High Brightness Negative Ion Sources with High Emission Current Density

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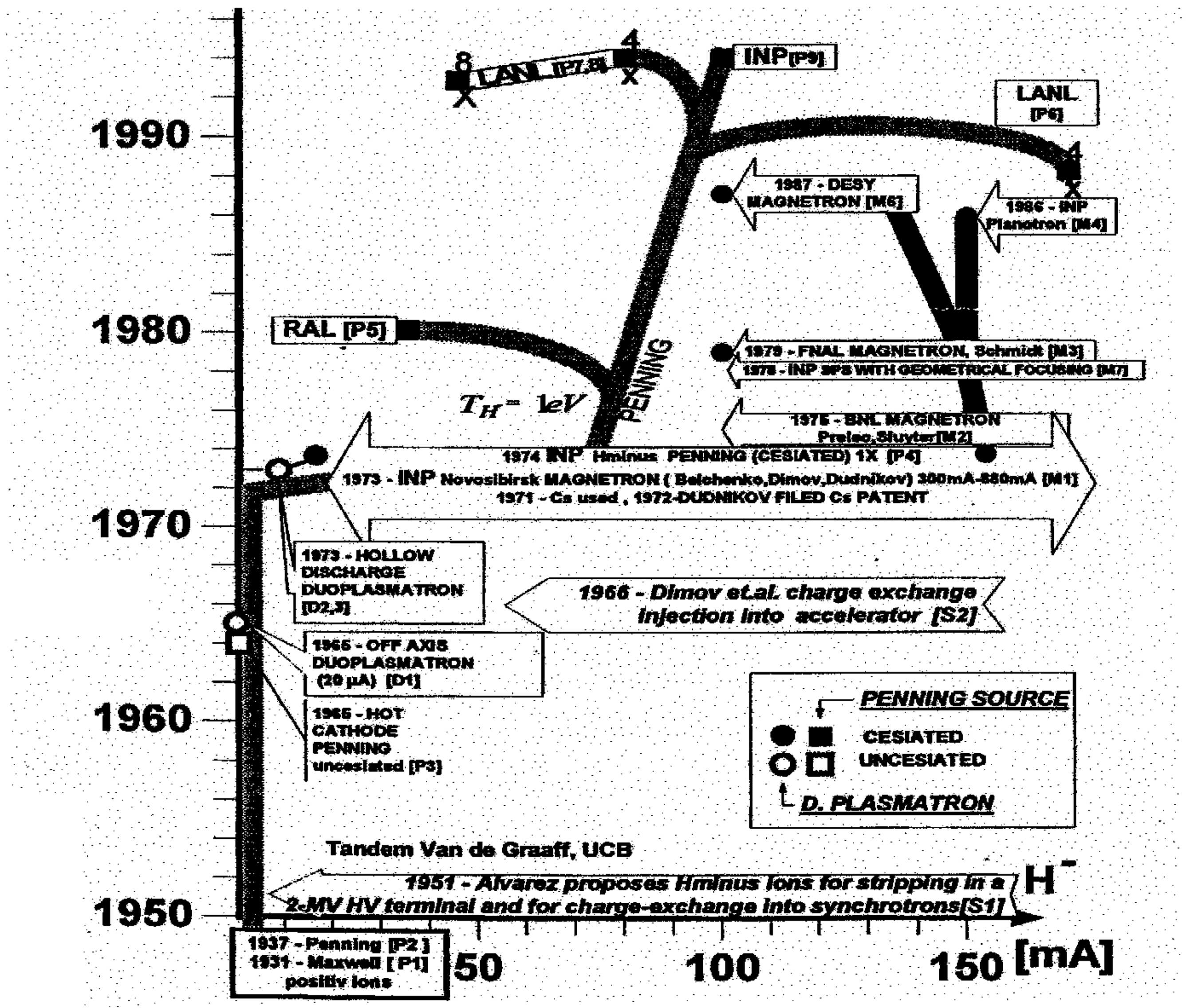
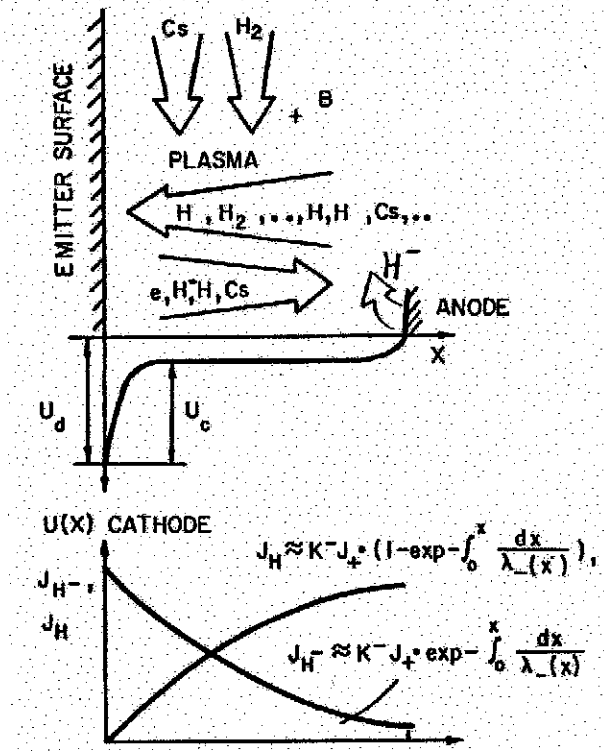
History of Surface Plasma Sources Development

