Positron sources and liquid target R&D at BINP

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Nanobeam 2008,

BINP, Novosibirsk.

Development of positron production system.

- High power positron production target
- Effective matching device
- Effective accelerating and focusing system for positron beam
- Joint optimization of all these three items.

Basic problems

- A huge increase of the target temperature during powerful pulse.
- Long macro pulse leads to stronger kick-effect and decreasing of useful magnetic field maximum in FC magnet.
- Longer pulse also means lower accelerating gradient in the first structure for positrons.
- High positron production rate leads to high activation level and radiation damages of positron production system elements.

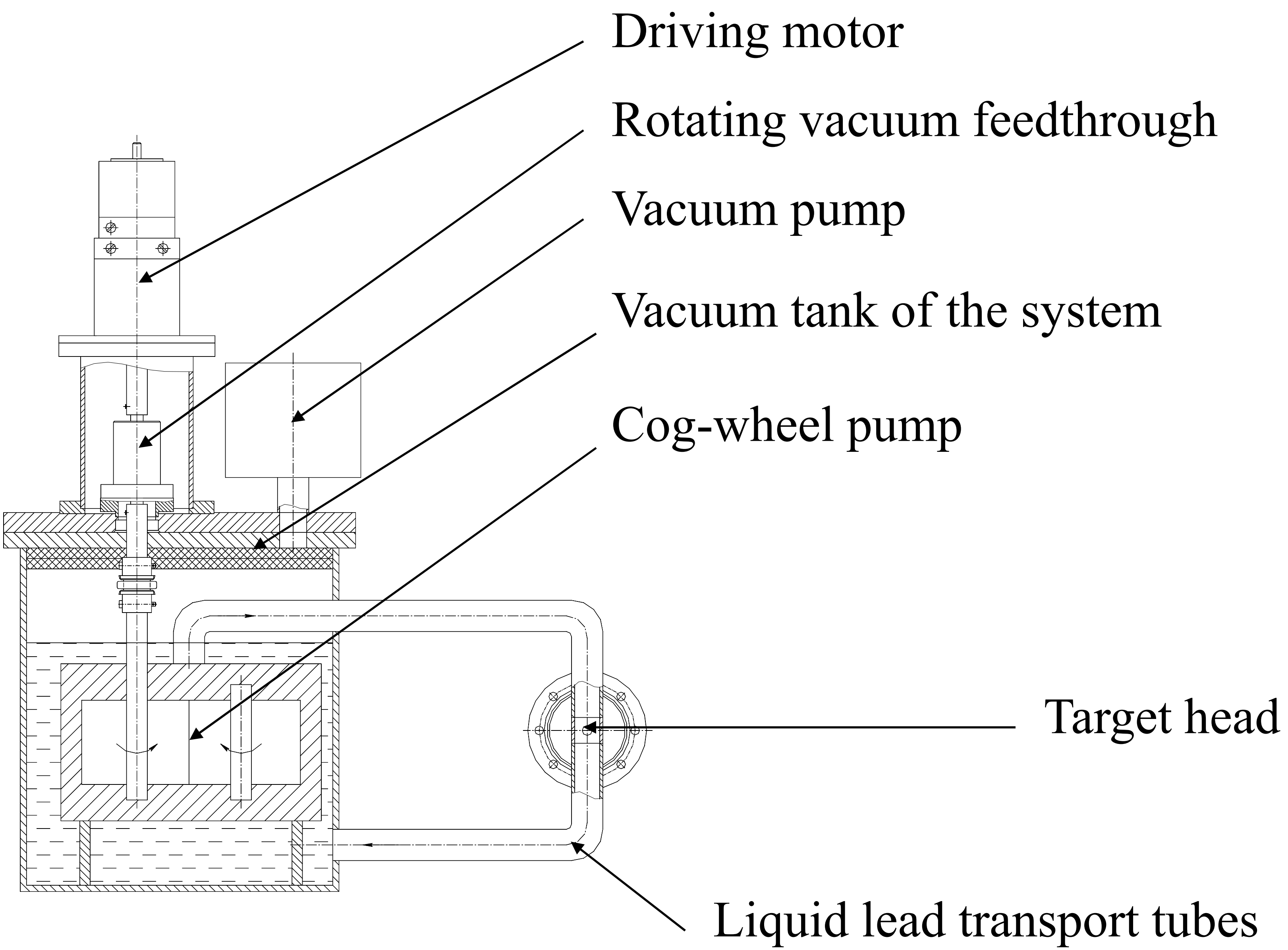
The basic directions of R&D

- High power liquid lead target in comparison with rotating solid-state WRe target.
- Effective matching device (Flux Concentrator, Lithium Lens).
- High gradient accelerating structure immersed in the max. possible DC magnetic field
- High radiation resistance of all elements.

The main aims of this R&D.

- To determine the technical limit of driving beam intensity and duration for each component of positron production system.
- To optimize each component for the best integrated system performance.

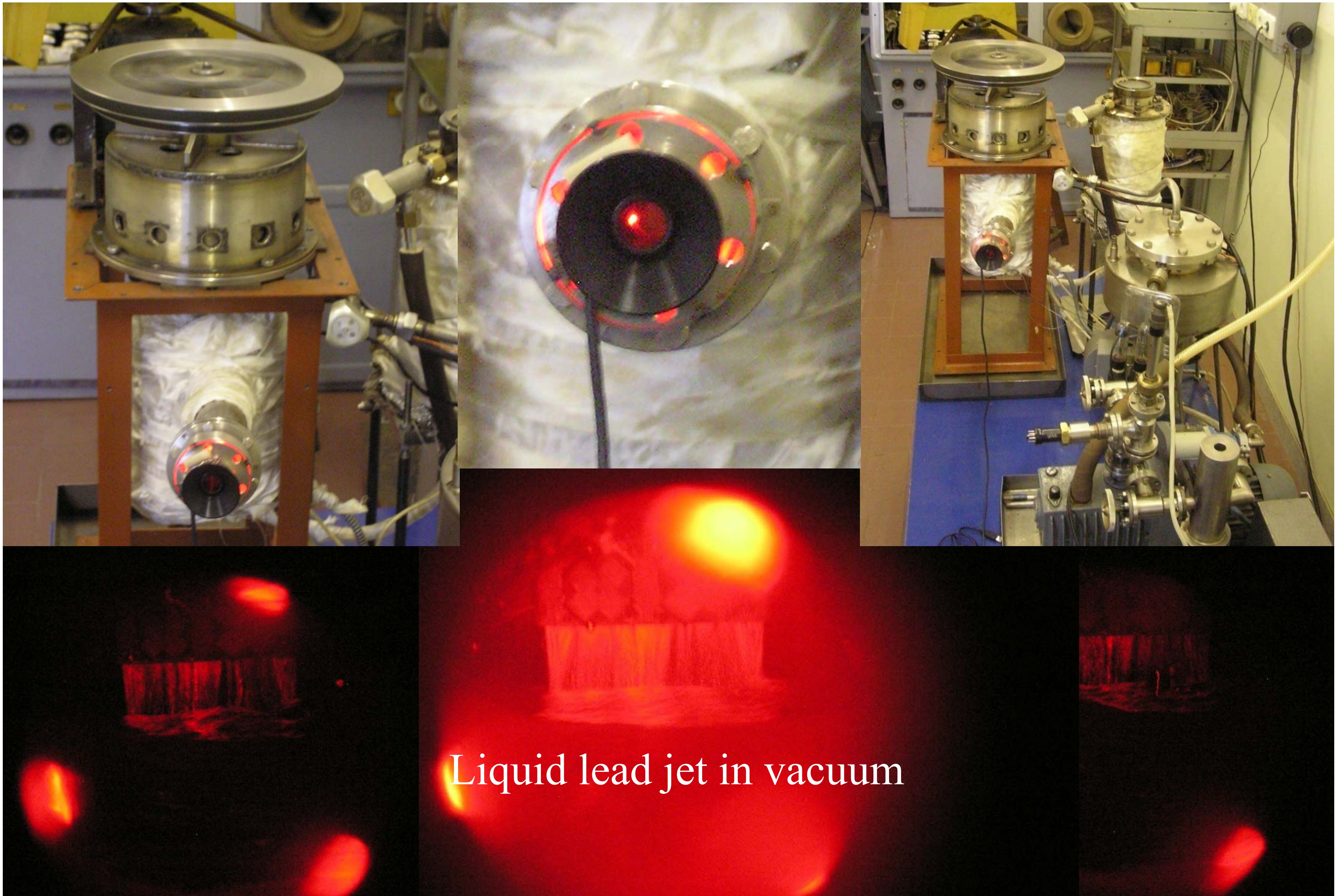
Scheme of the prototype of liquid lead positron production target.



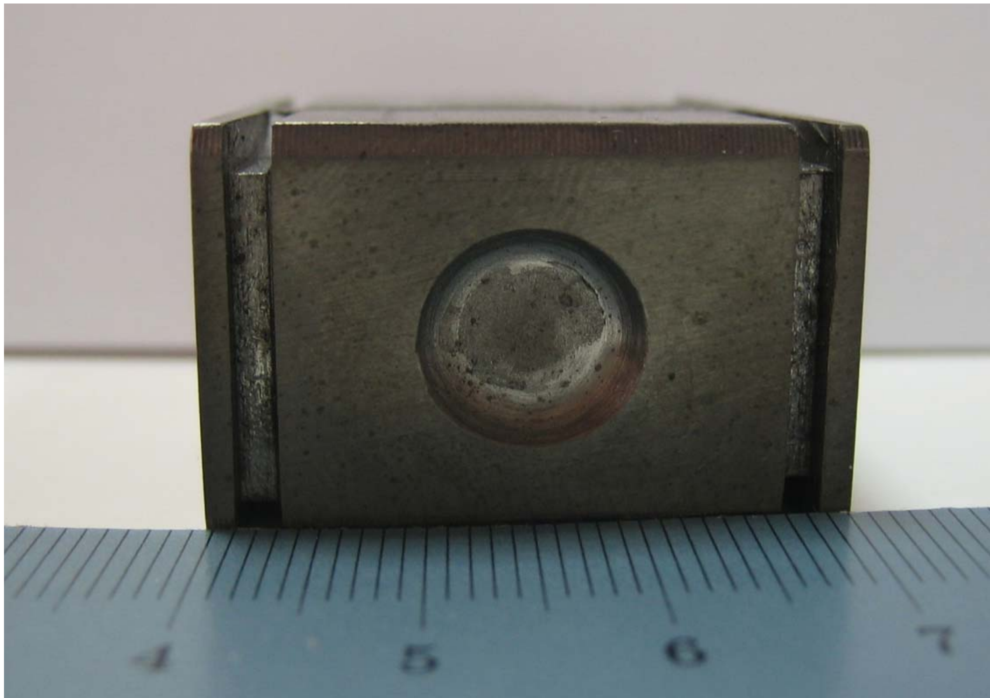
The present stage of BINP activity in liquid lead target development.

