

IAEA-CN301-139

ILU RF ELECTRON ACCELERATORS FOR E-BEAM AND X-RAY APPLICATIONS.

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INTERNATIONAL CONFERENCE ON

ACCELERATORS FOR RESEARCH AND SUSTAINABLE DEVELOPMENT

From good practices towards socioeconomic impact



23–27 May 2022

IAEA Headquarters, Vienna, Austria



Budker Institute of Nuclear Physics - leading Russian institute in accelerator development

Total employees: ~2900
440 scientists
60 PhD students
760 engineers,
350 technicians
1300 workers in workshop
5 academicians and 7 correspondent members of Russian Academy of Science
Main fields of research: Particle physics, Fusion



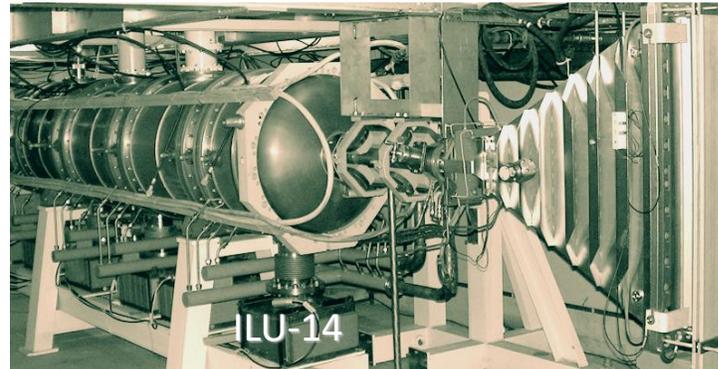
ИЯФ им. Г.И.Будкера разрабатывает и производит промышленные ускорители двух типов:
Budker INP is producing 2 types of industrial electron accelerators:



Electrostatic rectifier **ELV**

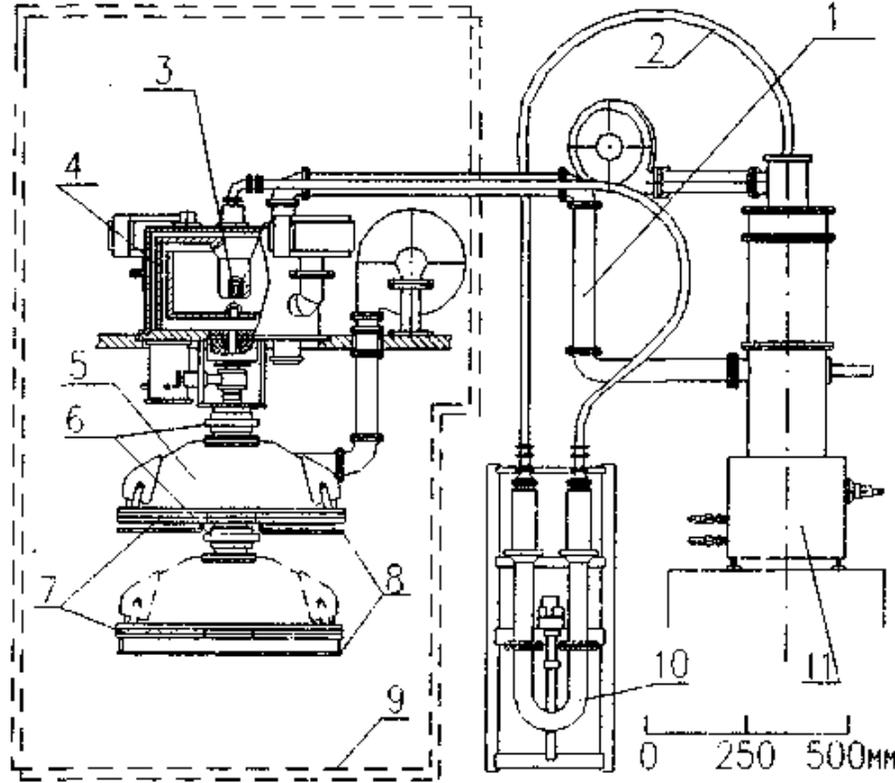
(energy 0,2 – 2,5 MeV, power up to 500 kW, efficiency about 80%)

Pulse RF **ILU** (energy 0,7 – 10 MeV, power up to 100 kW, efficiency ~ 30 %)



BINP produced more 250 accelerators in 1975 – 2021 (China, Russia, Korea, Japan, USA Poland, Philippines, India, Indonesia and others)

ILU-8 in Local Shield



Main features of
ILU accelerators

- Compact
- Self-excitation
- No insulation and gas systems
- Pulse
- GI-50

- Energy 0.8-1 MeV
- Av. Current 0-20 mA
- Pulse current 0-500 mA

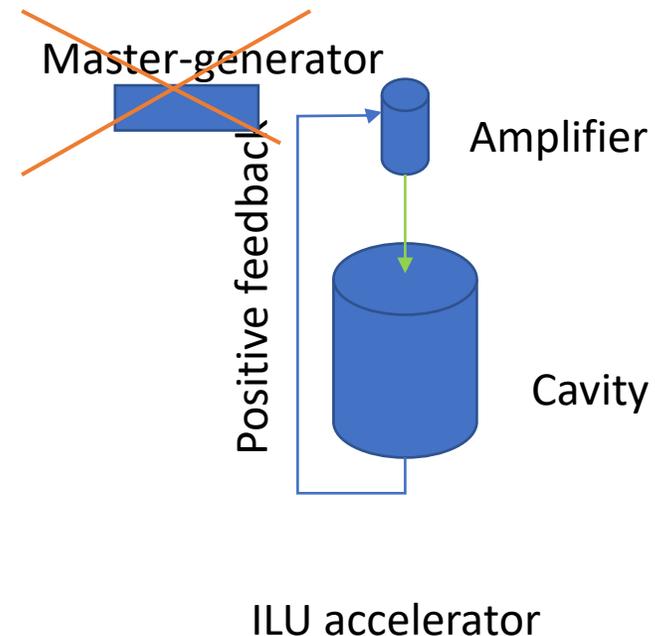
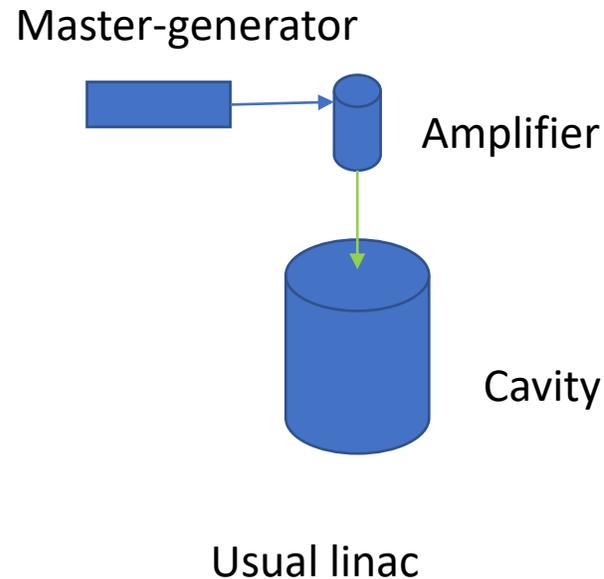
- Pulse duration 800 mks
- Pulse repetition 1-50 Hz
- RF frequency 175 MHz
- Dim D800x800 mm

