DESIGN AND CONSTRUCTION OF LOW ENERGY ELECTRON ACCELERATORS AT SINP MSU

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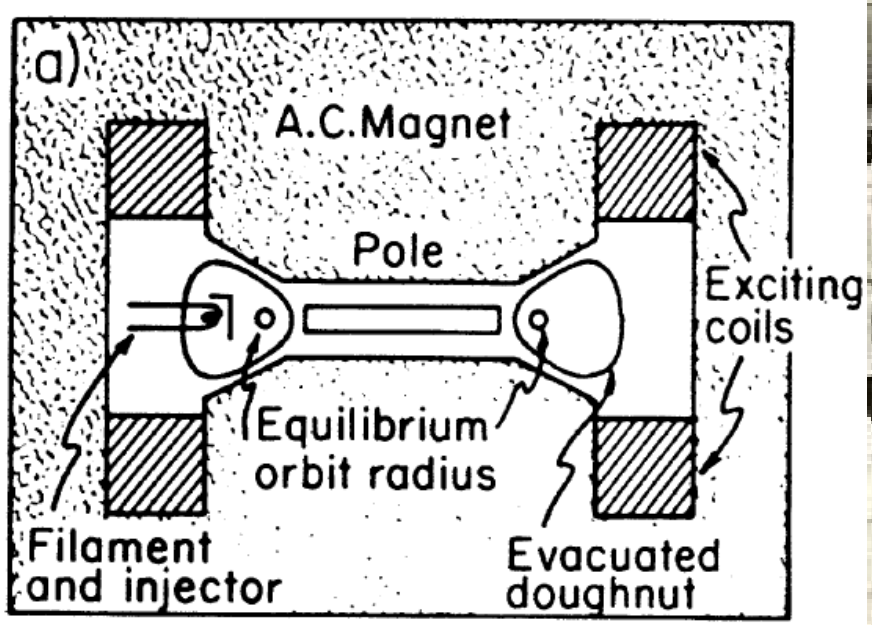
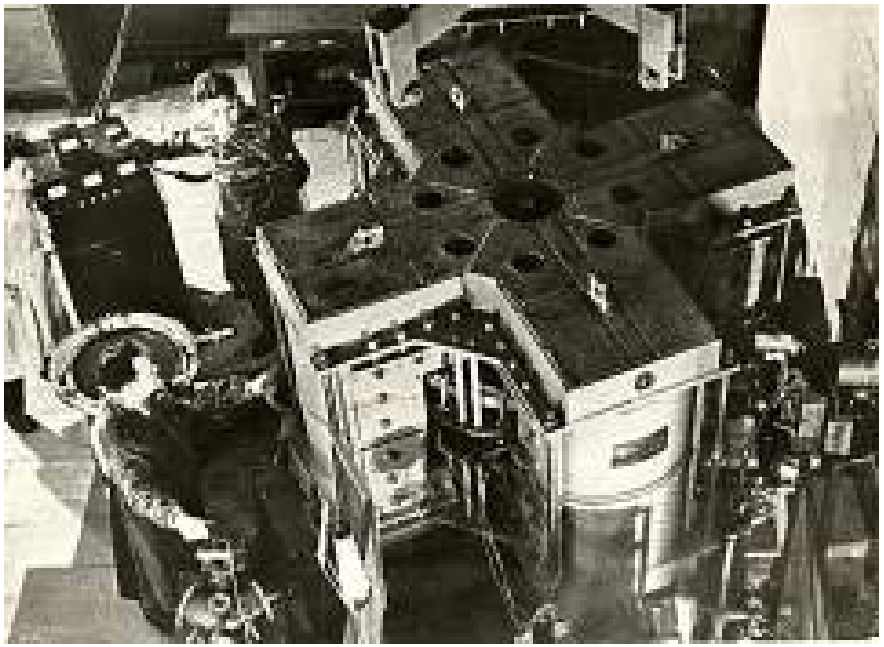
Betatron – 1959 - 1985

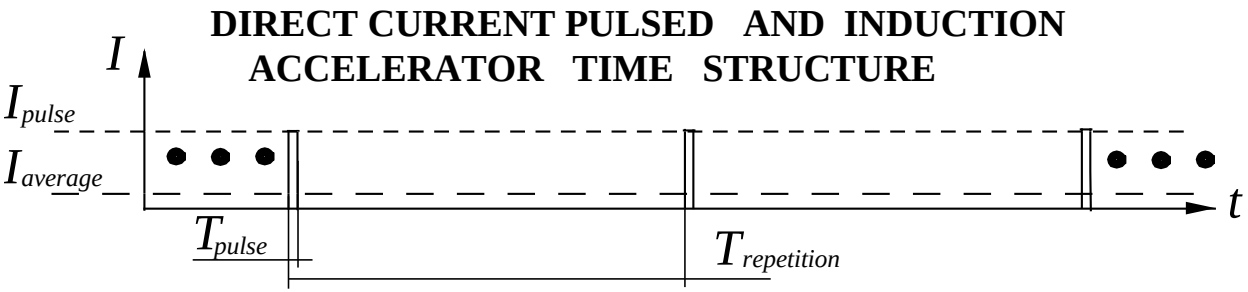




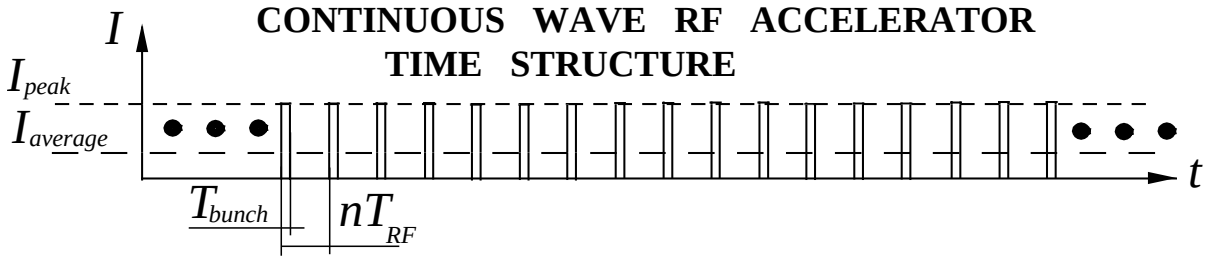
Low intensity
Low duty factor
Low energy

