ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

STATUS AND PROSPECTS OF CHARGED-PARTICLE ACCELERATORS DEVELOPMENT IN RFNC-VNIIEF

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FSUE RFNC-VNIIEF

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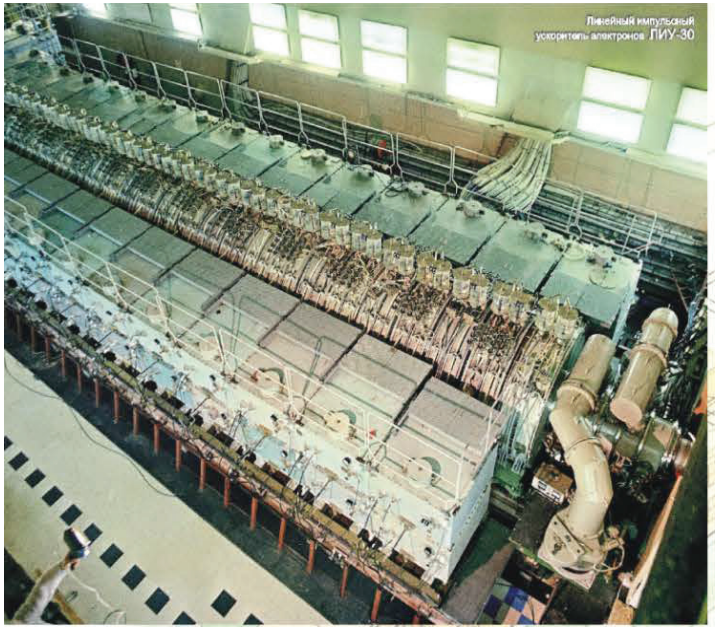
Irradiation complexes

Experimental and test base of RFNC-VNIIEF is a federal importance base and provides needs of enterprises: state corporation (SC) “Rosatom”, Department of Defense, Department of Industry and Trade and SC “Roscosmos”

For the first time in the world the unique irradiation complexes based on high-current linear induction electron accelerators and pulsed nuclear reactors have been created in VNIIEF to study common radiation impact in laboratory conditions

Multipurpose irradiating complex PULSAR



Linear induction electron accelerator LIU-30

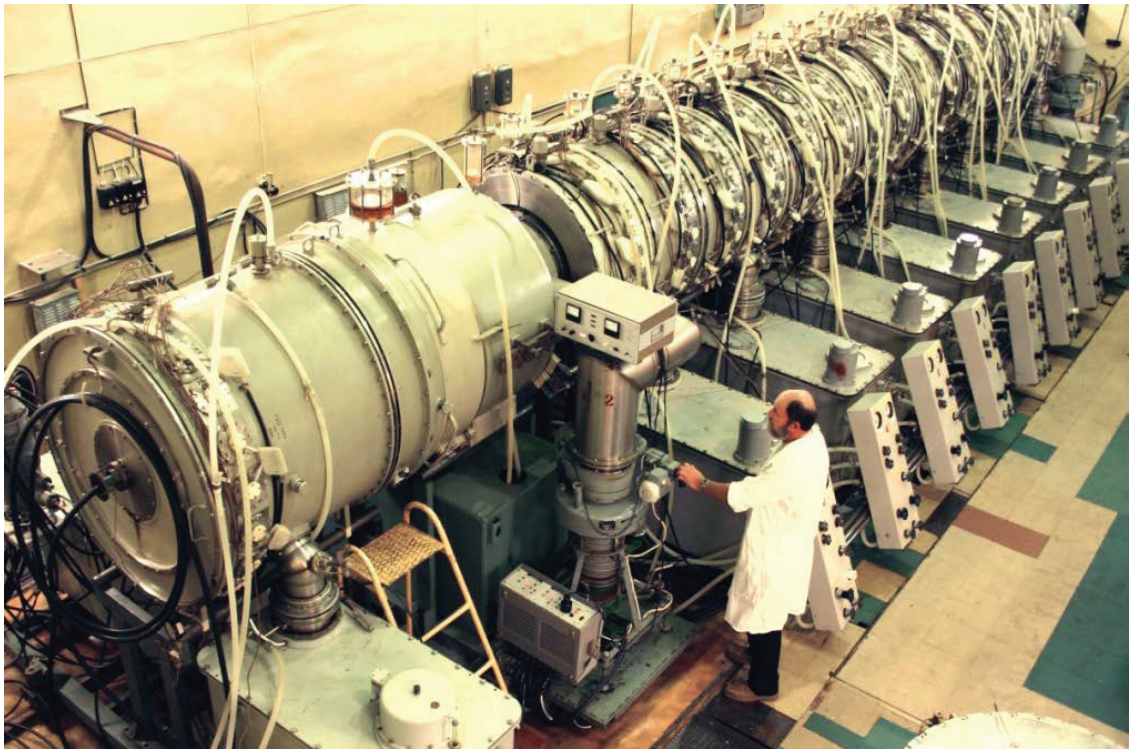
Ultimate electron energy……..…from several units to 40 MeV
Beam current.....up to 100 kA
Dose at a distance 1 m from the target ($t_{0.5}$≈ 18 ns)....up to 10 kR
Dose rate with irradiation heterogeneity 1:2
Ø 0.75 m .....$4 \cdot 10^{11}$ R/s
Ø 2 m .....$3 \cdot 10^{10}$ R/s
Pulse voltage generator W_{PVG}…..... 1.5 MJ
Magnetic field battery W_{MFB} ……6.5 MJ
Pulse width of bremsstrahlung……from 5 to 25 ns.