Features of ILU accelerators

- Not expensive RF tube GI-50 with lifetime > 7000 hour (~10000 USD) and pulse power 2 MW.
- Soft requirements for temperature stabilization cooling water ~5-10 degrees of Celsius.
- Fast start: not necessary warming of cavity, just fast warming of filaments.

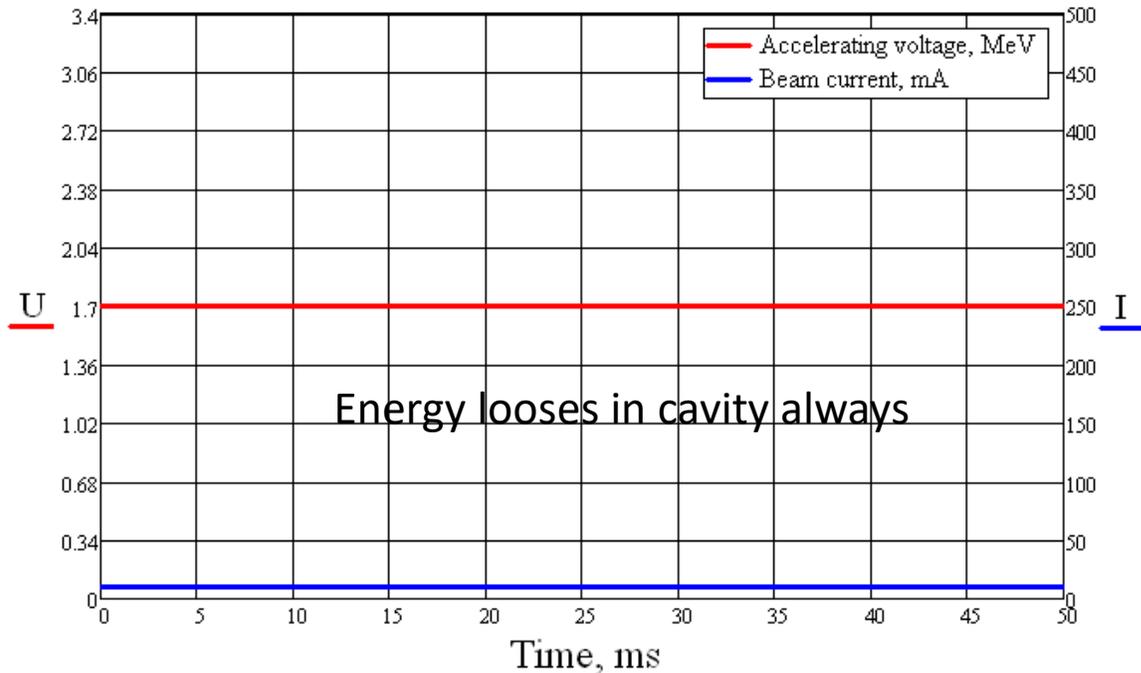


Tube GI-50A



Cavity voltage and beam current for one cavity.

