BELA

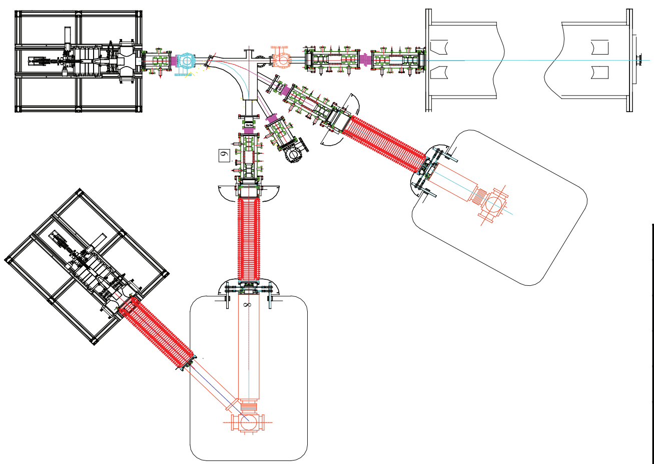
Project of Multidiscipline Facility Based on ECR Ion Source and Linear Accelerator

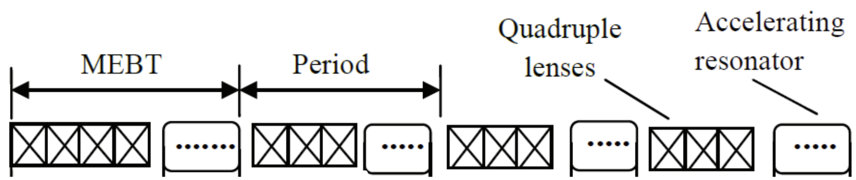
ION BEAMS APPLICATION

- ✓ **Material science – materials modification, fusion and fission reactor materials investigations;**
- ✓ **Facility for semiconductor industry – improvement of power electronics units by proton/ion beam irradiation;**
- ✓ **Neutron generator;**
- ✓ **Medicine (BNCT, Radiopharmaceutical for PET);**
- ✓ **Astrophysics;**
- ✓ **....**
- ✓ **....**

BELA

New “basic facility” for Institute for Theoretical and Experimental Physics Center for LINAC based compact facility development for different applications – industry, medicine et cetera

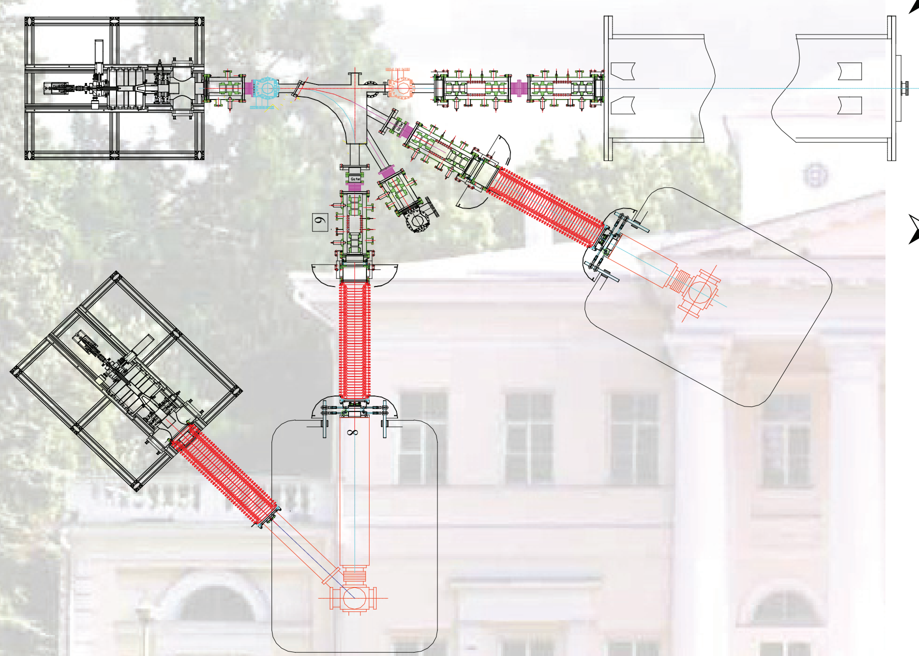




	Injection complex	RFQ	DTL
Ions	p - U	p	p
Currents, mA	0.01 - 20	10	10
Energy, MeV/n	up to 0.15	1.5 (3)	2/3/4/8...
Duty factor	dc	up to cw	
Frequency, MHz		148.5 (200)	

BELA

Stage I - ECR IS and cw RFQ (5 years)



ECR – from H to “U”
RFQ for 10 mA protons at 1.5 - 3 MeV

- **Material science – new facility for ITEP activity of fusion and fission Reactor materials investigations;**
- **Facility for semiconductor industry – improvement of power electronics units by proton beam irradiation (IGBT – Insulated Gate Bipolar Transistors, and FRD — Fast Recovery Diodes) (+ special target development);**
- **Neutron generator (Li target);**
- **BNCT (with Li target);**

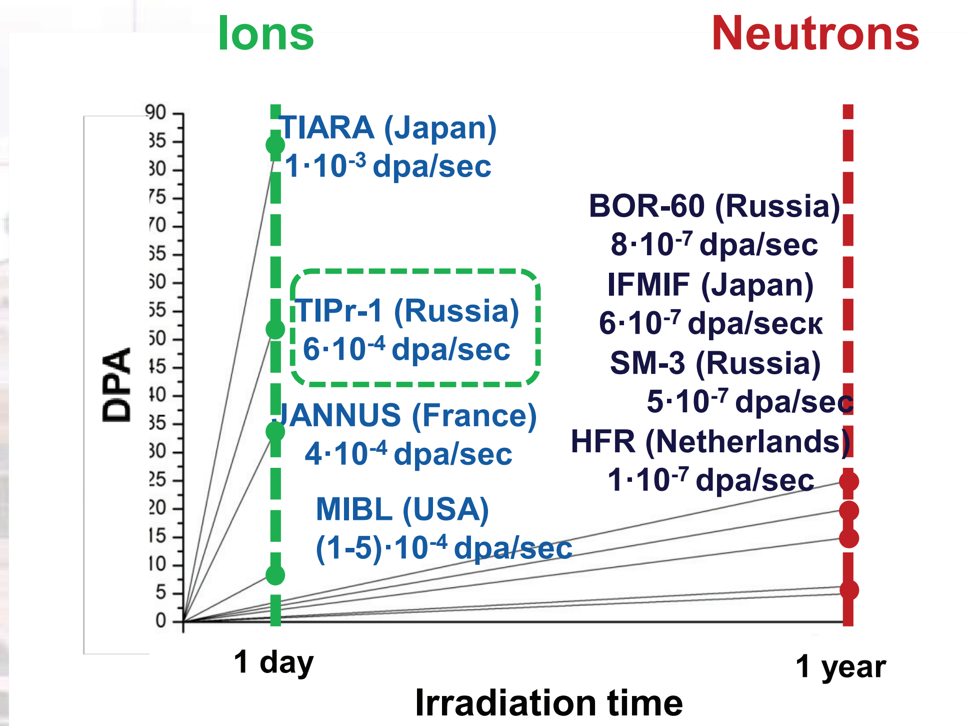
Heavy ion irradiation as a tool for simulation of neutron irradiation damage