Study of new accelerator <u>for nuclear physics</u> started in 1983

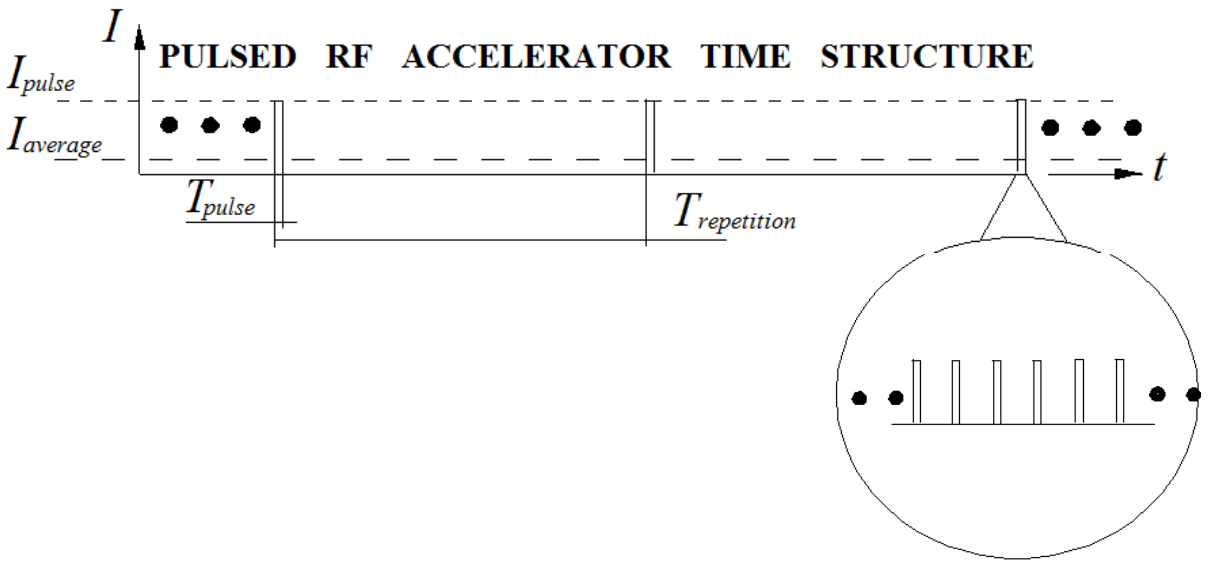
Beam time structure



D ~ 0.01%

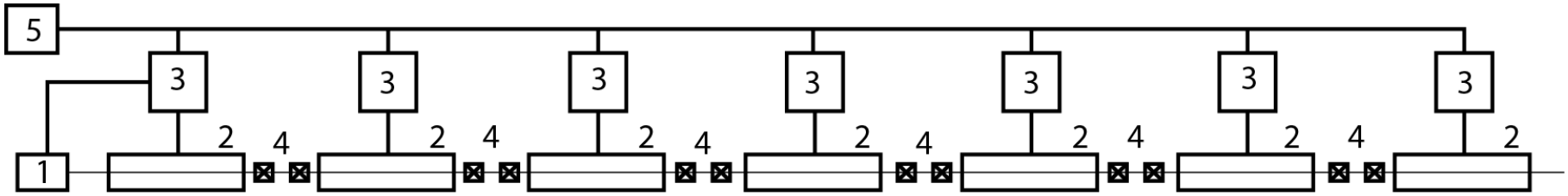


D = 100%



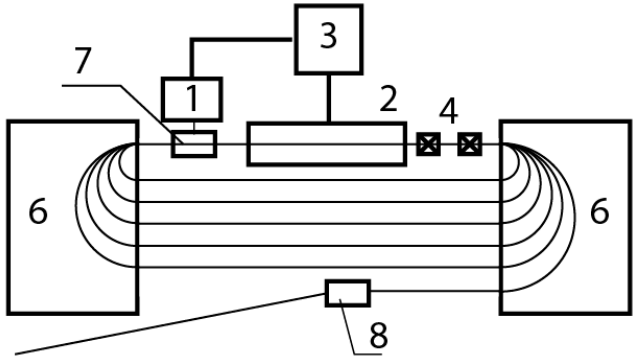
D ~ 0.01% - 10%

Linac and race-track microtron



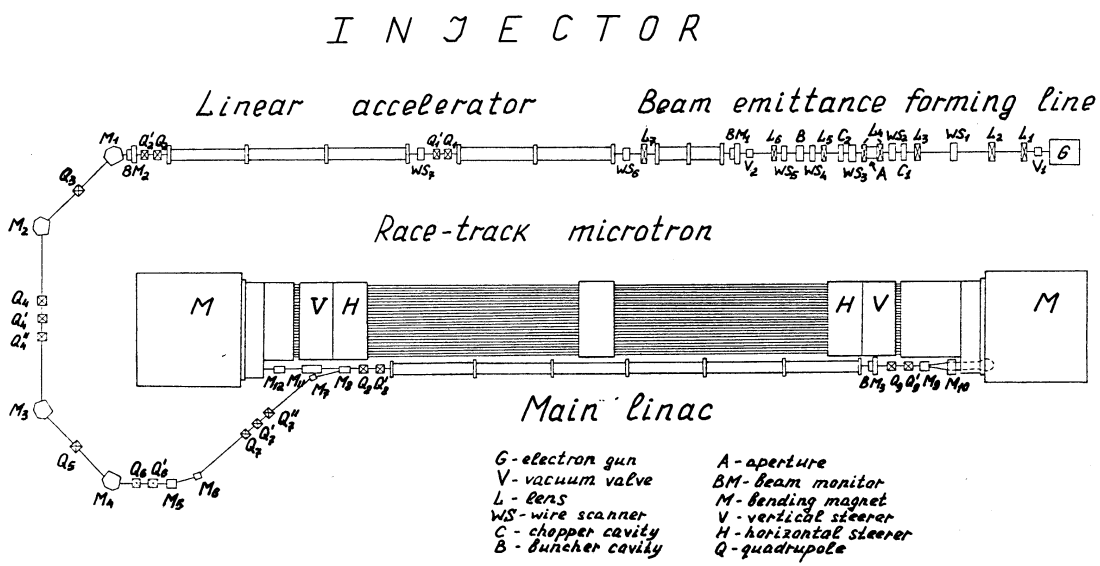
Linac

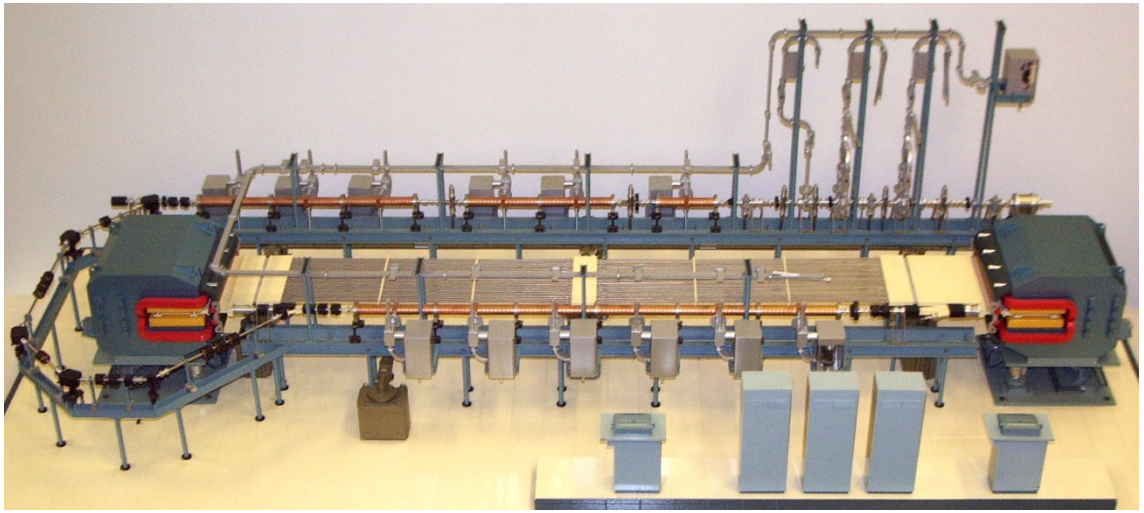
1 – injector
2 – accelerating structure
3 – RF source
4 – focusing
5 – master generator
6 – end magnet
7 – injection magnet
8 – extraction magnet



Race-track microtron

Continuous wave race-track microtron (RTM)
(1983-1992)