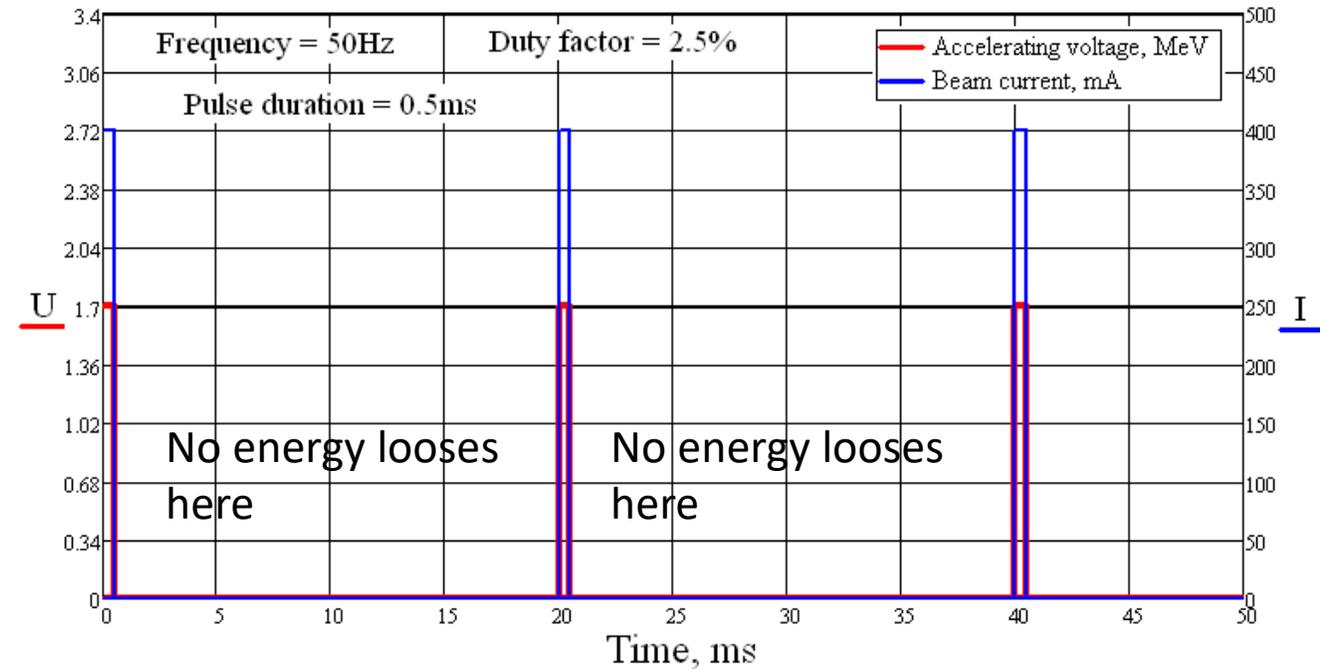
CW



$I_{\text{beam}} = 10 \text{ mA}$

Efficiency lower

Pulse



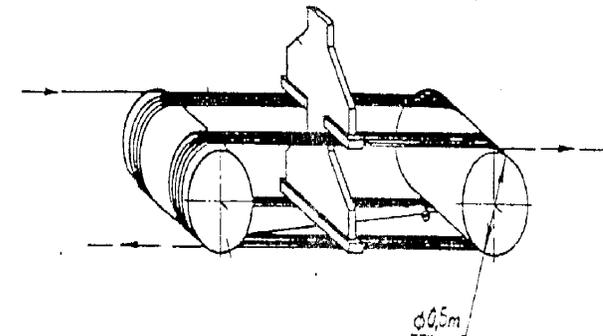
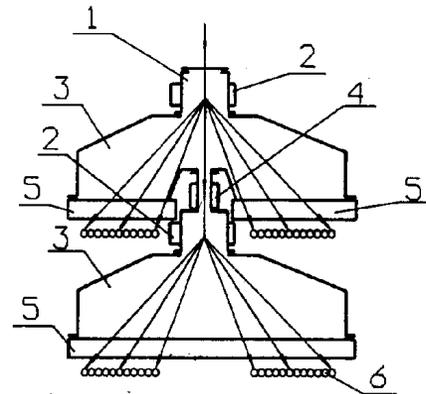
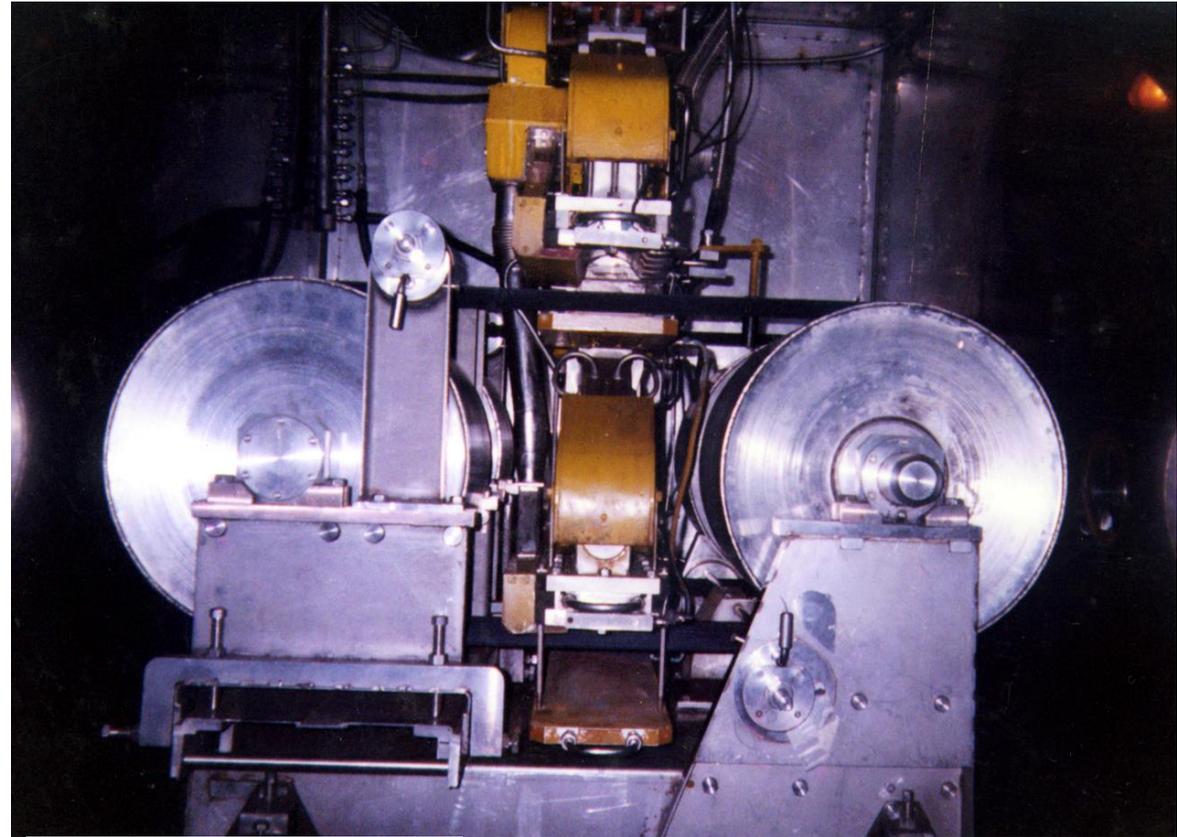
$I_{\text{beam (average)}} = 10 \text{ mA}$

Efficiency higher

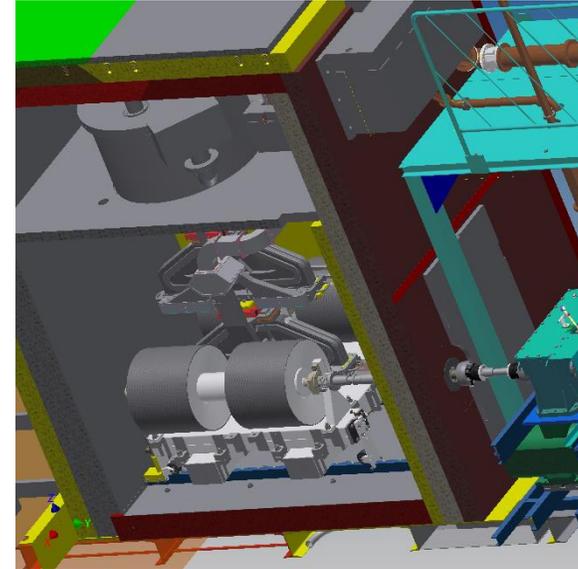
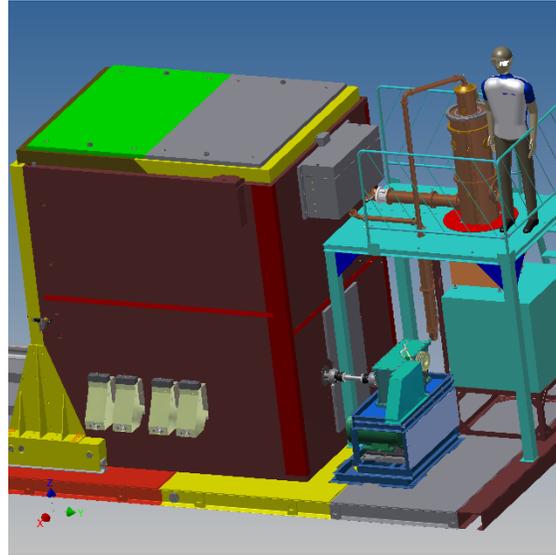
Pulse Linear Accelerator PLA=ИЛУ (ILU) in Russian

