N.Dmitriev et al. Proc. Nat. Ac

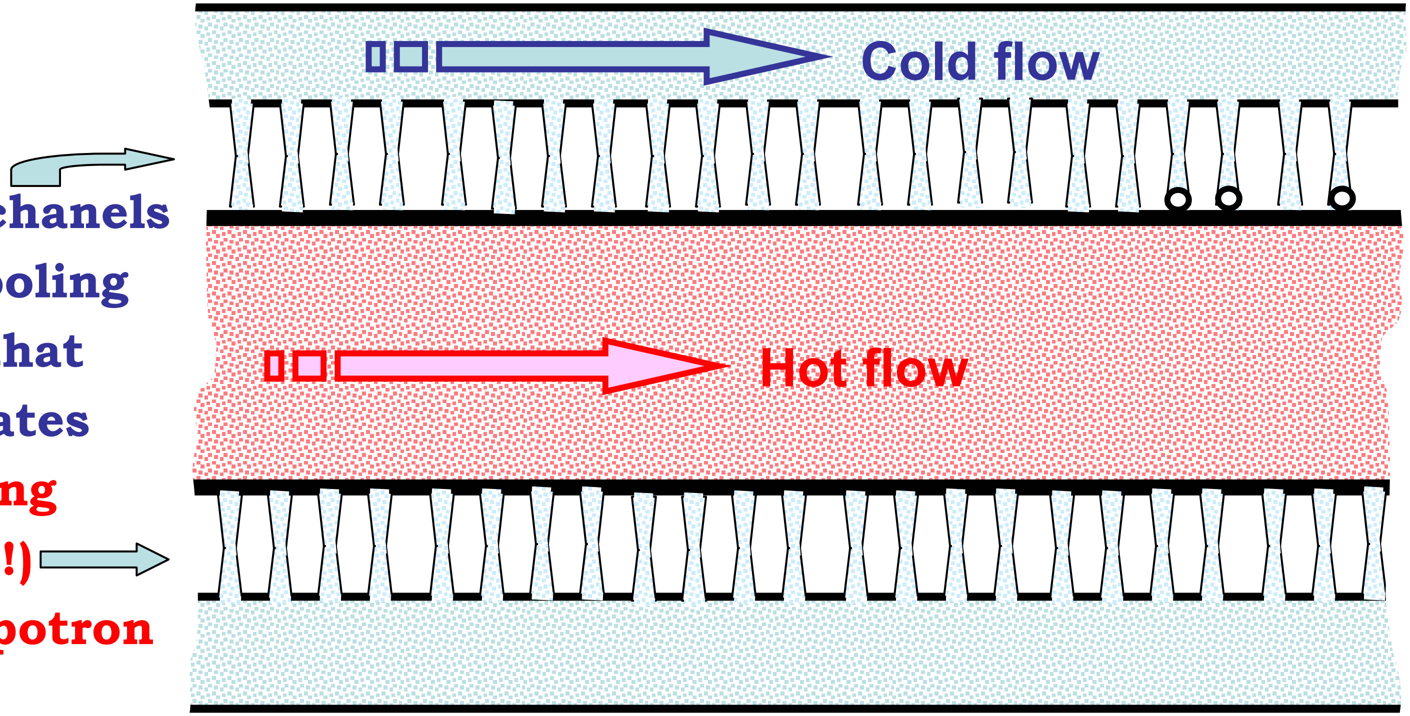
Irradiation with Bi (E = 710 MэB), etching with H_3PO_4 at 150°C. Unique radiation resistance of silicon nitride made it possible to produce pores as small as a few nanometers in diameter.

Track Membrane Based Technologies

Applications:
- Medicine
- Biology
- Industry

An example of track membranes application in technology: Heat exchange tubes with microstructure surface

Track chanels with cooling liquid that evaporates at boiling point (!)
The vapotron effect!



Track membrane production technology

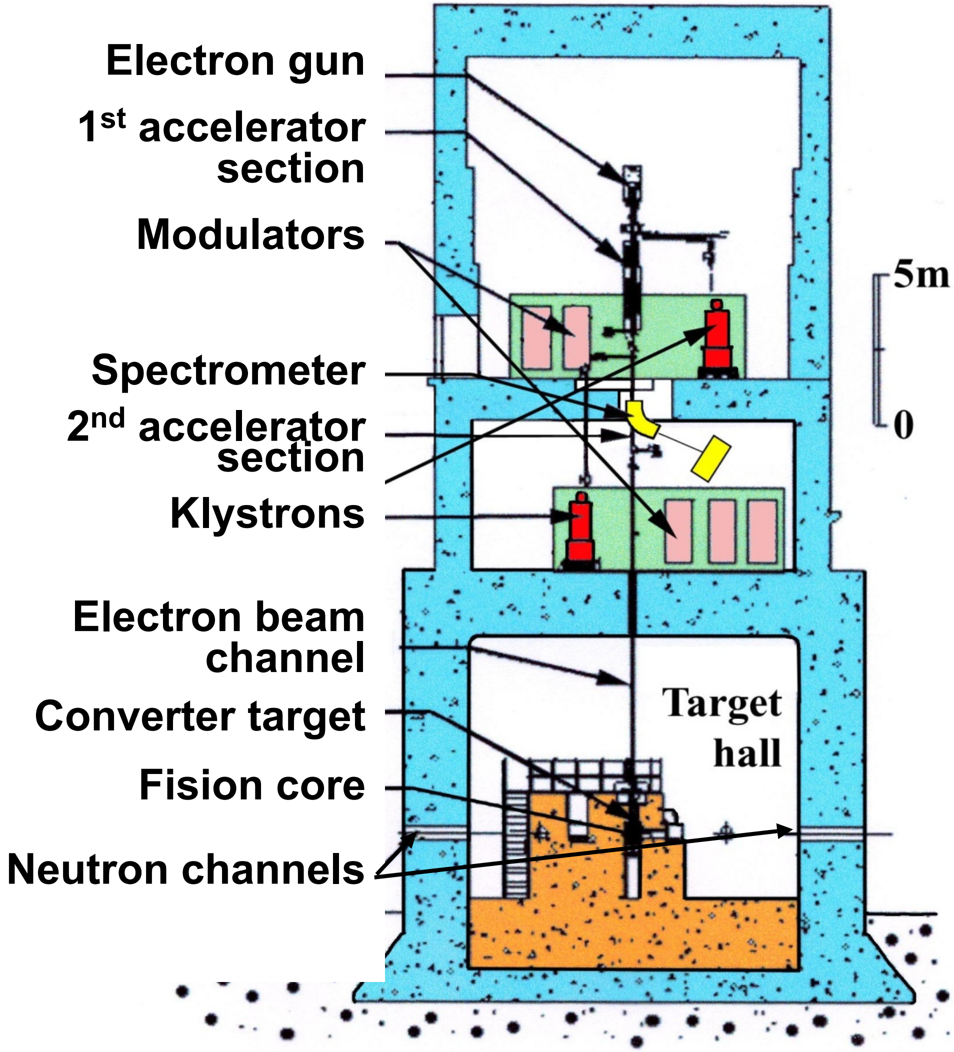
Project "Beta" at FLNR JINR

To be completed by 2012

Cyclotron DC-110

Ions	Energy [MeV/amu]	Intensity [10^{12} pps]
$^{40}Ar^{7+}$	2.5	6.25
$^{86}Kr^{15+}$		6.25
$^{132}Xe^{23+}$		3.12