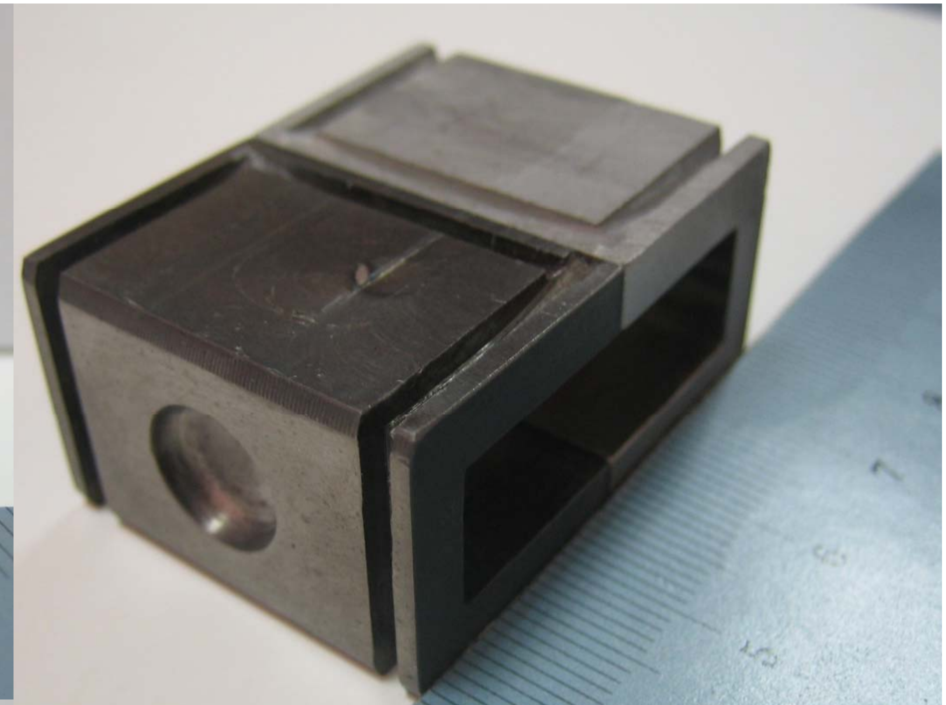
- 20000 h of liquid lead contour successful run with cog-wheel pump has been reached (90% Pb, 10% (mass)Sn alloy, 300ºC).
- The shock-wave test of BN windows showed the dynamical stretch limit at the level of 39 GPa. For previous NLC design the value of 3-4 GPa was estimated. For present ILC variant this value will be even less (about 0.01 GPa) due to longer macro pulse.
- The test of window braising technology successfully finished.
- The prototype of liquid lead positron production target is under commissioning now. This prototype is specially designed for output window destruction test on KEKB.

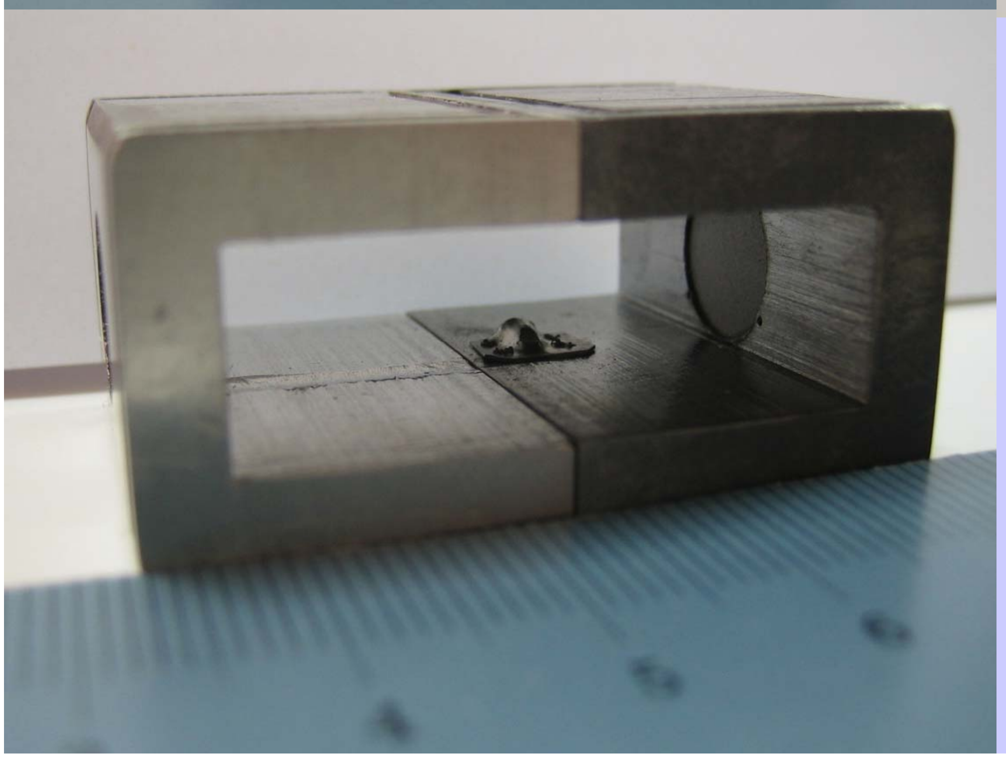
The parts of liquid lead cog-wheel pump



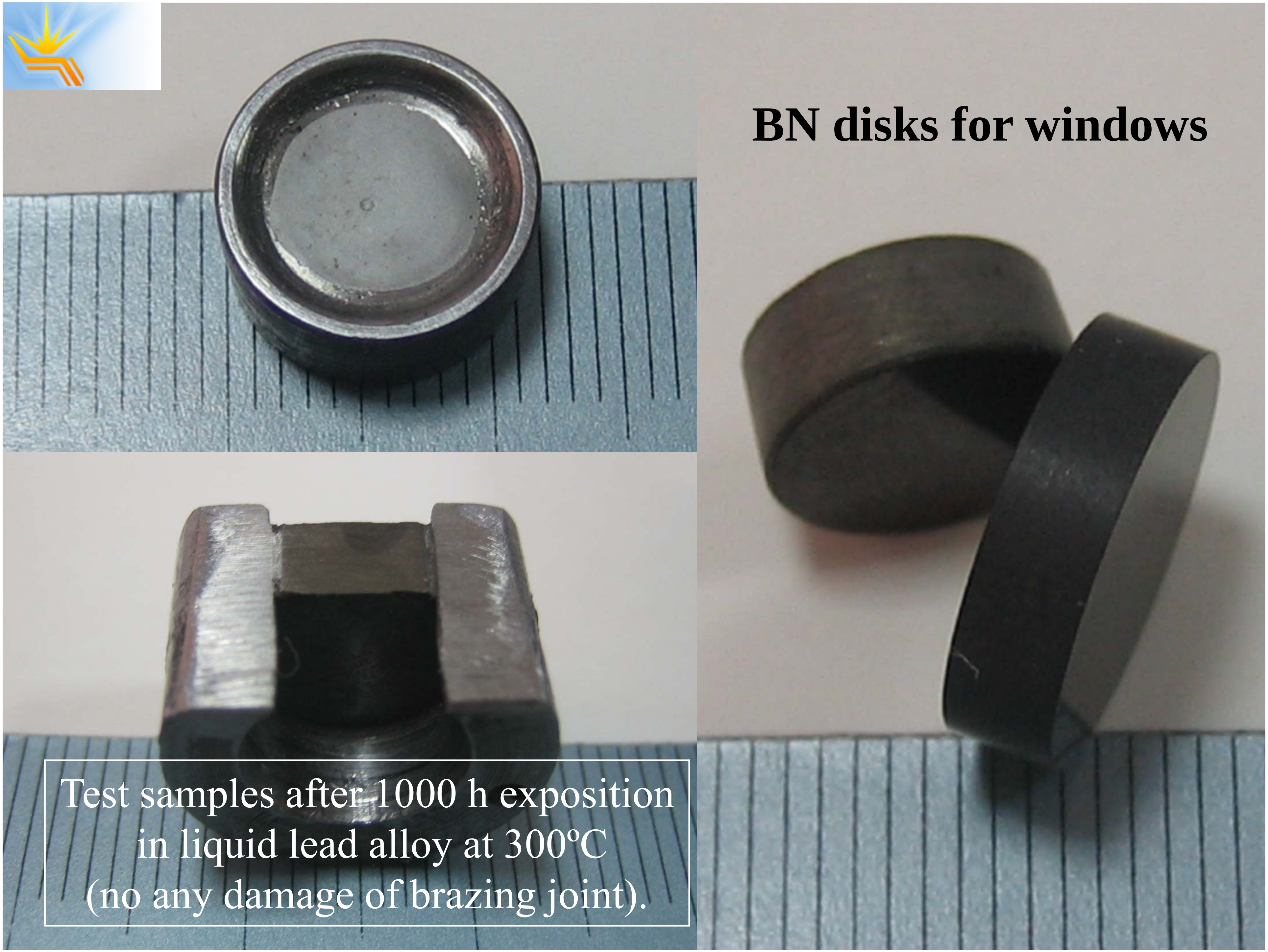
Cog-wheel pump test bench is in continues run
(20000 h) with liquid lead jet. 90% Pb, 10% Sn alloy at 300ºC.

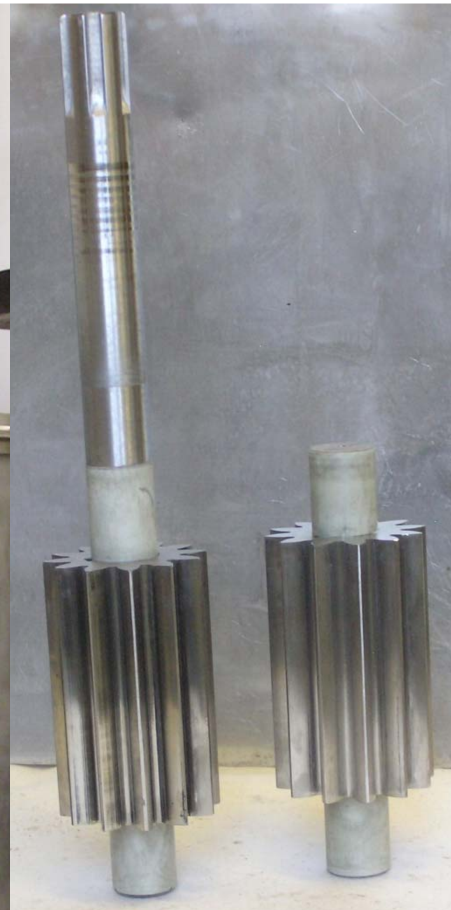
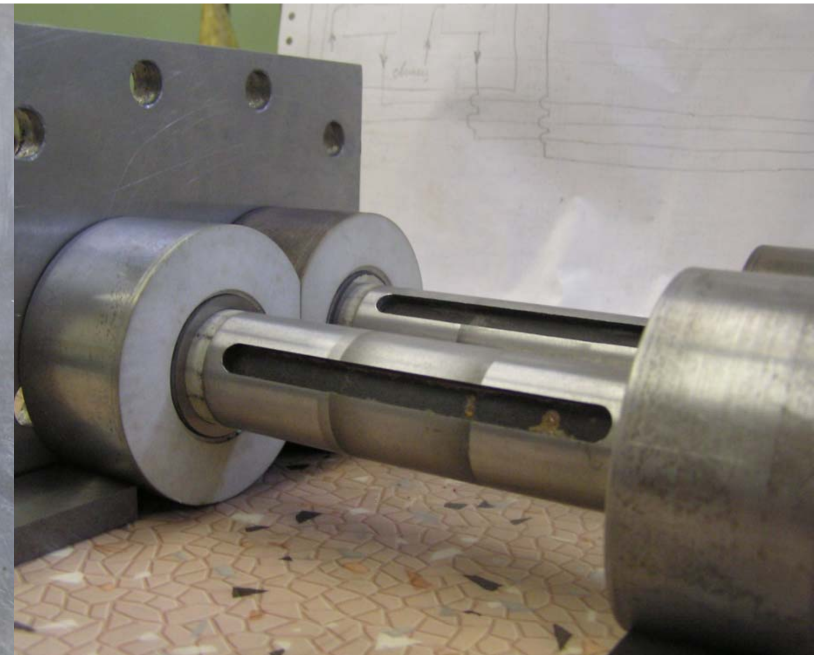
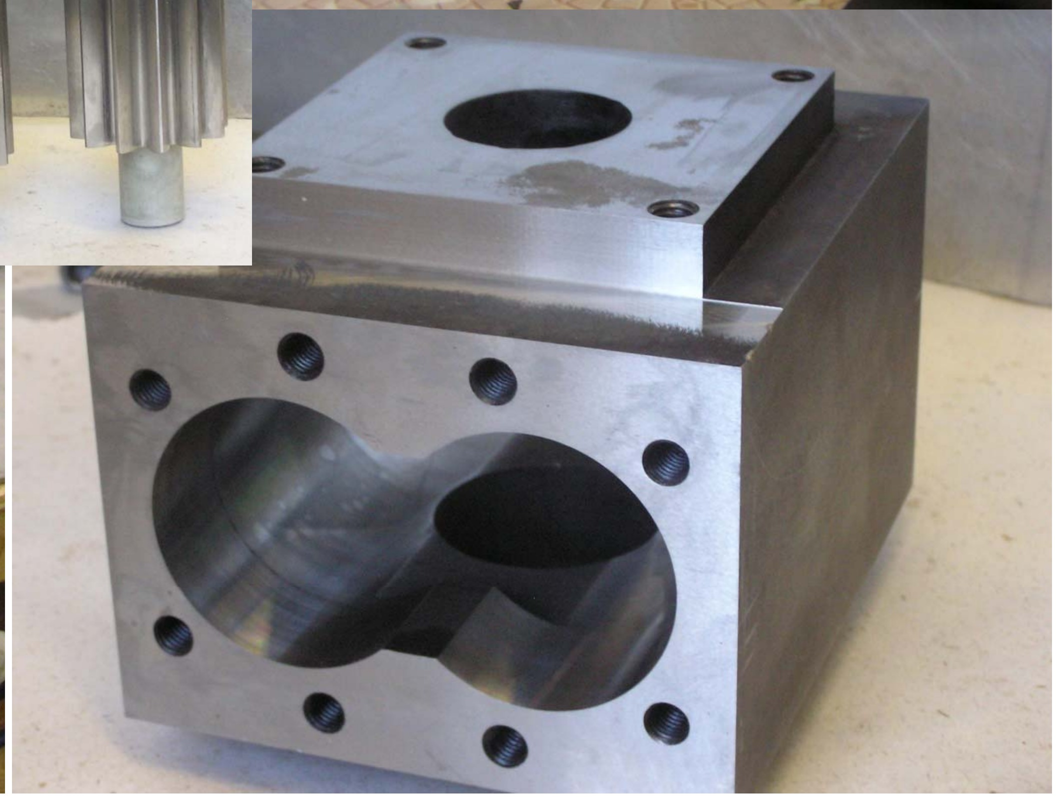