4-sided cable irradiation

- Beam extraction device for 4-sided irradiation allows to increase beam usage efficiency comparing with 2 sided irradiation
- No cable twist

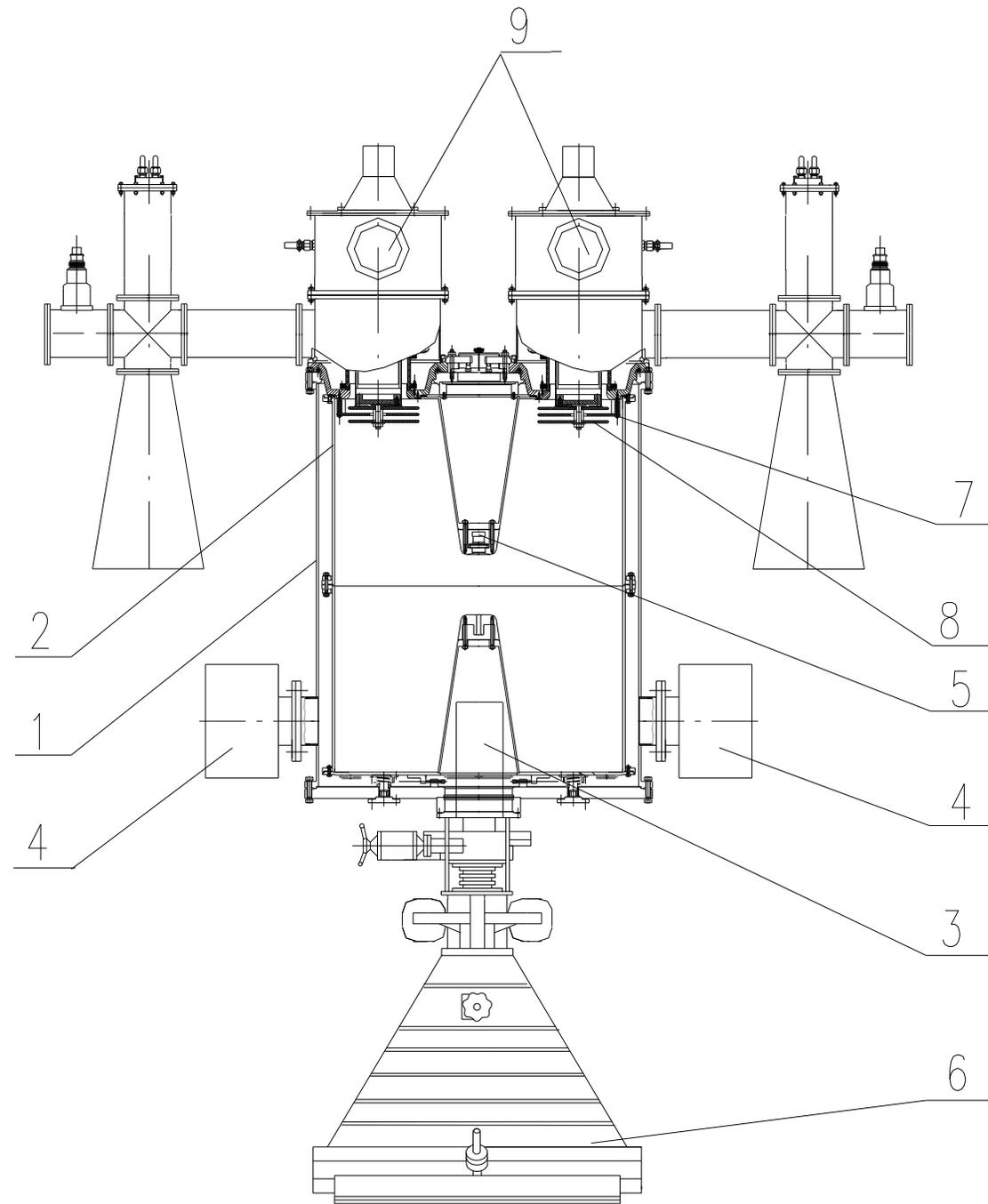


Accelerator ILU-8 in local shielding

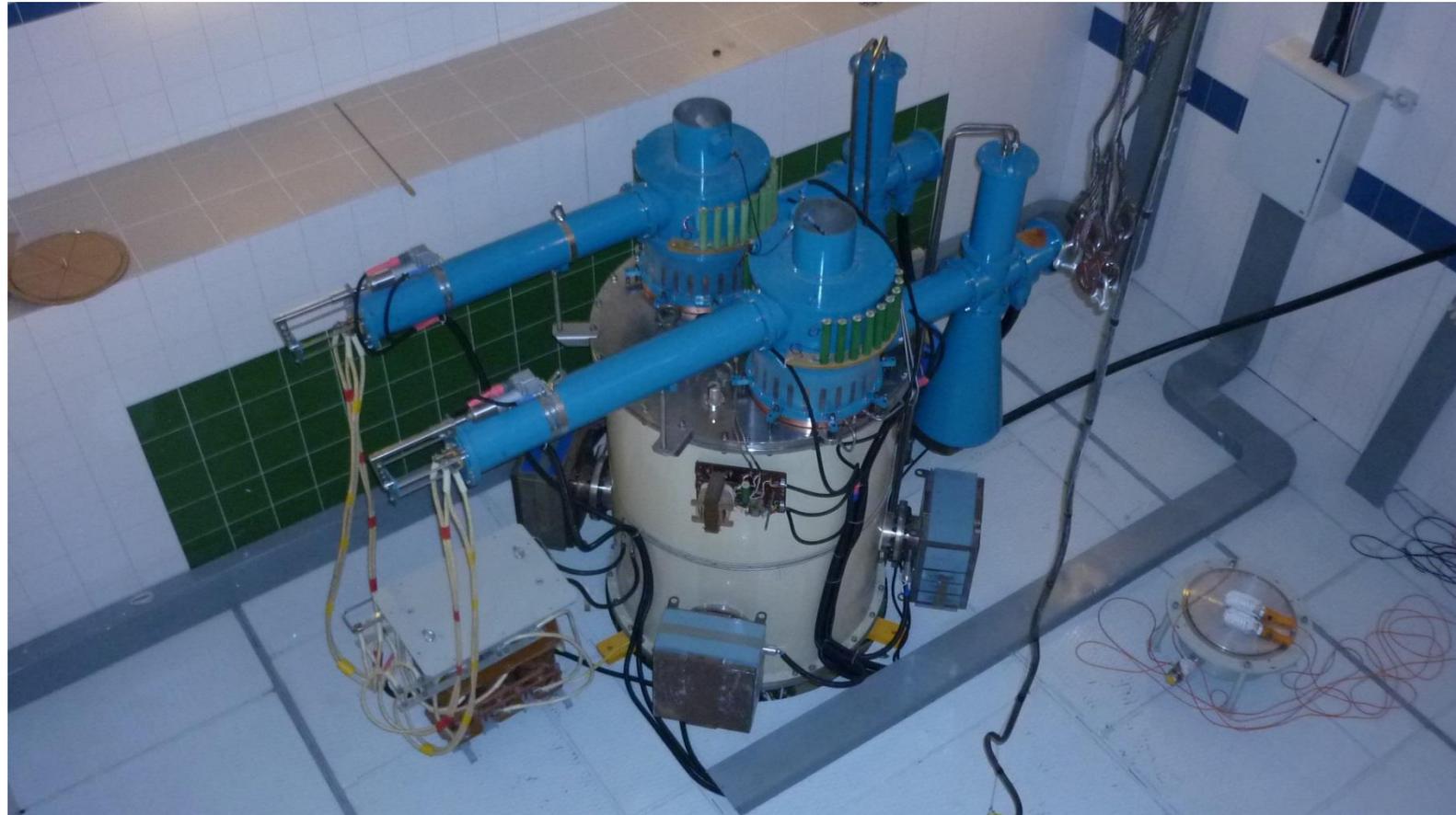


ILU-10

- Energy 4-5 MeV
- Av. Current 0-10 mA
- Pulse current 0-400 mA
- Pulse duration 500 mks
- Pulse repetition 1-50 Hz
- RF frequency 115 MHz
- Dim. D1280x1480 mm



ILU-10 in Novosibirsk pharmaceutical plant 2013



ILU-10 in Novosibirsk pharmaceutical plant 2013



ILU-10 in Novosibirsk pharmaceutical plant 2013



Centre of radiation technologies in Budker Institute (started 2014)