Two bremsstrahlung pulses generation mode with the pulse repetition rate from 0.1 to 1.5 μs is available.

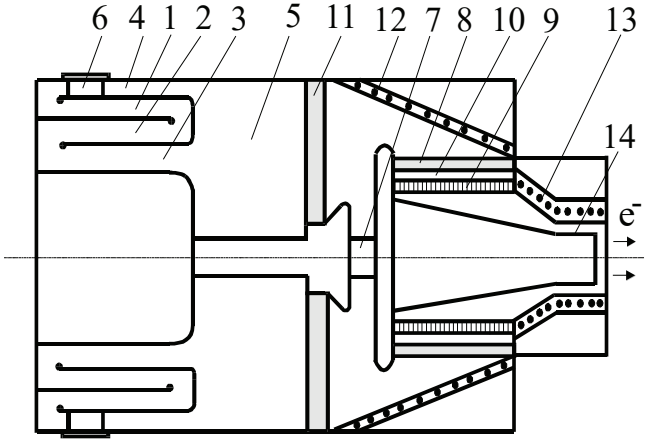
Electron beam compression mode:
$1.5 \cdot 10^{13}$ R/s, 240 kR, 16 ns, 100 cm^2.

1 – accelerating block of inductors
2 – cathode
3 – drift tube with a solenoid
4 – transport line
5 – target unit
e – symbolic representation of main electron fluxes
BR – bremsstrahlung

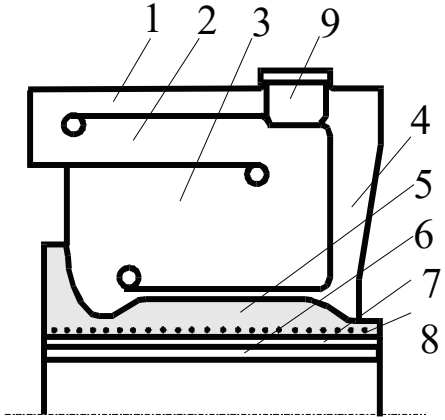
Linear induction accelerator LIU-10M



Injector configuration (a) and inductors (b)