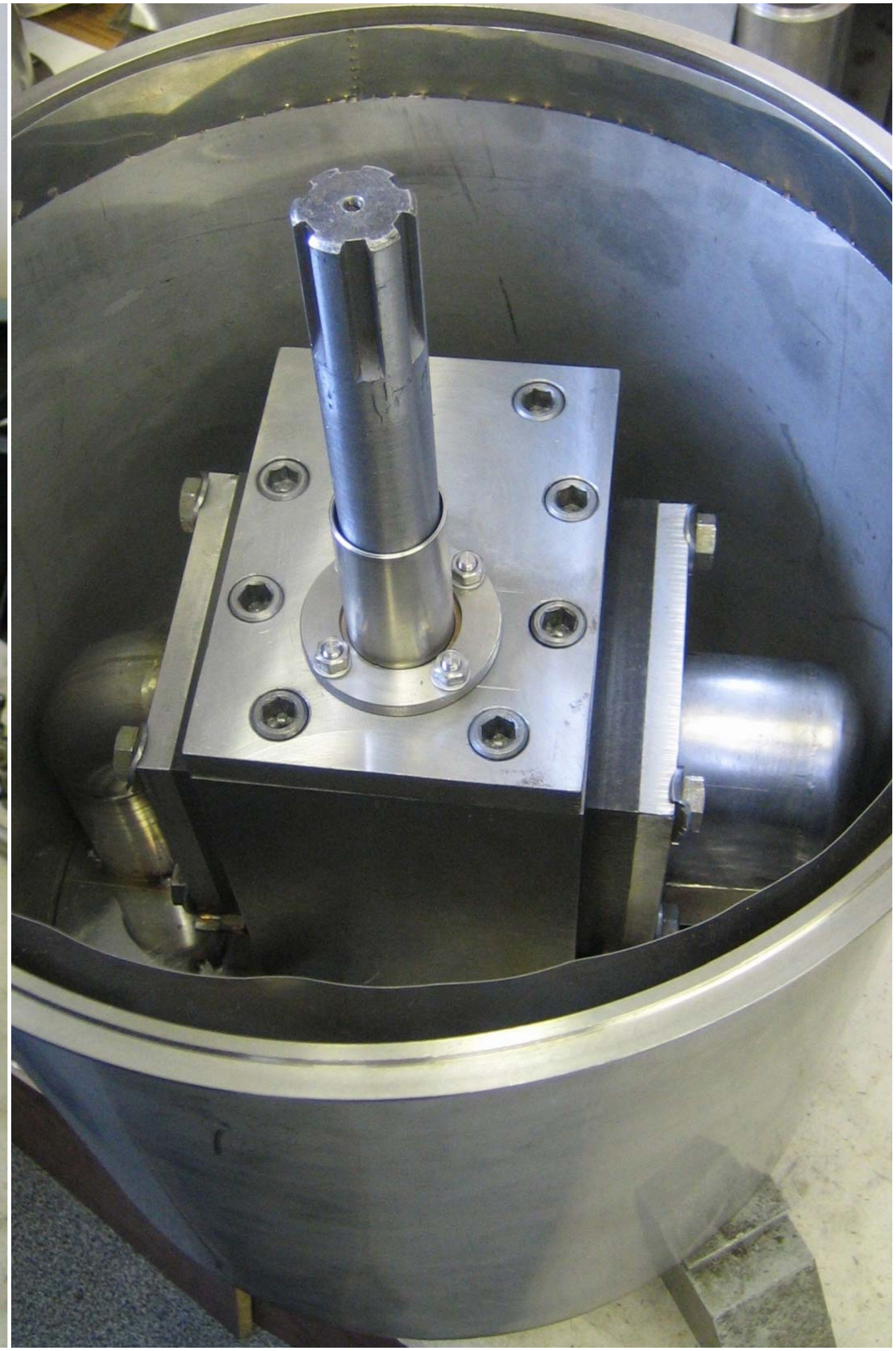


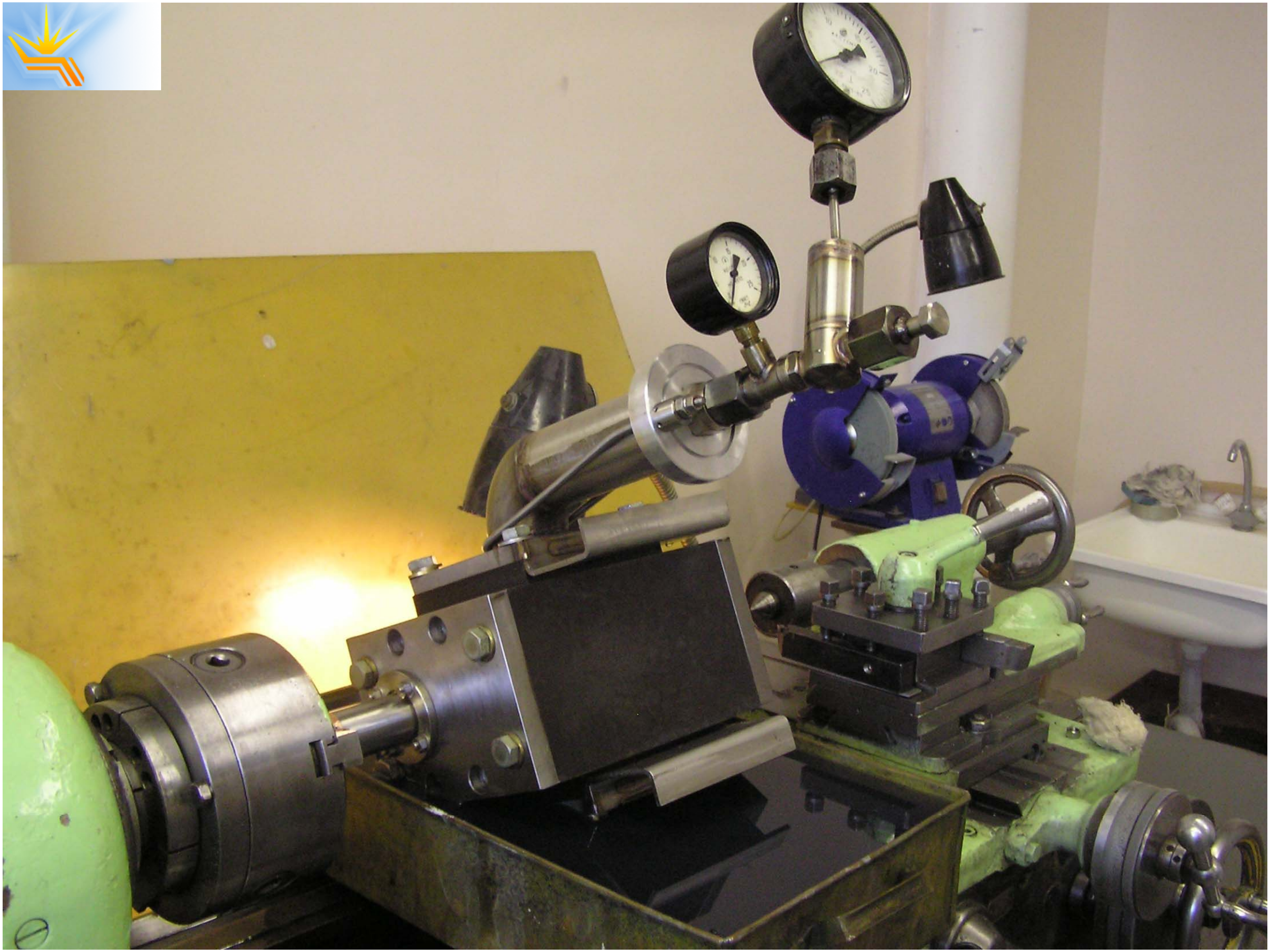


Prototype of target head with BN windows.


BN disks for windows
Test samples after 1000 h exposition
in liquid lead alloy at 300ºC
(no any damage of brazing joint).

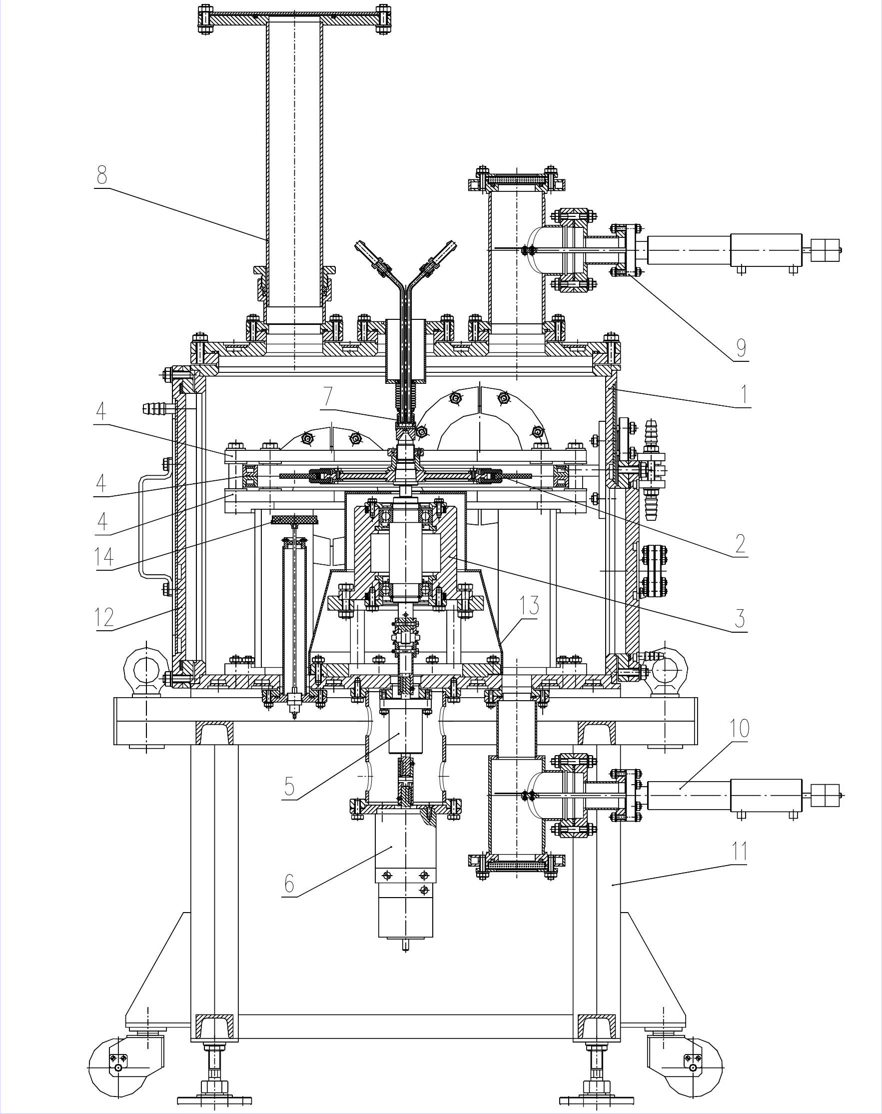




BINP experience in solid state rotating targets.