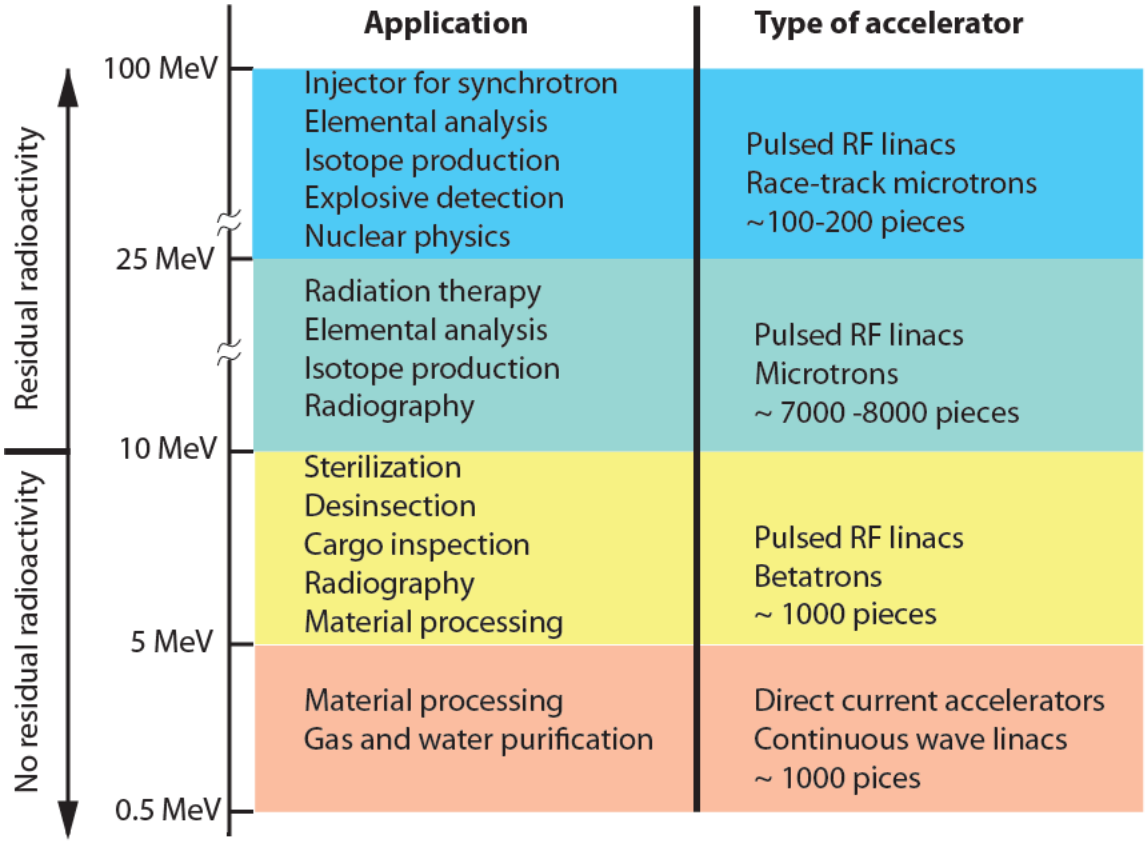


Injection energy	**6 MeV**
Energy gain	**6 MeV**
Maximum energy	**175 MeV**
Average current	**100 μA**
Operating frequency	**2450 MHz**
Magnet field	**1.027 T**
Klystron power	**22 kW**
Number of klystrons	**12+1**

In 1992 CW linac – RTM injector was put into operation and after few years of operation for nuclear resonance experiments CW RTM project was closed – main interest in accelerators activity at SINP MSU was shifted to applied machines

Electron accelerators in the range 0.5 – 100 MeV

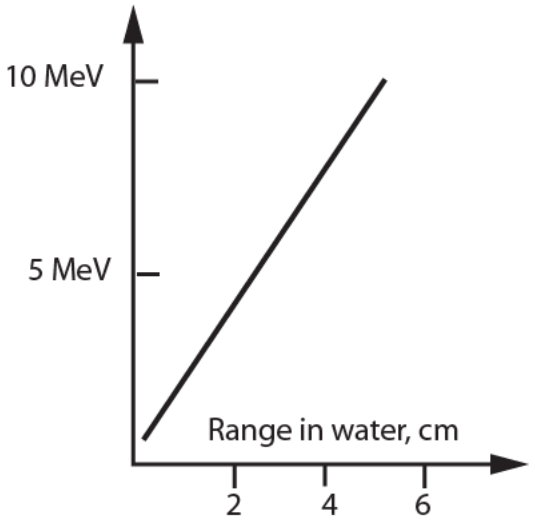
Some applications use bremsstrahlung (X-rays) radiation, some – electron beam.



For X-rays

$$I = I_0 \exp(-\mu x)$$

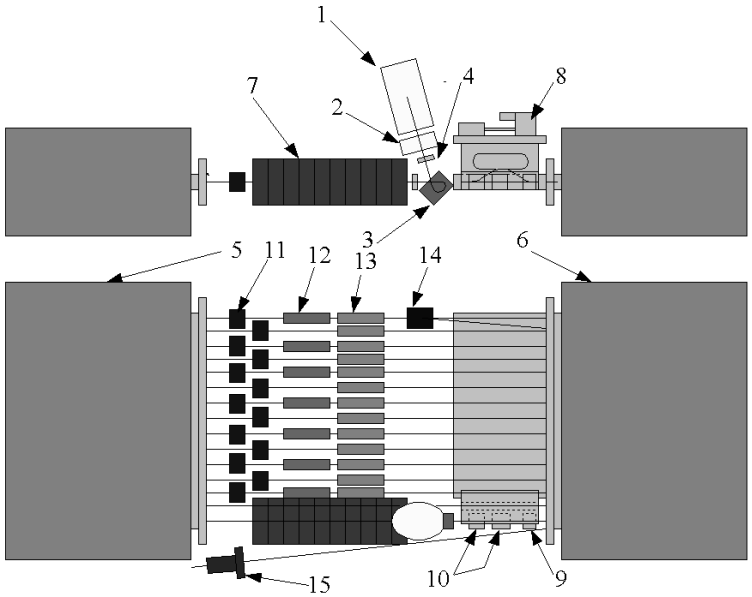
For electrons

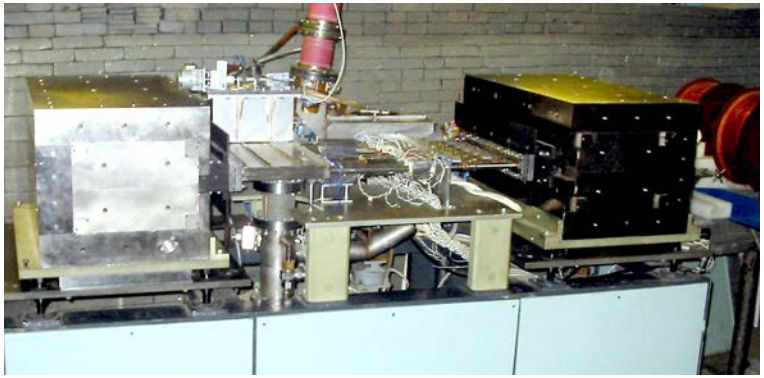


Different mechanisms of radiation interaction with matter are used for different applications - at level of molecules, atoms, nuclei

