FSUE “D.V. Efremov Scientific Research Institute
of Electrophysical Apparatus”

NOVEL COMPACT CYCLOTRONS FOR PRODUCTION OF RADIONUCLEDS

P.V. Bogdanov, I.N. Vasilchenko,
M.F. Vorogushin, A.V. Galchuk,
S.V. Grigorenko, V.G. Mudrolubov,
A.P. Strokach, S.E. Sychevsky

Three compact cyclotrons mainly intended for production of artificial radionuclides have been designed at the D.V. Efremov Institute (NIIEFA):

- **The CC-12** cyclotron, which generates beams of protons with an energy of 12 MeV. The machine is intended to produce ultra short- lived radionuclides for PET.
- **The CC-18/9** cyclotron serves to produce proton beams with a fixed energy of 18 MeV and deuteron beams of 9 MeV. Both ultra short-lived and short-lived radionuclides can be effectively produced.
- **The MCC-30/15** cyclotron, which is a special-purpose machine used to produce beams of protons and deuterons with the energy variable in the range 30-18 MeV and 15-9 MeV respectively. This cyclotron is intended for operating in regional radiological clinics and research centers.

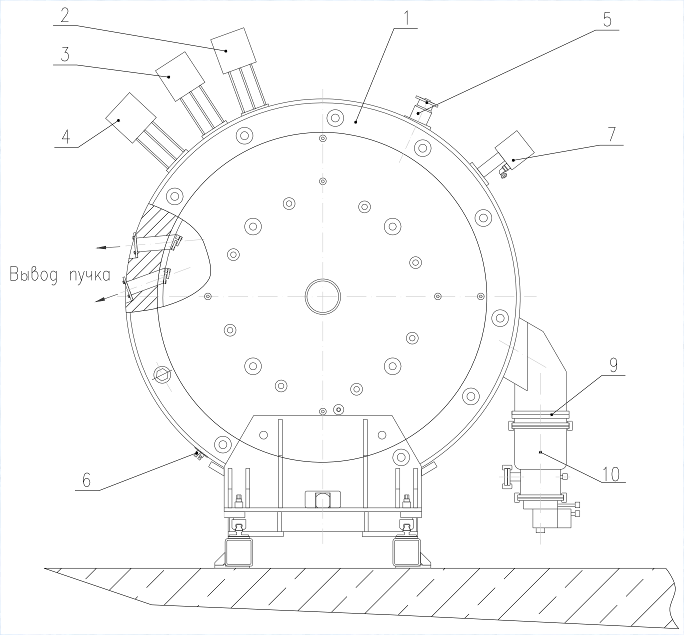
Main parameters of compact cyclotrons

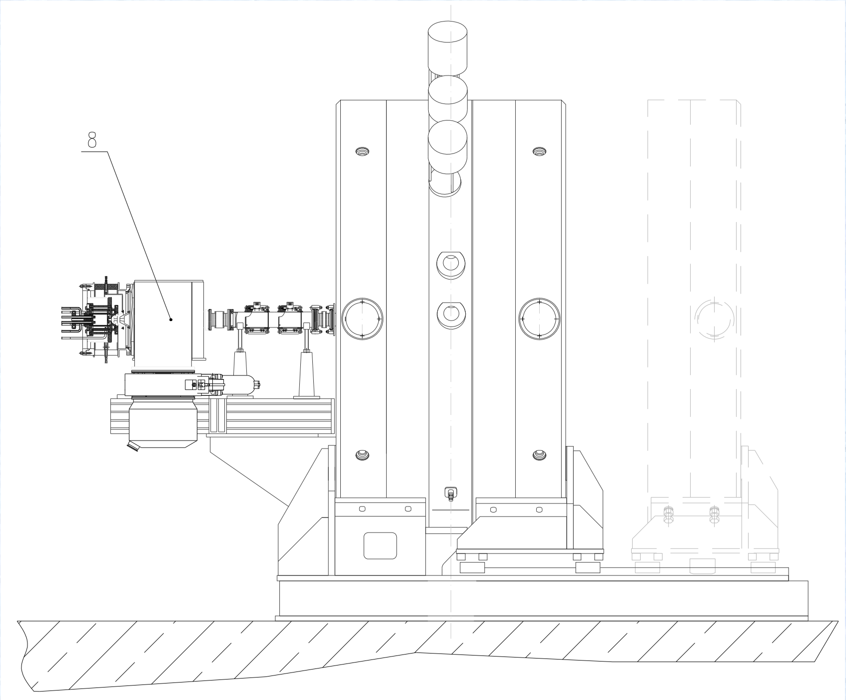
Cyclotron / Technical characteristics	CC - 12	CC – 18/9	MCC – 30/15
Ions accelerated	H^-	H^-/D^-	H^-/D^-
Ions extracted	H^+	H^+/D^+	H^+/D^+
Energy, MeV	12	18/9	18…30/9…15
Current, μA	50	100/50	100/50
Power consumed in the operating mode, kW	40	70	100
Magnet mass, t	10	20	41
RF oscillation frequency, MHz	76.4	38.2	40.68
Output power of the RF power supply system, kW	15	20	25

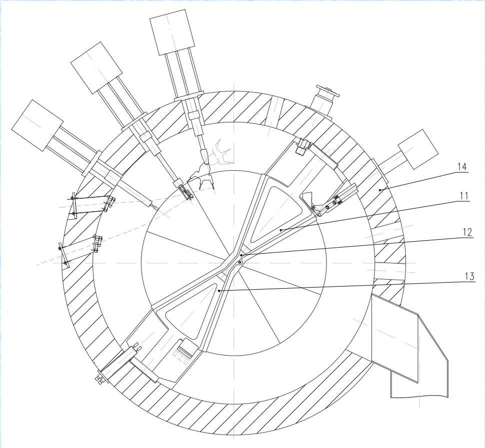
Design and Engineering Solutions applied:

- Shielding type magnet with the vertical median plane.
- Four-sector elements forming the isochronous field.
- On the CC-18/9 and MCC-30/15 cyclotrons movable shims are installed in specially made recesses on the iron core to correct the “shape” of the field and to ensure the isochronism when the type of ions accelerated is changed.
- Casings of the vacuum chambers are hollow thick-walled cylinders made of carbon steel, which simultaneously are parts of the iron cores.
- The pole pieces of the magnet with stainless steel flanges welded to them serve as the covers of the vacuum chambers.
- The external injection system of negative ions is used in the cyclotrons.
- The beams of accelerated negative ions of hydrogen and deuterium are extracted by stripping on carbon foils.
- An easy access to the in-chamber devices can be given by moving apart the movable part of the magnet to a distance of up to 800 mm along the guides.