(J.Peters, RSI, v.71, 2000)

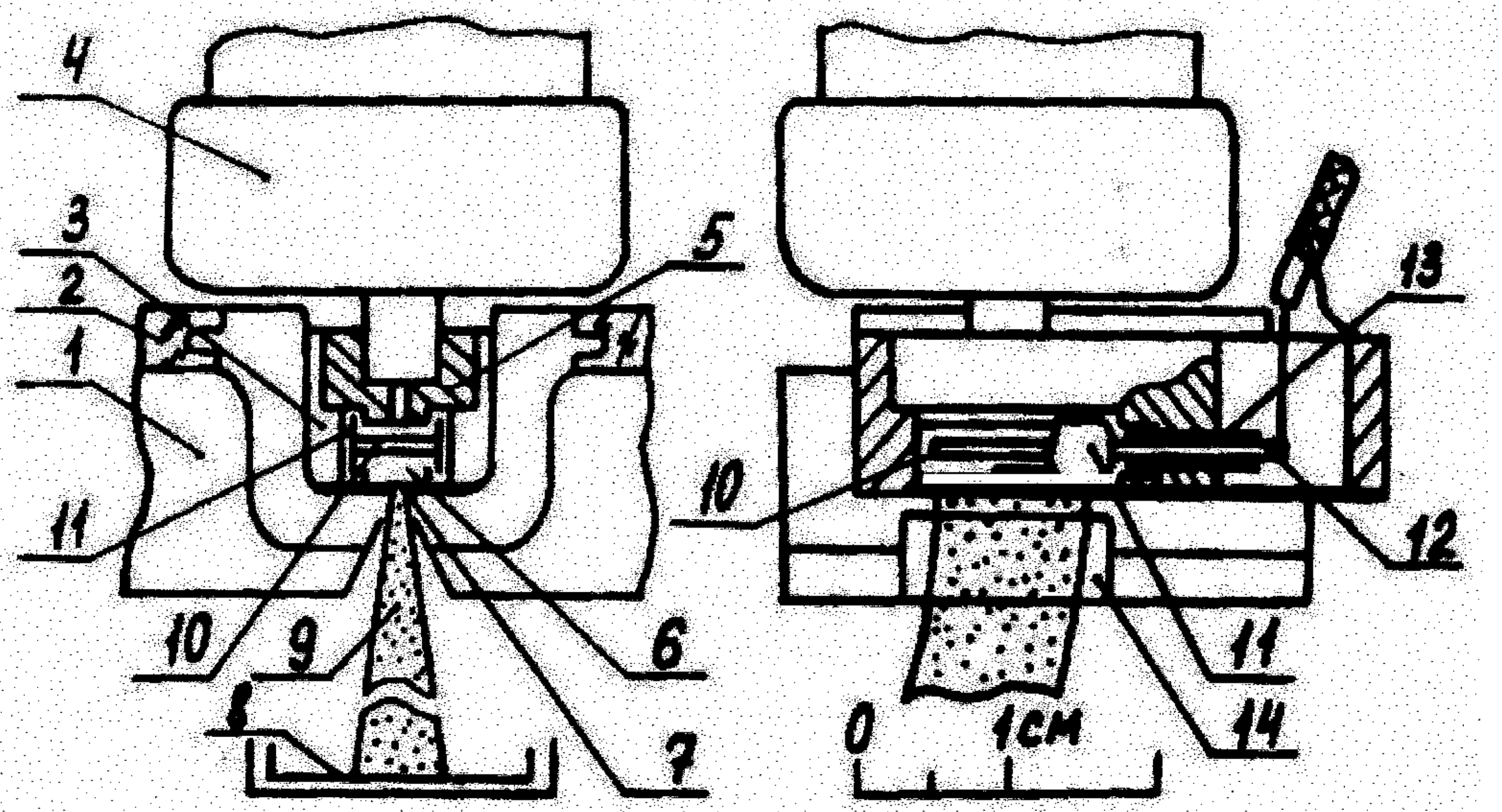


General Diagram of the Surface-Plasma Mechanism for Production of Negative Ions in a Gas Discharge

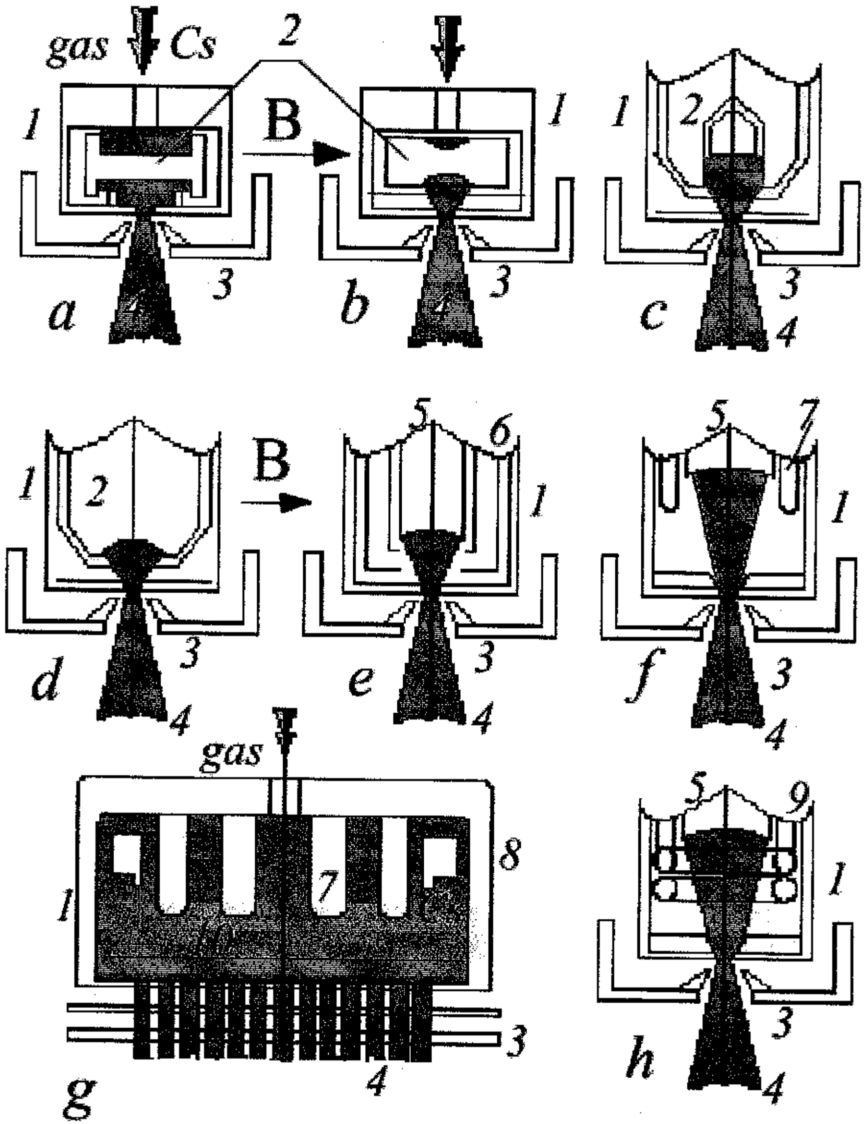


However, since the negative ions are rapidly destroyed as a result of passing through the plasma and gas, the majority of accelerated negative ions will not lose an electron to become an accelerate atom only when the layer of plasma and gas between the emitter and the beam-forming system is very thin.