70 MeV pulsed RTM

with World Physics Technologies USA, 2002



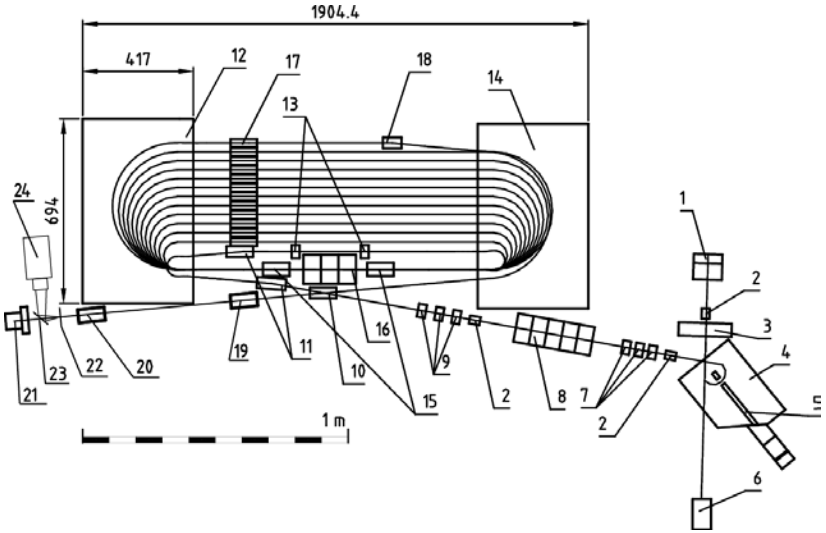


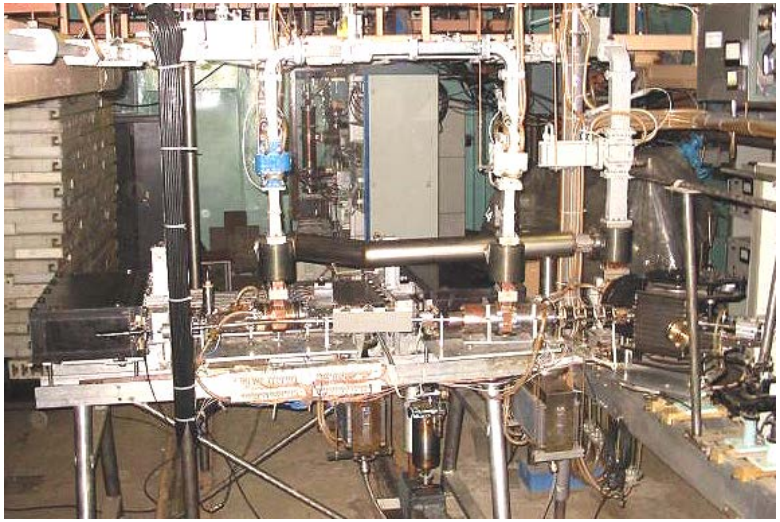
Explosive detection,
isotopes production,
elemental analysis,
nuclear physics

Injection energy	**48 keV**
Energy gain	**4.8 MeV / orbit**
Orbits	**14**
Output energy	**14.8 - 68.3 MeV**
Output current at 68.3 MeV	**10 mA**
Orbit circumference increase	**1λ/orbit**
Operating frequency	**2,856 MHz**
Klystron power pulsed	**6 MW**
End magnet field induction	**0.963 T**
RTM dimensions	**2.2x1.8x0.9 m^3**

Large dipoles built with rare-earth permanent magnet material

35 MeV high brightness beam pulsed RTM
with World Physics Technologies USA , 2004





Generation of radiation by short high charge bunches

Injected beam	**4.85 MeV**
Energy gain per turn	**2.43MeV**
Output beam	**4.85-34.2 MeV**
Normalized emittance	**10 mm mrad**
Longitudinal emittance	**200 keV deg**
Micro pulse	**5 ps**
Pulse repetition	**1-150 Hz**
Micro charge	**150 pC**
RF frequency	**2,856 MHz**
Pulsed RF power	**<3 MW**
End magnet field	**0.486 T**

Large dipoles built with rare-earth permanent magnet material, RF gun with photocathode

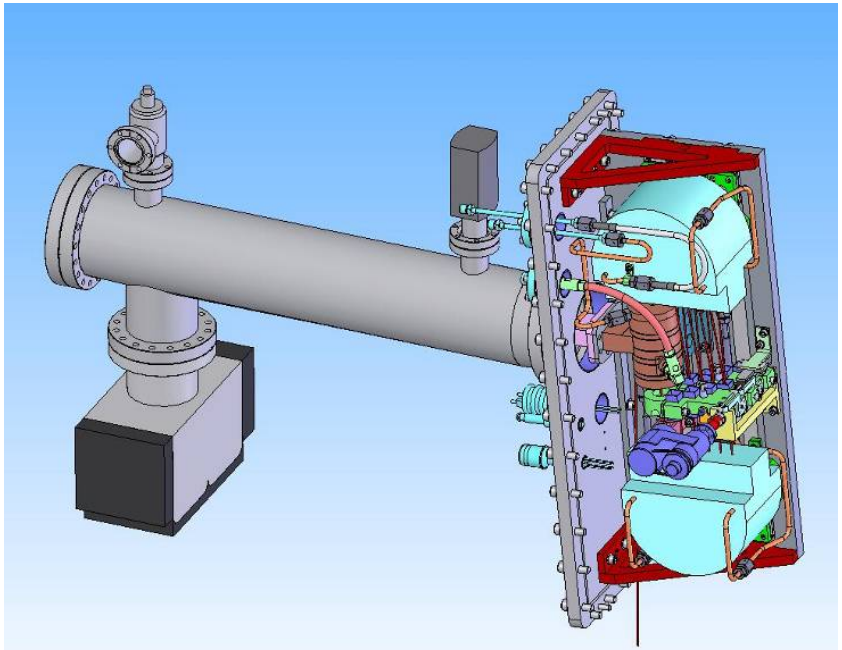
55 MeV race-track microtron
with Lebedev Physical Institute – 2008

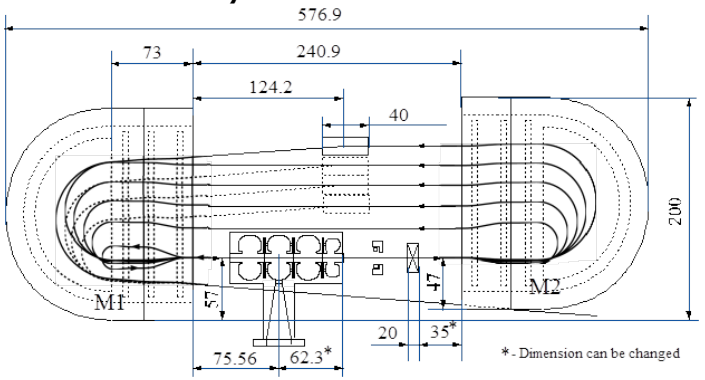
Explosive detection, isotopes production, elemental analysis, nuclear physics

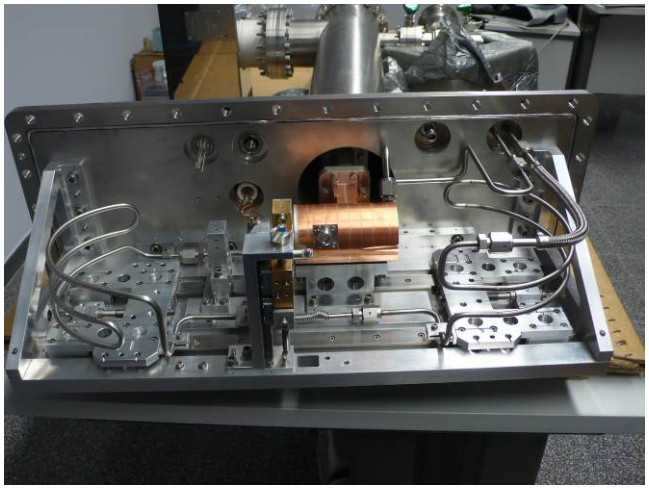
Output energy	55 MeV
Output pulse current	Up to 10 mA
Repetition rate	6.25 – 50 Hz
Number of linac passages	11
Energy gain / turn	5 MeV
Current pulse length	6 μs
Operating frequency	2856 MHz
End magnet field	1.0 T
Maximum RF power	6 MW
Orbit circumference increase / turn	1 λ