Centre of radiation technologies in Budker Institute (started 2014)



Centre of radiation technologies. Conveyor load zone.



Centre of radiation technologies. Control cabinet.



Sterilization center based on ILU-10 in Semipalatinsk nuclear test site (STS) in Kazakhstan.



ILU-10 in Kaitech university, Korea



ILU-10 in Poland, RadPol SA.



- Treatment of polymer pipes
- Treatment of cables
- Movable accelerator between two conveyors.

Increasing power of ILU-10

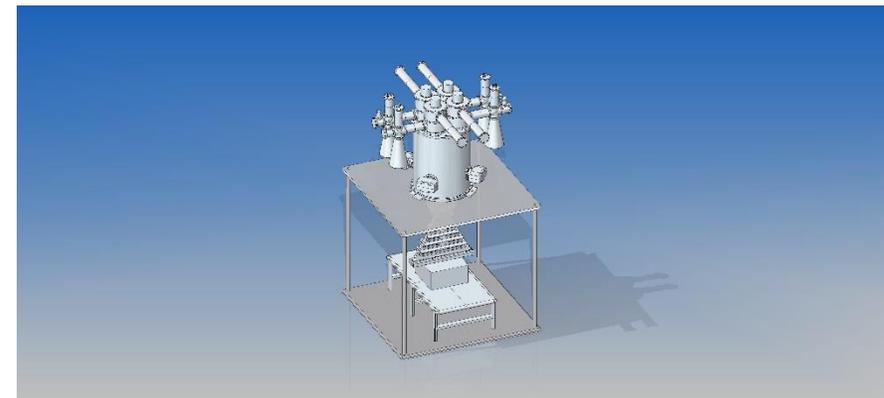
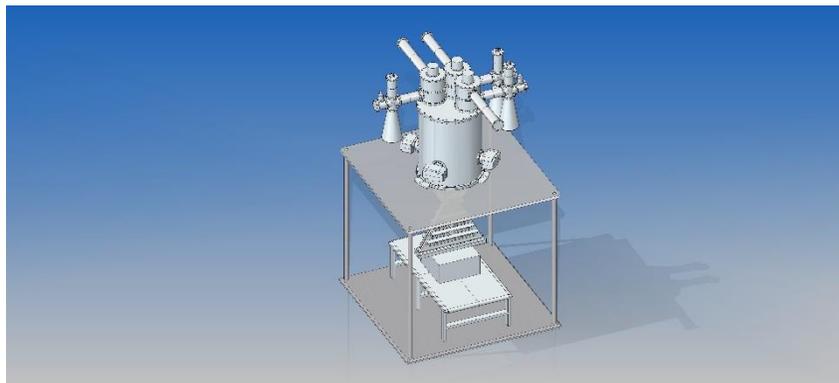
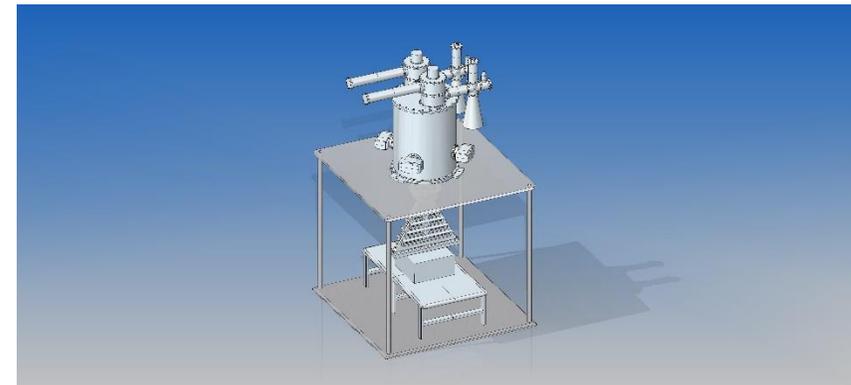
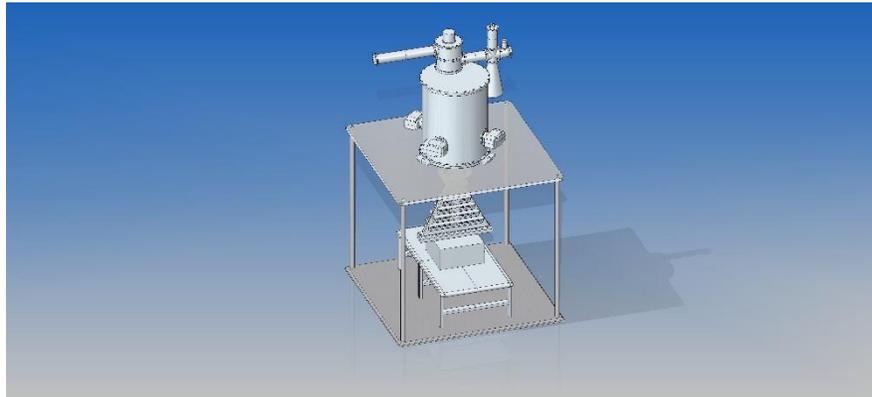
$$P_{loss} = \frac{U^2}{2R_{shunt}} = 1.77 \text{ MW}$$