The CC-12 cyclotron. Design

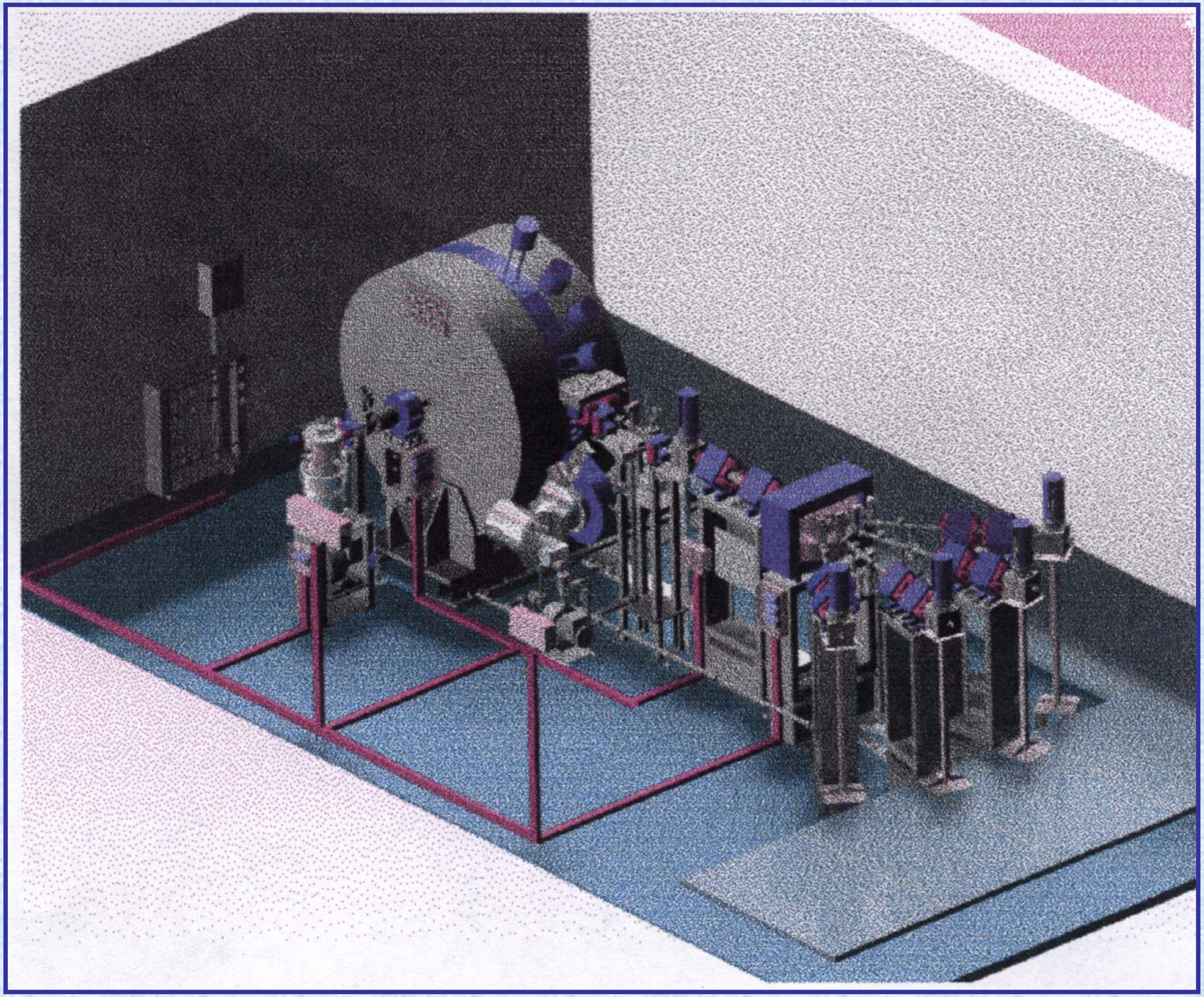




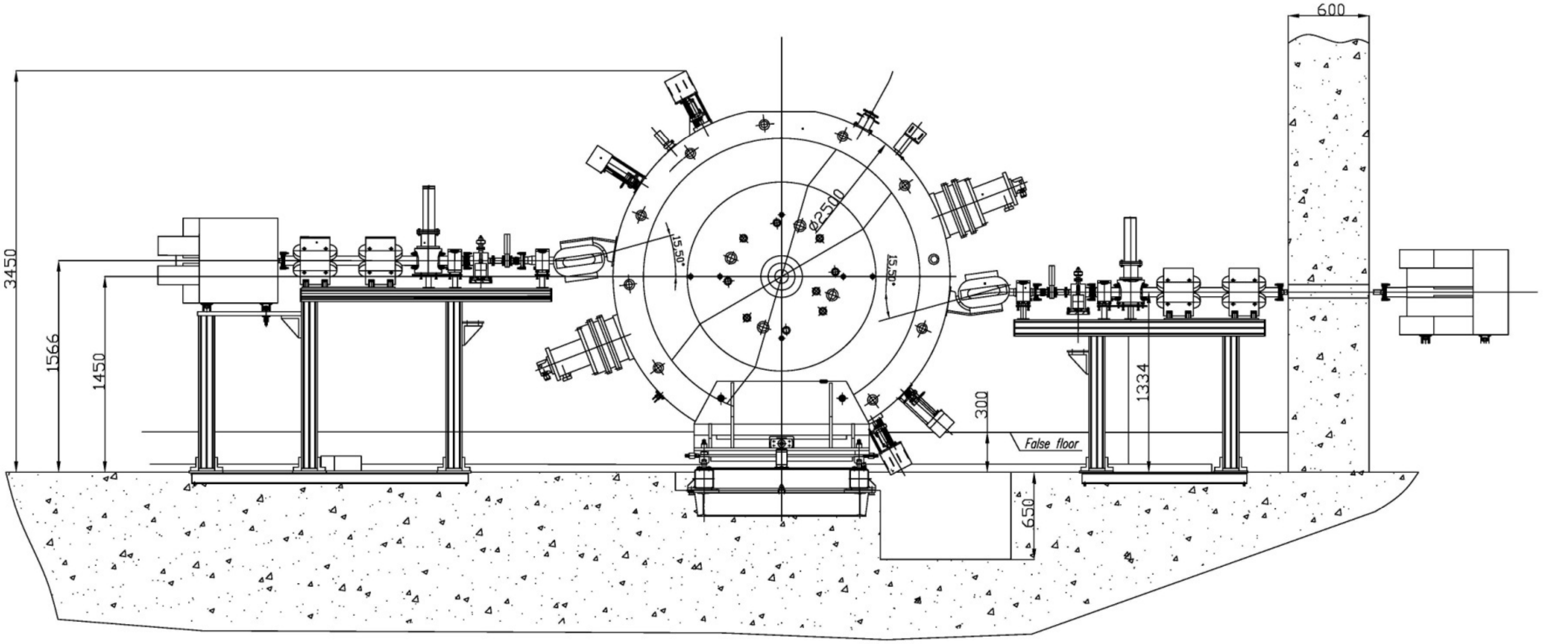


1-electromagnet; 2- stripping unit; 3- stripping unit; 4- probe; 5- RF power bushing; 6-RF probe; 7- AFT trimmer; 8- external injection system; 9-gate valve; 10- cryopump; 11- resonance system; 13-puller; 14- vacuum chamber