Very fast damage dose acquisition

No activation of irradiated material

Difficulties with the direct comparison with neutron data due to

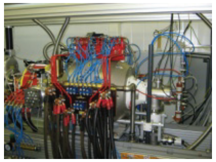
dose rate effect

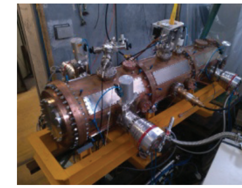


RFQ TIPr-1

BELA

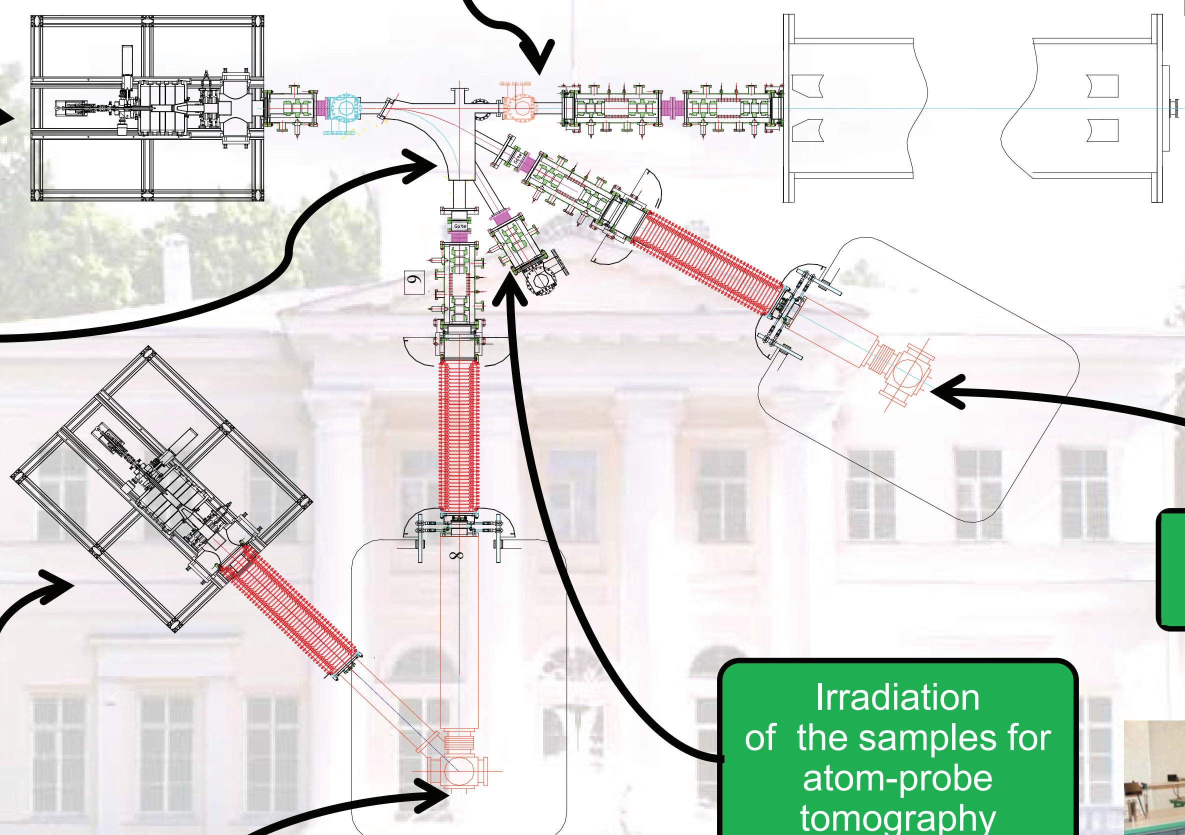
Stage I ECR IS and cw RFQ (5 years)





Injection into RFQ

Ion source (ECR)



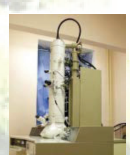
Distributing magnet

Heavy ions irradiation

Ion source (ECR)

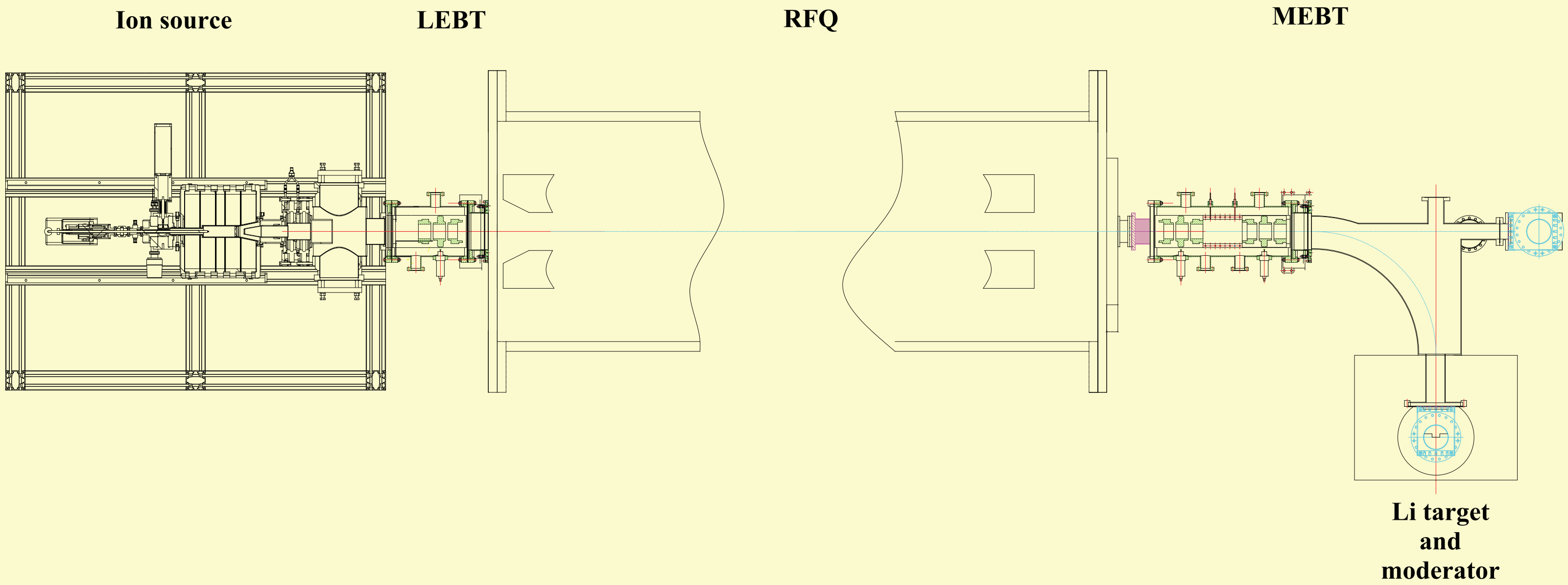
Irradiation of the samples for atom-probe tomography

2-beam experiments



RUPAC.2014, WEPSB27
ВАНТ. 2014. №3(91),
REV. SCI. INSTRUM. 85 , 02A910 (2014)