12 MeV RTM for intraoperative radiation therapy

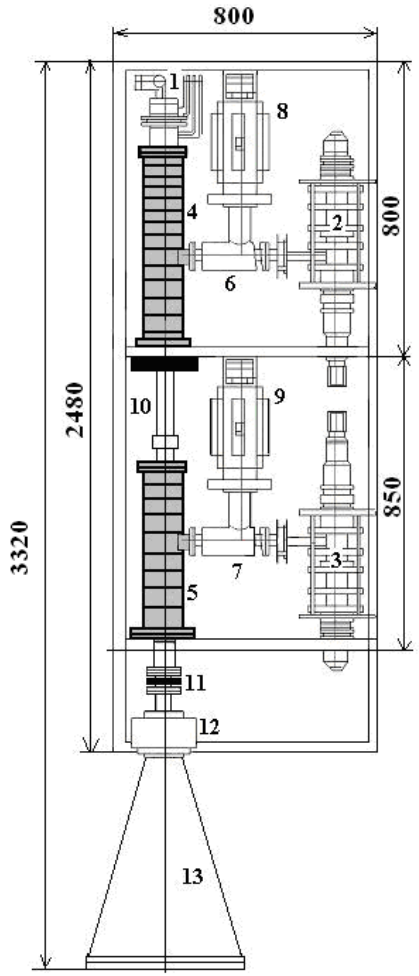
with Polytechnic University of Catalonia, under construction

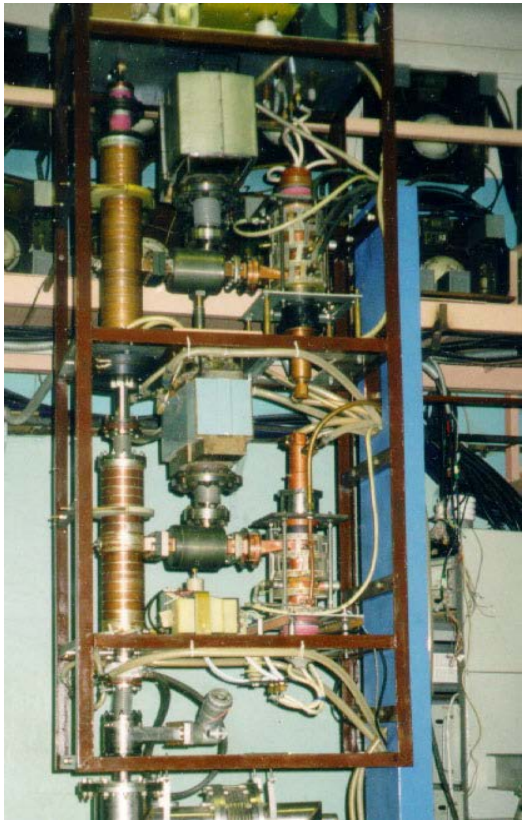






SINP MSU 60 KW, 1.2 MEV COMPACT CW LINAC FOR RADIATION TECHNOLOGIES



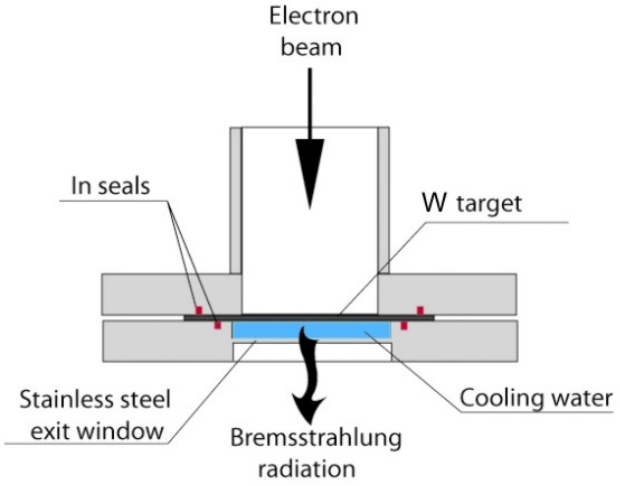


	One-Section	Two-Sections
Beam energy	**0.6 MeV**	**1.2 MeV**
Beam current	**0 to 50 mA**	**0 to 50 mA**
Maximum beam power	**30 kW**	**60 kW**
Length	**0.8 m**	**1.3 m**
Gun/klystron high voltage	**15 kV**	**15 kV**
Plug power consumption	**~75 kW**	**~150 kW**
Electrical efficiency	**~40%**	**~40%**

SOME CURRENT APPLICATIONS OF 1.2 MEV COMPACT CW LINAC

1. Test of spacecraft elements (solar batteries etc) for radiation effects
2. Source of high dose rate X-rays radiation
3. R&D for radiation technologies

Thermo shrinkable polyethylene film dimensions decrease after different doses. Optimal dose 120 kGy.



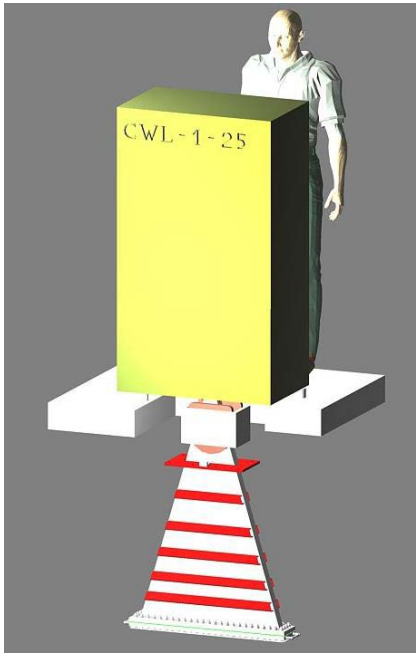
Intensive bremsstrahlung X-rays source (30 Gy/s at average energy 300 keV)

Compact CW linear accelerator for radiation technologies CWL-1-25

(under commissioning)

Beam energy	1 MeV
Average beam current	25 mA
Average beam power	25 kW
Operating frequency	2450 MHz
Klystron average power	50 kW
Wall plug efficiency	30%
Beam scanning width	80 cm
Accelerator dimensions	470 x 784 x 1375 mm[1)]