The CC-18/9 cyclotron with the beam transport system. Design

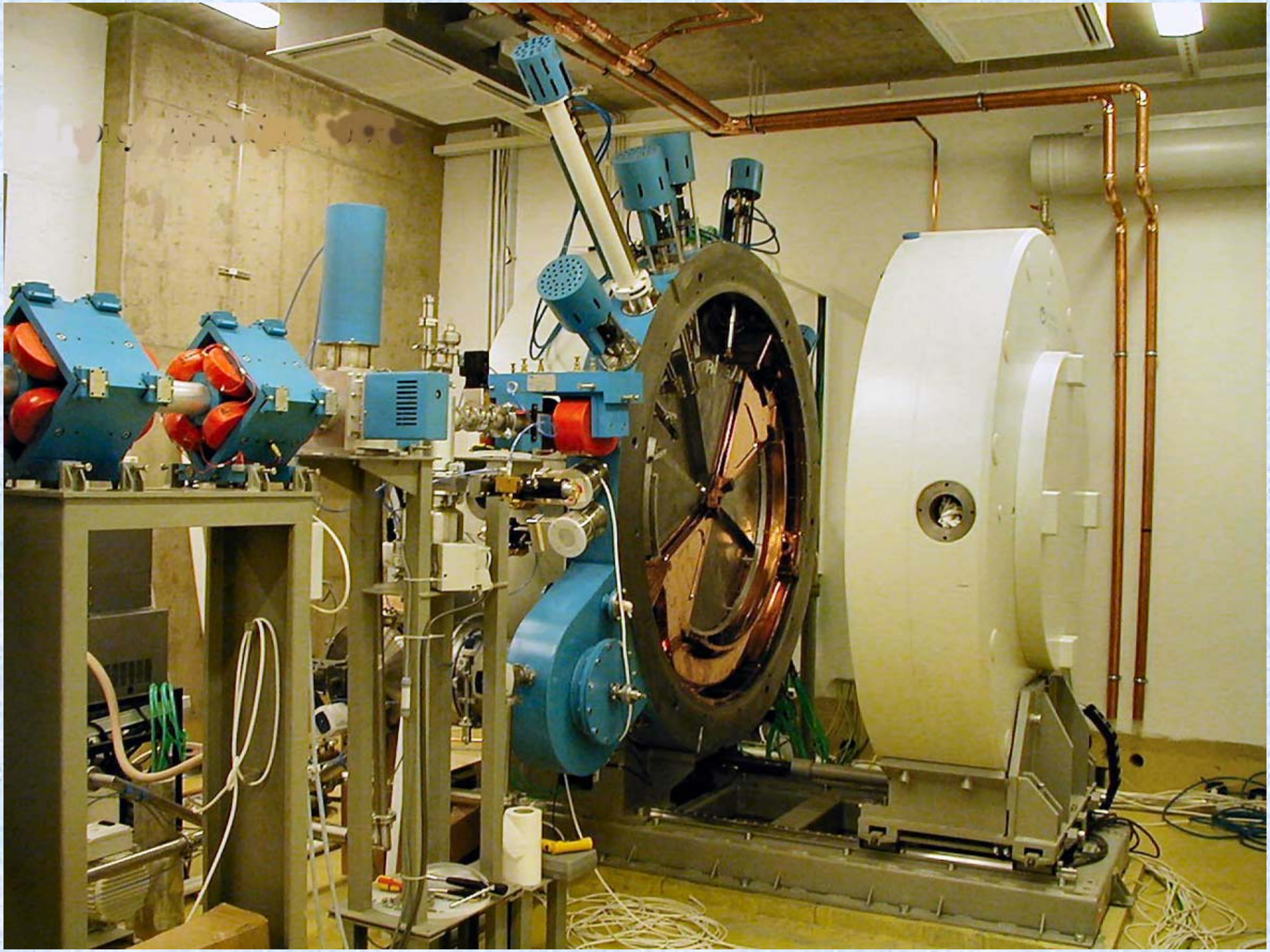


The MCC-30/15 cyclotron with the beam transport system. Design

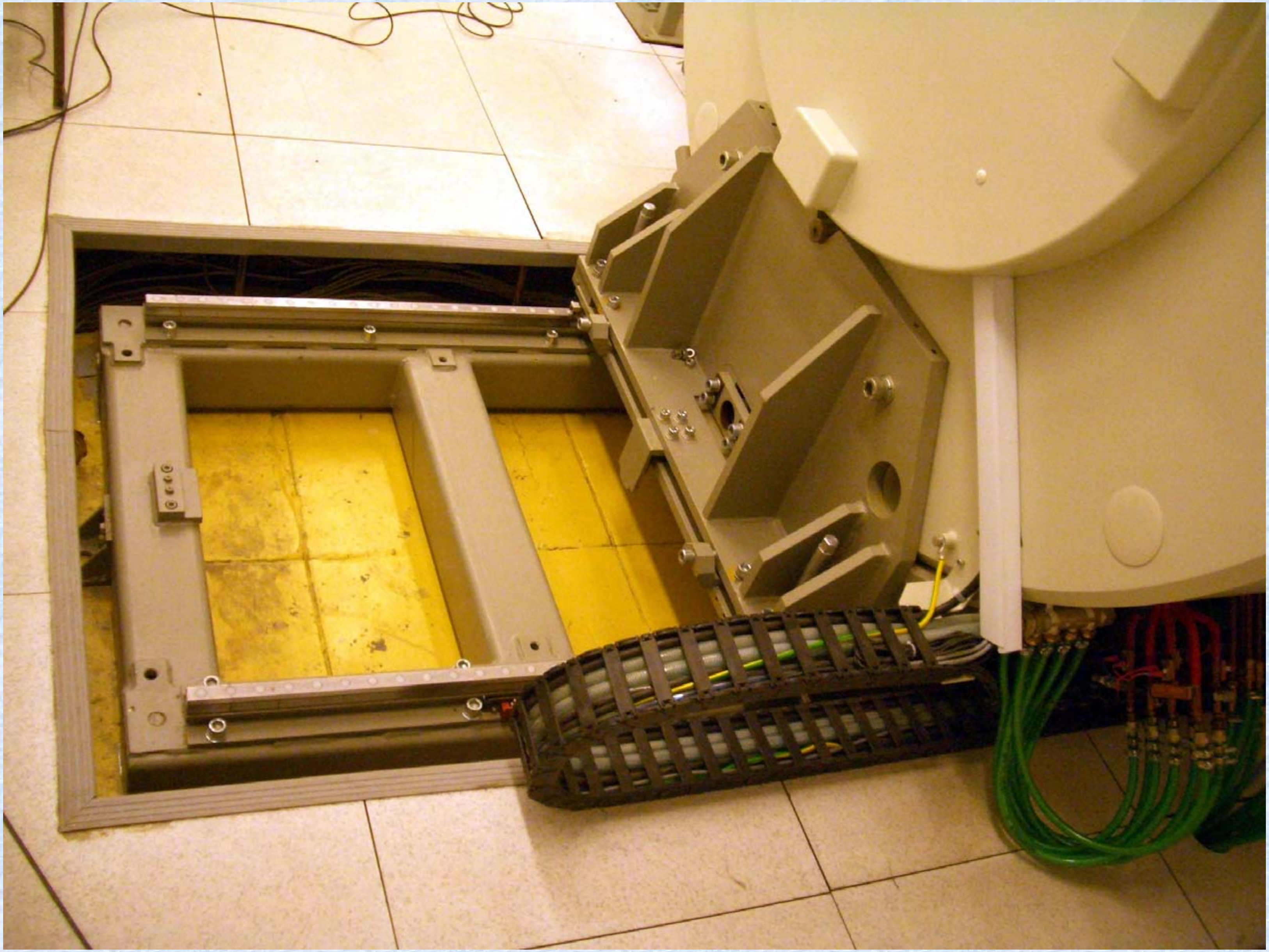


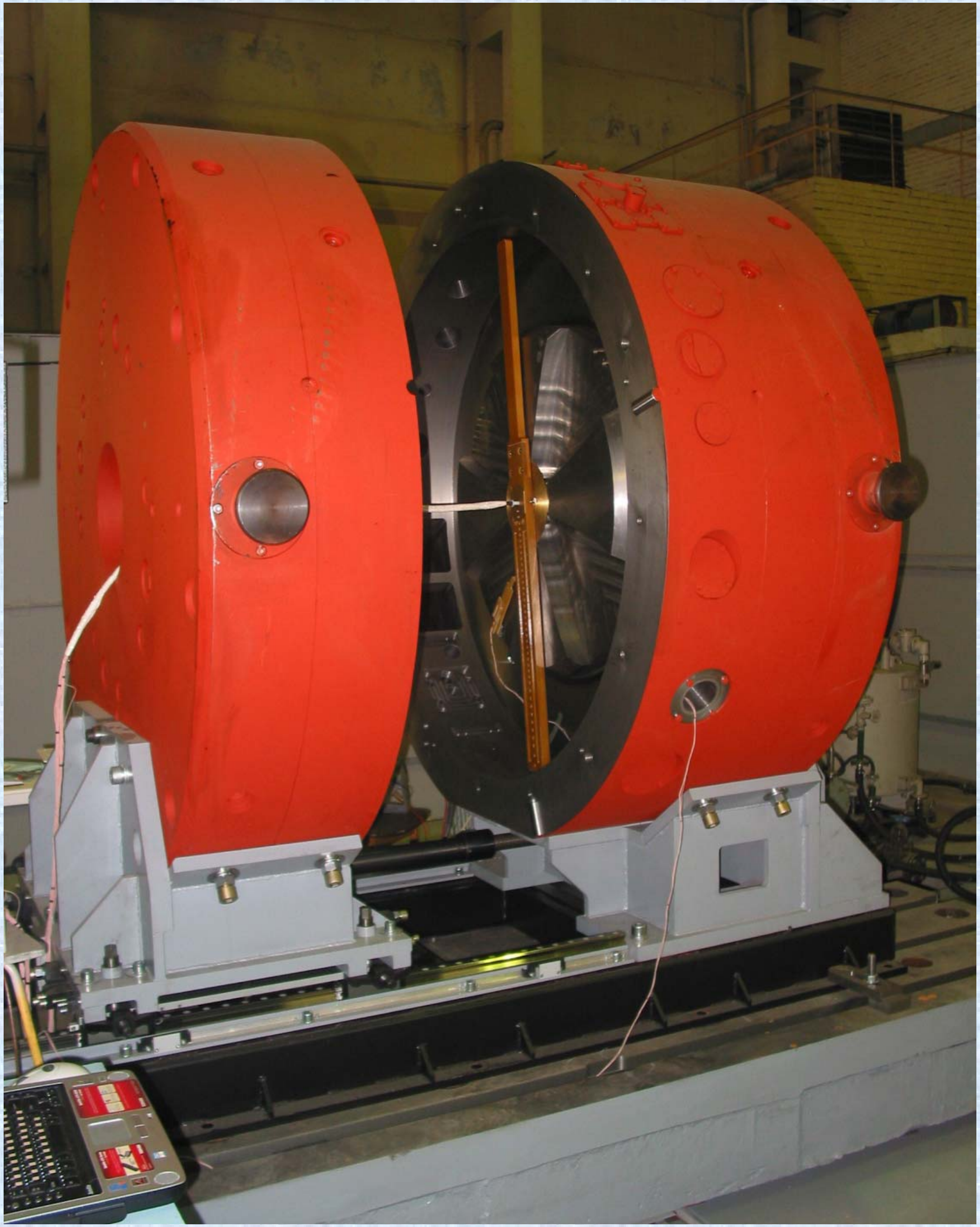
The CC-18/9 cyclotron in a PET center in Turky (Finland)

The movable part of the magnet is moved apart. The open vacuum chamber with the resonance system can be seen. In the left part of the photo one can see the part of the beam transport system, which is close to the magnet.