BNCT facility



BNCT

ECR ion source with total magnet system at permanent magnets

+

RFQ for 2.5 — 3 MeV

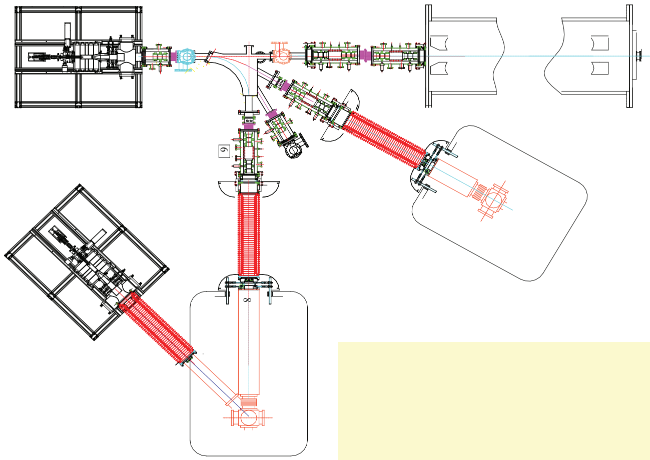
+

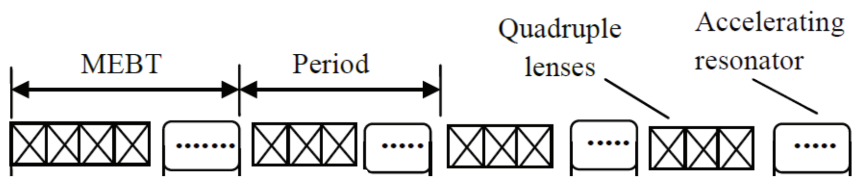
Li target and moderator

10 mA proton beam at energy 2.5 MeV generates 10^{13} нейтронов/секунду

BELA

Stage I ECR IS and cw RFQ (5 years)
and
Stage II - warm Linac up to 8 – 11 MeV (+2 year)



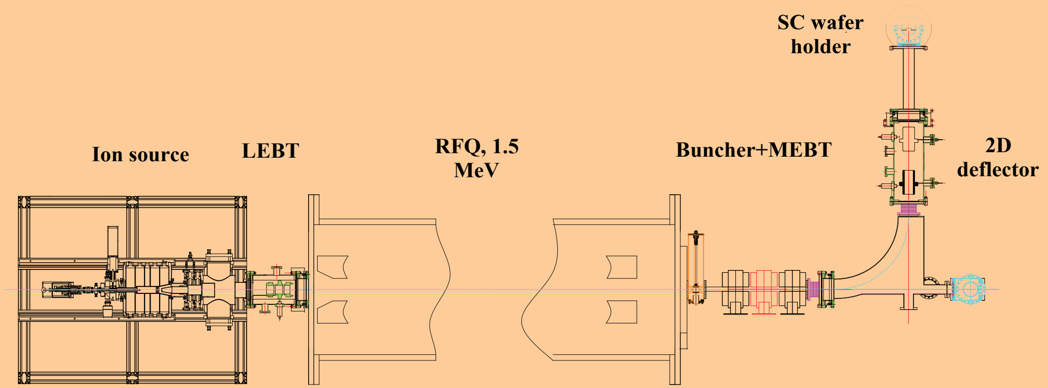


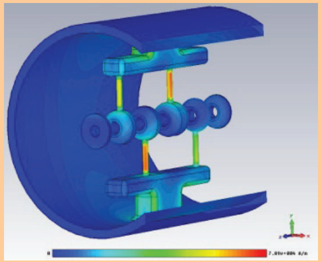
IH or CH DTL or ¼ or ½ cavity with magnetic quadruple lenses

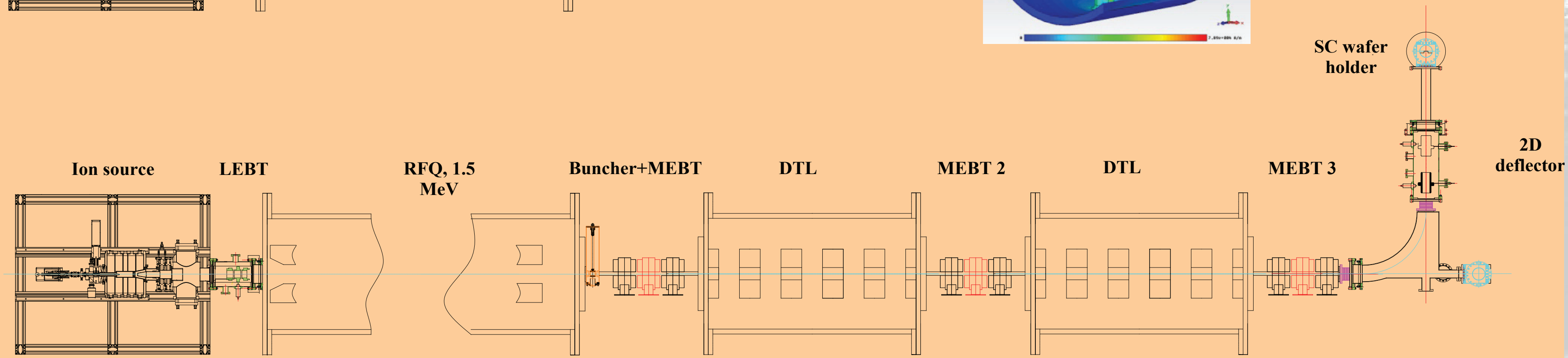
ELECTROMAGNETIC LENSES

- **Facility for semiconductor industry – improvement of power electronics units by proton beam irradiation (IGBT – Insulated Gate Bipolar Transistors, and FRD — Fast Recovery Diodes);**
- **Radiopharmaceutical for PET prototype of compact facility for clinic application;**
- **Astrophysics**
- **Initial part for ADS**

Facility for semiconductor industry





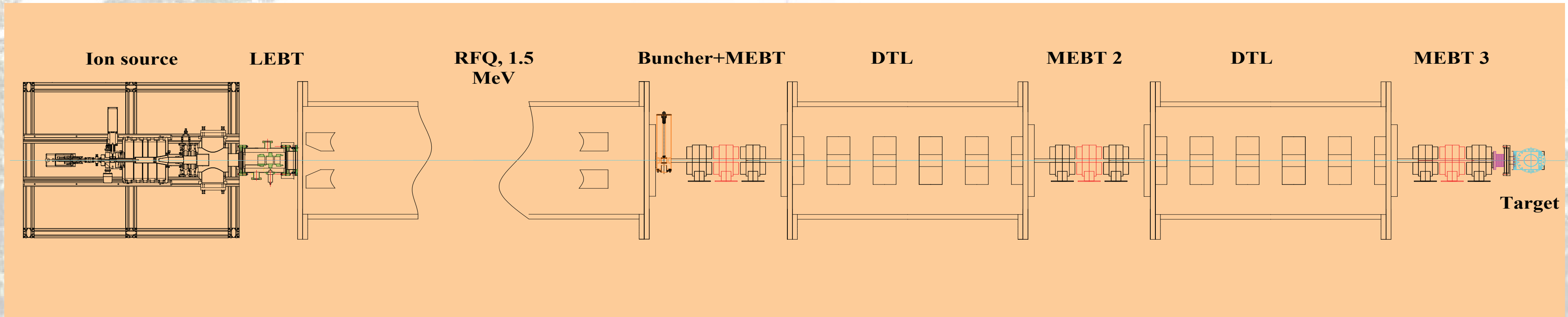


For semiconductor industry the serial production of facilities from the standard modules with different output energy and several intermediate energy