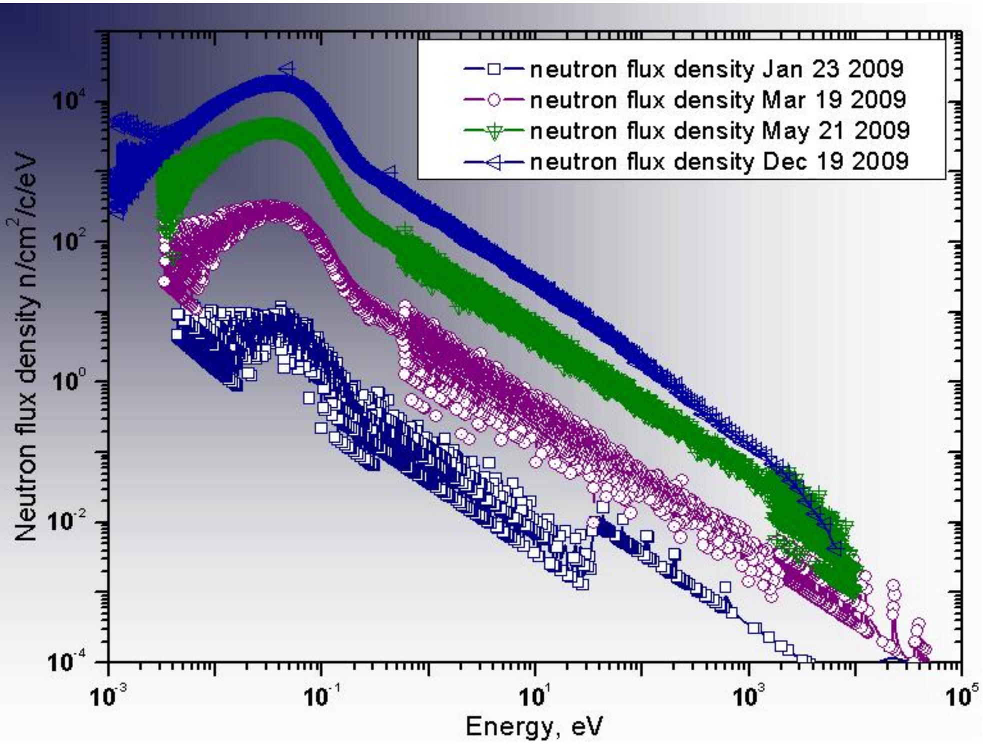
3. IREN - Intense REsonance Neutron Source

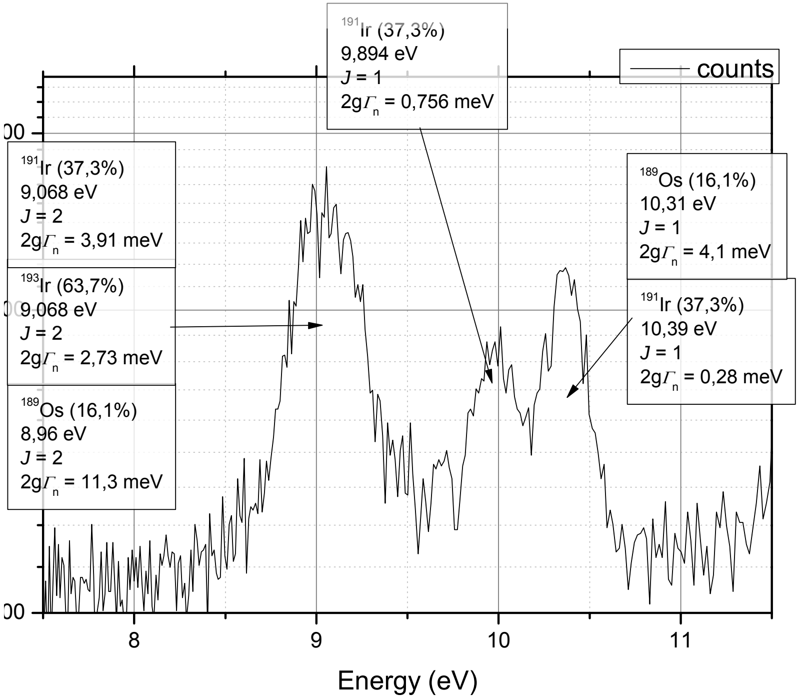


IREN Source Parameters		
Parameter	**Design**	**Stage I (2010)**
Electron energy, MeV	200	30
Peak current, A	1.5	3.0
Beam pulse duration, ns	200	100
Repetition frequency, Hz	150	25 ÷ 50
Average beam power, kW	9.0	0.225 ÷ 0.450
Multiplication target	Pt	W (no multiplctn)
Average neutron flux, s^{-1}	$1.16 \cdot 10^{15}$	$1 \cdot 10^{11}$

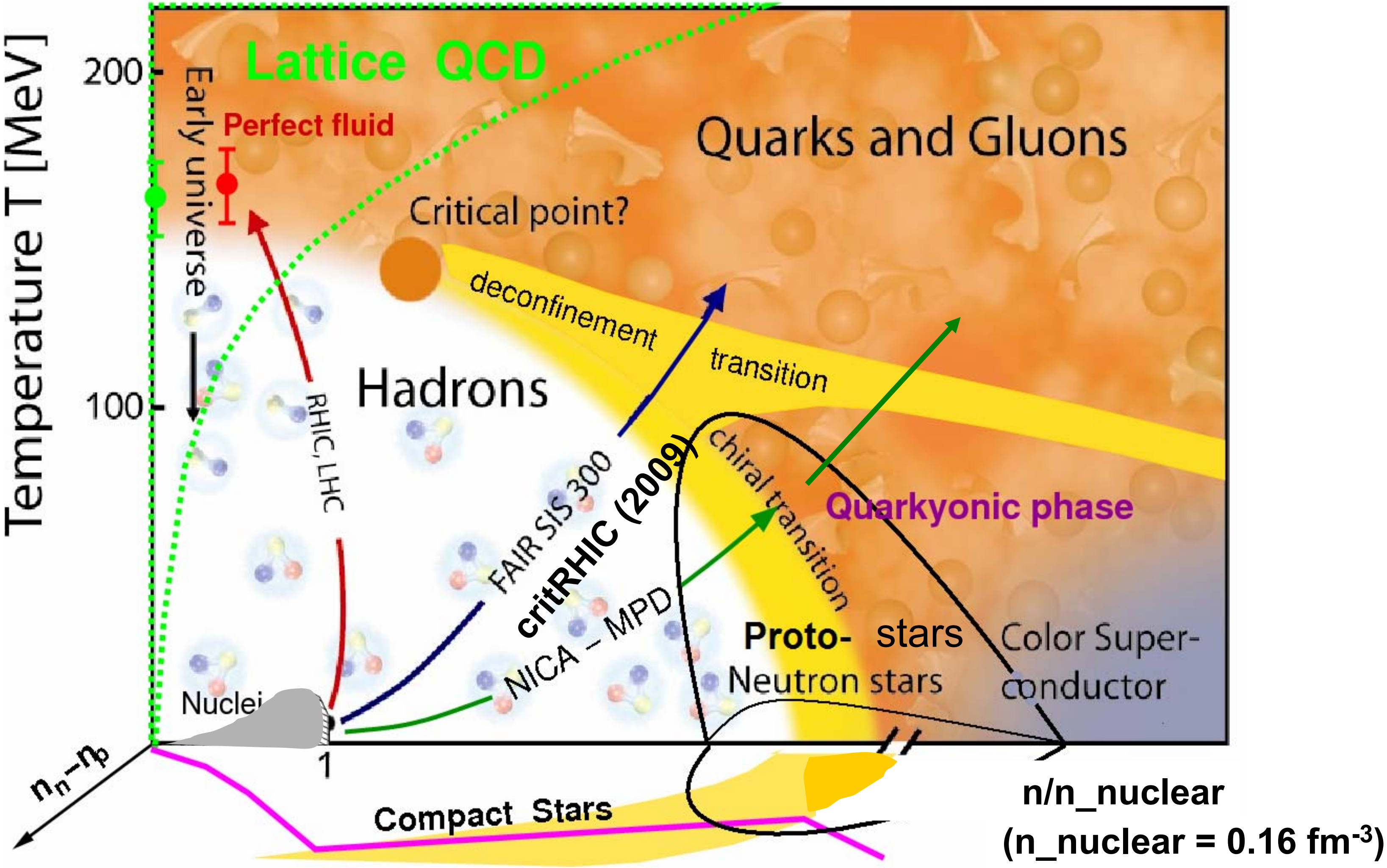
First examples of IREN source application:

- ✓ Radiation resistivity of GaAs and Si detectors;
- ✓ Analysis of Boron content in Boron-containing ceramics (from Belarus)
- ✓ Analysis of rare elements (Pd, Os, Ir, Pt,…) content in Gold-containing ore (from Mongolia)

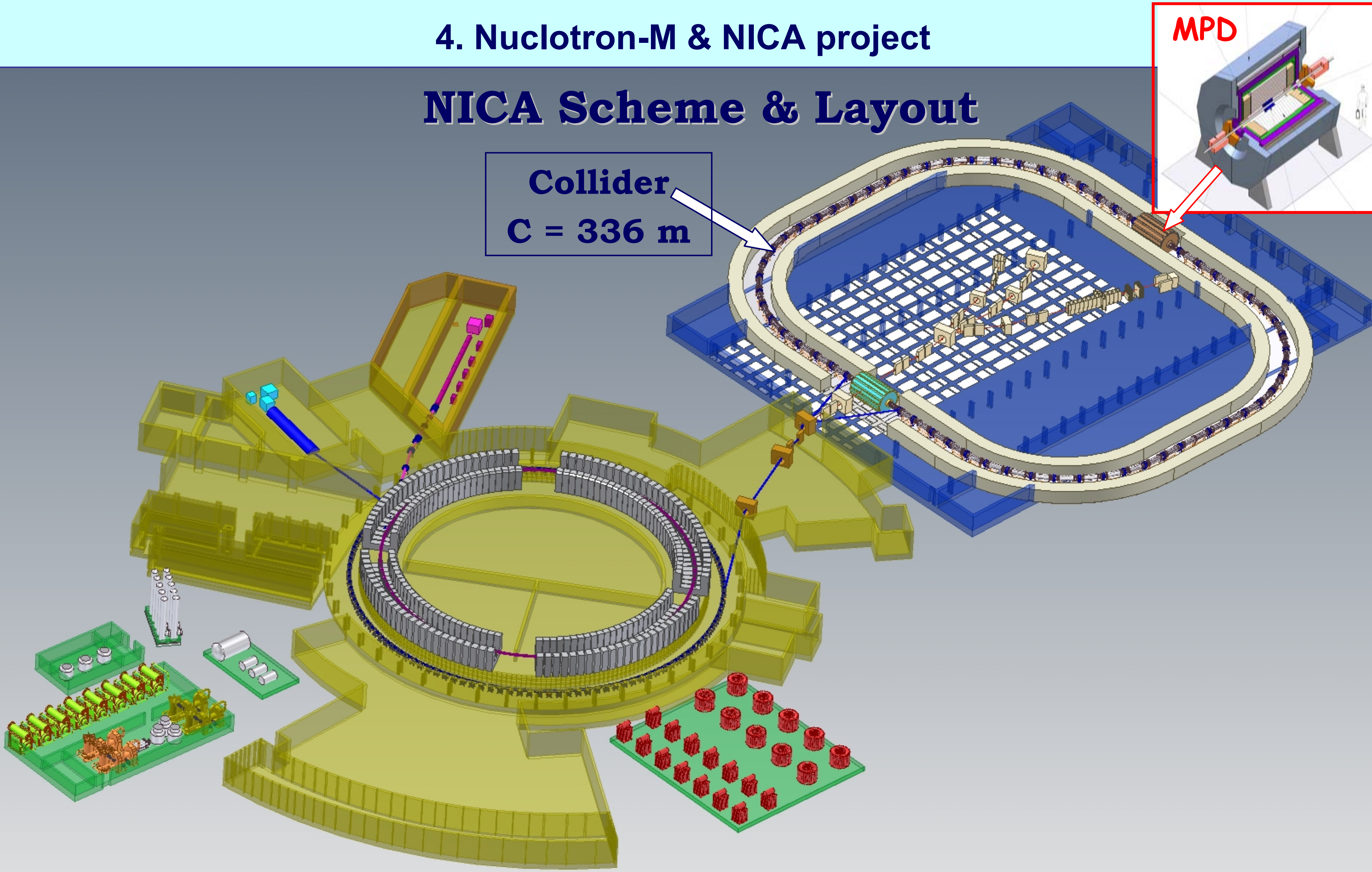




Relativistic nuclear physics today & "the physics case" for NICA

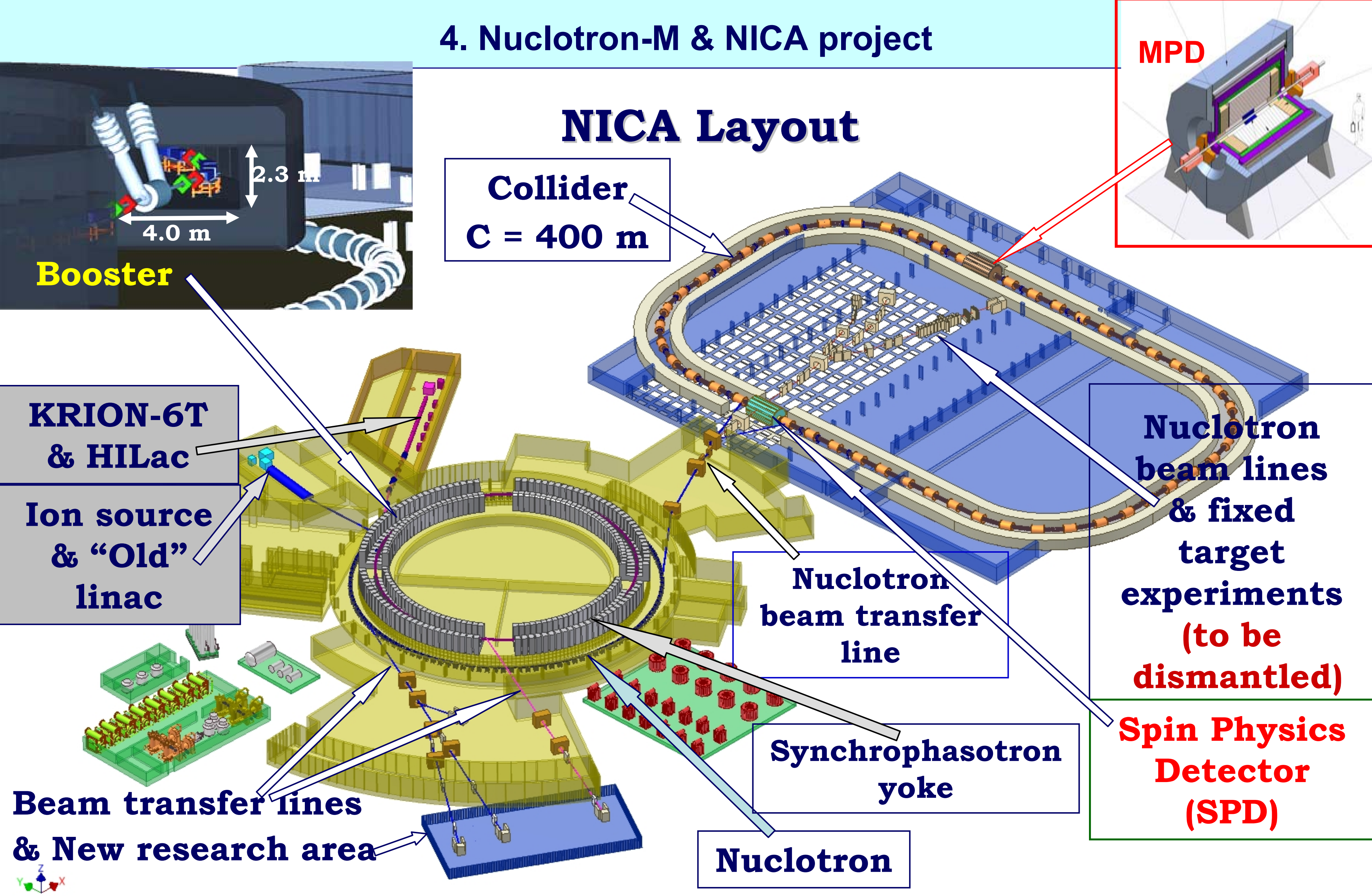


NICA Scheme & Layout



4. Nuclotron-M & NICA project

NICA Layout



Nuclotron-based Ion Collider fAcility (NICA)

The NICA Project goals :

1a) Heavy ion colliding beams $^{197}Au^{79+}$ x $^{197}Au^{79+}$ at

s_{NN} = 4 ÷ 11 GeV (1 ÷ 4.5 GeV/u ion kinetic energy)

at

$L_{average}$= 1E27 $cm^{-2}\cdot s^{-1}$ (at $\sqrt{s_{NN}}$ = 9 GeV)

1b) Light-Heavy ion colliding beams of the same energy range and luminosity

2) Polarized beams of protons and deuterons:

p↑p↑ $\sqrt{s_{NN}}$ = 12 ÷ 25 GeV (5 ÷ 12.6 GeV kinetic energy)

d↑d↑ $\sqrt{s_{NN}}$ = 4 ÷ 13.8 GeV (2 ÷ 5.9 GeV/u ion kinetic energy)

See details in MOPD007, MOPD008, MOPD009, MOPD010, MOPD011

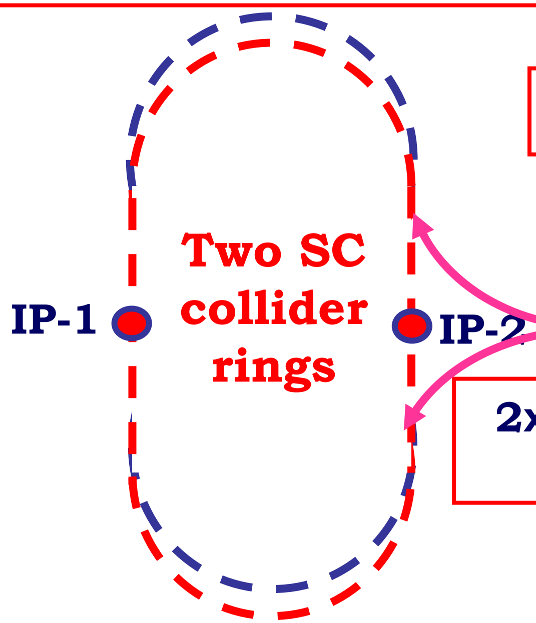
Operation regime and parameters

Injector: 2×10^9 ions/pulse of $^{197}Au^{32+}$ at energy of 6.2 MeV/u

Collider (45 Tm)
Storage of
30 bunches by 1×10^9 ions per ring
at 1 - 4.5 GeV/u,
electron and/or stochastic cooling

Booster (25 Tm)
1(2-3) single-turn injection,
storage of $2\cdot(4\text{-}6)\times10^9$,
acceleration up to 100 MeV/u,
electron cooling, acceleration
up to 600 MeV/u