Rshunt=7 Mohm, U=5 MV

Ploss_av=1770*0.025=44.25 kW

RF power of 1 generator – 2 MW of pulse power or 50 kW of average power for duty cycle 0.025 (F=50 Hz, Tpulse= 500 mks)

Number generators	Average beam power for 5 MeV (kW)
1	0
2	50
3	100
4	150



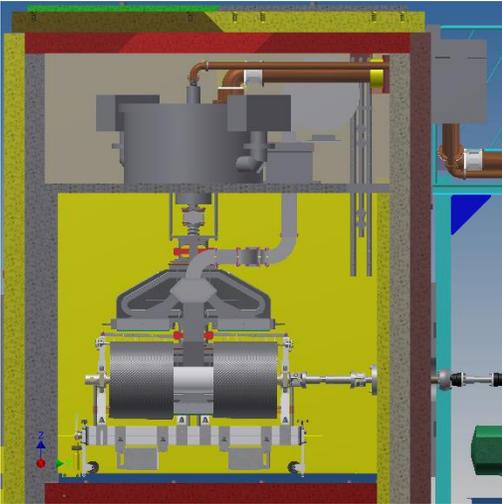
Medical sterilization and food irradiation markets required more energy and power.

Food irradiation requirements

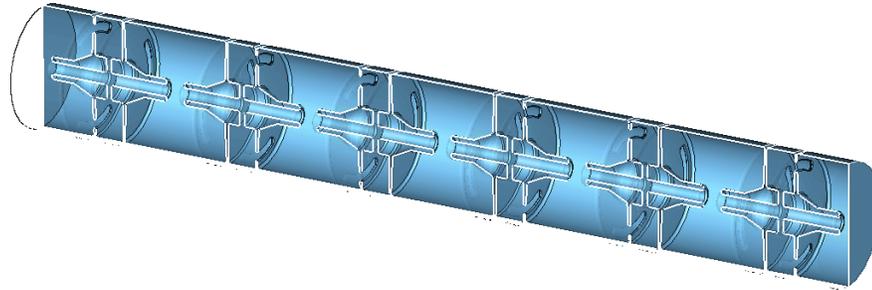
- 10 MeV E-beam → small power
- X-ray 5 MeV → huge power (conversion rate ~8%)
- X-ray 7.5 MeV (USA, Indonesia, Canada, India, Korea) → high power (conversion rate ~13%)