To provide the irradiation of the wafer with diameter 200 mm by proton beam to the fluence of $5 \cdot 10^{13}$ p/cm^2 for the 10 second the ion beam with average current of <0.5 mA is required

Facility for generation of Radiopharmaceutical for PET

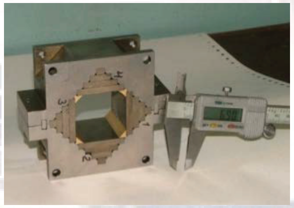
Details in WEPSB073



PERMANENT MAGNET LENSES

- Radiopharmaceutical for PET prototype of compact facility for clinic application;
- Astrophysics
- Initial part for ADS

PMQ module for PRIOR : the magnetic field gradient – *G*=123 T/m at aperture of Ø30 mm, nonlinearity of less than 0.7 %



NdFeB quadrupole section of 40×40 mm rectangle aperture for ITEP's 800 MeV PUMA proton microscopy facility quadruplet (field gradient – *G*=28 T/m at aperture of Ø40 mm, nonlinearity of less than 0.75 %)

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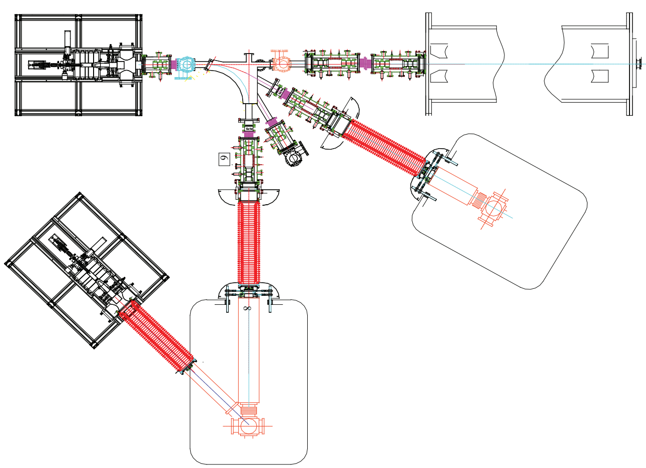
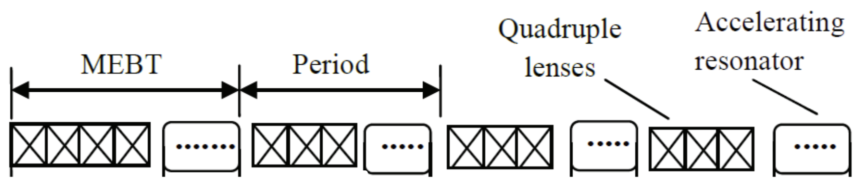
Center for LINAC based compact facility development for different applications – industry, medicine et cetera**





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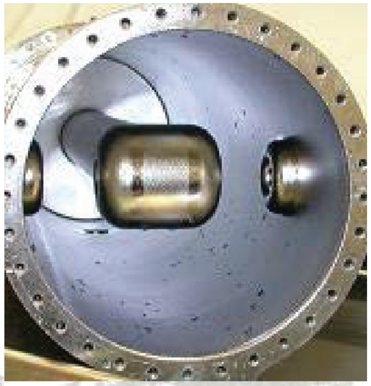
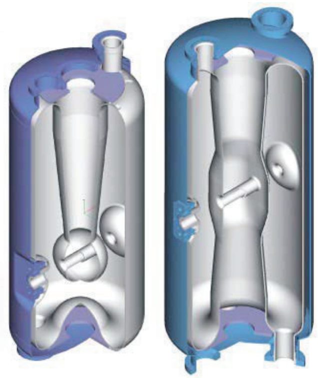
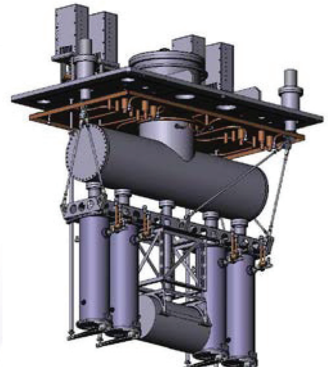
not END

SUPER CONDUCTIVITY !

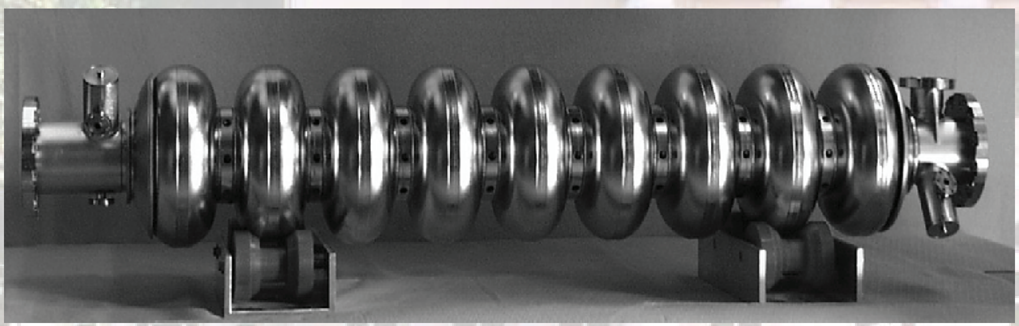




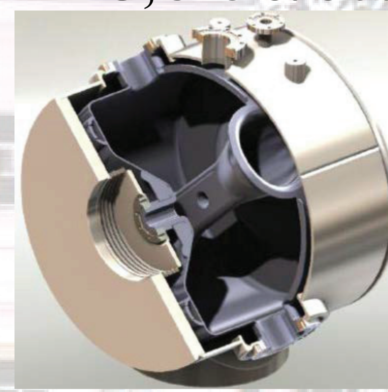


QWR and HWR, β=0.01-0.17, 6-7 MV/m (LNL INFN+E.Zanon, TRIUMF+PAVAC, Nb), 5-6 MV/m (LNL INFN, Nb/Cu)

CH, β=0.1, 5-7 MV/m (IAP FU, 325 & 360 MHz)



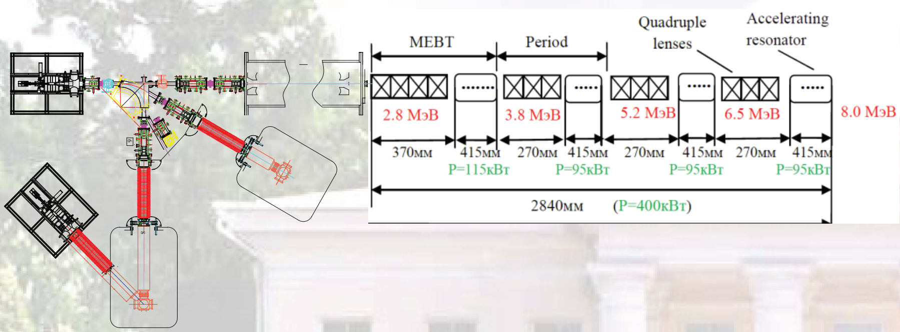
Эллиптические резонаторы, β=0.2-1.0 35 MV/m (1300 MHz, KEK, DESY, FNAL ...), 15-16 MV/m (704 MHz, ESS), 30-40 MV/m (800 MHz, LANL)