First version of Planotron (Magnetron) SPS, INP, 1971, Beam current up to 370 mA, 1x10mm^2



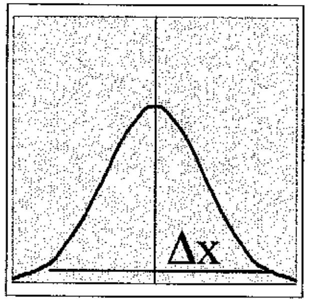
Schematic Diagrams of Surface Plasma Sources

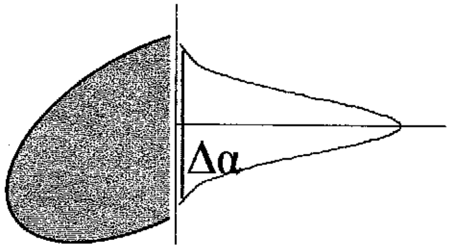


(a) planotron (magnetron) flat cathode
(b) planotron geometrical focusing (cylindrical and spherical)
(c) Penning discharge SPS (Dudnikov type SPS)
(d) semiplanotron
(e) hollow cathode discharge SPS with independent emitter
(f) large volume SPS with filament discharge and based emitter
(g) large volume SPS with anode negative ion production
(h) large volume SPS with RF plasma production and emitter

1- anode	6- hollow cathode
2- cold cathode emitter	7- filaments
3- extractor with magnetic system	8- multicusp magnetic wall
4- ion beam	9- RF coil
5- biased emitter	10- magnetic filter

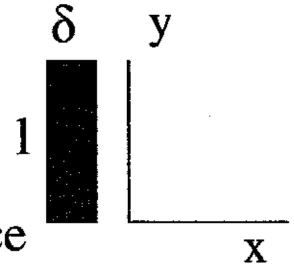
Emittance, Brightness, Ion Temperature





Emission slit

$$\delta \times l = 0.5 \times 10 mm^2$$



Emittance

$$V_x = \Delta x \cdot \Delta \alpha_x$$
$$V_y = \Delta y \cdot \Delta \alpha_y$$

Normalized emittance

$$E_x = V_x \cdot \beta = \Delta V_x \cdot \Delta x / c$$
$$E_y = V_y \cdot \beta = \Delta V_y \cdot \Delta y / c$$

$\beta = V_z / c$

Normalized brightness

$$B = \frac{2I^-}{\pi^2 E_x E_y} = \frac{2jc^2}{\pi^2 \Delta V_x \Delta V_y} = \frac{2jMc^2}{\pi^2 \sqrt{\Delta W_x}\sqrt{\Delta W_y}} \approx \frac{2jMc^2}{\pi^2 T_{if}}$$

Half spreads of energy of the transverse motion of ions

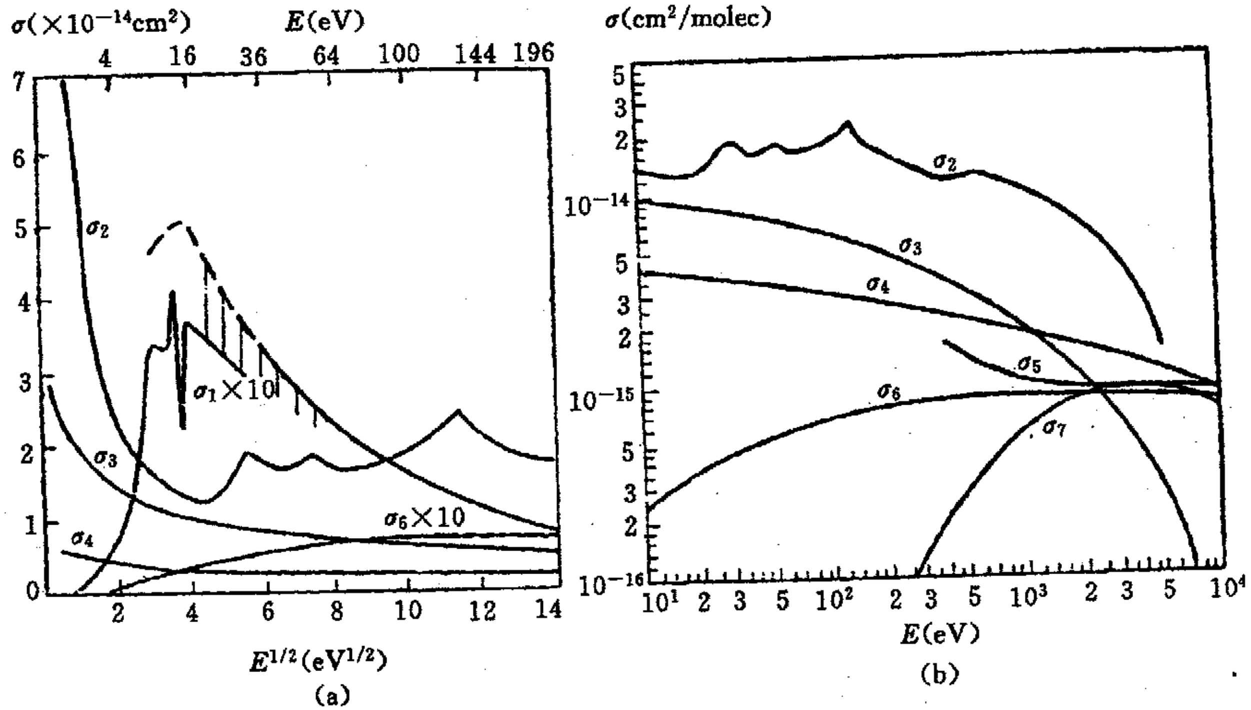
$$\Delta W_x = \frac{Mc^2 E_x^2}{2\Delta x^2} \qquad \Delta W_y = \frac{Mc^2 E_y^2}{2\Delta y^2}$$