- The target is cooled by thermal radiation
- Max reached power in 1 cm diameter spot – 70 kW DC.
- 1200 – 3000 RPM.
- Target operating temperature is 2200 K.
- Target material is high density graphite
- 80 h non-stop run at 50 kW.

The scheme of prototype.



1 - vacuum chamber,

2 – converters wheel,

3 - bearing unit,

4 - cooling panels,

5 - rotary motion feedthrough,

6 - electric motor,

7 - shaft cooling unit,

8 – connective vacuum chamber,

9,10 – optic windows units,

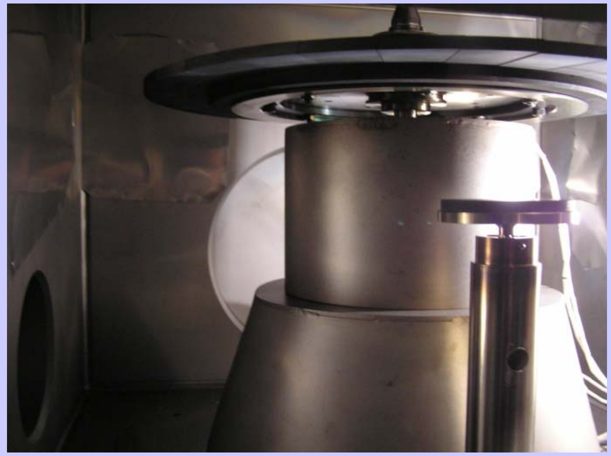
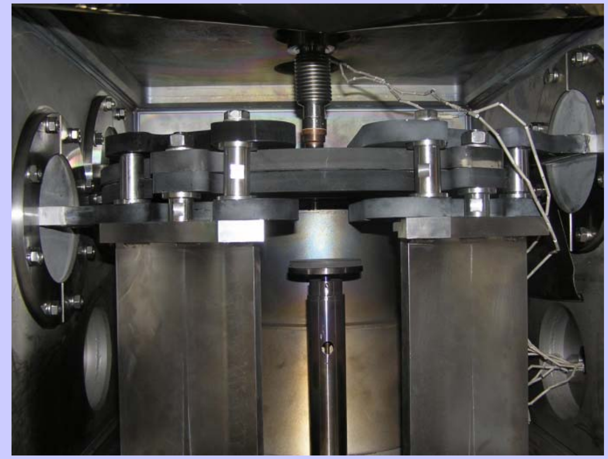
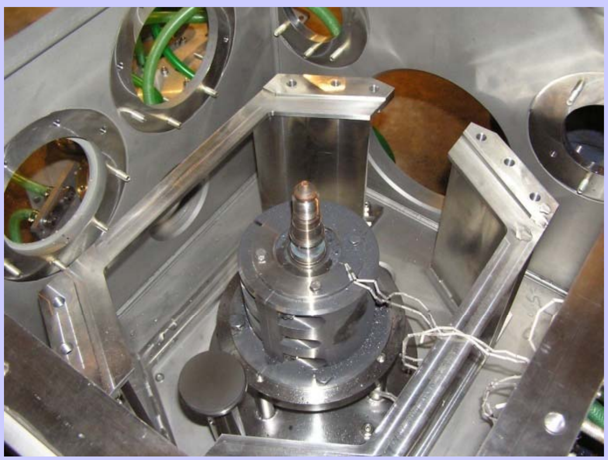
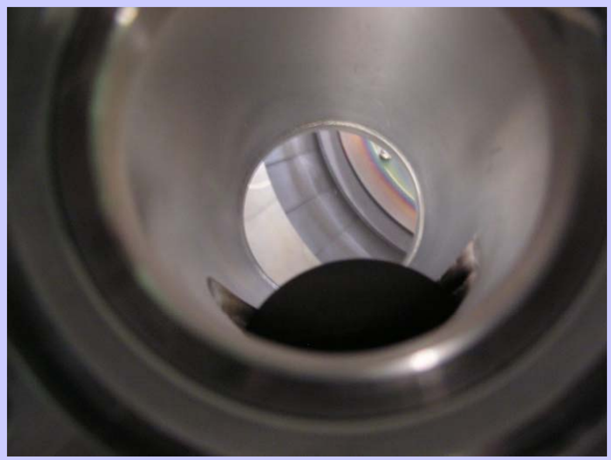
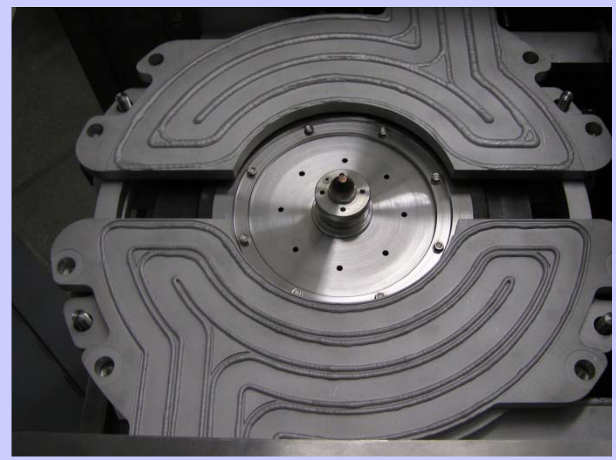
11 - stand,