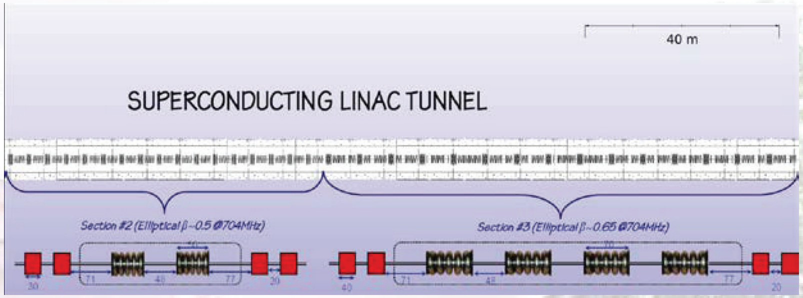


Spoke-cavity, β=0.1-0.25,
8 MV/m (ANL, 324 MHz)
12-16 MV/m (FNAL, 324 MHz),
15-18 MV/m (ESS, 325 MHz),
8 MV/m (JFZ, 700 MHz)

BELA

Stage III SUPER CONDUCTIVITY ~~?~~ !!





- **cw RFQ and SUPERCONDUCTIVITY**

“Come back” to the mainstream in linear accelerator technique for new ion accelerators projects and programs in Russia and abroad.

PARTNERS

ИФВЭ

IHEP

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЯДЕРНЫЙ УНИВЕРСИТЕТ

МИФИ

ОИЯИ

РФЯЦ-ВНИИТФ

Предприятие Госкорпорации «РОСАТОМ»

INFN

Istituto Nazionale di Fisica Nucleare

ИЯФ

МИСиС

FAIR

GSI

TRIUMF

AUTHOR

Кулевой Т.В.

AUTHORS

Алексеев Н.Н., Андрианов С.Л., Артемов В.А., Балабин А.И.,
Барабин С.В., Высоцкий С.А., Зарубин А.Б., Зиятдинова А.В.,
Канцырев А.В., Киселев В.А., Кленов Г.И., Козлов А.В.,
Кропачев Г.Н., Кузьмичев В.Г., Куйбида Р.П., Лагов П.А.,
Кац М.М., Лякин Д.А., Кулевой Т.В., Марков Н.В.,
Марченков А.И., Орлов А.Ю., Плотников С.В., Полозов С.М.,
Самсонов В.Г., Селезнев Д.Н., Семенников А.И.,
Семечкин В.К., Ситников А.Л., Скачков В.С., Стасевич Ю.Б.,
Трушин М.С., Фаткуллин Р.Д., Федин П.А., Фомиченко П. А.,
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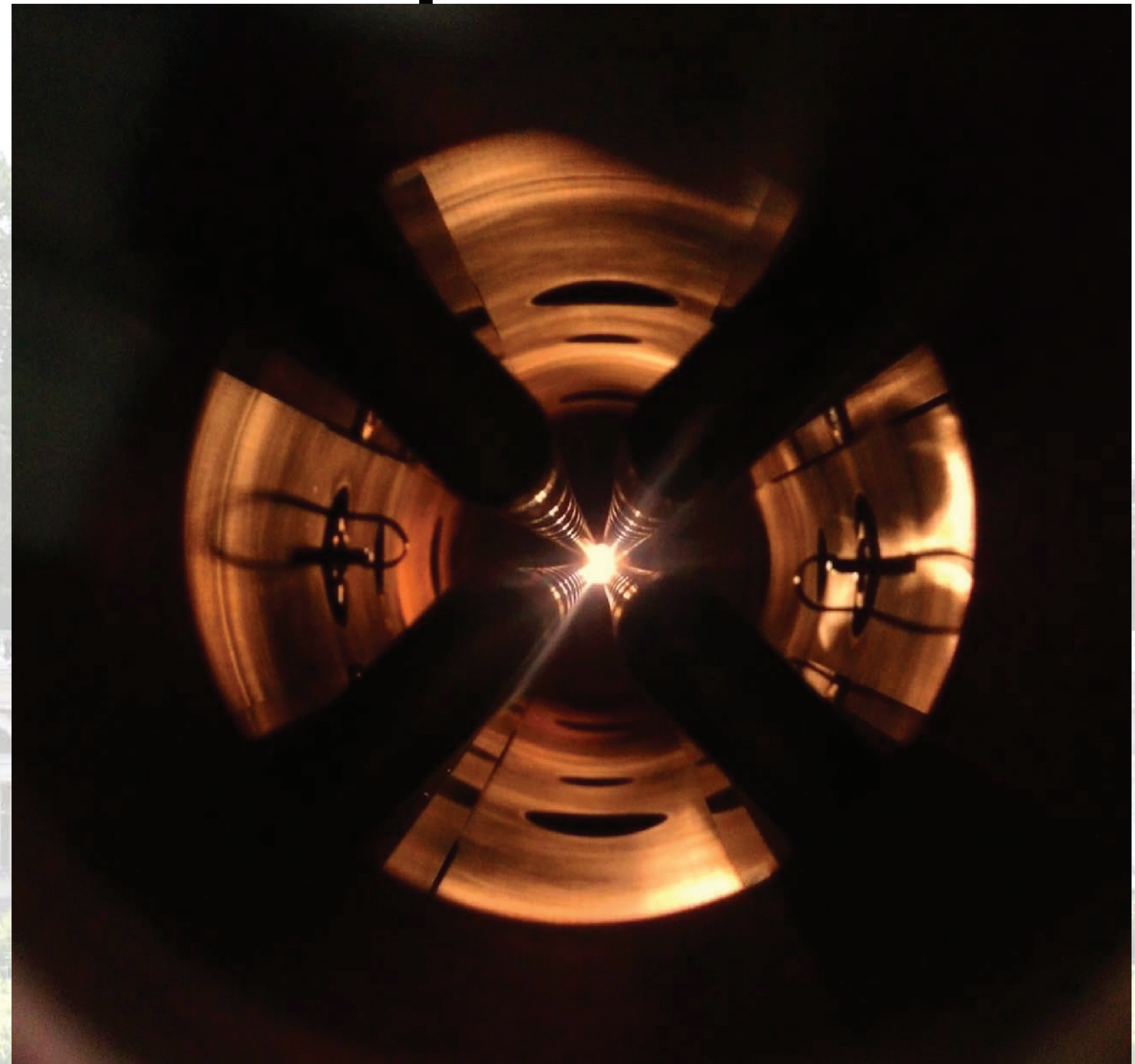
Per aspera ad astra



BELA - What for?