Reduced to the plasma emission slit

$$\Delta W_{ox} = \frac{2Mc^2 E_x^2}{\delta^2} \qquad \Delta W_{oy} = \frac{2Mc^2 E_y^2}{l^2}$$

Characteristics of quality of the beam formation: $\Delta W_{0x} = 5 keV \rightarrow 0.5 eV$

H^- Detachment by Collisions with Various Particles and Resonance Charge-Exchange Cooling



$\sigma_1 : H^- + e \Rightarrow H + 2e;$

$\sigma_2 : H^- + H^+ \Rightarrow H \;\; + H \;\; ;$

$\sigma_3 : H^- + H \Rightarrow H + H^- ;$

$\sigma_4 : H^+ + H \Rightarrow H + H^+;$

$\sigma_5 : H^- + H \Rightarrow H + H \;\; + e$

$\sigma_6 : H^- + H_2 \Rightarrow H + H_2 \;\; + e;$

Resonance charge -exchange cooling

Discharge Stability and Noise

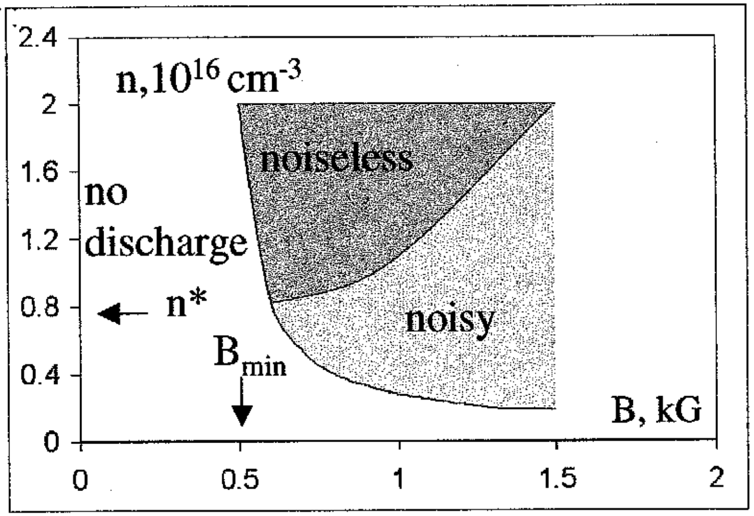
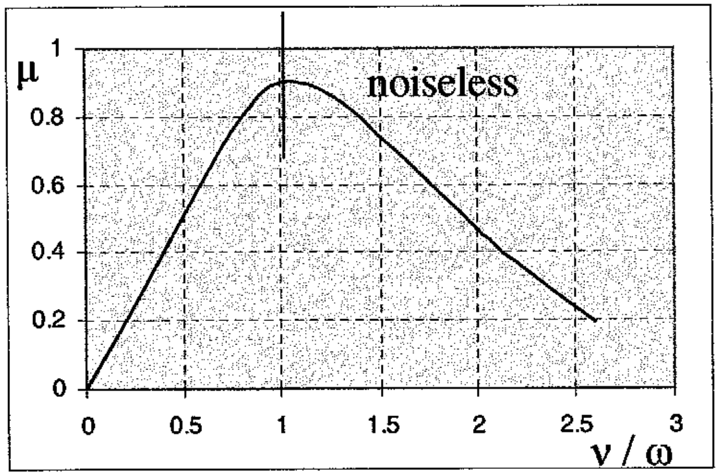