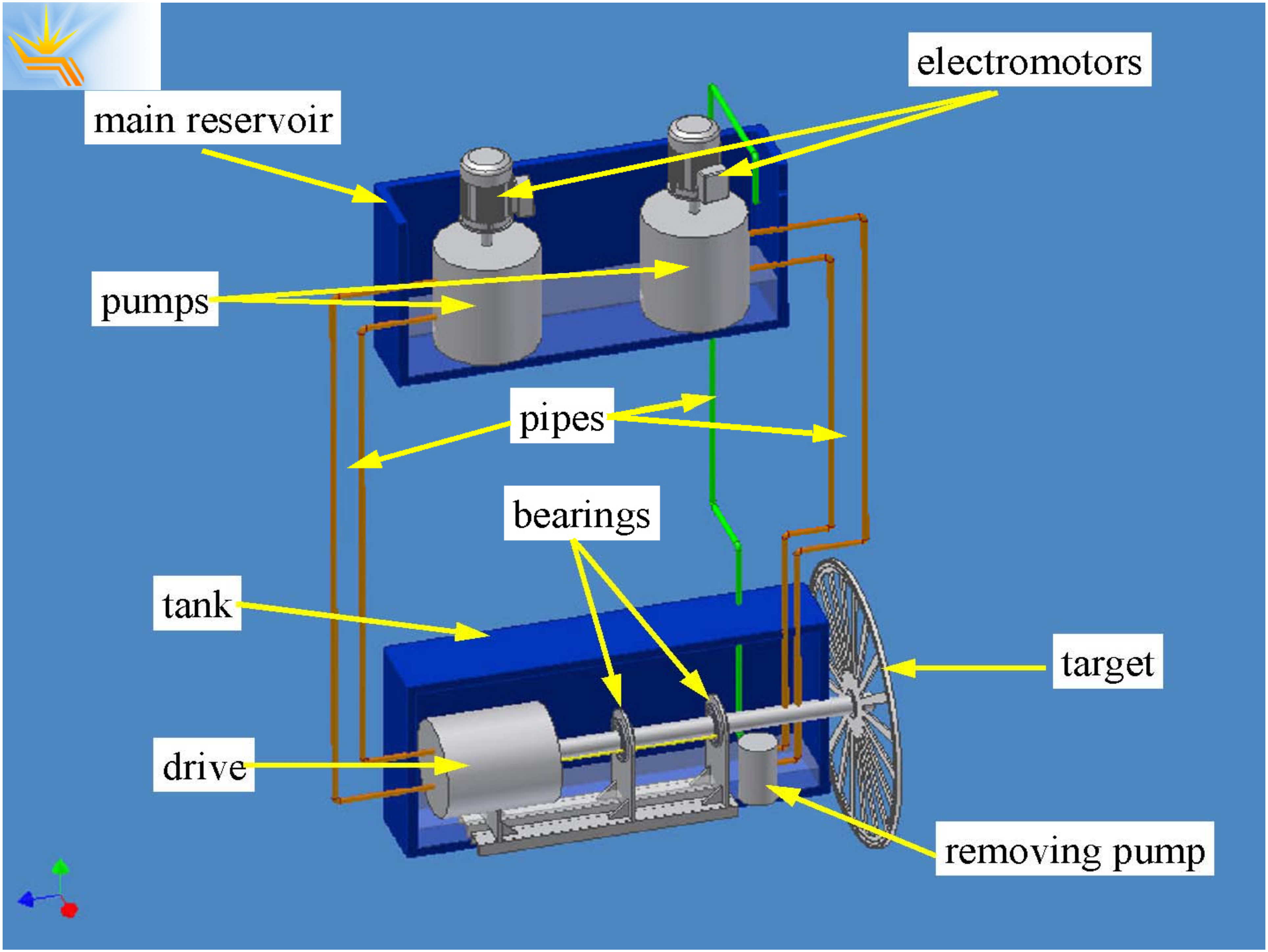
12 – removable flange,

13 - heat shield,

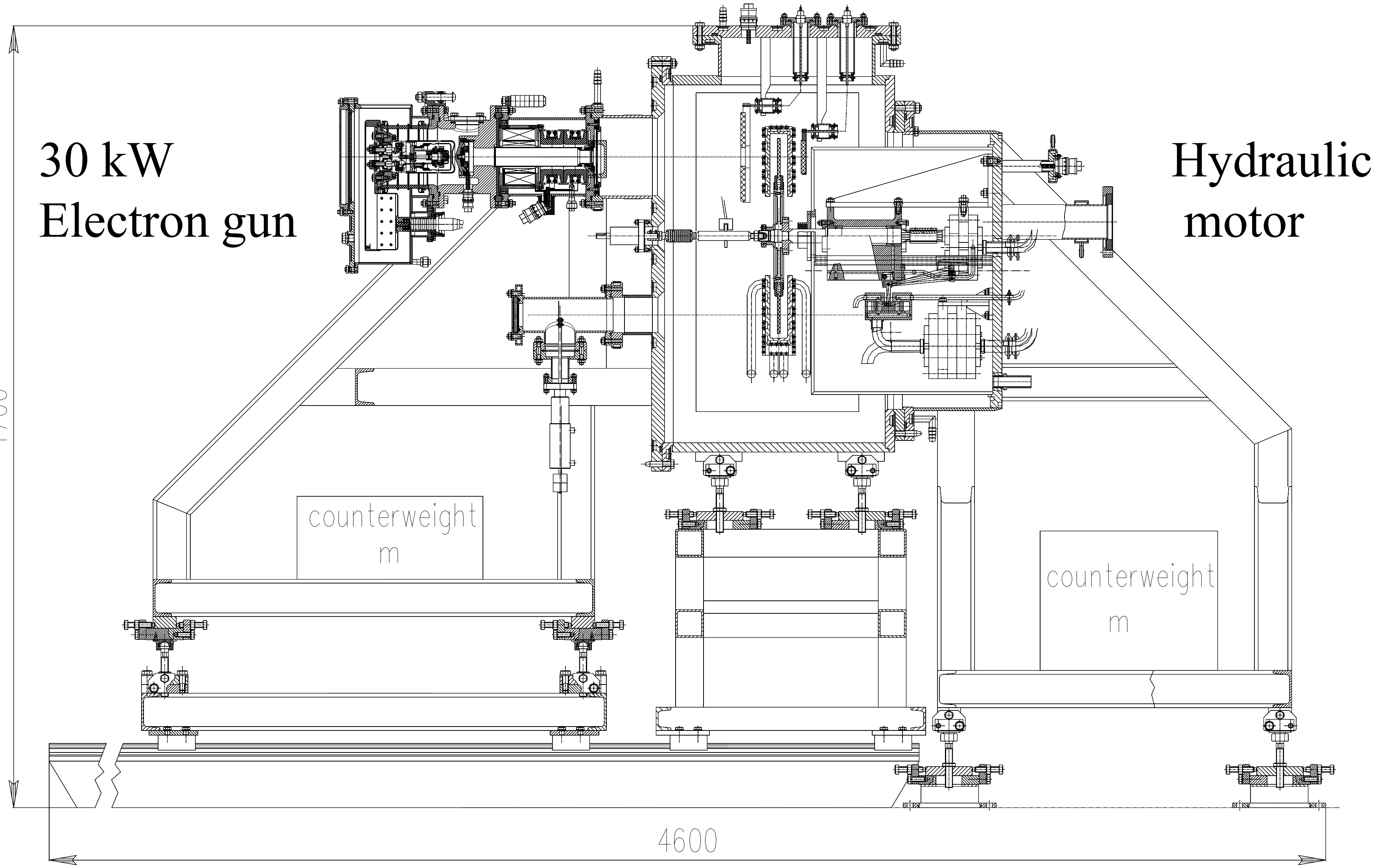
14 – measuring sensor

Views of prototype.

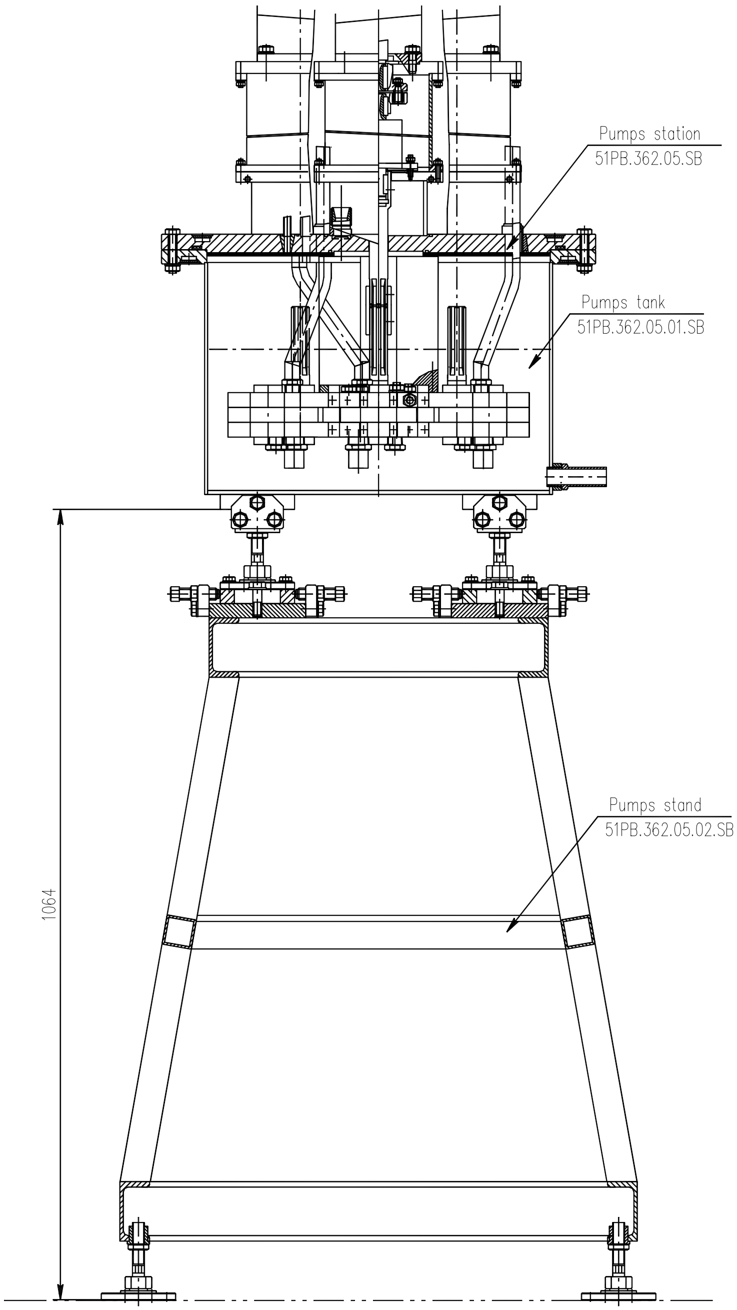







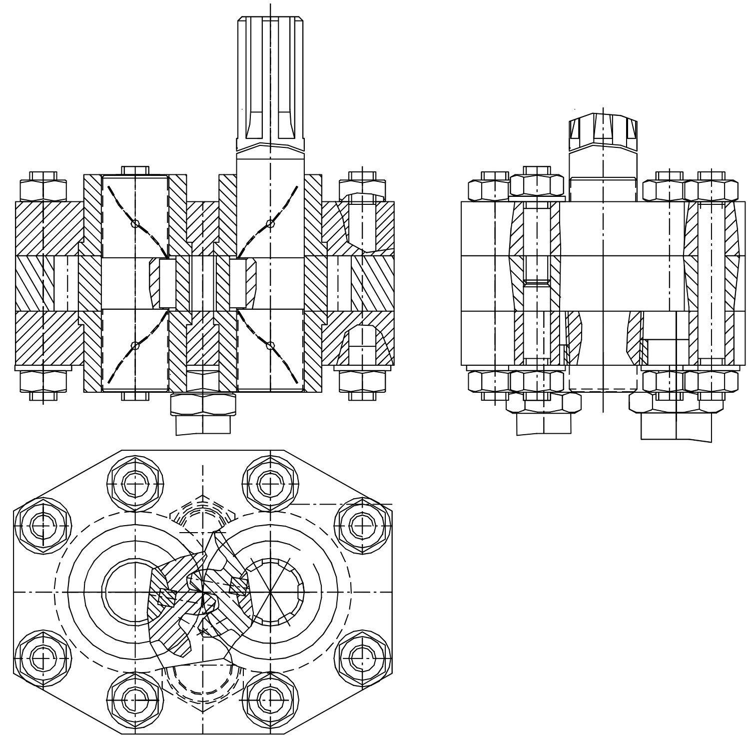

electromotors
main reservoir
pumps
pipes
bearings
tank
target
drive
removing pump