1)Without output horn and power supply

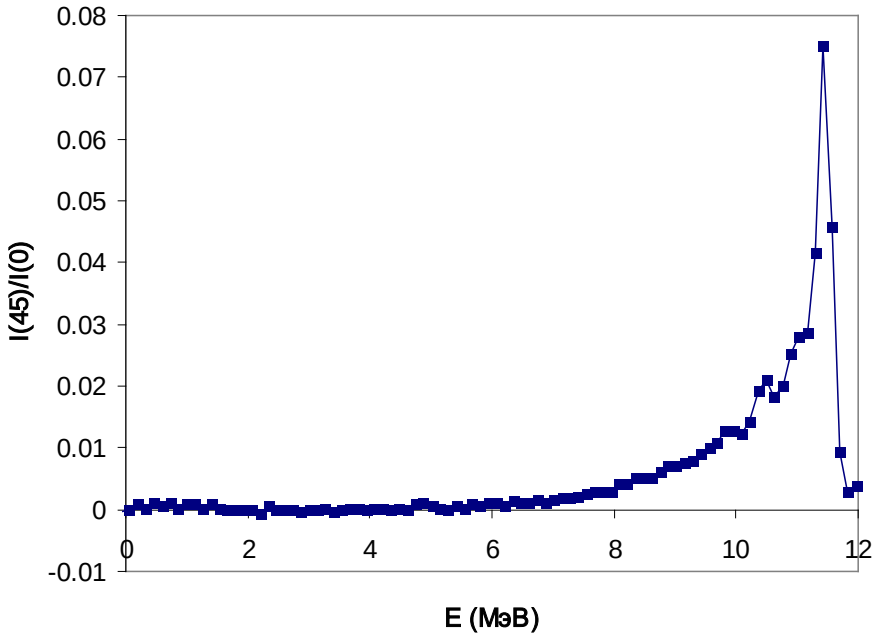


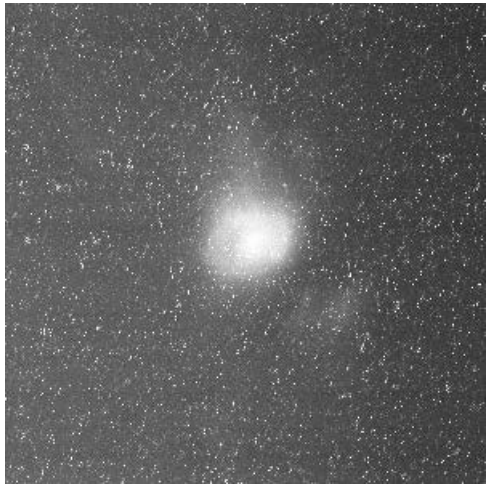
Accelerator is able to provide operation of thermo shrinkable polyethylene film facility with productivity up to 10000 tons/year

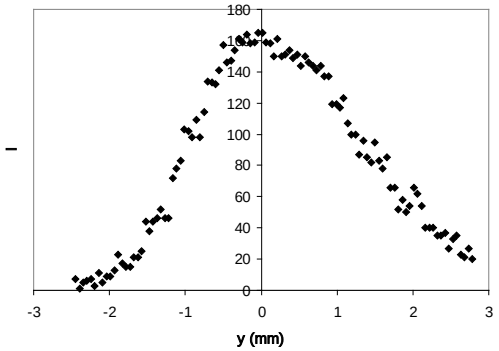
SINP MSU 10 MeV TECHNOLOGICAL LINAC (with “Toriy”, Moscow)

Beam energy	10 MeV
Pulsed beam current	430 mA
Average beam power	15 kW
Operating frequency	2856 MHz
Klystron pulsed power	6 MW
Klystron average power	25 kW
Wall plug efficiency	20%
Beam scanning width	80 cm

Energy spectrum, beam image and beam profile

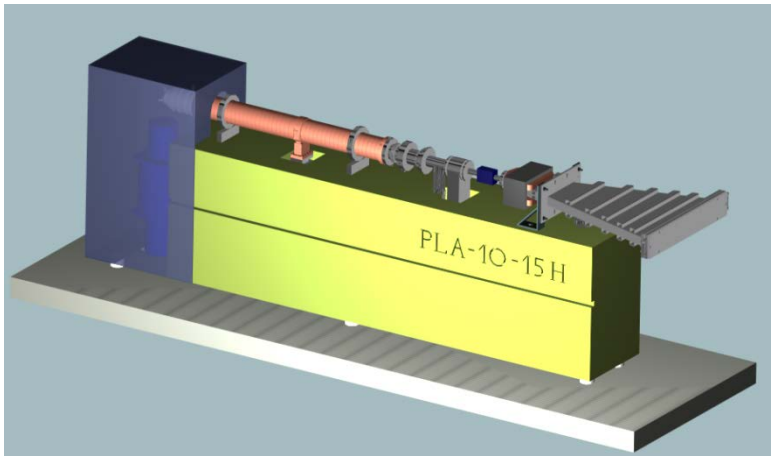




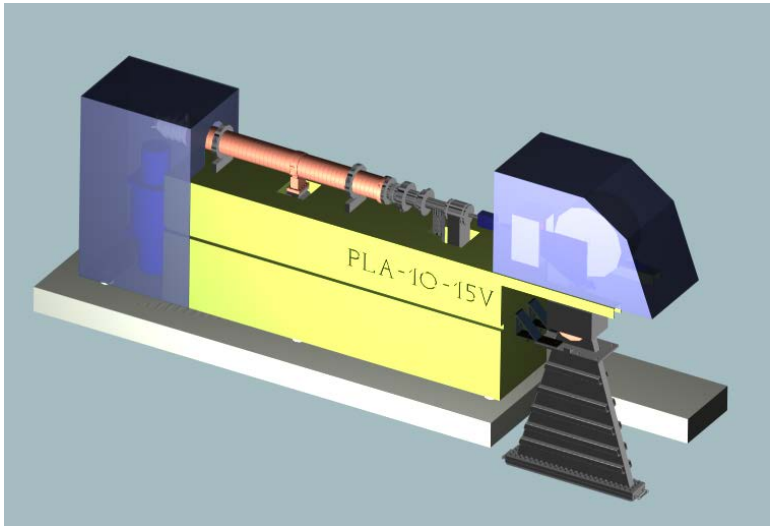


SINP MSU 10 MeV TECHNOLOGICAL LINAC (with “Toriy”, Moscow)

Proposal



Pulsed Linear Accelerator PLA-10-15H



Pulsed Linear Accelerator PLA-10-15V

Beam energy	10 MeV
Pulsed beam current	430 mA
Average beam power	15 kW
Operating frequency	2856 MHz
Klystron pulsed power	6 MW
Klystron average power	25 kW
Wall plug efficiency	20%
Beam scanning width	80 cm
Accelerator dimensions	470 x 784 x 1375 mm[1)]

[1)]Without output horn and power supply

Design by SINP MSU team and “Toriy” team of 3/6 MeV linac with interlaced energies for cargo inspection. Variant 1.