New multi-cavity ILU accelerator

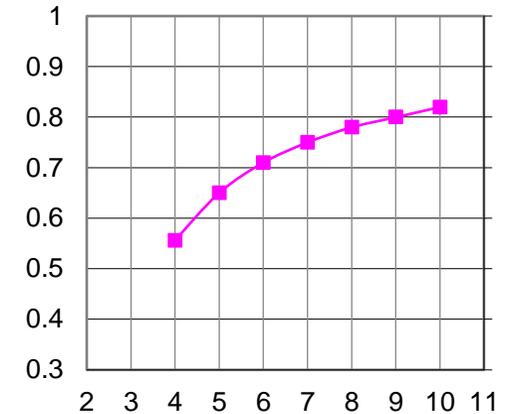
One cavity



Multi-cavity

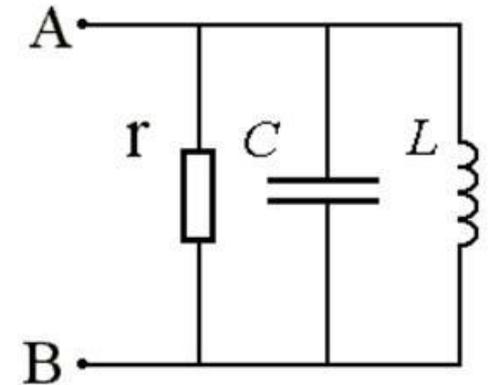


Efficiency on Number of cells

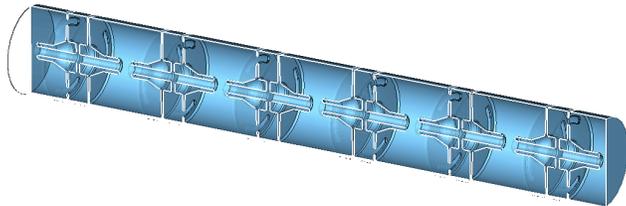
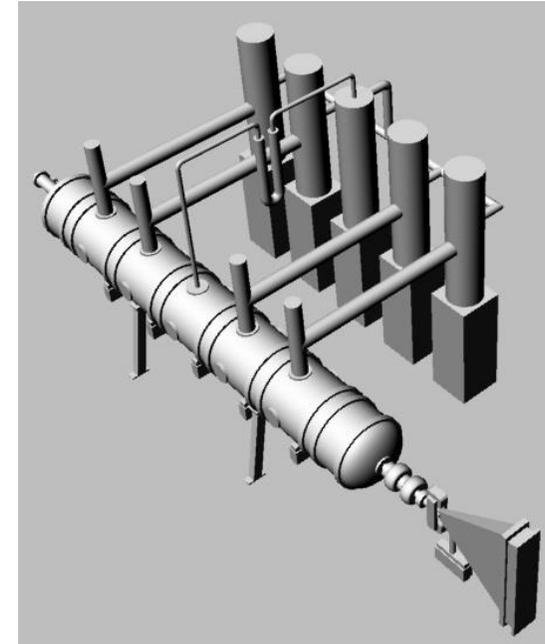
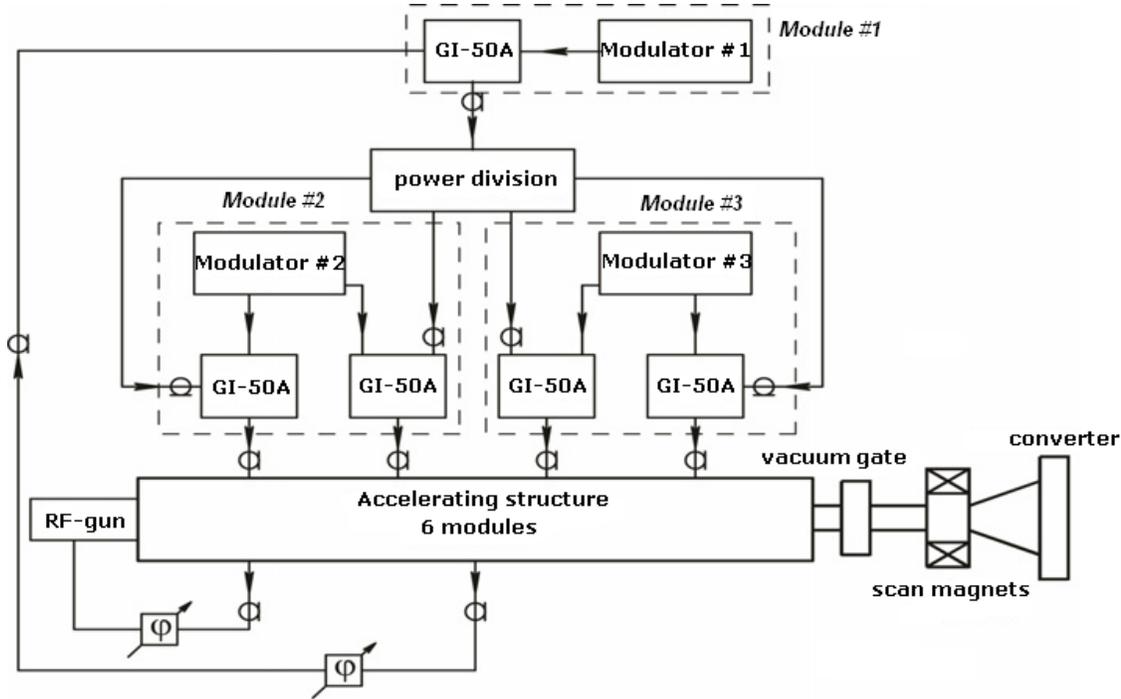