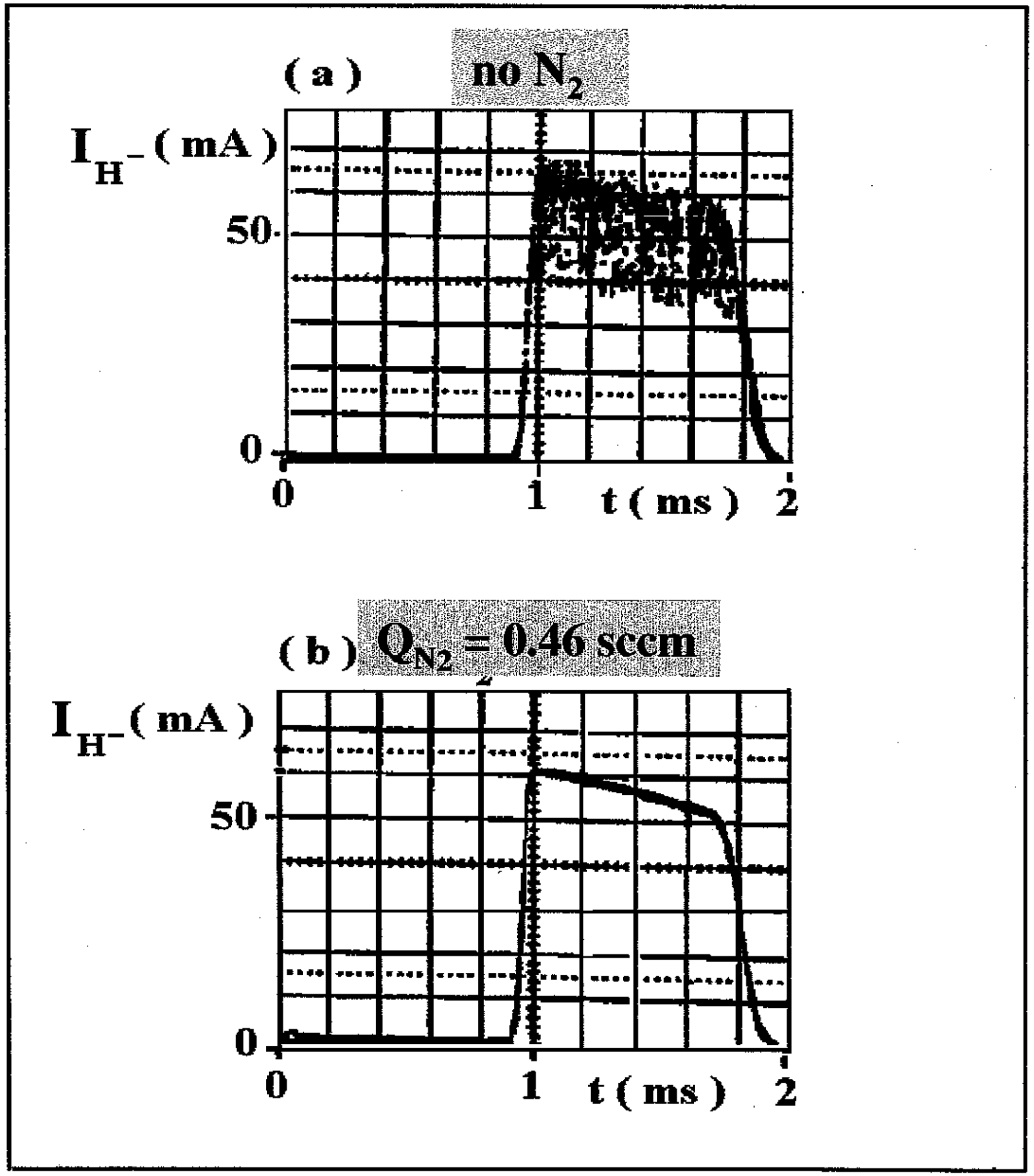
Diagram of discharge stability in coordinates of magnetic field B and gas density n