Solid state rotating target test bench

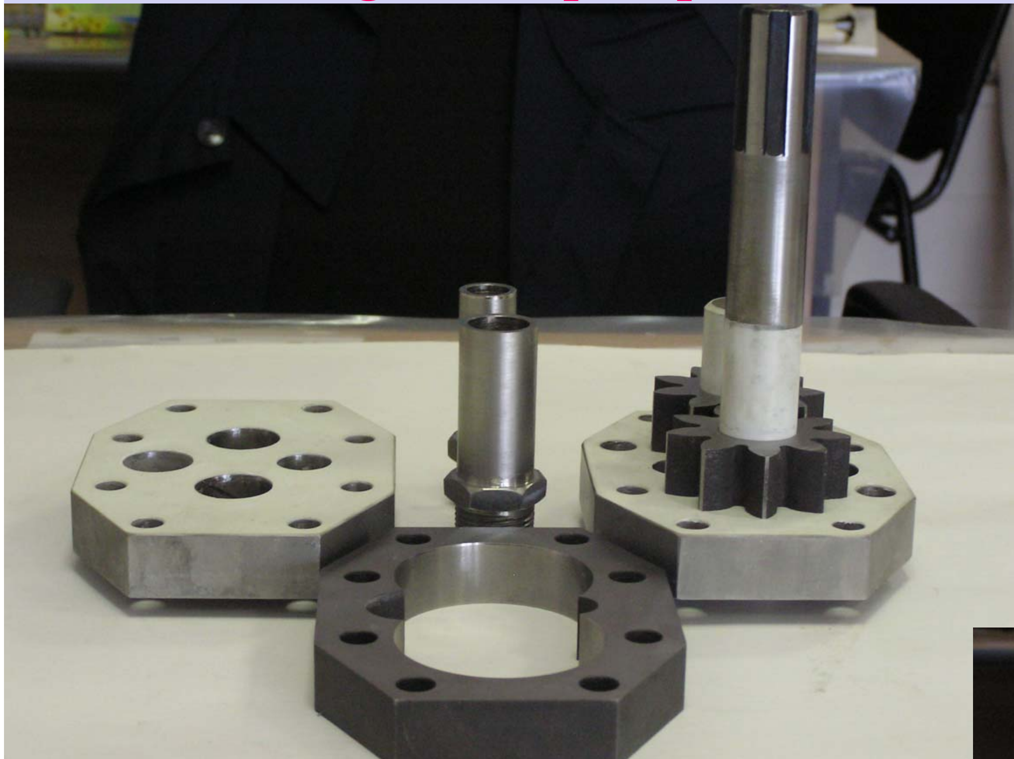


Hydraulic pumps





Cog-wheel pump



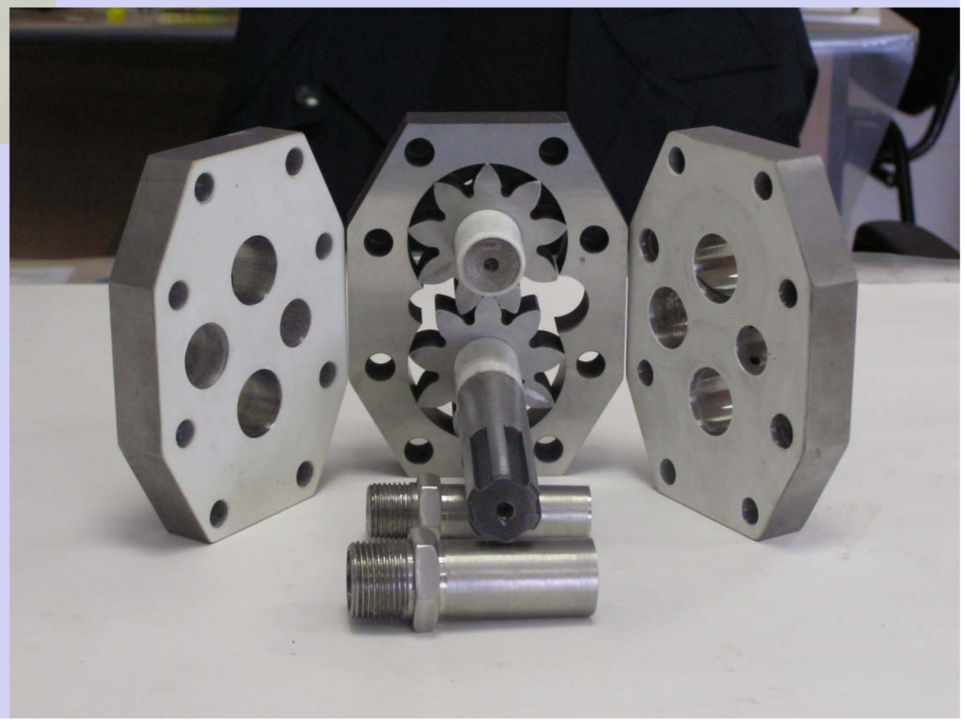
•Volume of pump

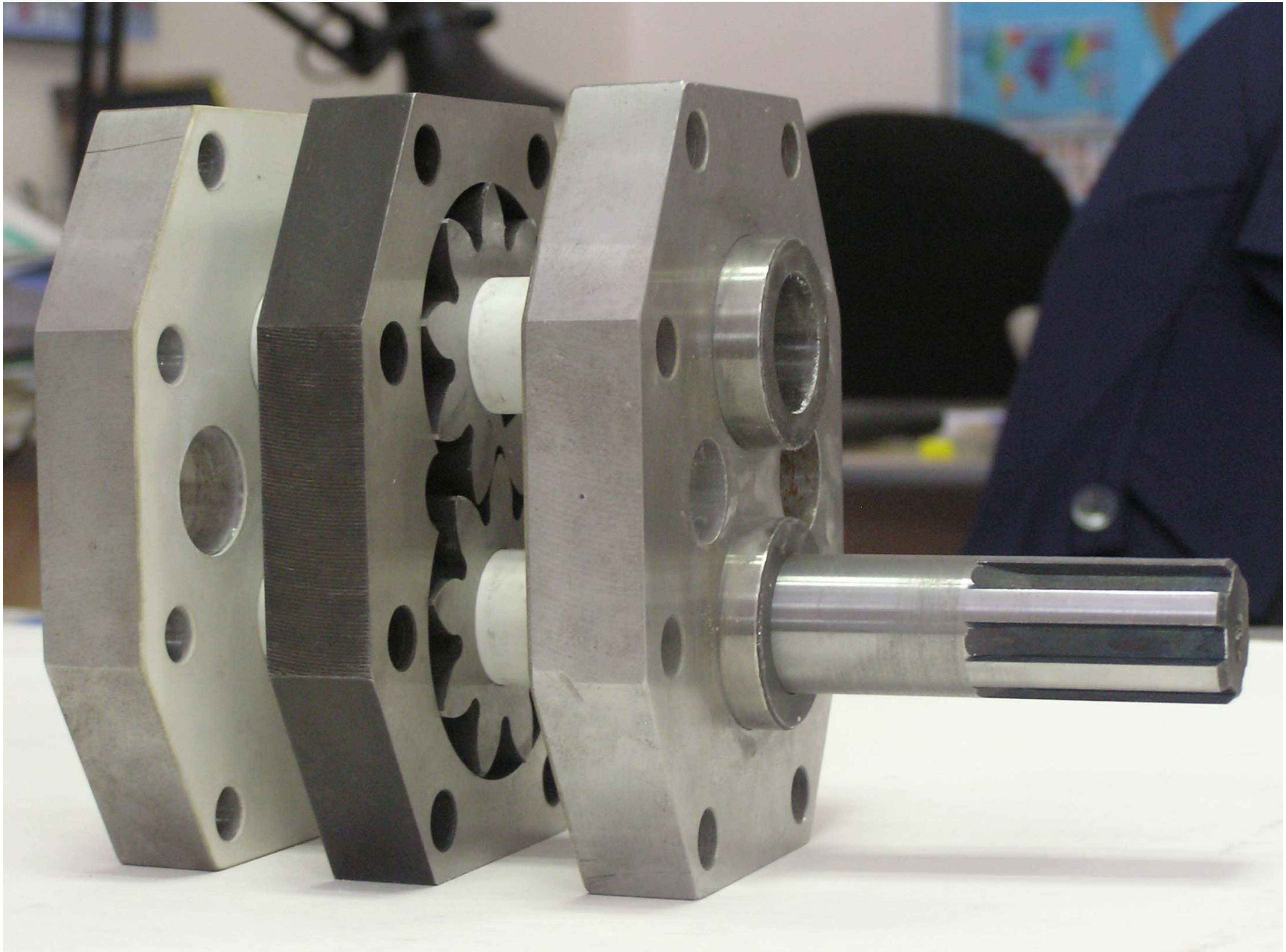
$$V_0 = 2\pi Dmb = 35.06\,\mathrm{cm}^3$$

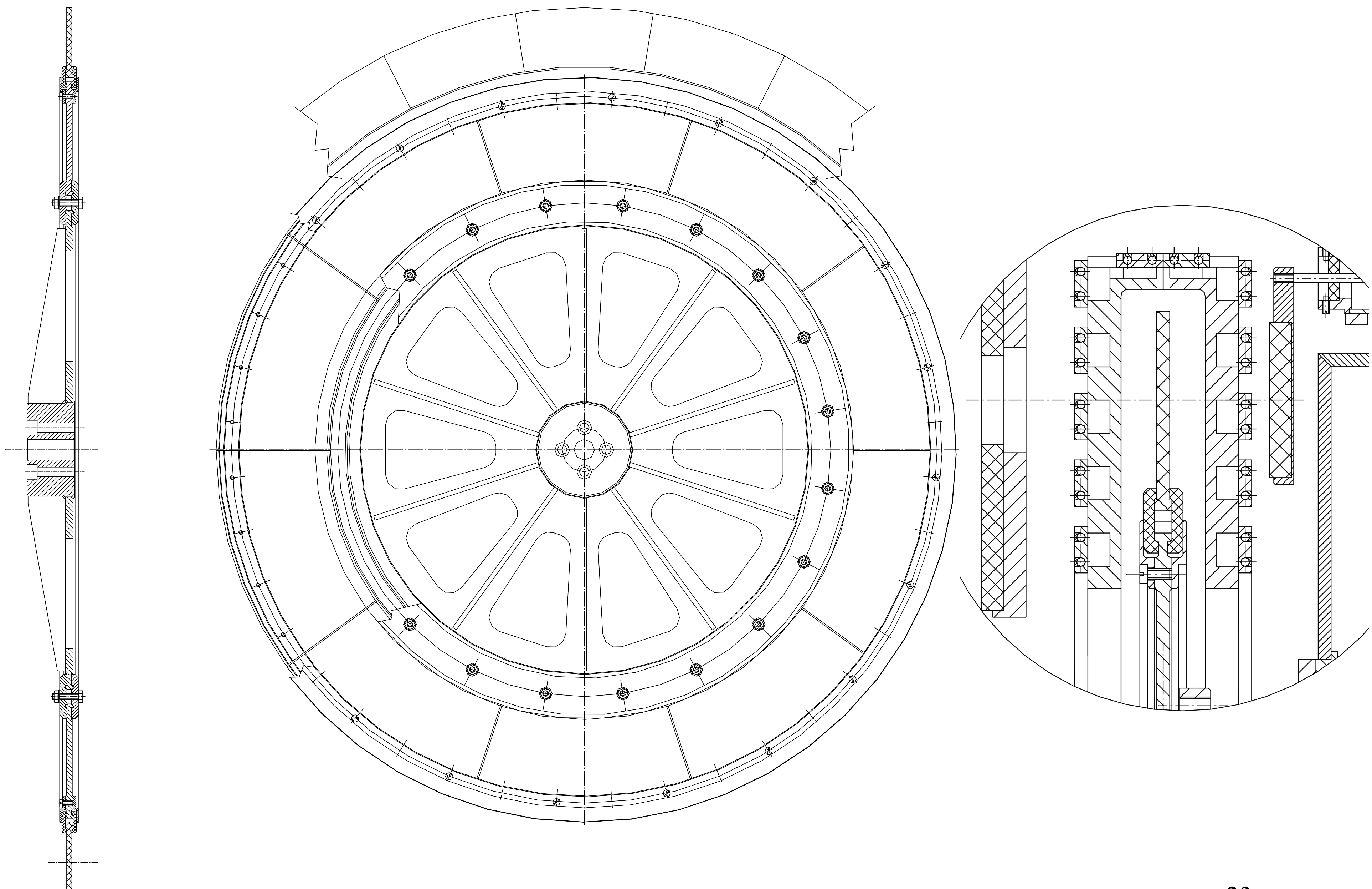
•Mechanical efficiency (liquid friction + dry friction) $\eta_m = 0.8$

•Volume efficiency (clearance leakage)

$$\eta_V = 0.9$$





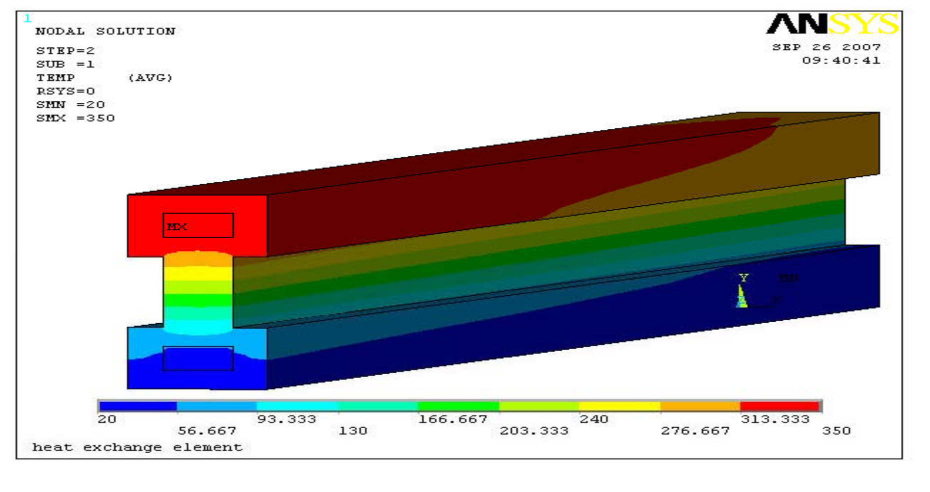


Heat exchanger

density ρ = 1 g/см^3
kinematic viscosity ν = 6.59·10^-7 м^2/s
thermo conductivity λ = 0.63 W/м*К
thermal capacity C = 4200 J/кg*К
heat power P = 50 кW
Prandtl number 4.39
Nusselt number

$$Nu = \frac{\alpha \cdot d_g}{\lambda} = 0.023\,\mathrm{Pr}^{0.4}\,\mathrm{Re}^{0.8}$$