Stripping (80%) $^{197}Au^{32+} \Rightarrow {}^{197}Au^{79+}$



2x30 injection cycles

Nuclotron (45 Tm)
injection of one bunch
of 1.1×10^9 ions,
acceleration up to
1 - 4.5 GeV/u max.

Nuclotron: Superconducting Proton Synchrotron (since 1993)

Alexander Baldin

Nuclotron parameters

Parameter	Project	Status (March 2010)
1. Circumference, m	251.5	
2. Max. magn. field, T	2.05	1.8
3. Magn. rigidity, T·m	45	39.5
4. Cycle duration, s	2.0	5.0
5. B-field ramp, T/s	2.0	1.0
6. Accelerated particles	p–U, p↑, d↑	p-Xe, d↑
7. Max. energy, GeV/u	12.6(p), 5.87(d) 4.5($^{197}Au^{79+}$)	5.1(d), 1.0($^{238}Xe^{24+}$)
6. Intensity, ions/cycle	1E11(p), 1E9 (A > 100)	$1E10^{11}$ (p), 1E10 (d↑) 1E6 (Xe^{24+})

Present Basic Research on Nuclotron Beams

Relativistic nuclear physics

- ✓ FAZA - phase transitions in hot nuclear matter: p (8 GeV) + Au …
- ✓ DELTA-2 – Fine resonant structure at π- meson generation:
  d (350 MeV/u) + Ag => π^+ + …
- ✓ MARUSYA – Cumulative generation of antimatter in heavy ions collisions at below threshold energy

Spin physics in few body nuclear systems (d↑)

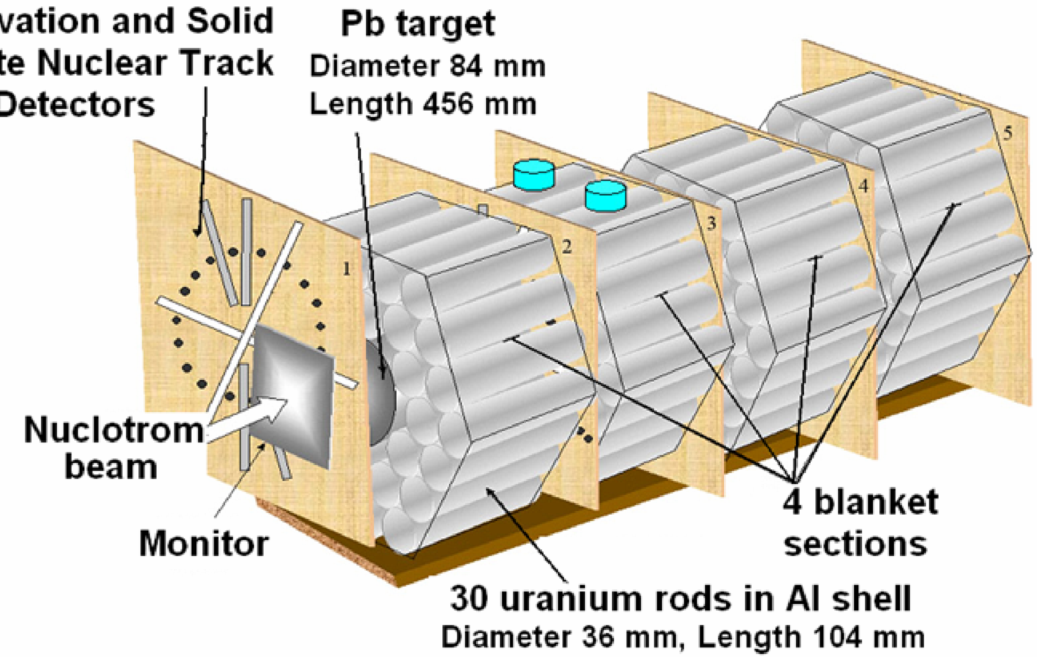
- TPD - Tensor polarization detection in d↑ crossing a target
- LNS - Light nuclei spin polarimetry in d↑ scattering on p and ^{3}He
- NN amplitude - d↑ + p => n + $2p_{s\uparrow}$
- Polarization effects in cumulative particle production:
  d↑(3.5 Gev/u) + A => π^+ + X, A = H, C, Be
- Δσ - Determination of the np elastic scattering matrix element at zero degree in the few GeV energy region