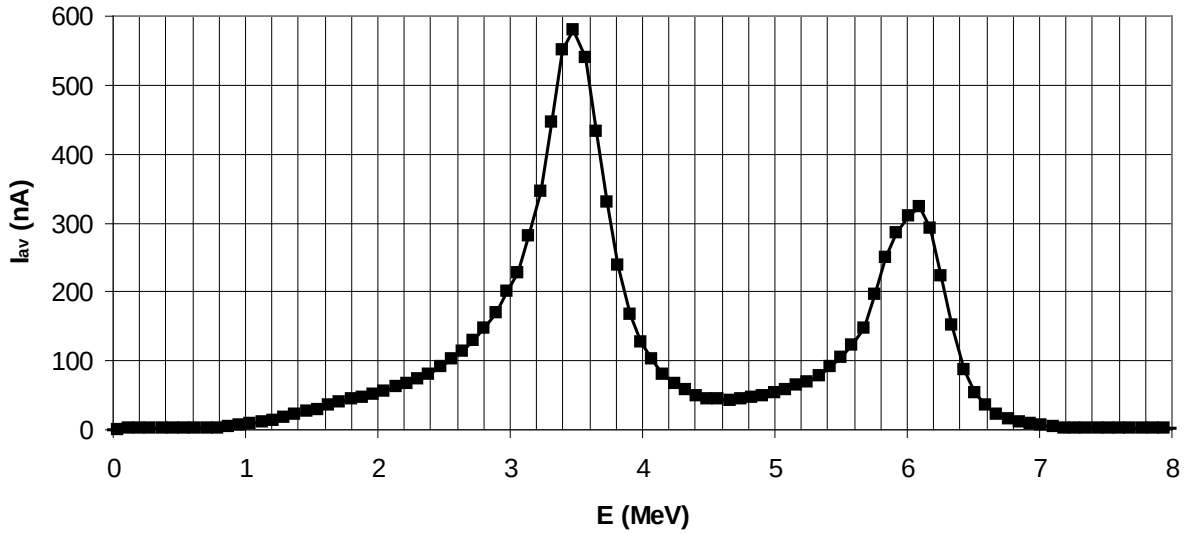
X-rays head

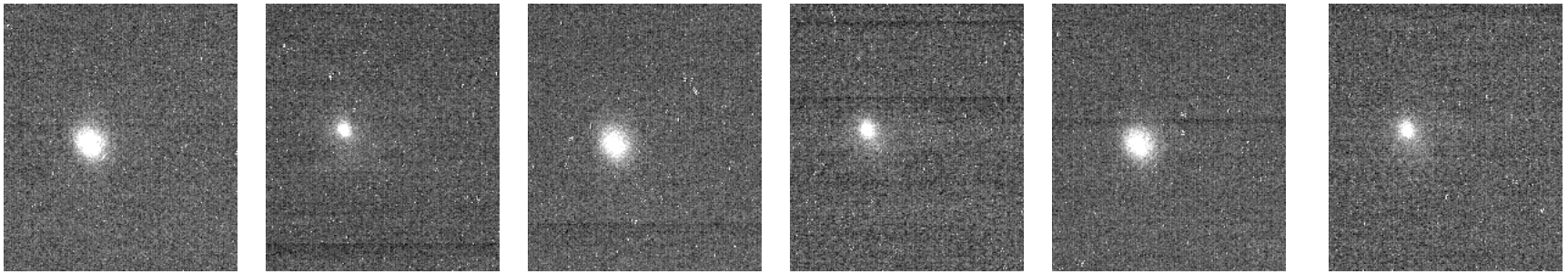
Beam energy	3.5/6 MeV
Dose rate at 1 m	0.2 – 2 Gy/min
Operating frequency	2856 MHz
Pulse repetition frequency	50 – 400 Hz
Accelerator dimensions	1000x600x900 mm
Accelerator weignt	900 kg[1)]

[1)]Including local radiation shielding

Control console

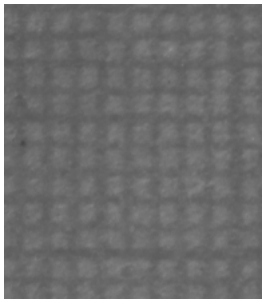
Energy spectrum in interlaced energies mode





Low

High



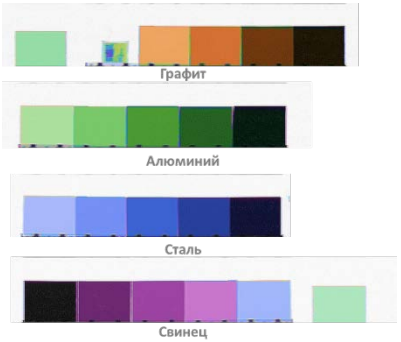
Scale:
1 square=
1×1 mm

Beam spots diameters are well below 2 mm

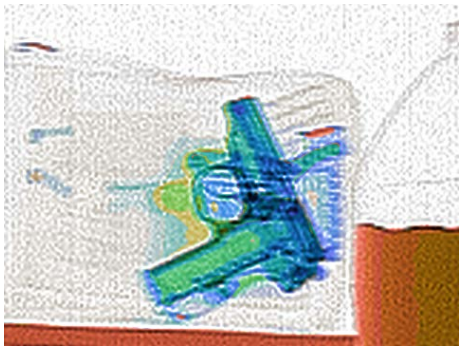
Interlaced energies 6/3.5 MeV linac for cargo inspection. Variant 2.

with Scantronic Systems, Moscow, 2012

Material recognition with $\triangle Z \sim 1$



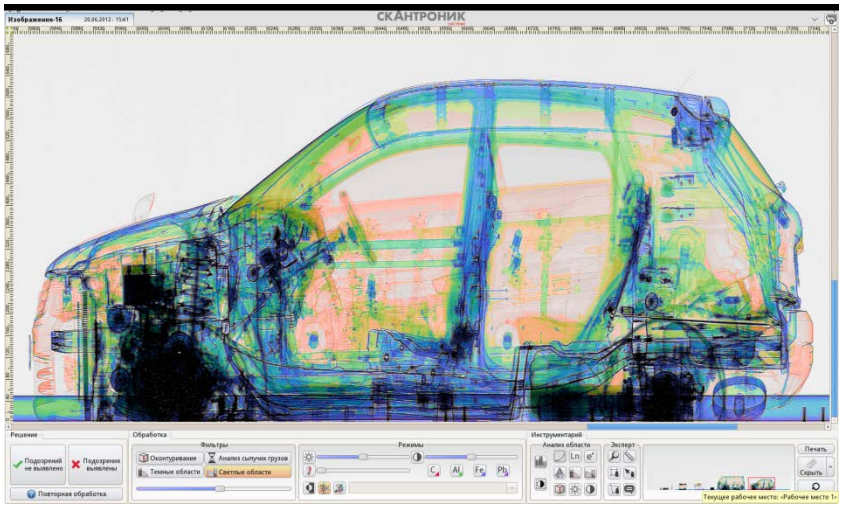
High spatial resolution

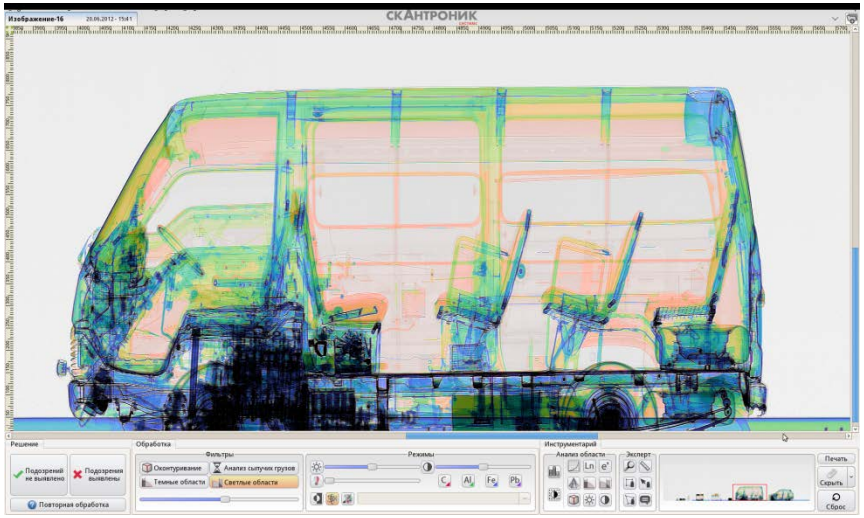


Experiments on industrial tomography have been conducted

Interlaced energies 6/3.5 MeV linac for cargo inspection. Variant 2.