8 parallel channels
length 1 m
cross section 1x0.5 cm^2

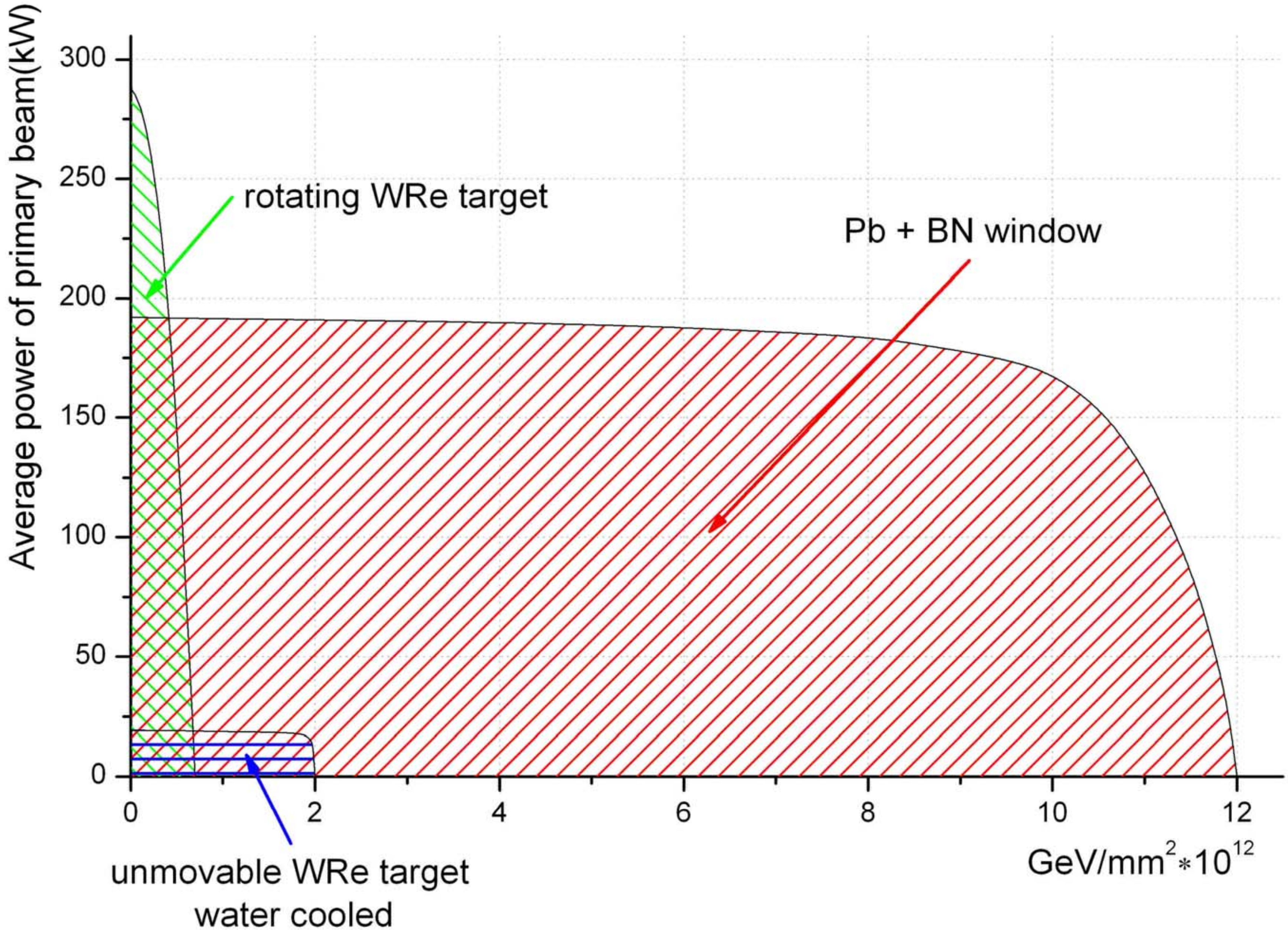


Minimum acceptable value

$$\mathrm{Re}_{\min} = \left(Nu_{\min} \middle/ \lambda \cdot 0.023\,\mathrm{Pr}^{0.4} \right)^{1.25} = \left(\frac{P}{S_c \Delta T_{\max}} \cdot \frac{d_g}{\lambda \cdot 0.023\,\mathrm{Pr}^{0.4}} \right)^{1.25} = 1.9 \cdot 10^4$$

Minimum acceptable flow velocity

$$V_{\min} = \mathrm{Re}_{\min} \frac{\nu}{d_g} = 0.4 m/s$$



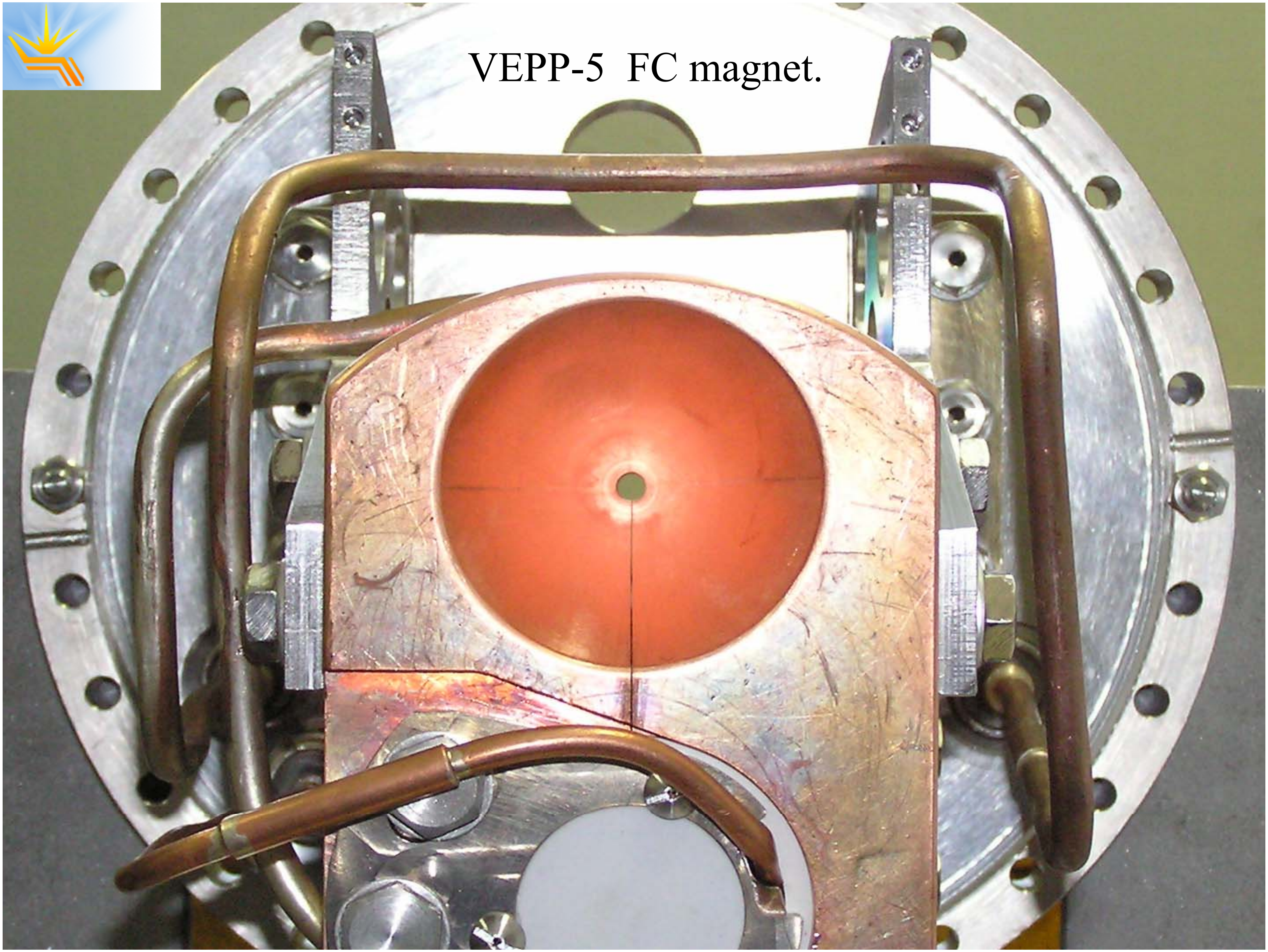
Average power of primary beam(kW)
300
250
200
150
100
50
0
0
2
4
6
8
10
12
rotating WRe target
Pb + BN window
unmovable WRe target
water cooled
GeV/mm^2*10^{12}

The present stage of BINP activity in Matching Device development.

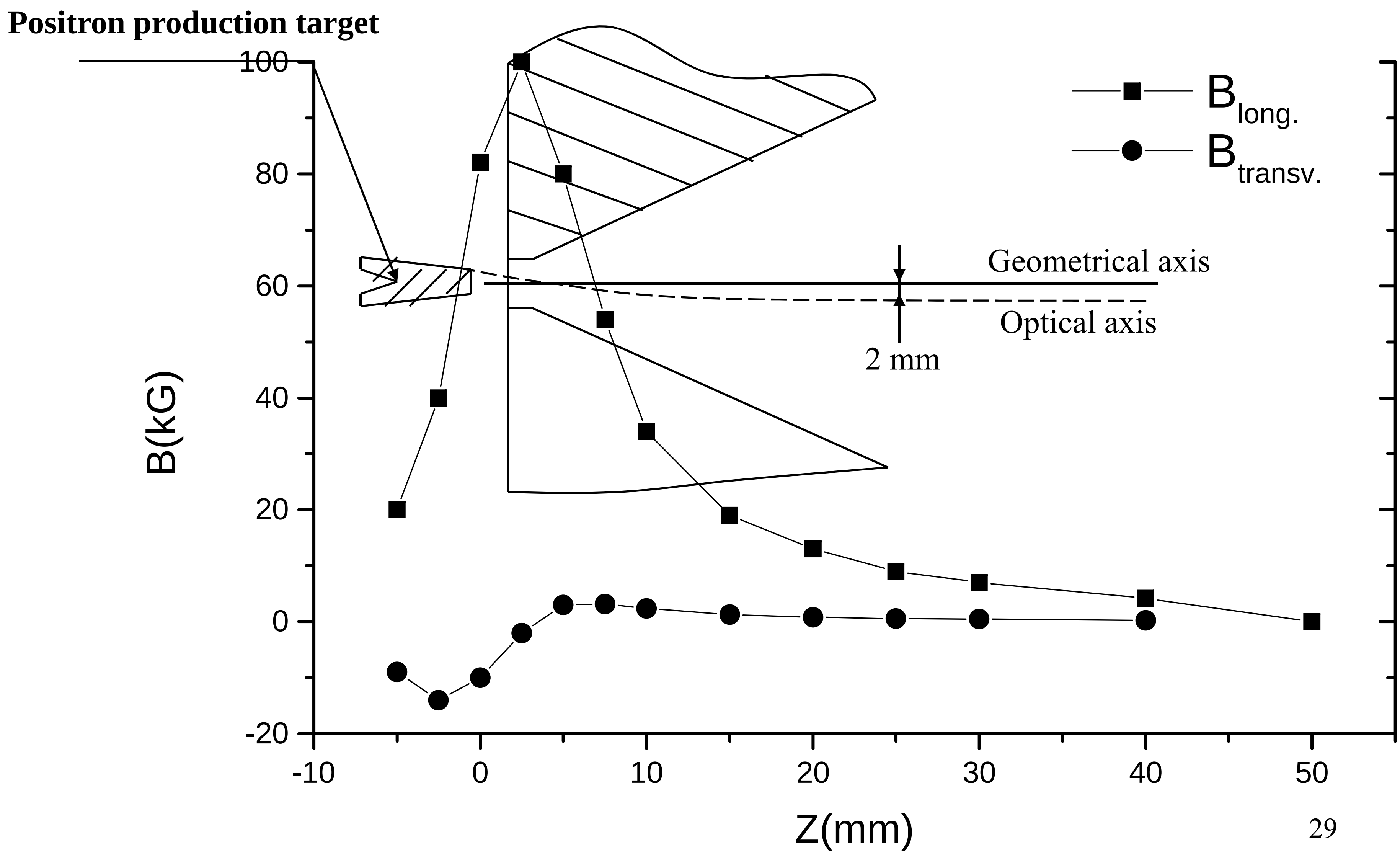
- The successful test of VEPP-5 positron production system was performed. Flux Concentrator magnet (FC) was tested up to 70 kG (30 μs pulse duration) without saturation in positron yield.
- The investigation of the technical limit for maximum FC pulse duration is in progress.
- Flat face FC for 30 μs pulse duration, 10 T maximum field and good field quality for KEKB is under the tests now at BINP.