Mechanism to move apart the movable part of the magnet





The electromagnet of the CC-12 cyclotron at a test facility for magnetic metering

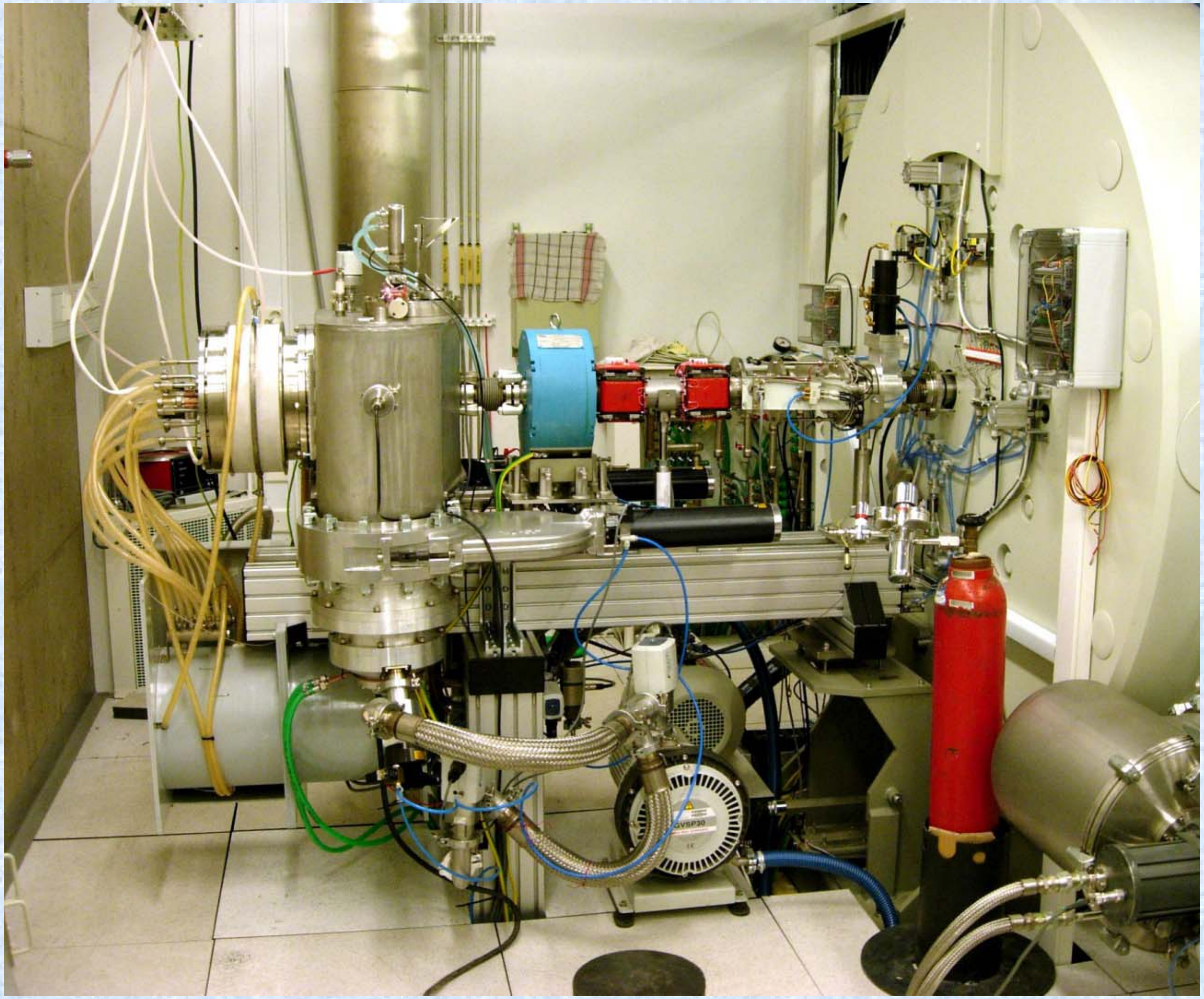
Machining of the magnet yoke of the MCC-30/15 cyclotron

Machining of the vacuum chamber of the MCC-30/15 cyclotron

External Injection System

This system consists of :

- **multi-pole source of negative ions;**
- **vacuum chamber and two correcting magnets;**
- **electrostatic lens and helical inflector;**
- **power supply and gas supply units**



The resonance systems of the cyclotrons are located completely inside the vacuum chambers and fixed at the lateral surfaces of the chamber casings. The systems are equipped with capacitors for frequency tuning, AFT trimmers and RF probes.

RF power supply systems consist of control modules and RF power amplifiers.

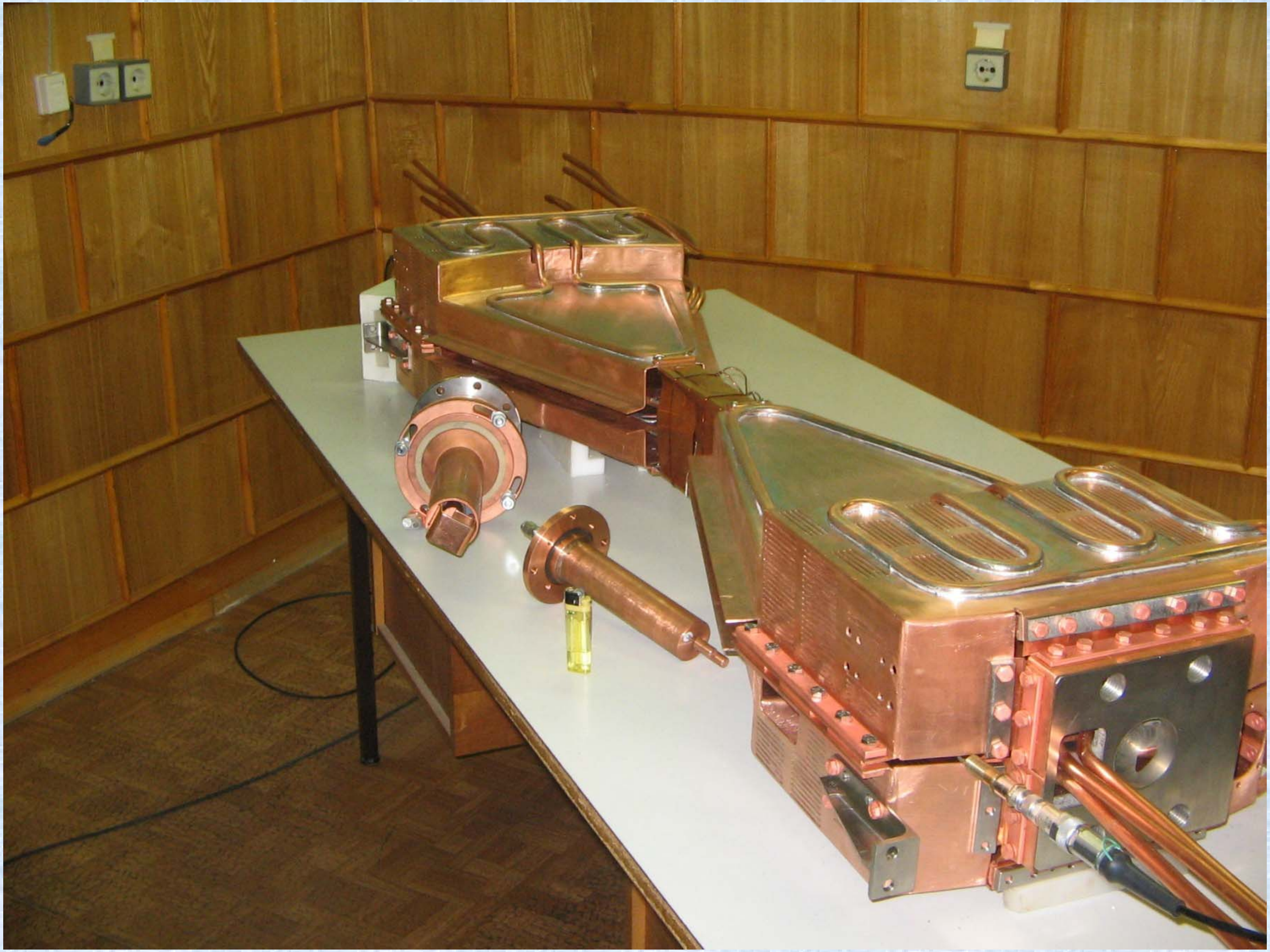
The control module is intended :

- to choose the operating mode (continuous or pulse with a specified duty factor),
- to measure and stabilize the accelerating voltage amplitude,
- to tune and stabilize automatically the resonance system frequency.

The rack of the RF power amplifier is installed in the room housing power supply systems. The RF power is transmitted from the amplifier to the resonance system via a flexible coaxial feeder.