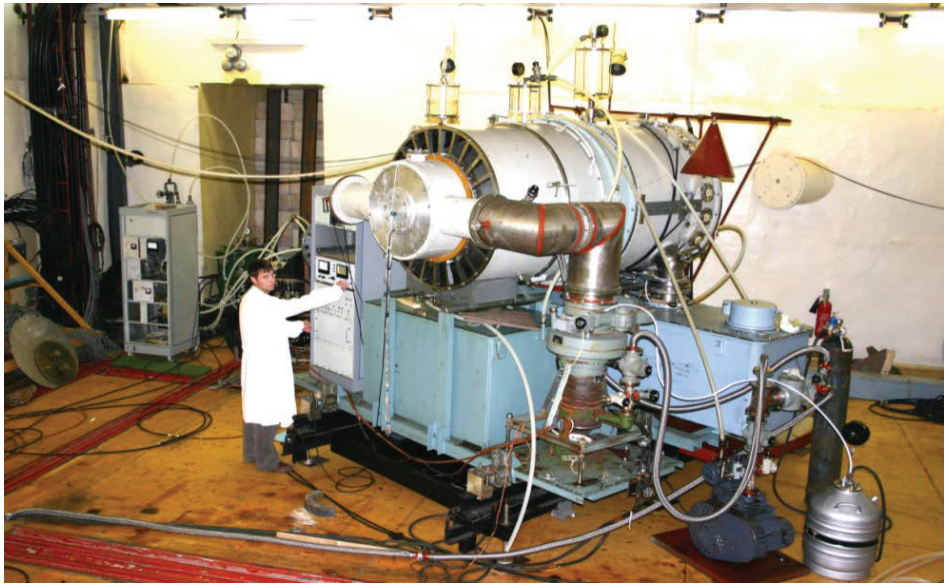
a



b

Maximal electron energy……25 MeV
Beam current……...50 kA
Dose at a distance 1 m from the target……700 R
Dose rate……..$3 \cdot 10^{12}$ R/s
Pulse width of bremsstrahlung……15 ns

Pulsed electron accelerator STRAUS-2



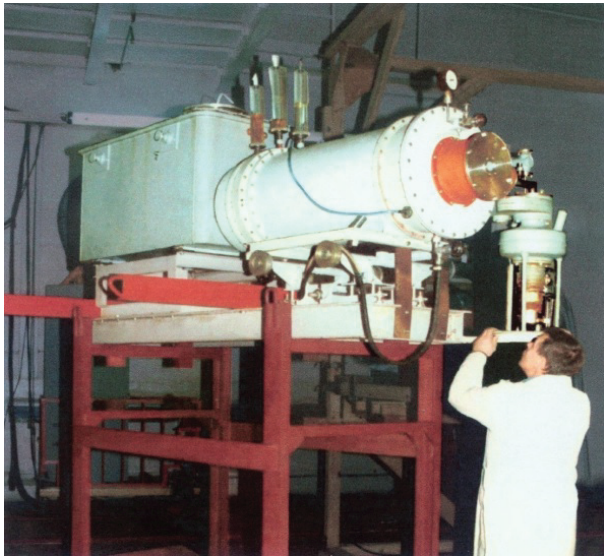
Maximal electron energy.....3 MeV
Beam current .....50 kA
Dose at a distance 1 m from the target
($t_{0.5} \approx 25$ ns) .....20 R
Dose rate with irradiation heterogeneity 1:2
Ø 7 cm .....$4 \cdot 10^{11}$ R/s
Ø 80 cm .....$8 \cdot 10^{8}$ R/s
Average quantum energy.....600 keV
$W_{PVG} = 24$ kJ

X-ray mode parameters

X-ray capacity (lead) at a distance 1 m from the target.....125 mm
Focal spot diameter ..... ≤ 5 mm