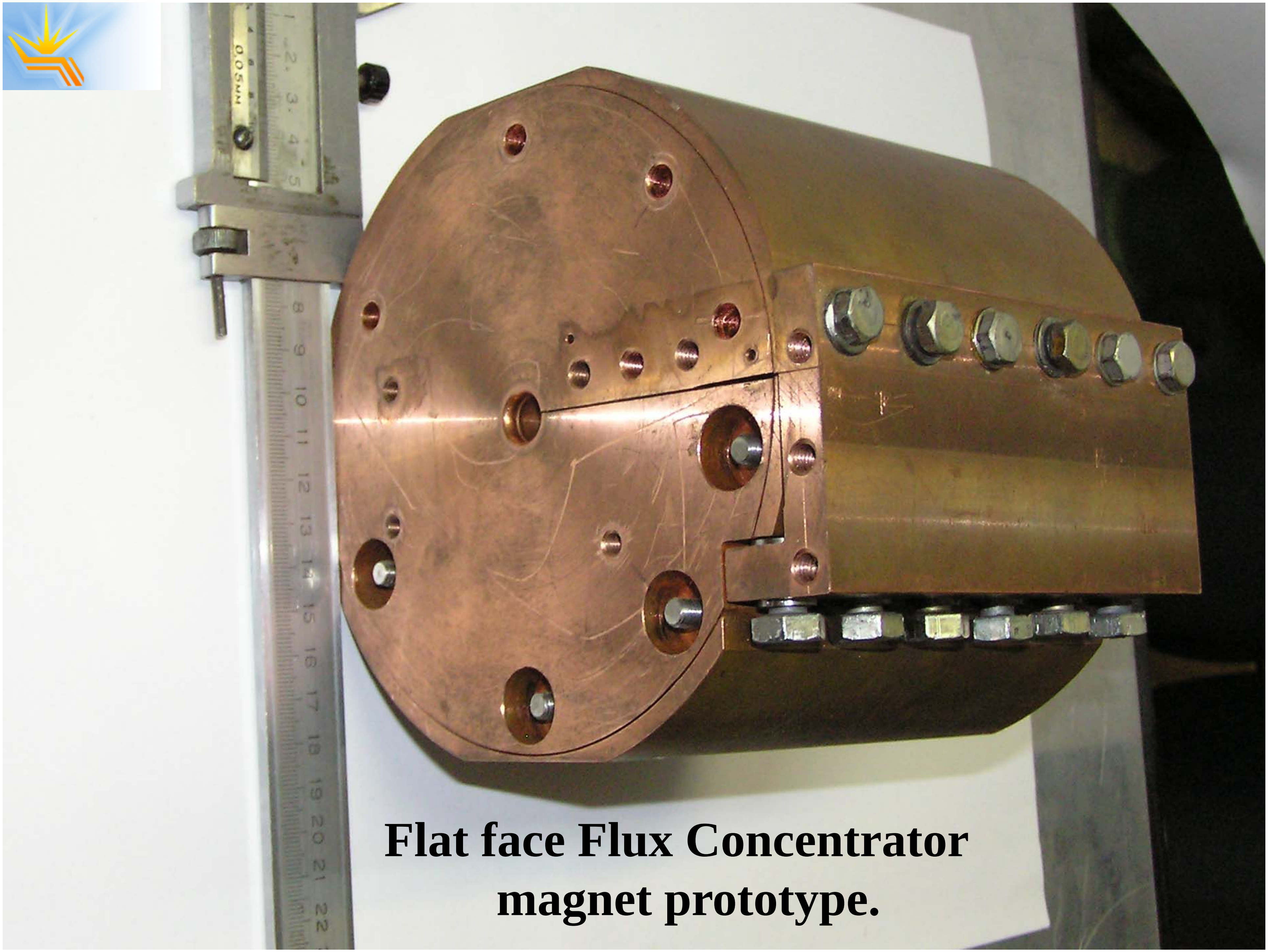
Positron system of VEPP-5 Injection complex in BINP.

VEPP-5 FC magnet.



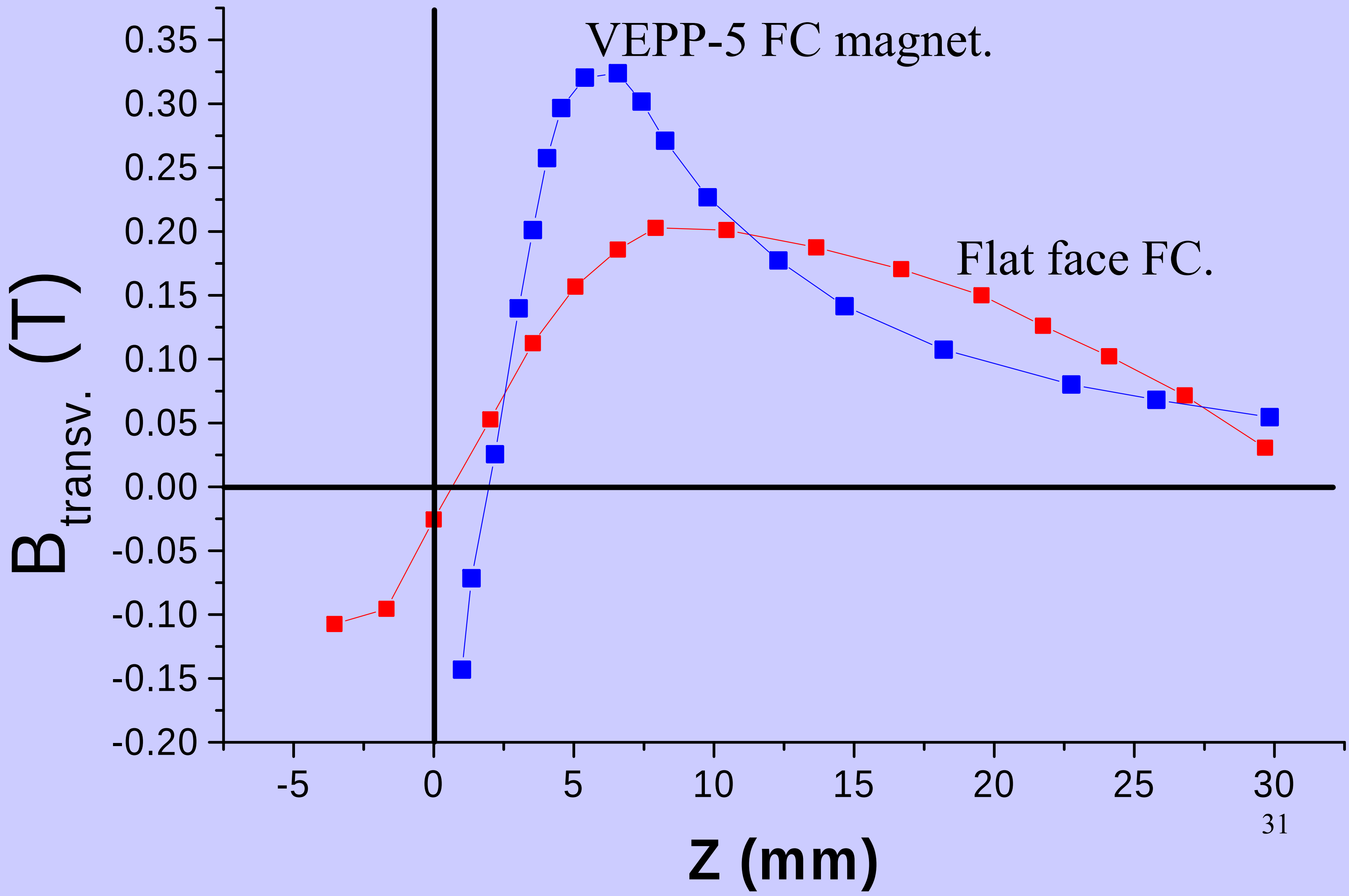
The dependencies of longitudinal and transverse magnetic fields on the geometrical axis of VEPP-5 FC magnet (measurements).





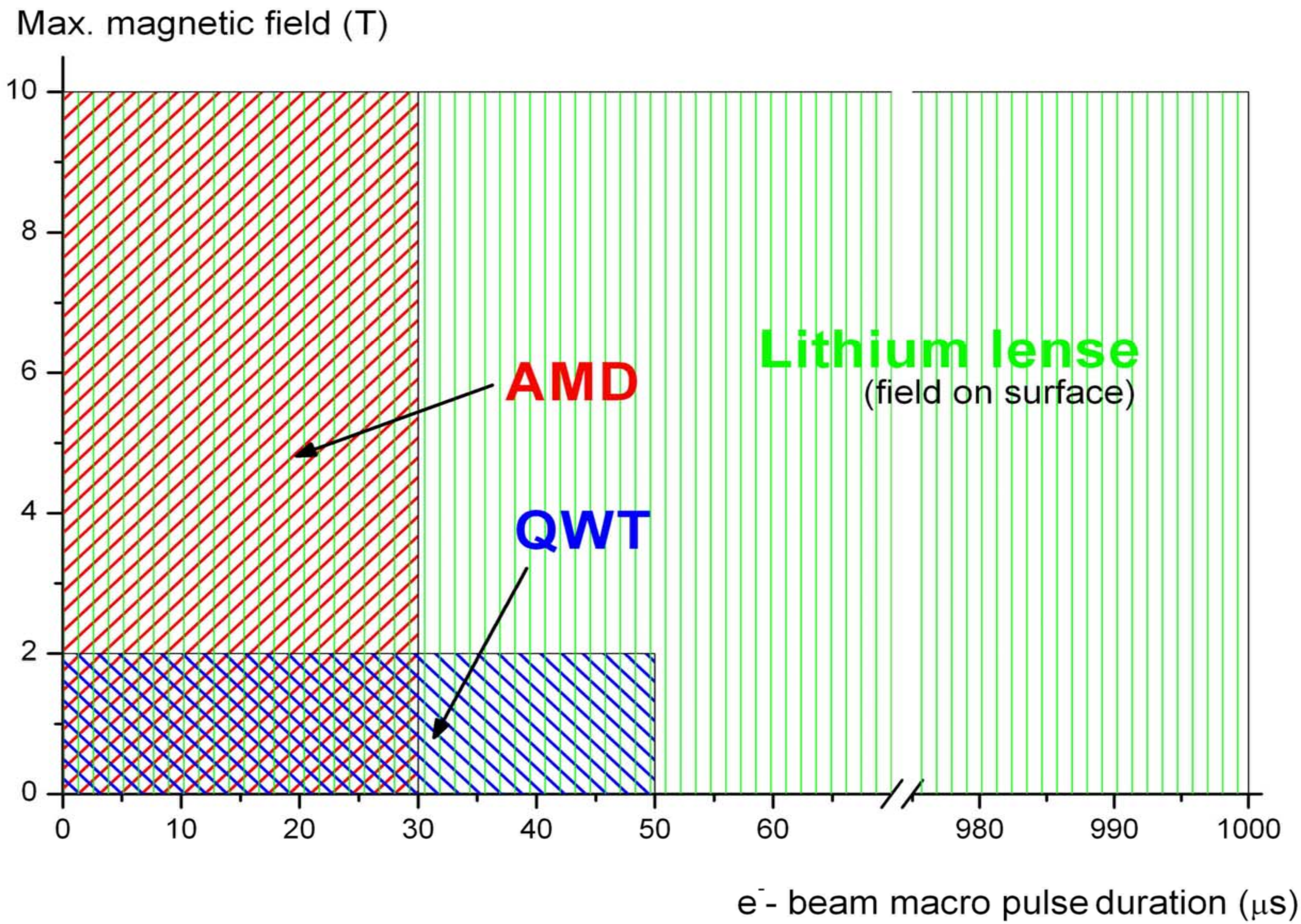
Flat face Flux Concentrator magnet prototype.

The dependencies of transverse magnetic field in matching devices upon the coordinate along the axis (magnetic measurements).



Problems with long macro pulse in ILC

- The skin-depth increasing leads to effective increasing of the device aperture and a region size with asymmetric transverse magnetic field. The longitudinal integral of this field determines the kick effect.
- For longer pulse – more problems with the field quality.
- For longer pulse – the energetic efficiency of all the system is less.
- Also the mechanical problems arise with the increasing of the pulse length.
- The technical limit for pulse duration should be determined.



Max. magnetic field (T)
10
8
6
4
2
0
AMD
QWT
Lithium lense
(field on surface)
0
10
20
30
40
50
60
980
990
1000
e⁻- beam macro pulse duration (μs)

Summary

- Existing positron sources, which are in operation, haven't reached yet the limits of their application areas.
- Significant improvements in some directions may lead to about one order of magnitude increase in positron production rate for best existing installations.
- Conventional positron production technology still has some reserves for such up-to-date projects as International Linear Collider (ILC) or Super B-factory.