Physics of flavours

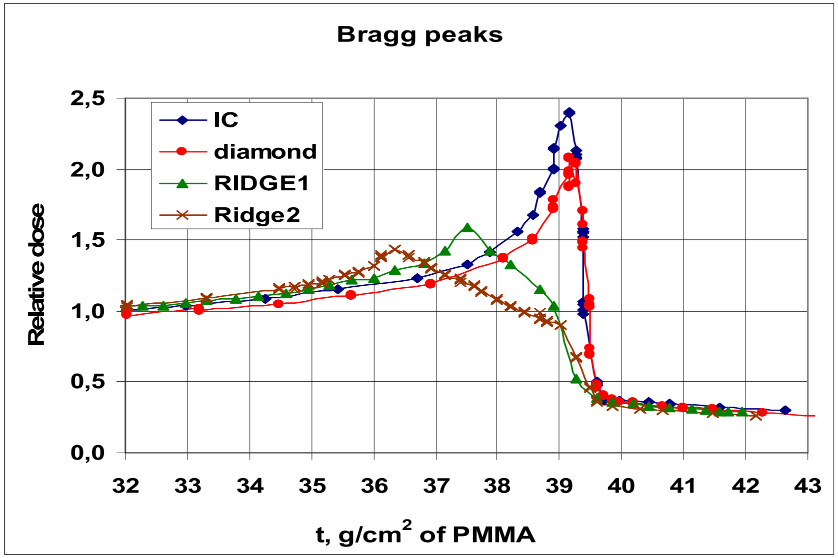
NIS – Nucleon intrinsic strangeness: test of OZI rule in
p + p => 2p + φ/ω and n + p => n + p + φ/ω near threshold

Applied Research on Nuclotron Beams

- Energy + Transmutation



- Development of cancer therapy technology: depth-dose distribution (Bragg peak) studies



- Radiobiology studies on ion beams at Nuclotron

Next slides

The NICA Project Milestones

• Stage 1: years 2007 – 2011

- Upgrade and Development of the Nuclotron
- Preparation of Technical Design Report of the NICA and MPD
- Designing MPD and NICA elements

• Stage 2: years 2010 – 2015

Manufacturing and mounting NICA and MPD

• Stage 3: years 2014 - 2015

- Commissioning

• Stage 4: year 2015

- Beginning of operation

The NICA Collaboration

Budker INP

- ✓ Booster RF system
- ✓ Booster electron cooler
- ✓ Collider RF system
- ✓ Collider SC magnets (expertise)
- ✓ HV e-cooler for collider
- ✓ Electronics
- ✓ Injector linac (under discussion)

IHEP (Protvino): Injector Linac

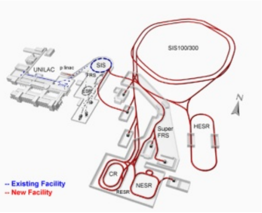
FZ Jűlich (IKP): HV E-cooler & Stoch. cooling

Fermilab: HV E-cooler, Beam dynamics, Stoch. cooling

CERN: Beam dynamics, E-cooling, Acceler. technique

All-Russian Institute for Electrotechnique
HV Electron cooler

BNL (RHIC)
Electron & Stoch. Cooling



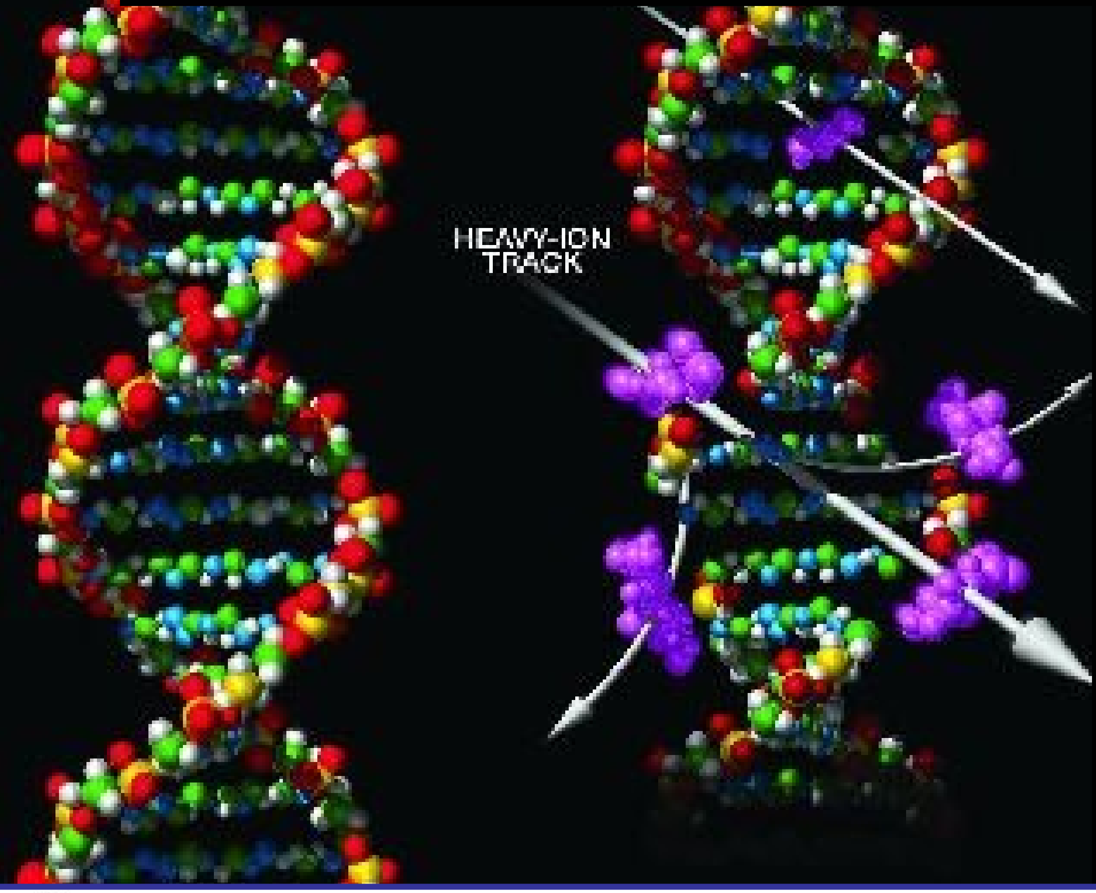
GSI/FAIR
SC dipoles for Booster/SIS-100
SC dipoles for Collider

ITEP: Beam dynamics in the collider

Corporation "Powder Metallurgy" (Minsk, Belorussia): Technology of TiN coating of vacuum chamber walls for reduction of secondary emission