Simulating facilities : ILTI-1, LU-7-2, ARSA

ILTI-1

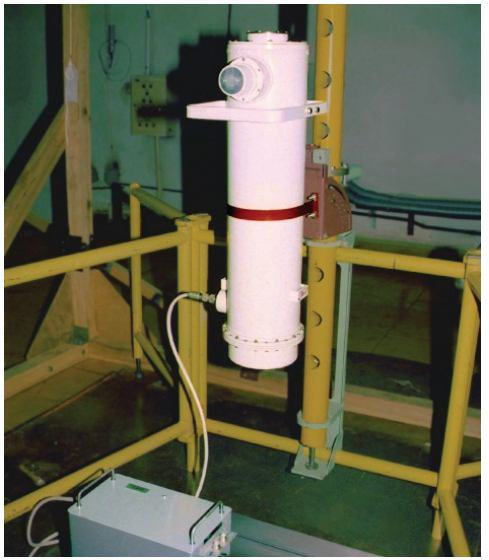


Ultimate electron energy.....700 keV
Beam current.....70 kA
Dose at a distance 1 m from the target ($t_{0.5}$≈ 50 ns).....$5 \cdot 10^7$ R/s
at a distance 4 cm (Ø 7 cm, irradiation heterogeneity 20 %).....$3 \cdot 10^{10}$ R/s
Average quantum energy.....80 keV
W_{PVG} =8.8 kJ

LU-7-2

Electron energy.....6.5 MeV
Average electron beam power.....2 kW
Average beam current.....0.3mA
Pulse length…….....4.5 μs
Pulse repetition rate……600 Hz
Bremsstrahlung dose rate at a distance 1 m from the target……....25 R/s
Spot area with irradiation heterogeneity 30%.....800 cm^2

ARSA



Operating mode – pulsed or frequence (f ≤ 1 Hz)
Ultimate electron energy…....1MeV
Electron radiation dose rate near the target.....$1 \cdot 10^{14}$ $rad \cdot s^{-1}$
Bremsstrahlung dose rate near the target ($t_{0.5}$=4 ns, Ø 1 cm)…..$3 \cdot 10^{10}$ $R \cdot s^{-1}$
Productivity – up to 100 pulses per working shift

Linear resonance accelerator LU-10-20

Accelerated electron energy.....5 ÷ 9 MeV

Average beam current.....1.3 mA

Pulse length.....3.5 μs

Electron beam diameter.....25 mm

Pulse repetition rate.....10 ÷ 1000 Hz

Electron radiation dose power.....up to 5 Mrad/s

Bremsstrahlung dose power at
a distance 1 m from the target
on the area Ø 360 mm…….....up to 300 R/s

A system of electron beam scan and a transporting line allow irradiation of objects with width up to 600x700 mm^2 and height up to 500 mm

Linear resonance accelerator LU-50

Linear resonance electron accelerator LU-50 is aimed at studying nuclear reactions taking place under the effect of fast neutrons (0.1 ÷ 14 MeV) with aid of a time-of-flight method.

The accelerator is employing as well to study radiation resistance of materials, to elaborate radiography methods at large mass thicknesses of materials and to get of accelerated electrons pulses with picosecond length.

Accelerated electron energy	55 MeV
Pulsed current	10 A
Pulse length	10 ns
Pulse repetition rate	2400 Hz
Neutron yield from the uranium target	$3 \cdot 10^{13}$

Electrostatic tandem accelerator EGP-10

РФЯЦ ВНИИЭФ

Type of accelerated particle – *p*, *d*, *t*, O, C.