- ✓ **Material science**

  In ITEP the imitation experiments for reactor material radiation resistance investigation on the ion beams ongoing since 2007. The facility with two dc beam irradiation of the samples under controlled heating till the 700ºC together with Laser atom-probe tomography will create the “world level” center. (In word - JANNUS French, FRANZ Germany, DuET Japan, MIBL USA) .

- ✓ **Facility for semiconductor industry**

  Improvement of power electronics units by proton beam irradiation (IGBT – Insulated Gate Bipolar Transistors, and FRD Fast Recovery Diodes). Russian market today requires irradiation of several thousands samples per year and will increase. The facility in ITEP both for samples irradiation and for development of compact linac for serial production.

- ✓ **Medicine (BNCT, Radiopharmaceutical for PET)**

  - **Experimental facility in ITEP for BNCT development with medics (Oncological centre “N. N. Blochin”, Botkin Hospital, Herzen Institute);**
  - **Prototypes of compact facilities based on linac for hospital application - serial production of BNCT complex for hospitals.**
  - **Experimental facility in ITEP together with chemical laboratory provides Radiopharmaceutical complex.**
  - **Prototypes of compact facilities based on linac for PET centers.**

  Now more than 50 PET are bought for Russian medical centers (according word standard it is necessary to have 1 PET for 1.5 million of citizens). About each of them needs Radiopharmaceutical complex based on accelerator but less than 10 Cyclotrons is under operation now.

- ✓ **Neutron generators**

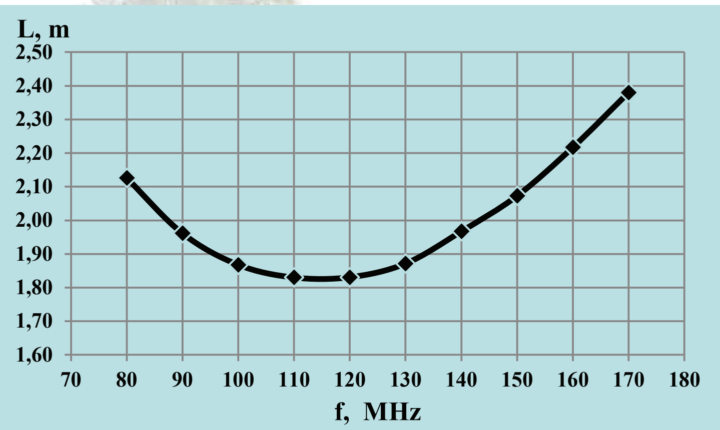
  experimental facility for scientific researches

Выбор частоты для RFQ непрерывного типа (cw) на энергию $W_k/A = 1.5$ MeV/u;

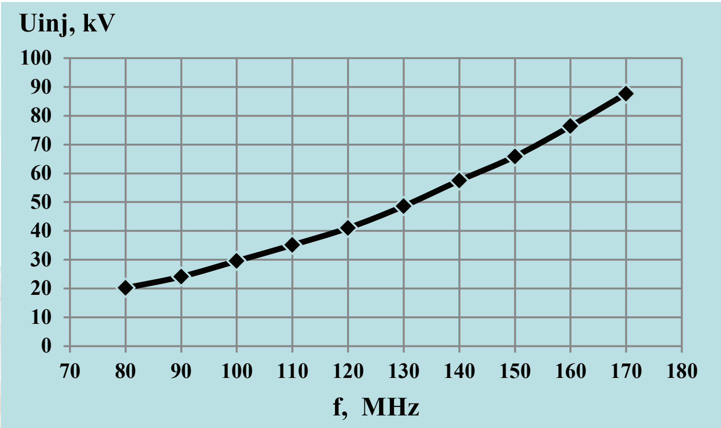
$\varepsilon_{n\ inp} = 0.1\ \pi$ cm·mrad $A_k = 1\ \pi$ cm·mrad

$A_k\ /\varepsilon_{n\ inp} \sim 10$; $E_{smax}\ /\ E_{kp} = 1.6 \leftrightarrow$ cw

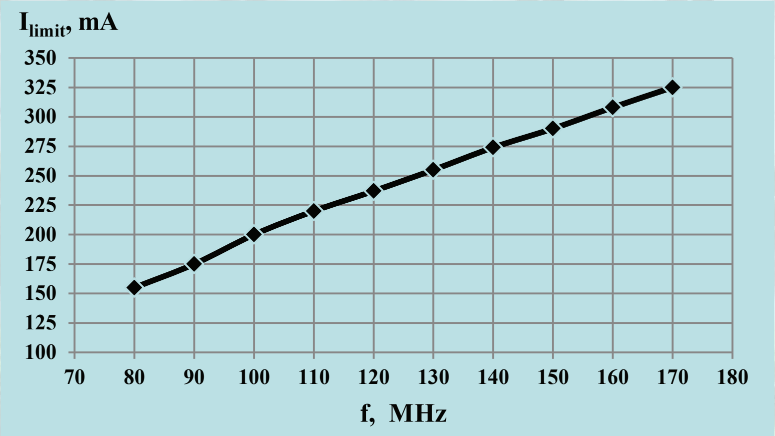
$Z/A = 1$



Зависимость длины ускорителя от частоты



Зависимость напряжения инжекции от частоты



Зависимость предельного тока от частоты

RF system

Оконечный каскад
на ГИ-27АМ

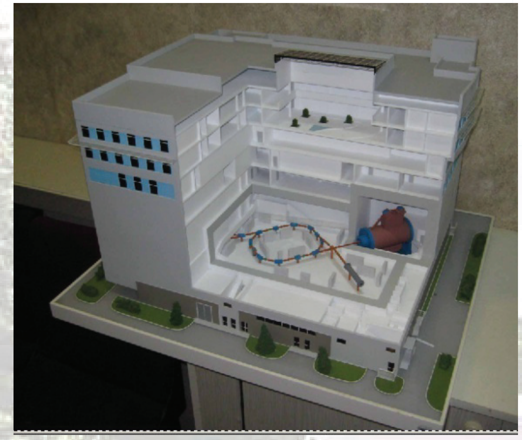
Двухкаскадный
генератора на триодах
ГИ-50А

Твёрдотельный ВЧ генератор
для ускорителя HILAC, ОИЯИ

Твёрдотельный ВЧ генератор для
ПЭТ циклотронов на рабочую
частоту 72 МГц с выходной
мощностью 10 кВт (слева)