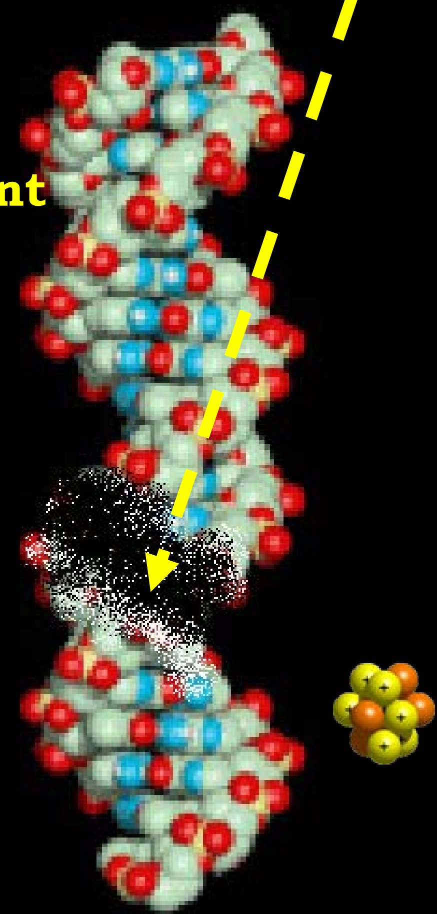
“New radiobiology” with accelerated heavy ions

New quality – a great damage of DNA produced by heavy ion passing a tissue



Clustered DNA damage

Fragment of DNA



"New radiobiology" with accelerated heavy ions

JINR Accelerators Used in Radiobiology Research

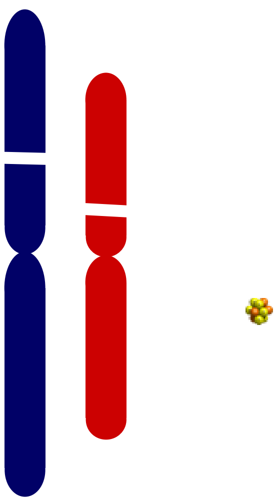
Accelerator	Particles	Max. energy
Phasotron	Protons	660 MeV
Cyclotron U200	Heavy ions	10 MeV/amu
Cyclotron U400M	Heavy ions	50 MeV/amu
Nuclotron	Ions (d - Xe)	6 - 3 GeV/amu

"New radiobiology" with accelerated heavy ions

A. Heavy ions – a powerful tool for studies of fundamental problems of radiation genetics

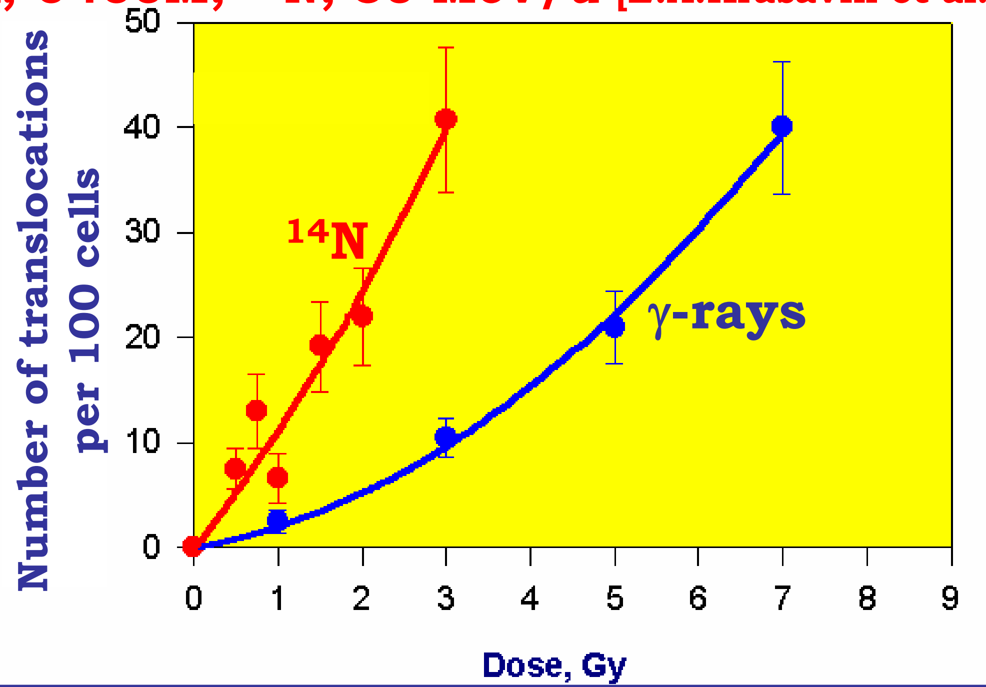
Formation of chromosomal aberration of human cells with heavy ion irradiation

1. Ionization



Translocations of chromosomes vs irradiation dose

JINR, U400M, ^{14}N, 50 MeV/u [E.A.Krasavin et al.]



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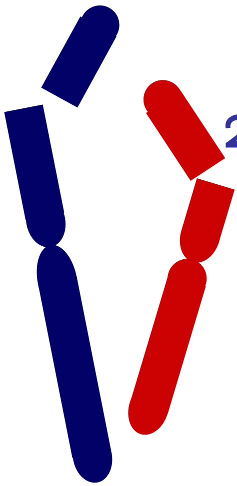
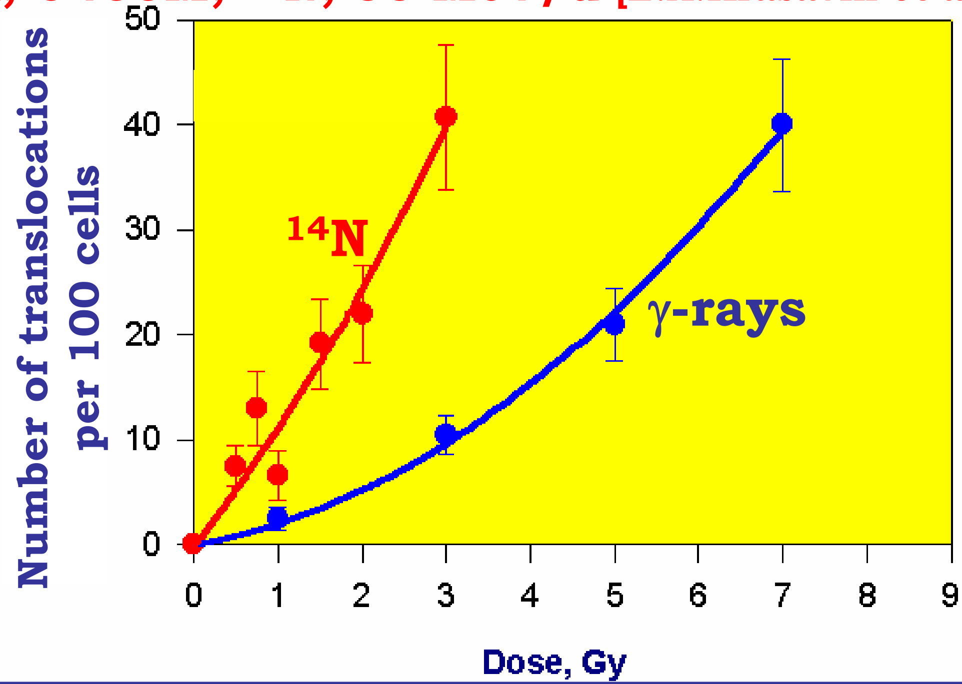


2. Chromosoms disruption

Translocations of chromosomes vs irradiation dose

JINR, U400M, ^{14}N, 50 MeV/u [E.A.Krasavin et al.]