Adjustment of the resonance system

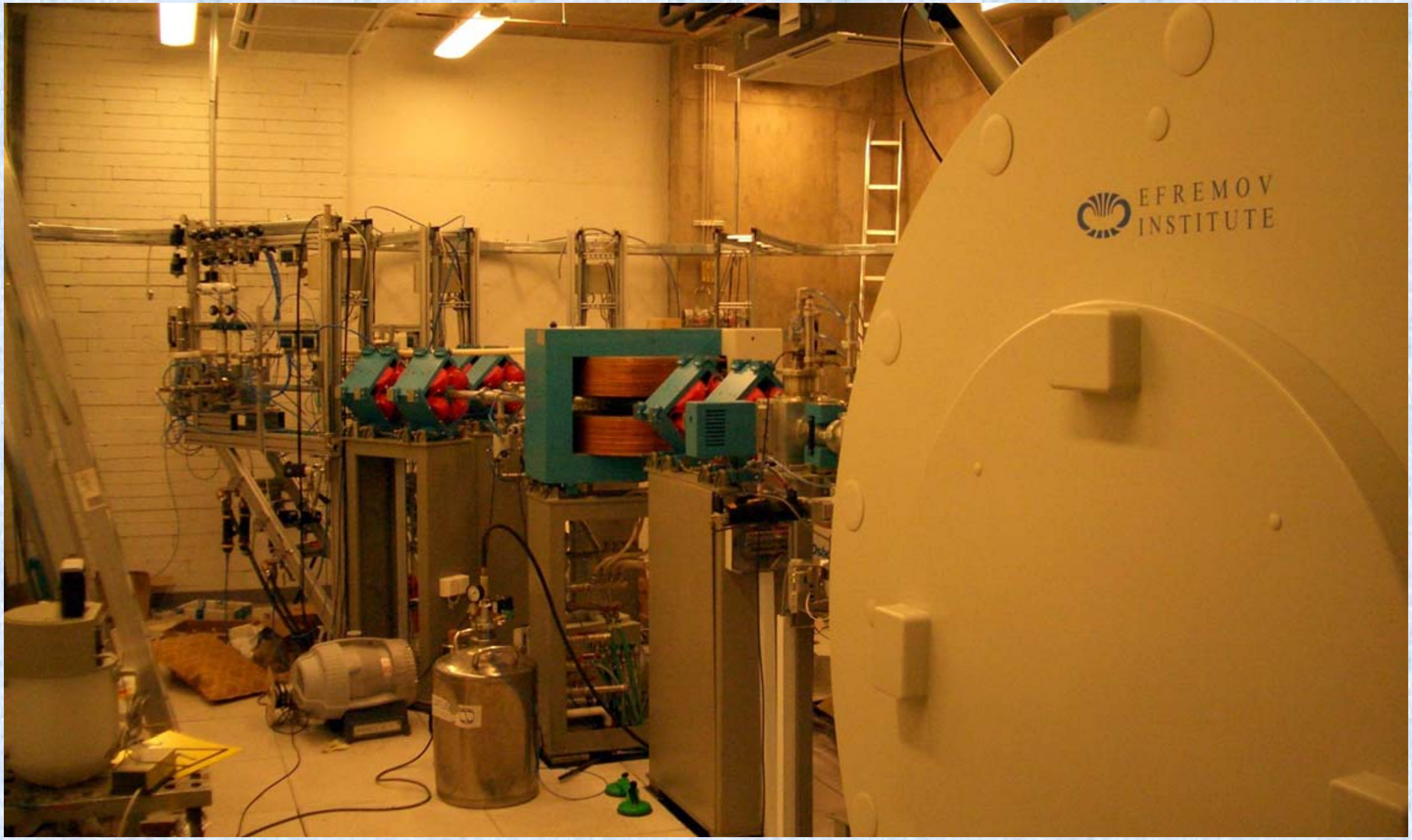
The resonance systems of the CC-12 cyclotrons

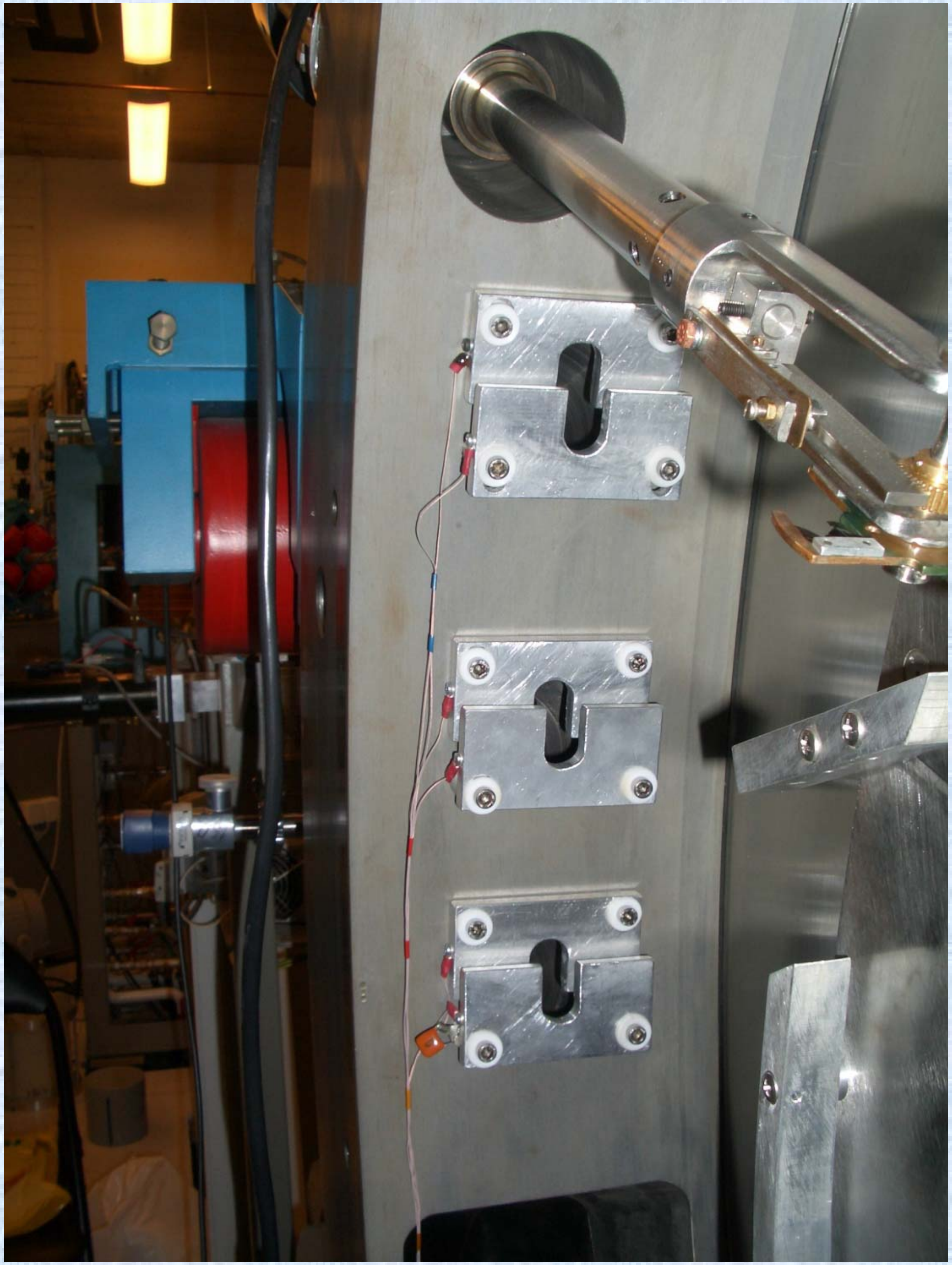


Beam Extraction

Beams of protons and deuterons are extracted from the cyclotrons through windows made in the vacuum chambers. On the CC-18/9 cyclotron, 3 beams are extracted; on the MCC-30/15 cyclotron, two beams are extracted.