Accelerated proton energy range.....1.5 ÷ 12 MeV

Monochromaticity of accelerated protons

(at energy 9.345 MeV)..... < 1 keV

Maximal proton beam current.....1 μA

Conductor diameter.....1.3 m

Maximal conductor voltage.....7 MV

Negative ion source – duoplasmatron

Overall dimensions

diameter.....3 m

height.....11.5 m

Insulating gas – 20 % SF_6, 12 % CO_2, 68 % N_2

Accelerator LIU-R-T

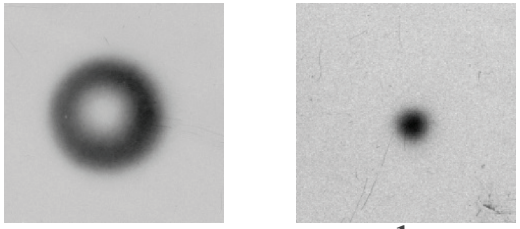
РФЯЦ ВНИИЭФ

Accelerating system

Control desk

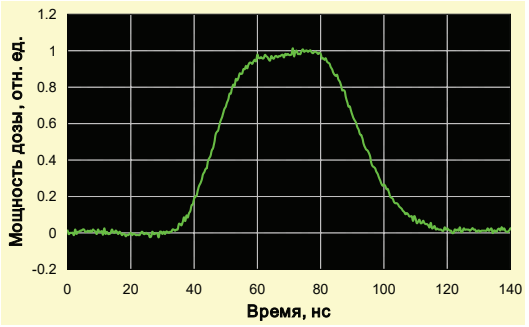
Electron energy.....12 MeV
Regulated beam current.....5 ÷ 20 kA
Pulse length.....60 ns
Radiation pulse length..... ≤ 50 ns
Radiation dose at a distance 1 m
from the target.....up to 300 R
Focus spot diameter.....5 mm
Overall dimensions.....24×2.5×2.5 m^3

X-ray patterns of the beam at the input (a) and output (b) of the accelerator



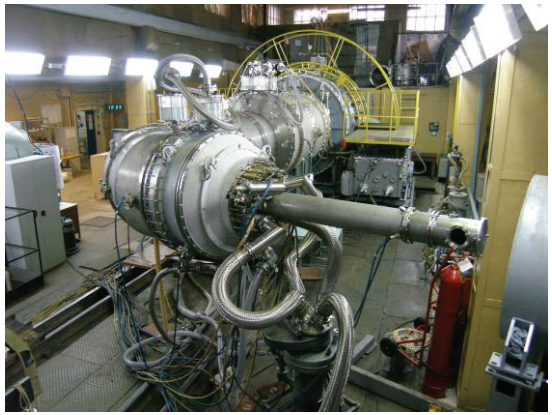
a b

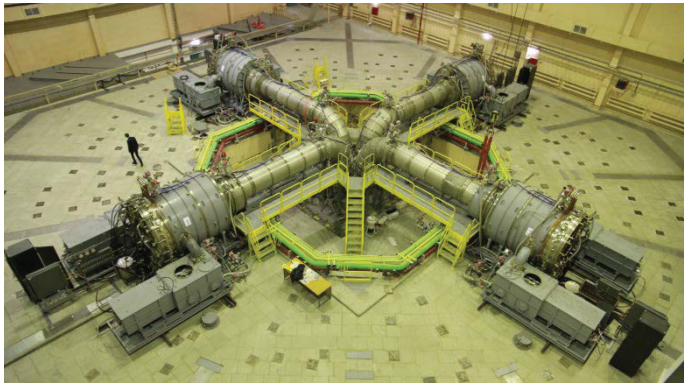
Radiation pulse

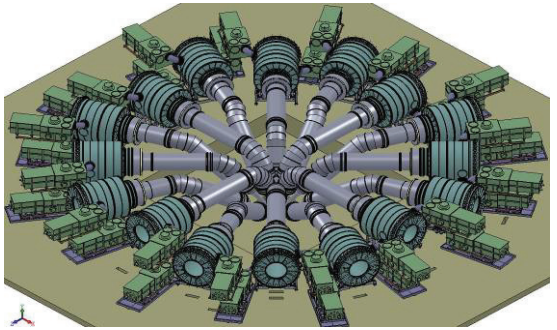


Development of a multi-terawatt multi-module electrophysical facility

Typical module (2011) | Four-module installation (2016) | Sixteen-module facility







The time spread of bremsstrahlung pulse with respect to dischargeres launch pulse of the module is equal to ± 3 ns. It is possible to produce multi-module facilities based on such modules

Electron beam characteristics	1-module	4-module	16-module
Maximal electric power, TW	1.5	6.0	24
Electron beam energy, kJ	80	320	1300
Diode voltage, MV	2.0	2.0	2.0
Diode current, MA	0.75	3.0	12
Pulse length, ns	65	65	65

Perspective electrophysical facility operating modes

- **Bremsstrahlung generation mode**

  - each module operates to an independent high-current diode forming irradiator in the form of a matrix of independent diodes to irradiate “large” areas (7.5 kR on the area of 2300 cm^2)

  - all modules carry the common diode load to achieve maximal bremsstrahlung fluency energy on a small area (40 kR on the area of 180 cm^2).