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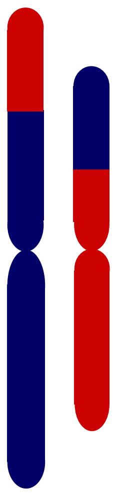
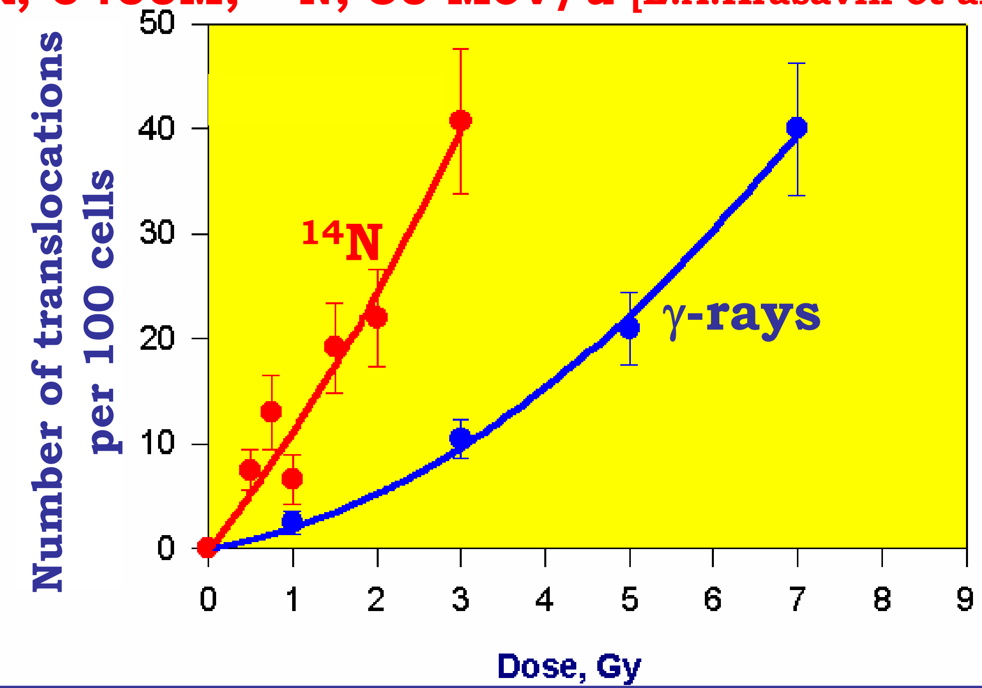


2. Chromosoms disruption

3.Stable aberration formation

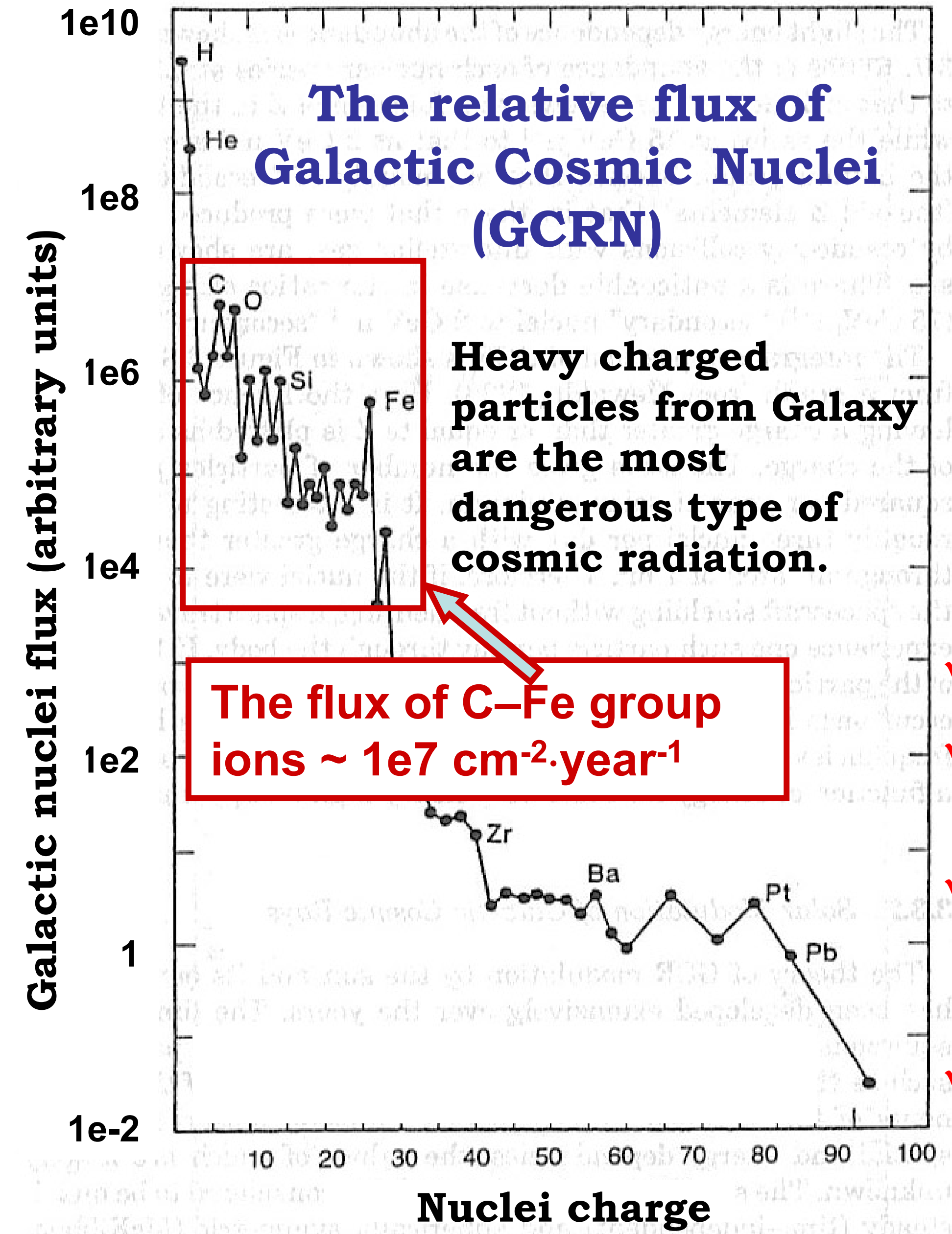
Translocations of chromosomes vs irradiation dose

JINR, U400M, ^{14}N, 50 MeV/u [E.A.Krasavin et al.]