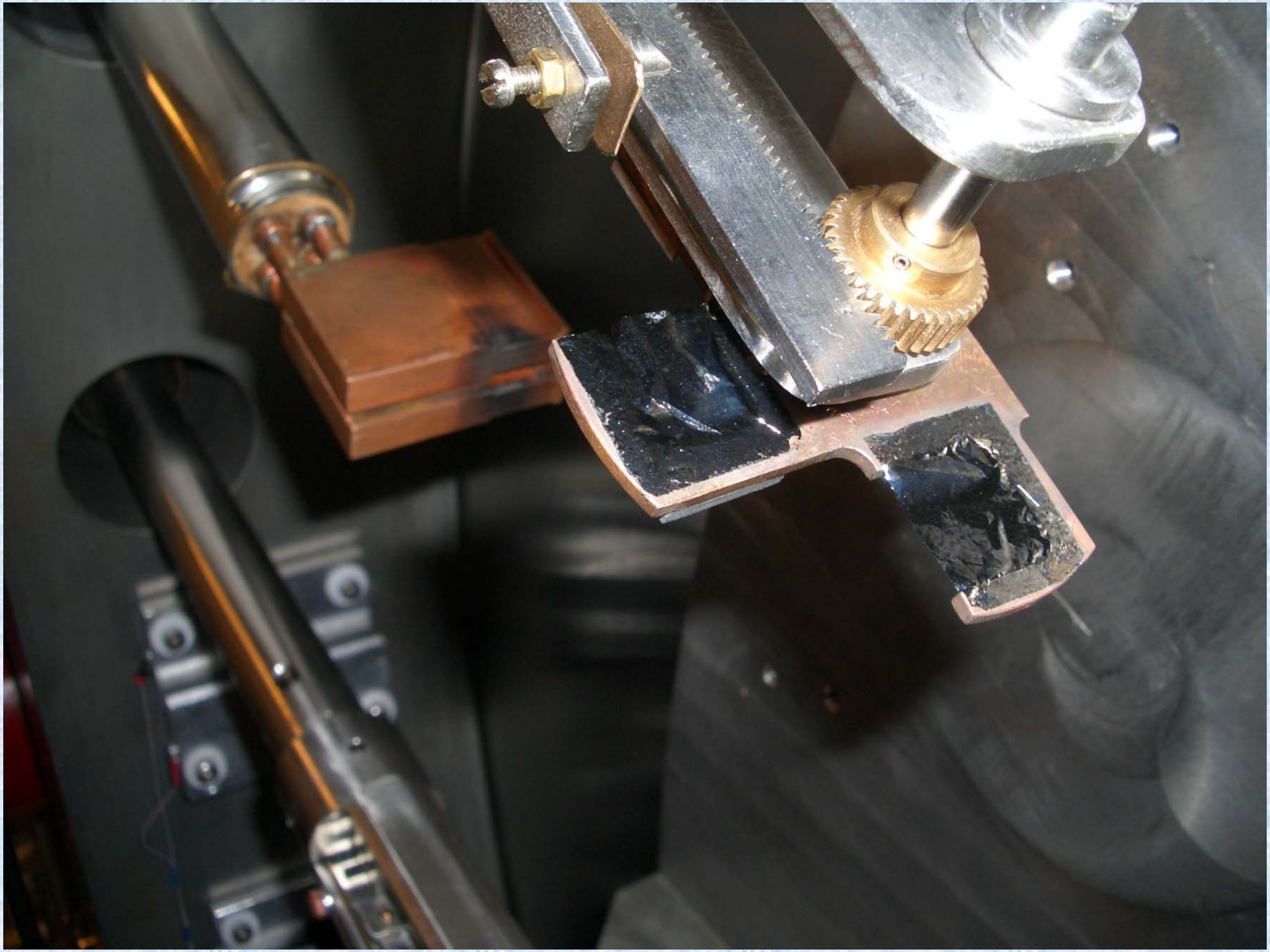
Simultaneous irradiation of two or three targets is possible on these cyclotrons





Beam extraction windows of the CC-18/9 cyclotron

Stripping foils



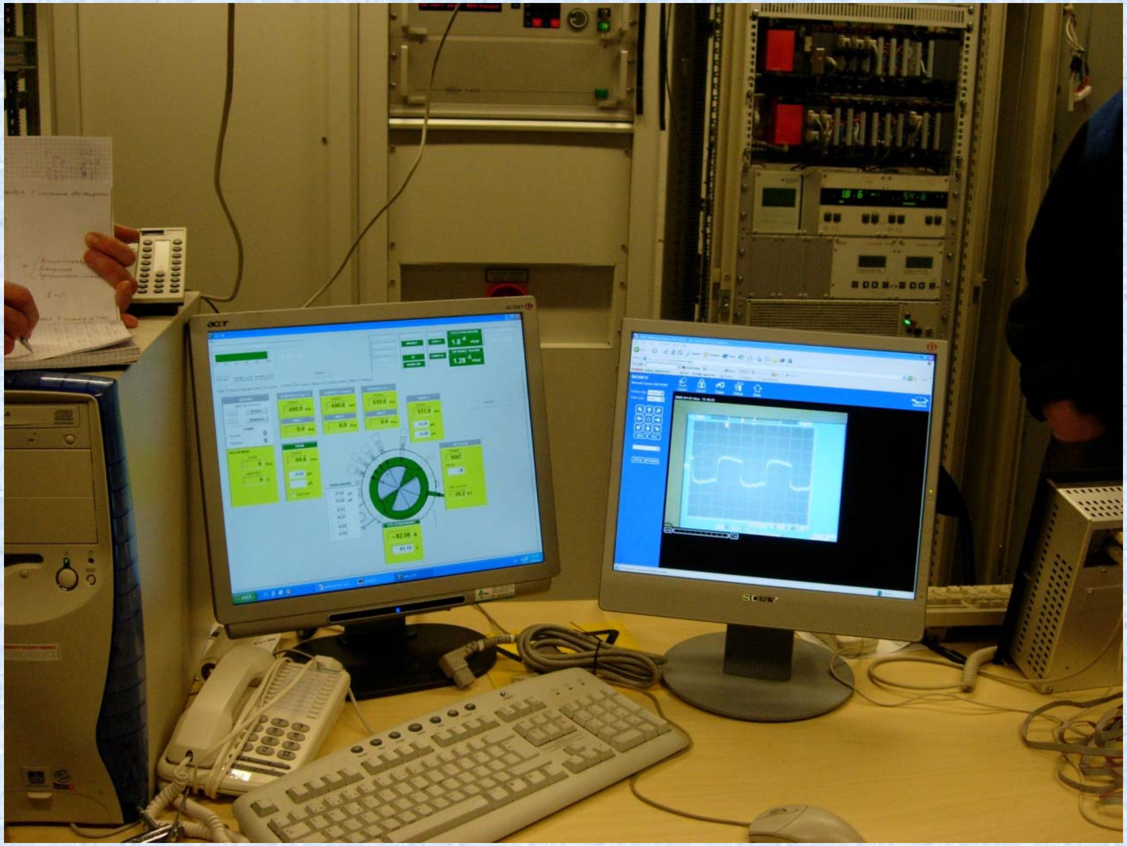
Power Supply System

is built on standard units produced by the Bruker, Glassman and Xantrex firms

The distributed automated control system is built on the basis of programmable logic controllers PLC produced by the Mitsubishi firm. The PROHIBUS and ETHERNET interfaces for data transmission are used.

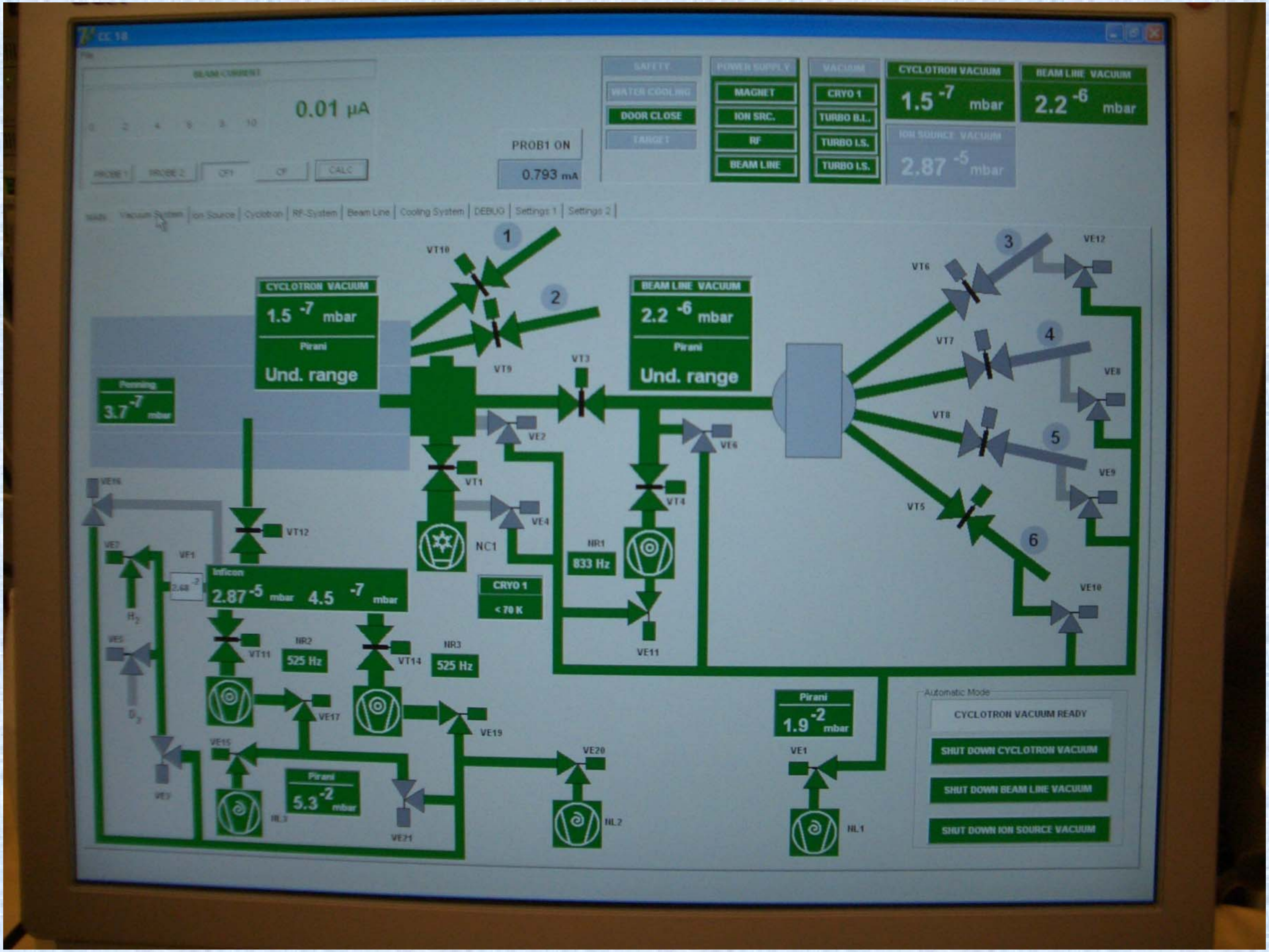
The computer allows the operation of all the systems of the cyclotron to be automatically controlled and a necessary information to be displayed automatically or by demand of the operator.