http://scantronicsystems.com/





Accelerator for radiography
2011

Maximum energy	8 MeV
Range of energy regulation	3-8 MeV
Max dose rate at 1 m at 8 MeV	10 Gy/min
Range of dose rate regulation	1-10 Gy/minн
Beam spot dimension	<1 мм

Control pannel

Accelerator tests

Steel 340 mm

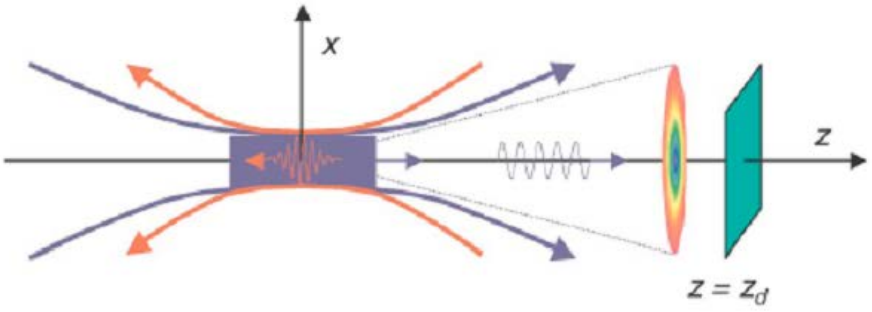
Resolution 0,5% for steel thickness 340 mm.

Accelerator for radiography operation

More than 15 000 expositions during 1.5 year

Project of laser-electron X-rays generator (LEXG)

Since 2004, joint with Lebedev Physical Institute



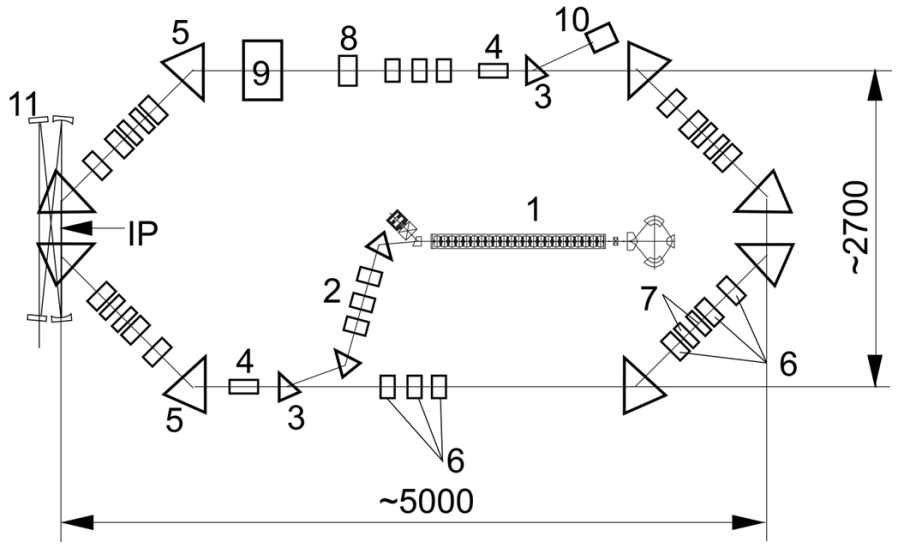
$$E_\gamma = 4\gamma^2 E_{ph}$$

$$E_{ph} = 1.16\,\text{eV}$$

$$E_\gamma = 10 - 45\,\text{keV}$$

$$E_e = \gamma m_0 c^2 = 25 - 50\,\text{MeV}$$

$$B_{av} > 10^{12}\ \text{c}^{-1}\text{mm}^{-2}\text{mrad}^{-2}(0.1\%\text{BW})^{-1}$$



Close to limit value of photons per one interaction for ring machine:

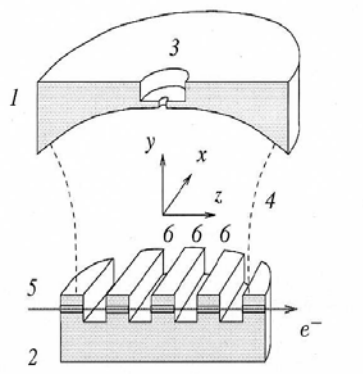
$$q_e = 1\,\text{nC},\ w_{ph} = 20\,\text{mJ},$$

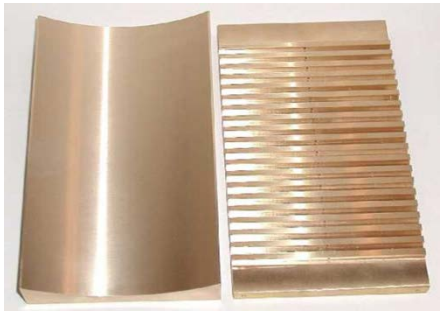
$$N_e = 5\times10^9,\ N_{ph} = 10^{17},$$

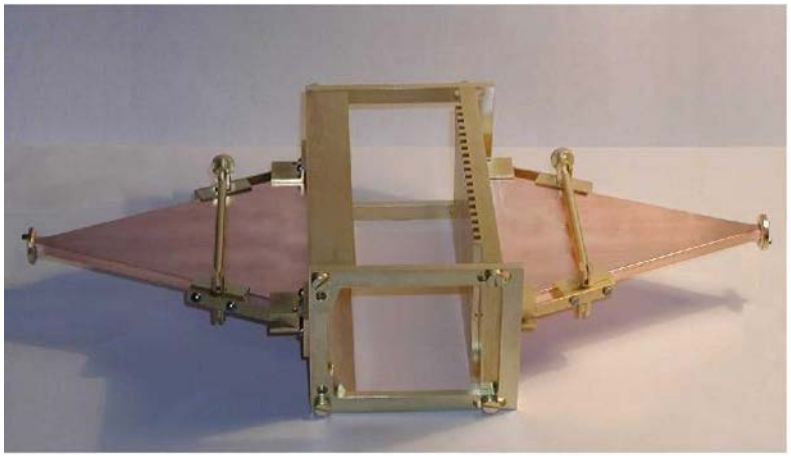
$$\sigma_r = 2\times10^{-5}\ \text{m},\ N_\gamma \approx 10^7$$

High average flux due to multiple frequent collisions

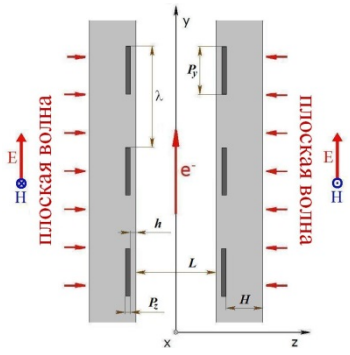
Laser acceleration in vacuum (up to 1 GeV/m)

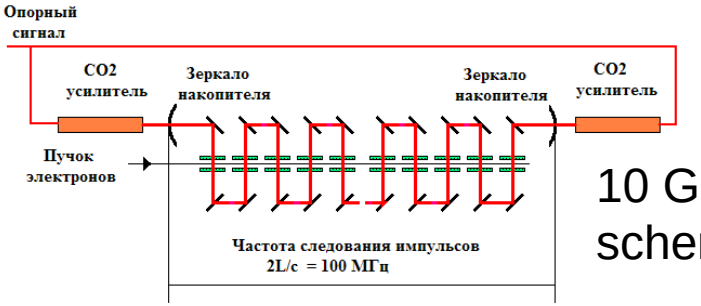






First version – open resonator with special mirror 1998-2002





10 GeV scheme

Second version – diffraction accelerating structure 2002 - 2008