$$P_{loss} = U^2 / 2R_{shunt}$$

$$P_{loss} = \sum_n U^2 / 2R_{shunt}$$



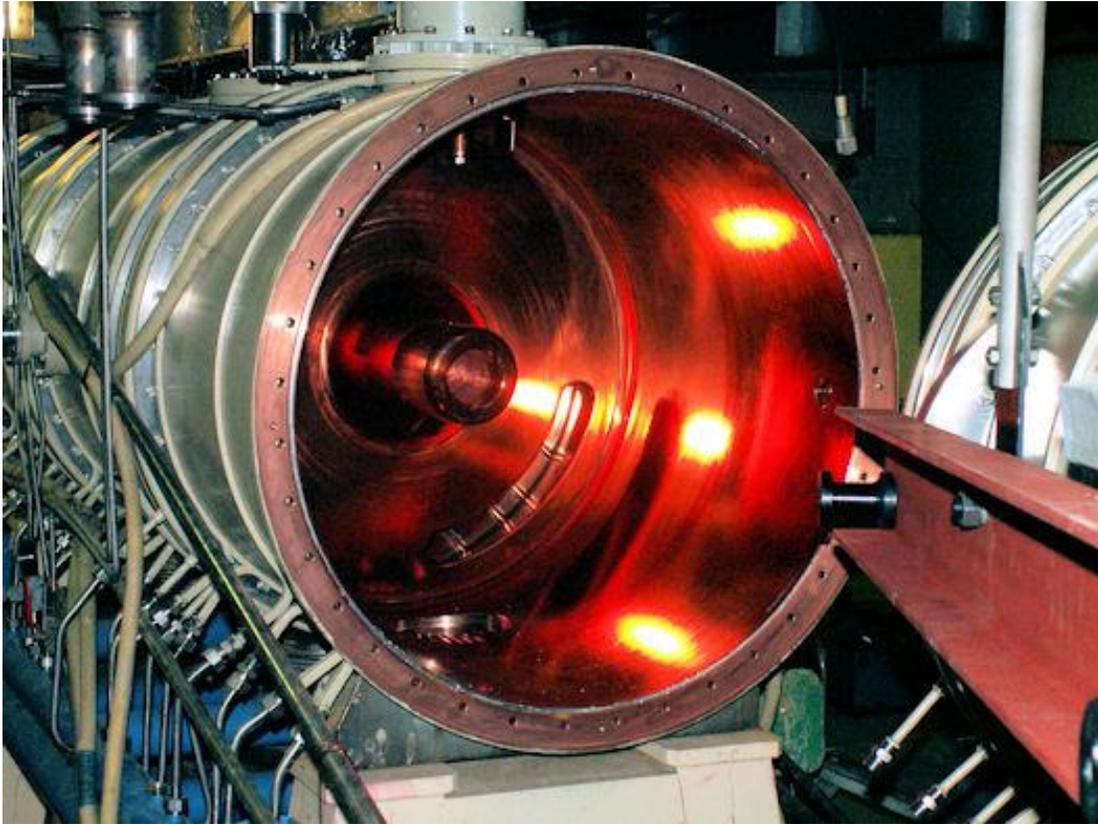
ILU-14 10 MeV 100 kW



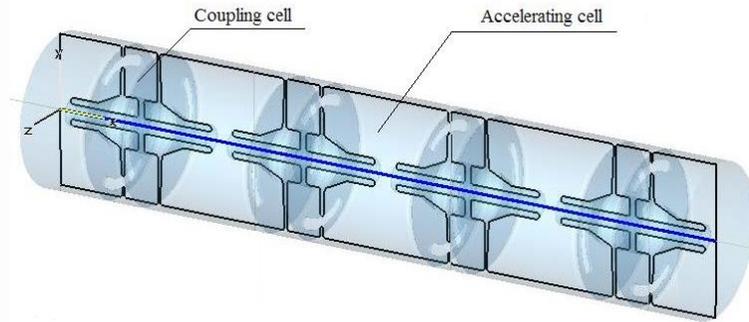
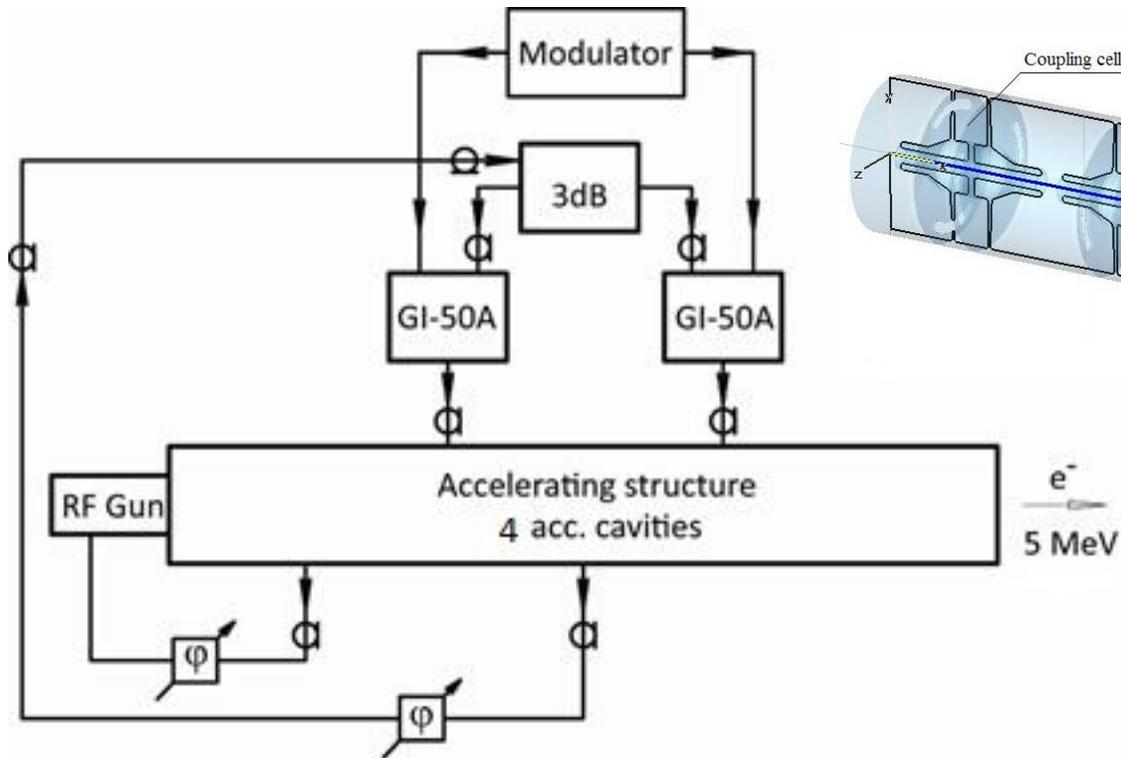
<i>Operating frequency, MHz</i>	<i>176</i>	<i>Full efficiency, %</i>	<i>26</i>
<i>Electron energy, MeV</i>	<i>7,5-10</i>	<i>Modulator pulse duration, μs</i>	<i>500</i>
<i>Average beam power, kW</i>	<i>100</i>	<i>Repetition rate, Hz</i>	<i>Up to 50</i>

New multi-cavity ILU accelerator.

In operation from 2014 in Moscow

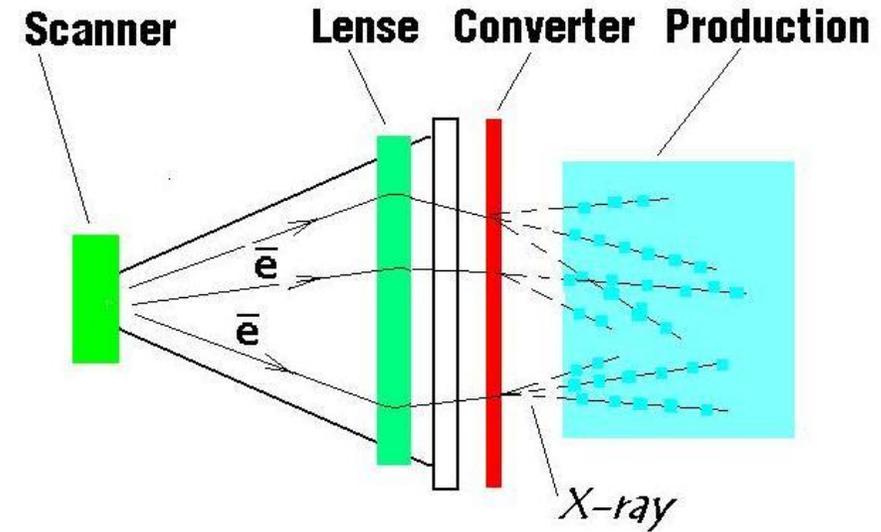
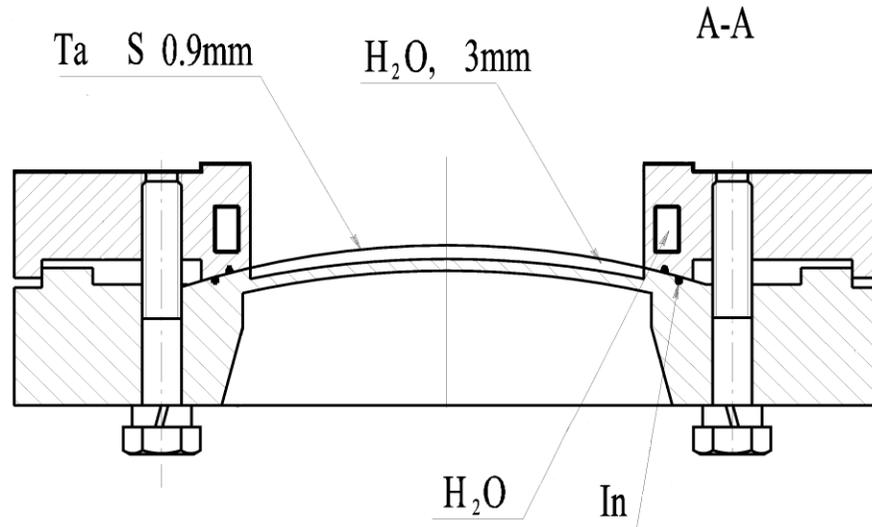


Shorter version – ILU-12



- 5 MeV 60 kW
- 7.5 MeV 40 kW
- 4 cavities
- Possible upgrade to ILU-14

X-ray converter



Conversion rate X-ray/Ebeam power

E(MeV)	Ta thickness	60 deg	360 deg
7.5	0.9	13,2%	16,9 %
5	0,7	8,3%	12%

Thank you

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