The configuration chosen ensures the real-time operation of the control system, allows the rapid exchange of information between systems of the cyclotron and display of information.

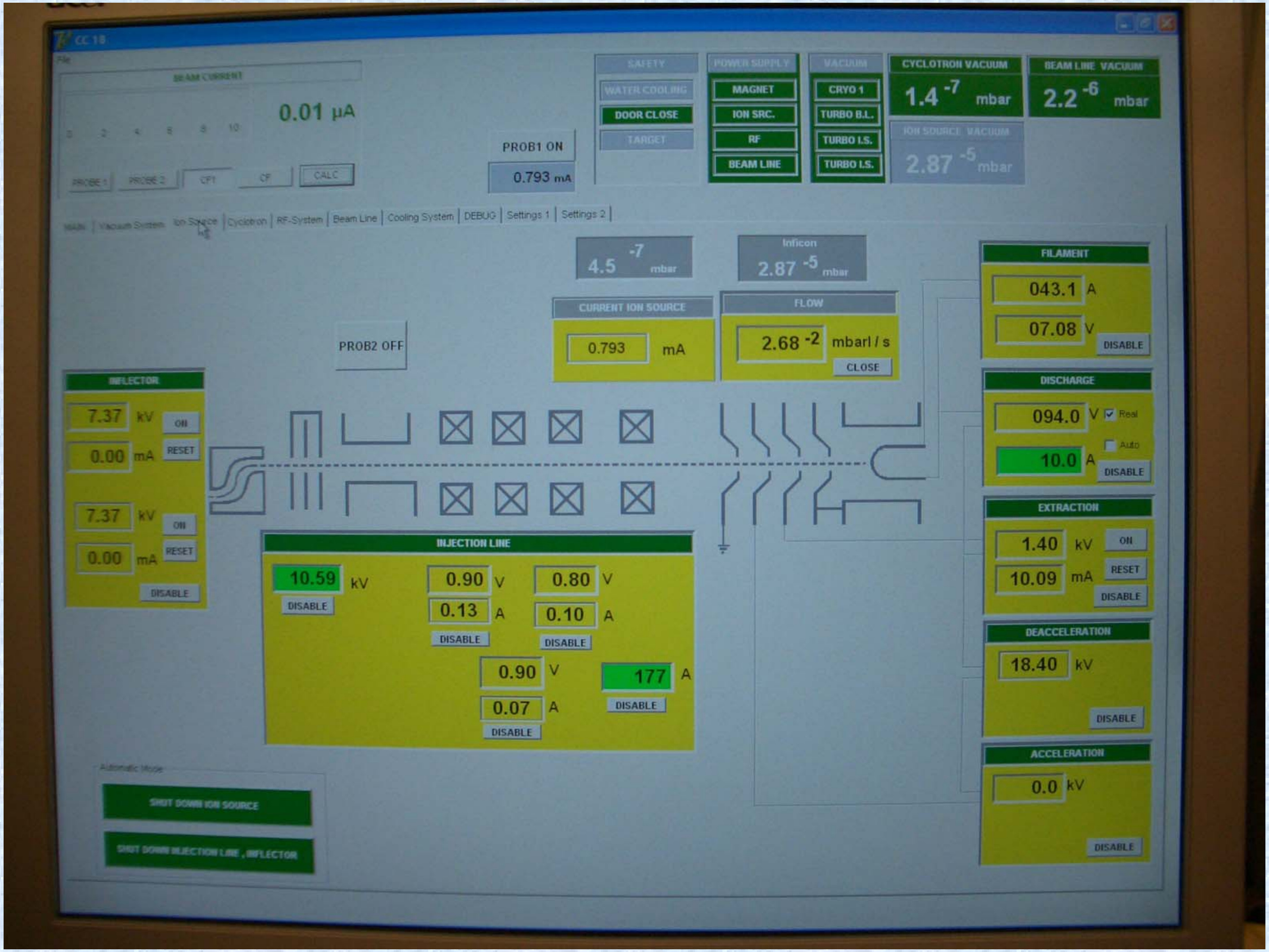


Operator’s workstation.