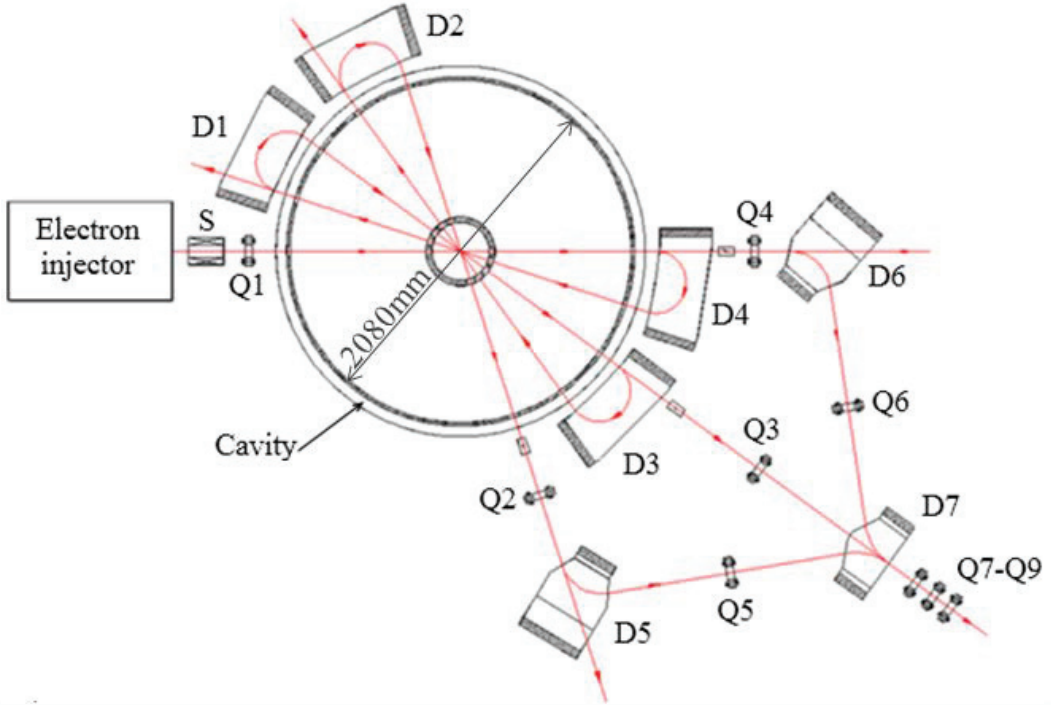
- **Soft X-ray generation mode (75 kJ, 5 ns)**

- **Shock-wave and quasi-isentropic compression of structural and fissile materials by pressure up to 50 GPa**