5. Radiobiology research at JINR

"New radiobiology" with accelerated heavy ions

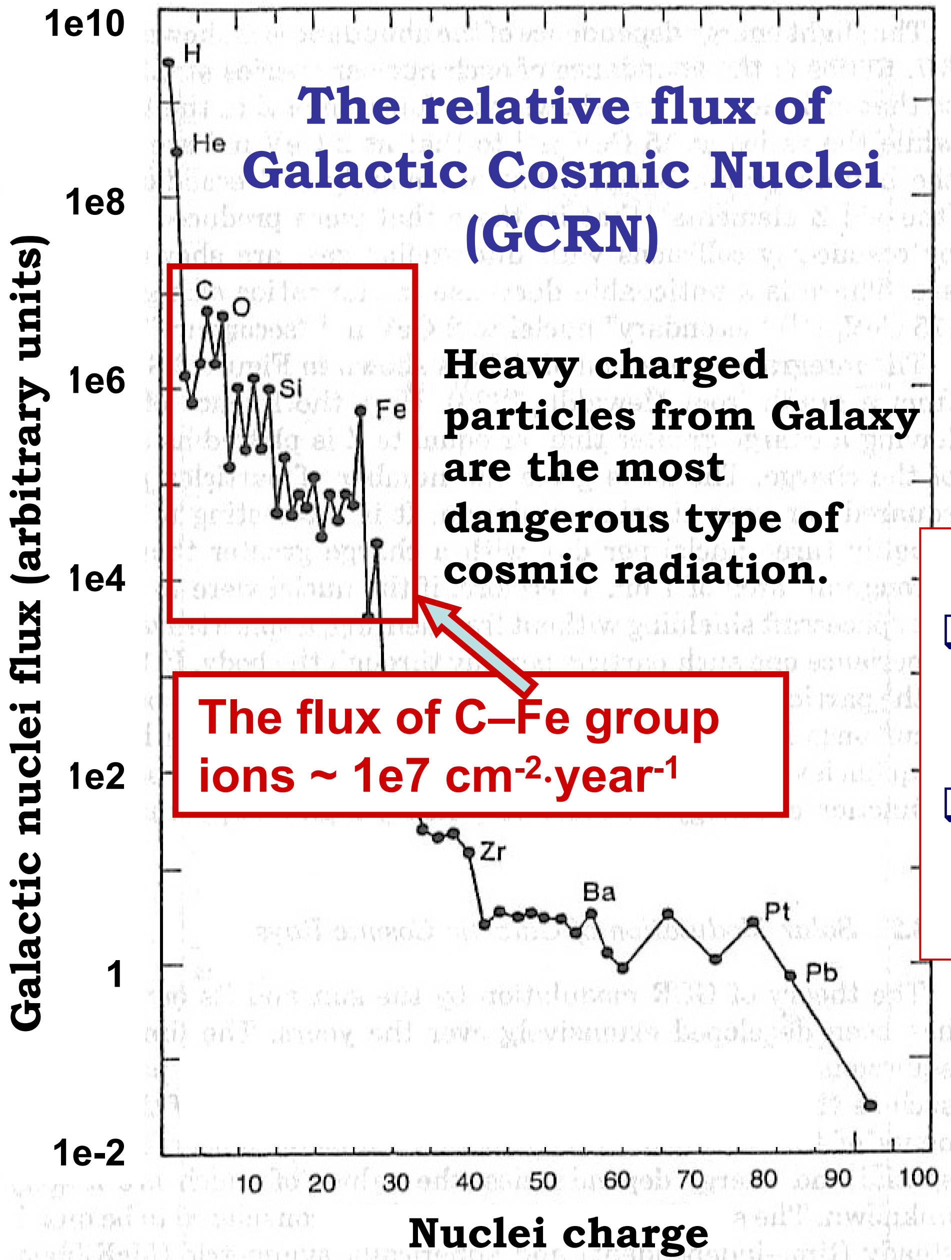


B. Modeling of space radiation biological action with accelerated heavy ions

<u>Consequences of Galactic heavy ions action</u>

- ✓ Induction of cancer;
- ✓ Formation of gene and structural mutations;
- ✓ Violation of visual functions: damage of retina and cataract induction;
- ✓ Central Nervous System violation.

"New radiobiology" with accelerated heavy ions



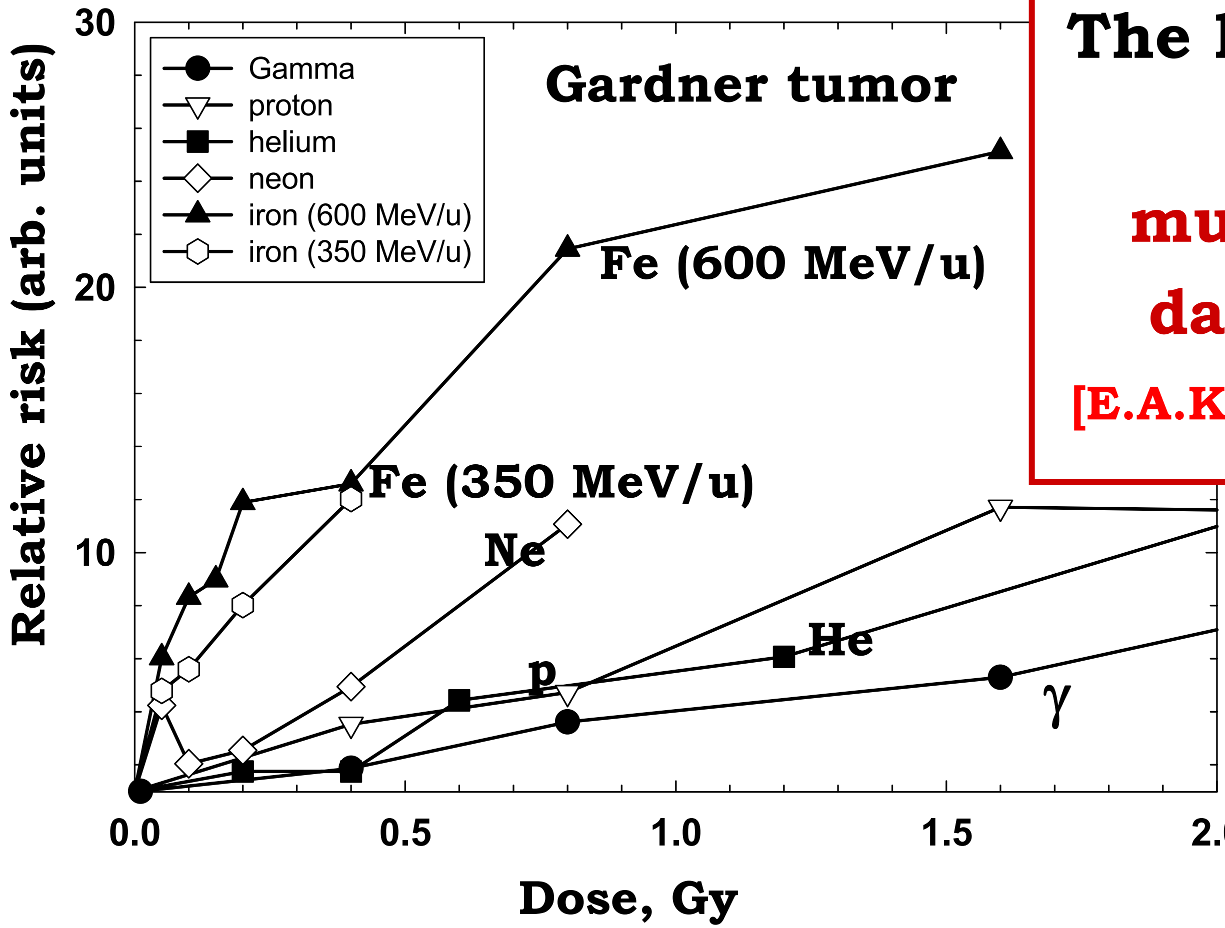
B. Modeling of space radiation biological action with fast heavy ions

During Mars mission:

- **2 ÷ 13 % nerve-sells will be passed by 1 Fe ion at least and 8 ÷ 46 % by ion with Z ≥ 15;**
- **Every center of nerve-sell will be passed by proton once per 3 days and by α-particle once per month.**

"New radiobiology" with accelerated heavy ions

B. Modeling of space radiation biological action with accelerated heavy ions



The heavy ions are much more dangerous!

[E.A.Krasavin et al.]

Conclusion

1. The numerous accelerator facilities existing at JINR define its distinctive feature as

   multidisciplinary institution

   that differs it from laboratories of "monoculture" and allows to perform both

   basic and applied research

   in a wide range of particle beam parameters.

2. Realization of the projects being presently under development at JINR –

   DRIBS-III, IREN, NICA

   promises a further advancement in the experimental studies in the fields of particle and nuclear physics, radiobiology

   and

   technology applications.

Thank you for your attention!