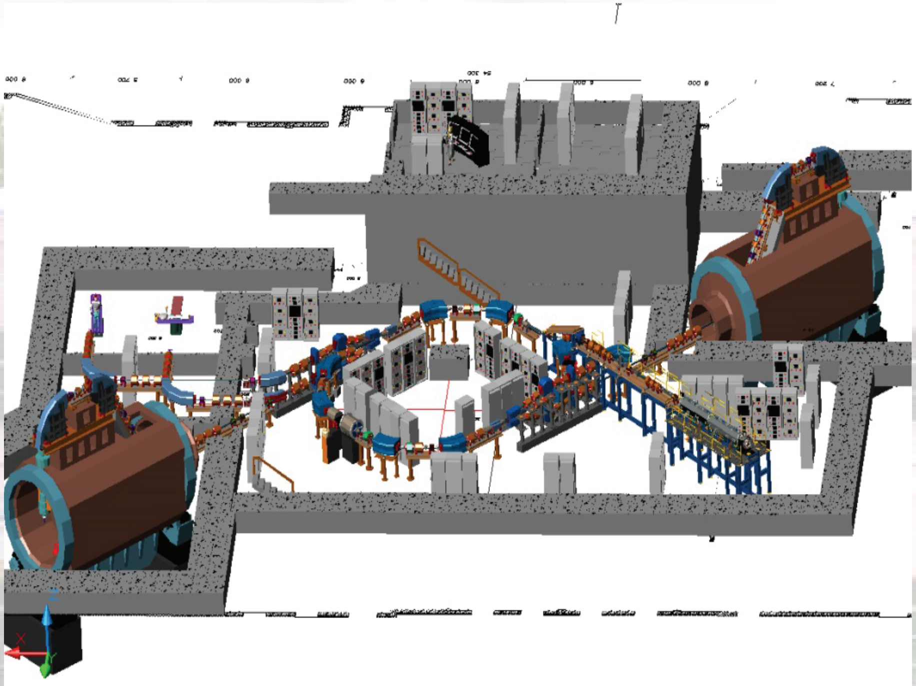
твёрдотельный ВЧ усилитель для
ускорителя ESS (Швеция) на рабочую частоту
352 МГц с выходной мощностью 400 кВт.

Project of CENTRE for Proton Therapy

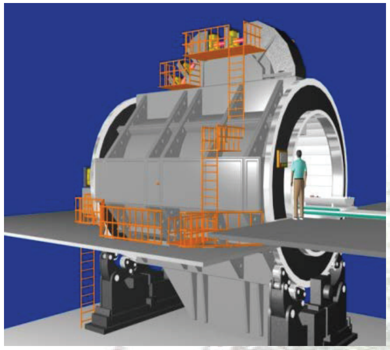


Layout of CPT for Botkin hospital (Moscow)

Linac



Gantry



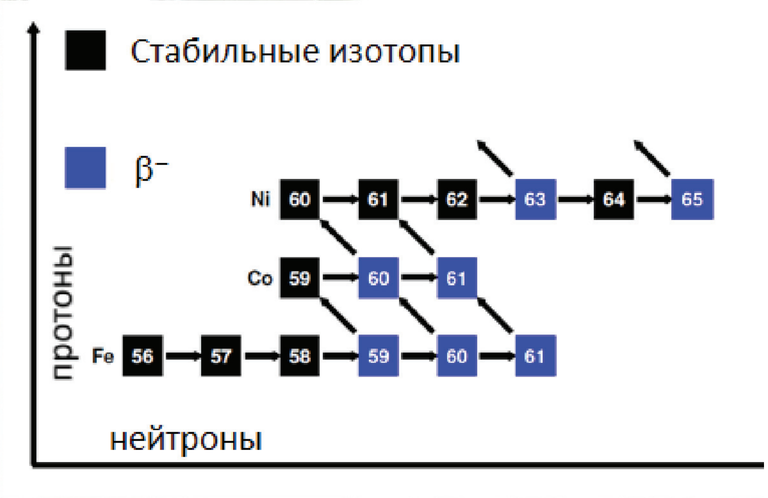
Synchrotron magnet

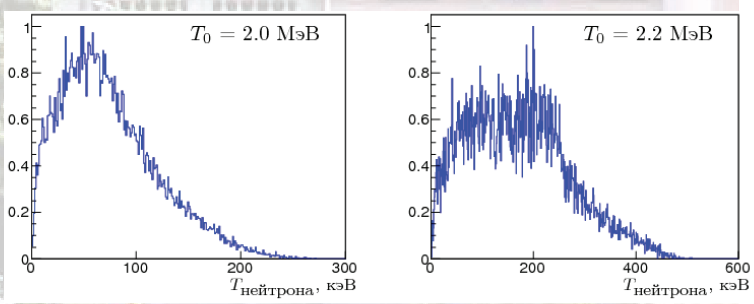
International ion accelerator facilities used for radiation damage studies

	DuET (Kyoto University, Japan)	TIARA (JAERI, Takasaki, Japan)	MIBL (Michigan University, USA)	JANNUS (Saclay, France)	DCF (University of Manchester, UK)	TAMU (Texas A&M University, USA)
Target temperature, C	crio-1773	RT-800	RT-600	cryo-800	RT-400	RT-800
Accelerator type	1.7 MV Tandetron	3 MV tandem 400 kV injecttor 3 MV single-ended	3 MV Pelletron 1.7 MV Tandetron 400 kV injector	3 MV Pelletron 2.5 MV Van de Graaff 2 MV tandem	5 MV tandem Pelletron	1.7 MV Tandetron 400 kV Van de Graaff 3 MV NEC tandem accelerator
Type of ions/ion source	Fe, Si, Ni, C, He	Fe, Si, Ni, C, He	ECR source Fe, Ni, Cr…. He, H	ECR source Fe, Ni, Au…. He, H	SNICS for heavy ions TORVIS for He, H	Fe, Si, Ni, C, He
Beam currents and energies	Fe 6.8 MeV 10 μA He 1 Mev 100 μA	Ni 18 MeV 6 μA He 3 MeV 50 μA Ar 400 keV 50 μA	Fe 2-9 MeV >200nA He 5MeV >200nA	Heavy ions <100 μA He 2.5 MeV 40 μA	Heavy ions 10 μA He 15 MeV 15μA	
Simultaneous irradiation	2 beam	3 beam	2 beam	3 beam	1 beam	2 beam

Astrophysics

ОБРАЗОВАНИЕ ^{60}Fe В *S*–ПРОЦЕССЕ





Взвешенный спектр нейтронов, образующийся в реакции ^{7}Li(p,n)^{7}Be на мишени радиусом 5 мм и толщиной 30 мкм. Данные приведены для двух энергий протона T_0.