Development of CW resonance accelerator with high average power electron beam

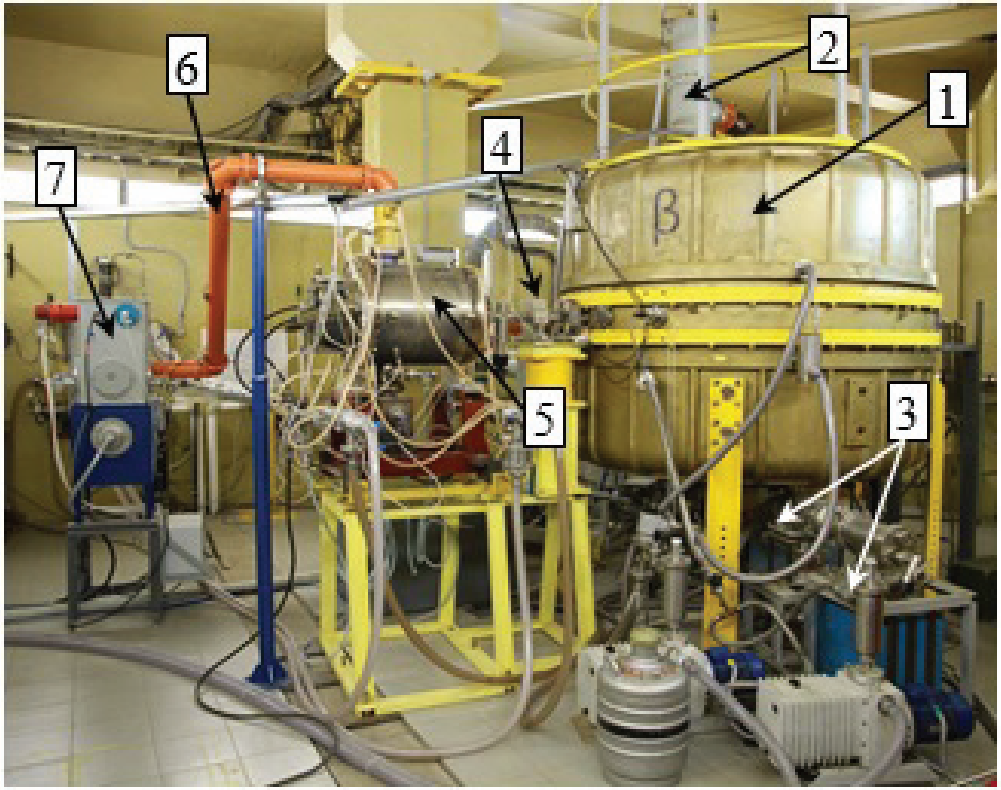
As of today a resonance electron accelerator with a high average beam power is being developed in RFNC-VNIIEF. The accelerator has been designed for technological process testing required high values of beam power and absorbed dose of electron radiation and bremsstrahlung.

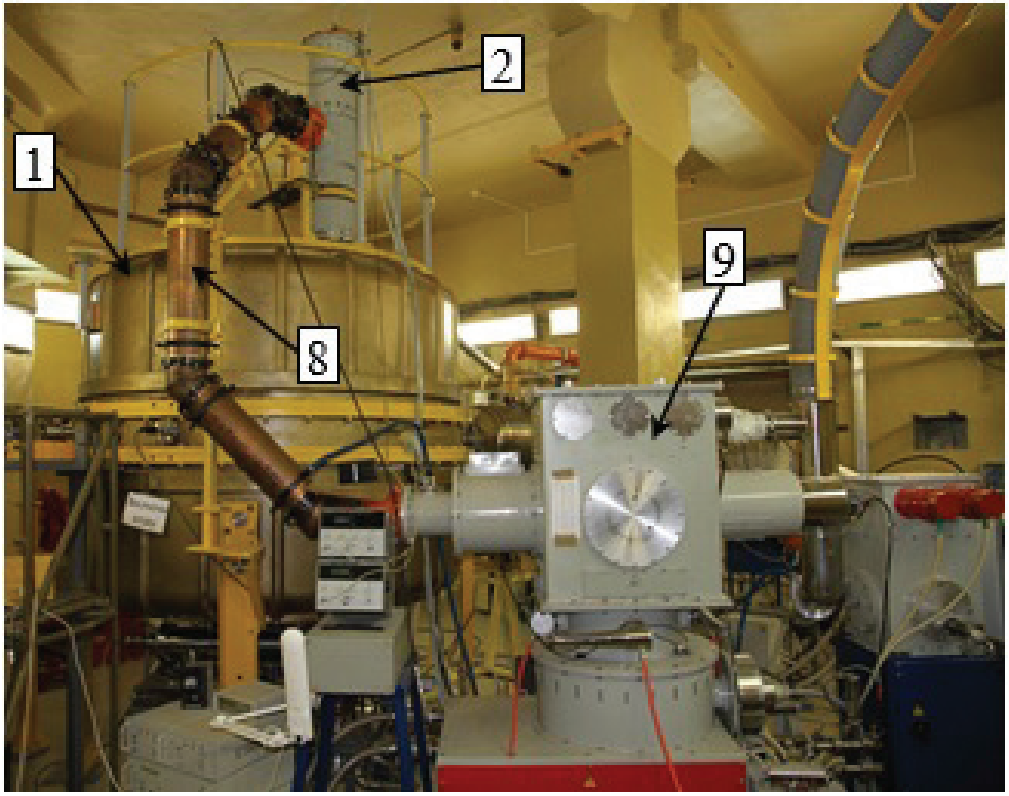
- Output energy of electrons……..…1.5, 4.5, 7.5 MeV
- Maximal average power of electron beam……...300 kW
- Operating resonance frequency ……100 MHz
- Operating modes…..….....continuous and pulse-periodic