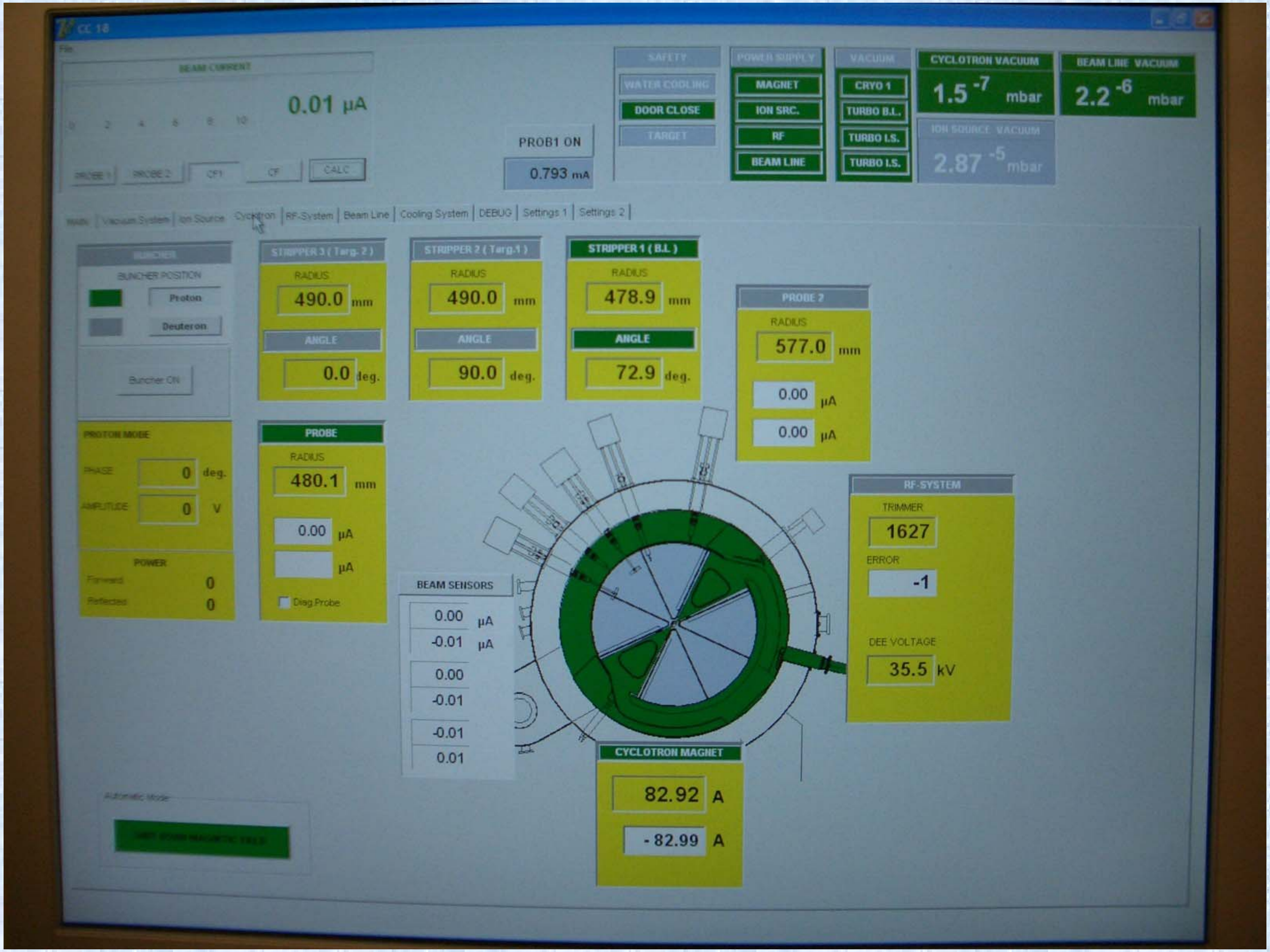
The vacuum system window



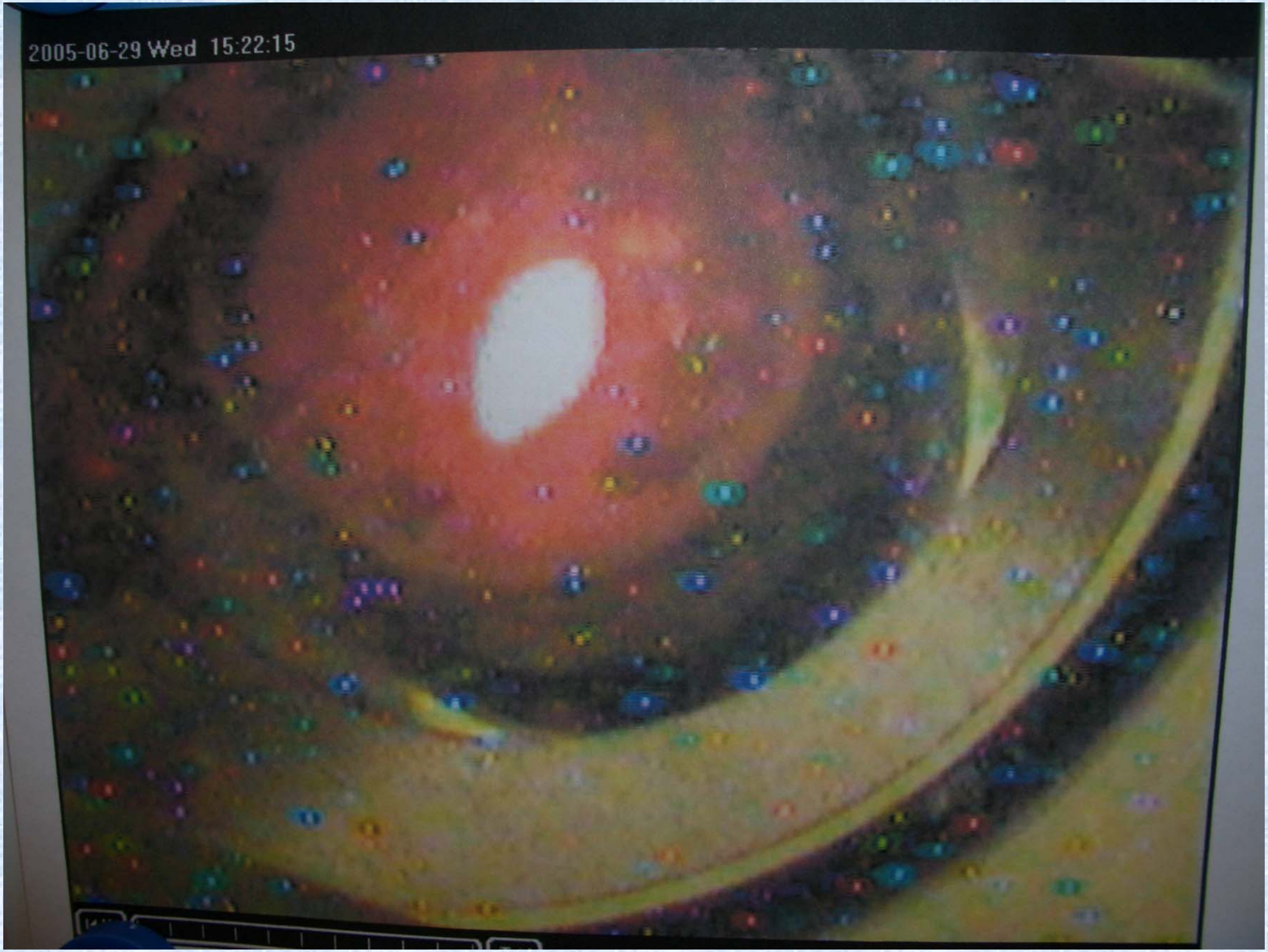
The injection system window

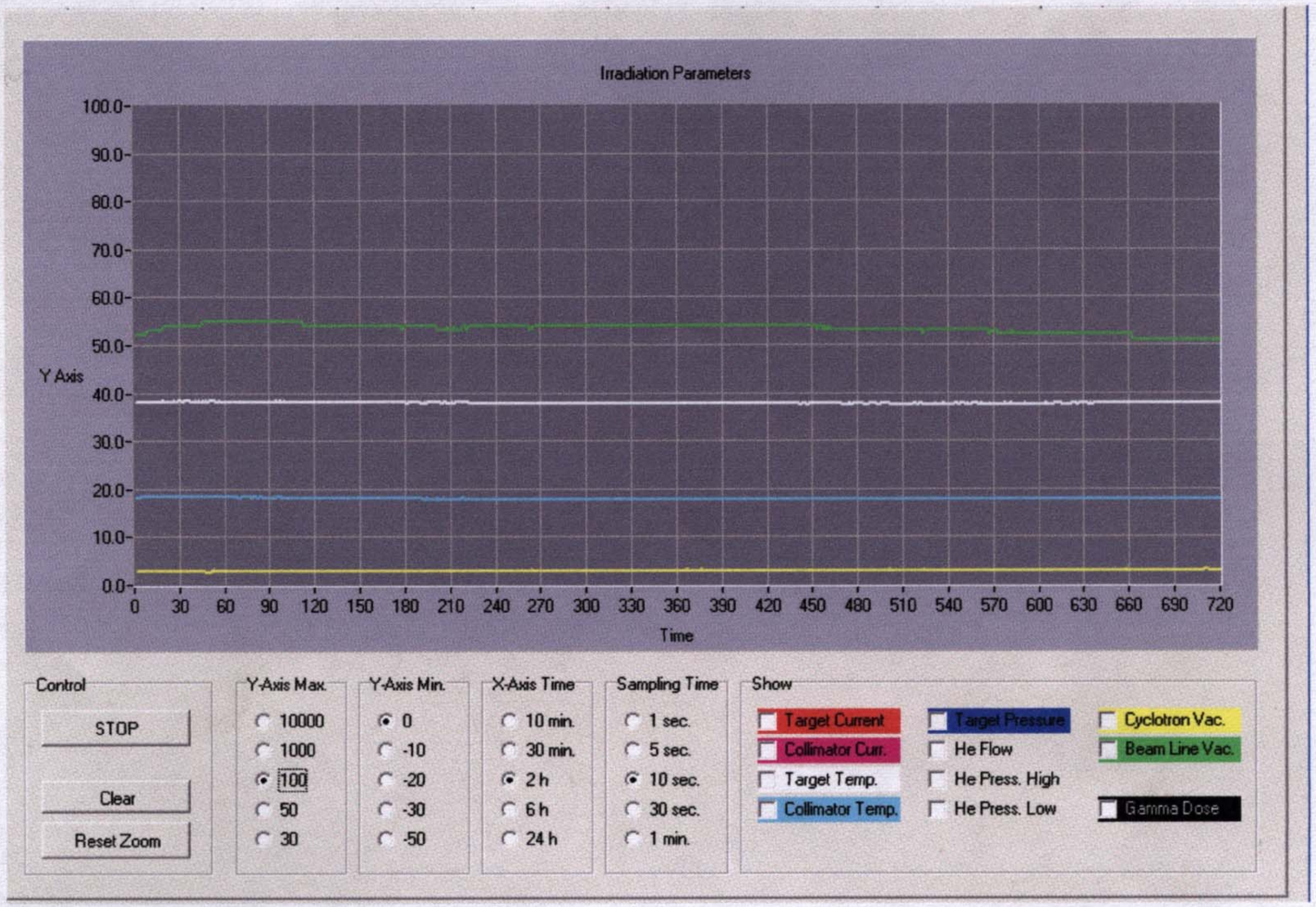


The cyclotron vacuum chamber window



Trace of the 18 MeV accelerated beam of protons on a diagnostic target





Graphs showing temperatures and vacuum during a 2 hour long run to Target position 6 with an average beam current of 39,1 uA, deviation 2.3%. Beam on collimator 2.8 uA.

Two CC-18/9 cyclotrons have been put into operation in PET centers; one in Turku, Finland, and the other in the Central Roentgen Radiological Institute (CRRI) in Pesochnyi, St.Petersburg.

These machines differ in the beam transport systems, four and three remote targets, respectively, are used.

The CC-12 cyclotron is under commissioning now and the MCC-30/15 is at the stage of manufacturing.

THANK YOU FOR ATTENTION!