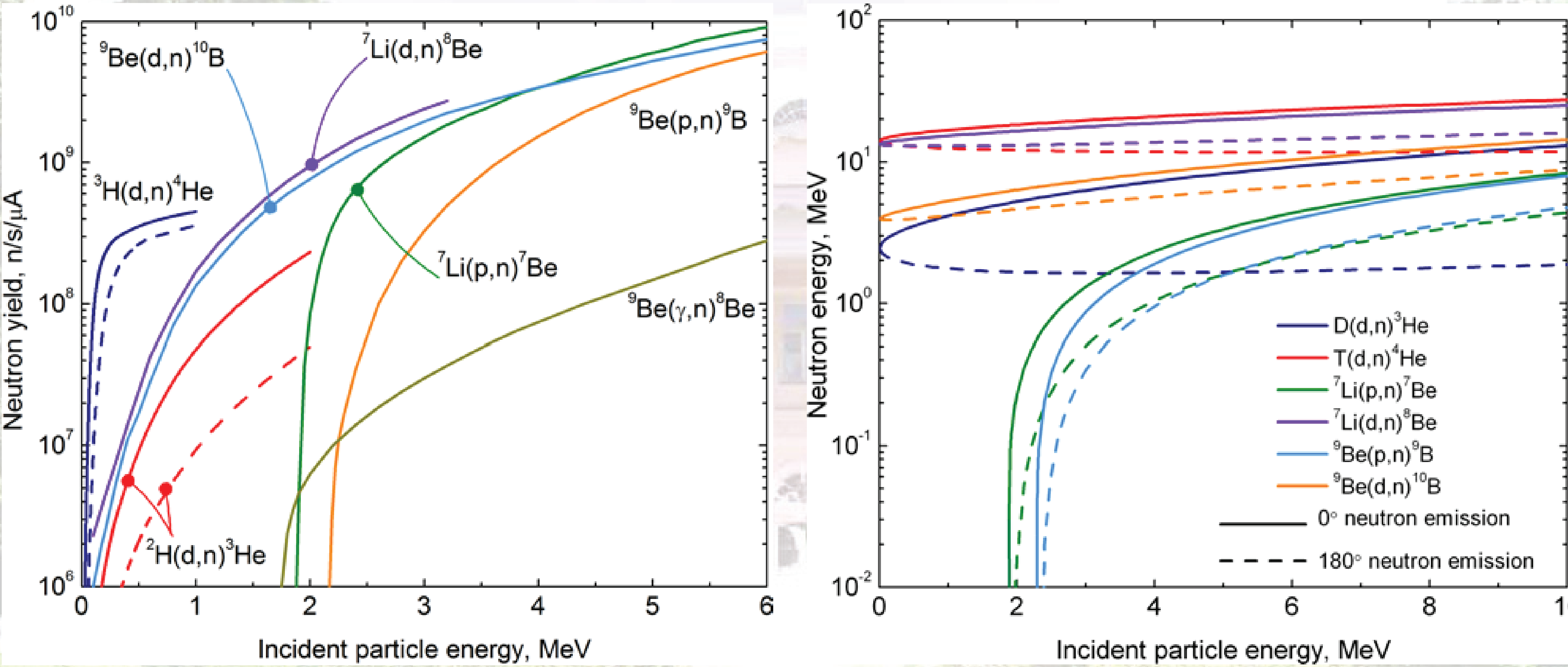
Важную роль в процессе эволюции Вселенной играют s-процессы, т.е. образование более тяжелых ядер через захват нейтронов. По современным представлениям, примерно половина наблюдаемого количества тяжелых ядер образуется в результате s-процесса. Для эффективного протекания s-процессов в звездах, необходимо, чтобы температура вещества была более 10^9 К при плотности нейтронов около 10^{10} см$^{-3}$ нейтронов. Исходным элементом для такой цепочки ядерных реакций служит ^{56}Fe. Наибольший интерес в последние десятилетие вызывает нуклеосинтез ^{60}Fe, распространенность которого в межзвездном пространстве свидетельствует о формировании массы объектов Солнечной системы из нескольких массивных звезд. Для большинства моделей эволюции Вселенной, процессы ^{59}Fe(n,γ)^{60}Fe и ^{60}Fe(n,γ)^{61}Fe являются определяющими. Кроме того, в настоящее время не существует экспериментальных данных по сечениям для реакции ^{59}Fe(n,γ)^{60}Fe, а теоретические предсказания дают различие в 100%. На рисунке показан путь от начала цепочки к элементу ^{60}Fe через ^{59}Fe, время жизни которого составляет примерно 44 дня.

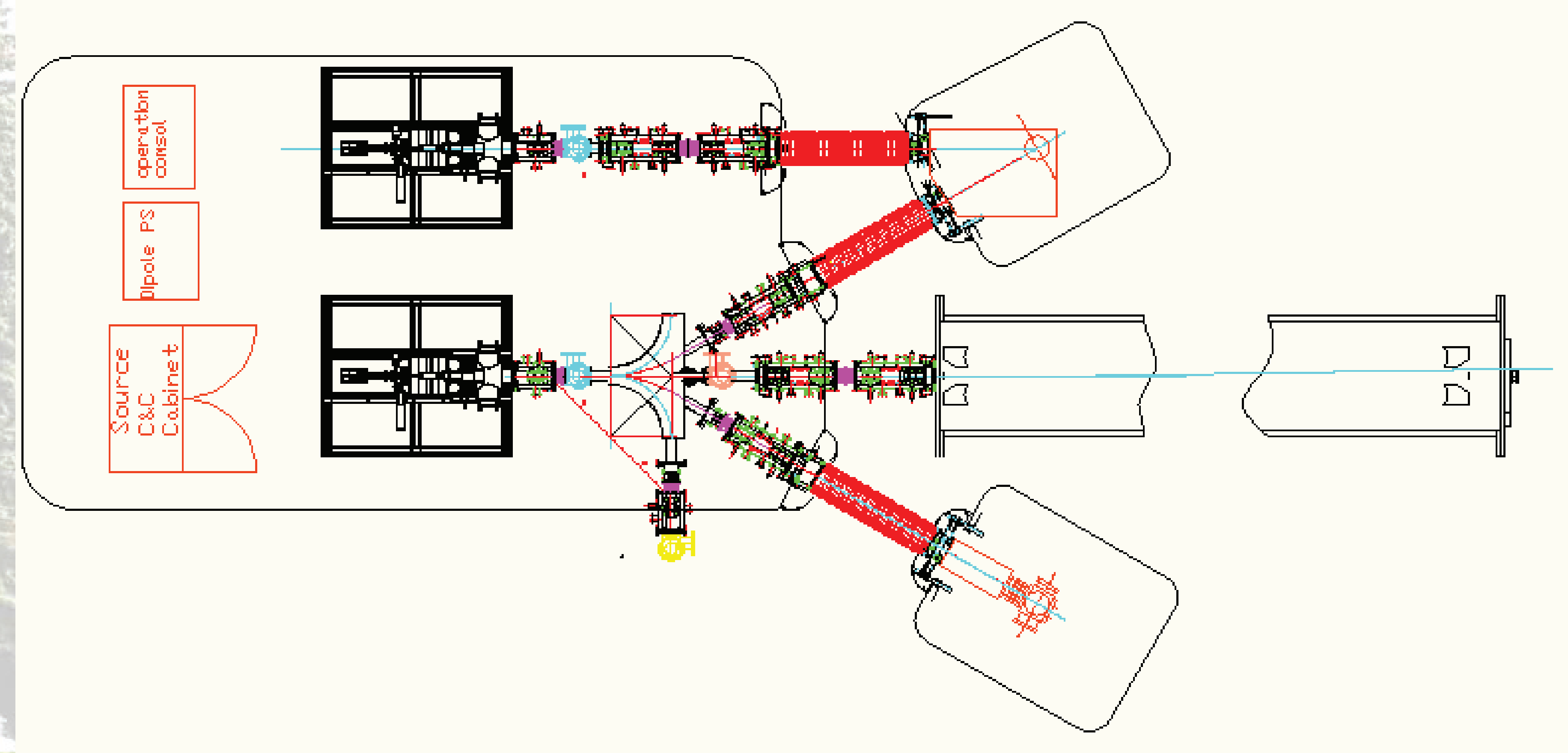
Измерение сечений нейтронного захвата изотопами железа входит в программу исследований экспериментов FAIR и FRANZ.

Neutron production by ion beam

INDUSTRIAL ACCELERATORS AND THEIR APPLICATIONS

Edited by **Robert W. Hamm, Marianne E. Hamm**

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