D1 – D7 – bending dipole magnets;
S – focusing solenoid;
Q1 – Q9 – quadrupole magnet lenses

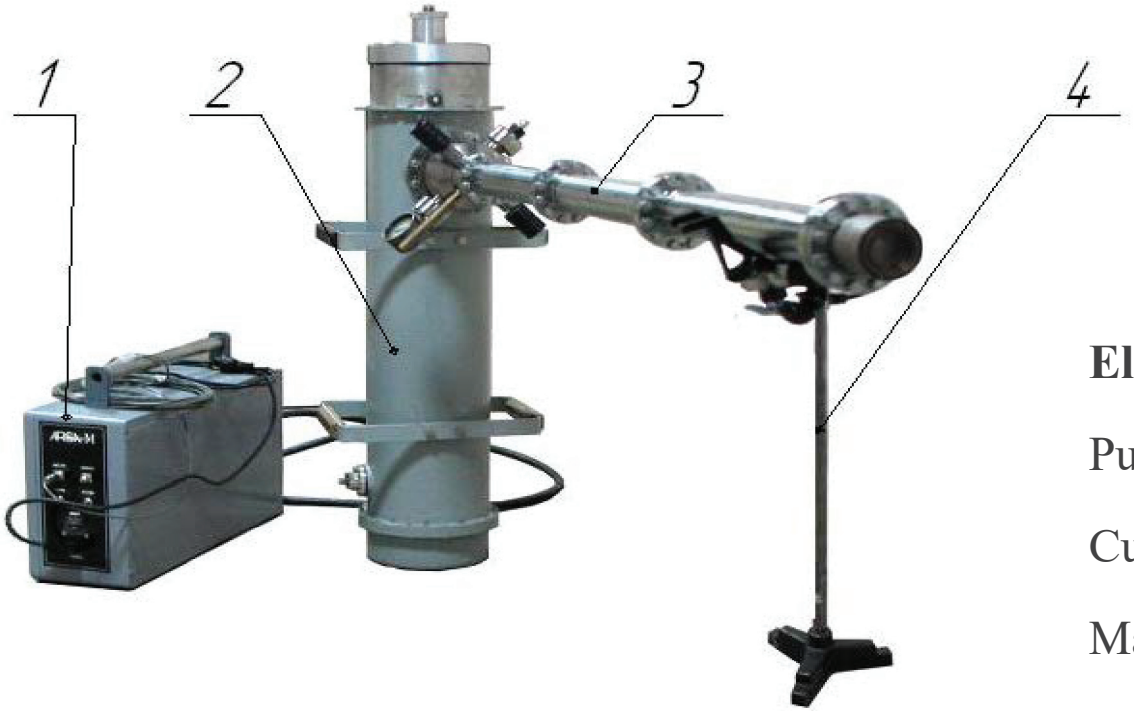
Current status of resonance accelerator with high average power electron beam





1 – accelerating coaxial cavity; 2 – RF power input unit;
3 – vacuum system ; 4 – electron beam injection channel;
5 – RF electron injector of; 6 – RF injector feeder; 7 – generator of RF injector (14 kW);
8 – accelerating cavity feeder; 9 – RF power generator (180 kW)

Subnanosecond electron accelerator with a gas-filled shaper



1 – charging unit
2 – high-voltage block of accelerator
3 – subnanosecond pulse shaper
4 - rack

Electron beam characteristics:

Pulse length…....0.23 ÷ 0.27 ns

Current pulse amplitude.....~ 1.5 kA

Maximum electron energy..... ~ 850 keV

Thank you for your attention!