$\mu = e\nu/m\,(\nu^2 + \omega^2)$



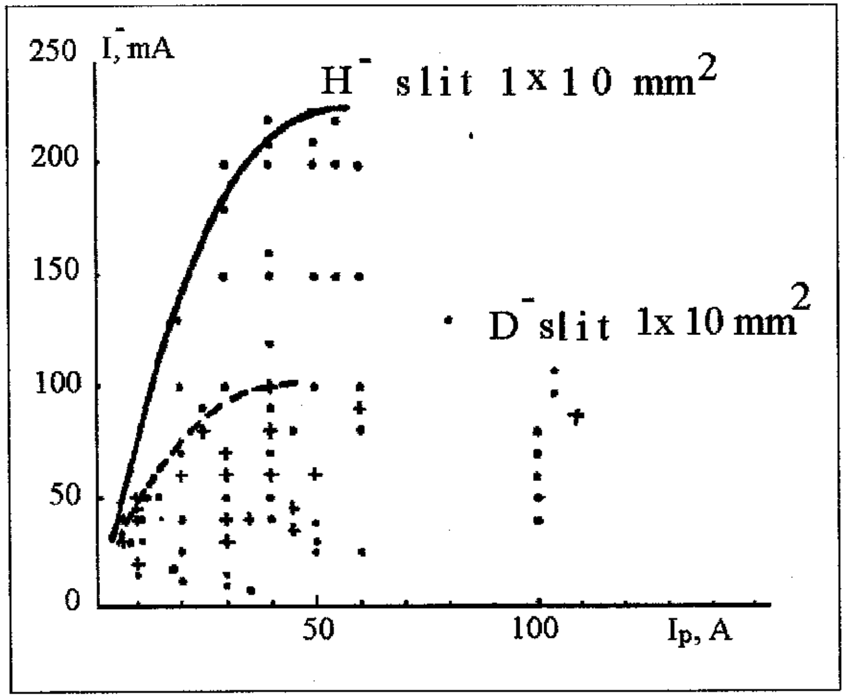
The effective transverse electron mobility μ vs effective scattering frequency ν and cyclotron frequency ω

Discharge Noise Suppression by Admixture of Nitrogen

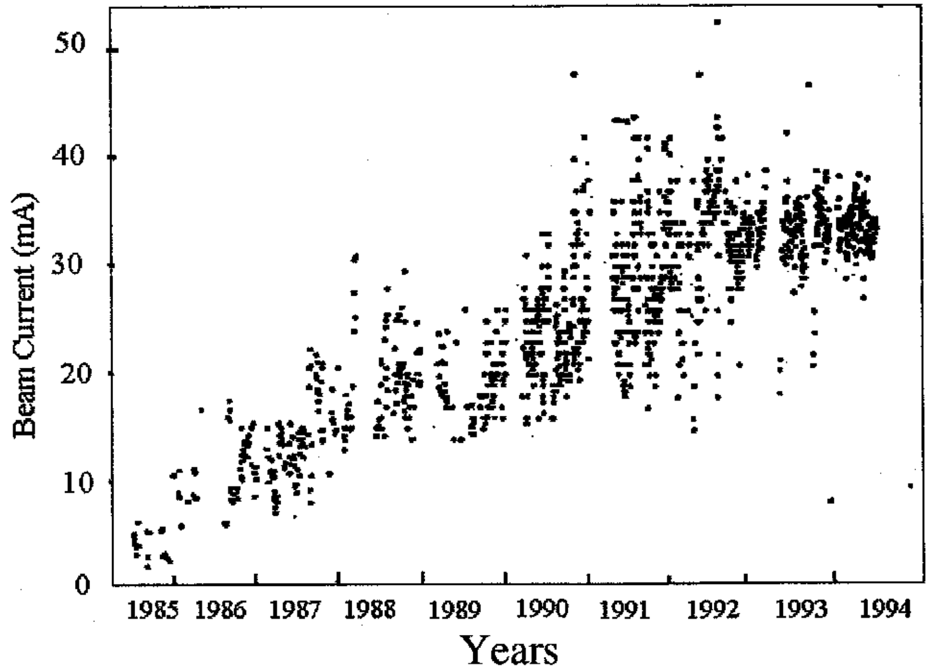


P.Allison, V. Smith, et. al. LANL

H^- Beam Intensity of SPS



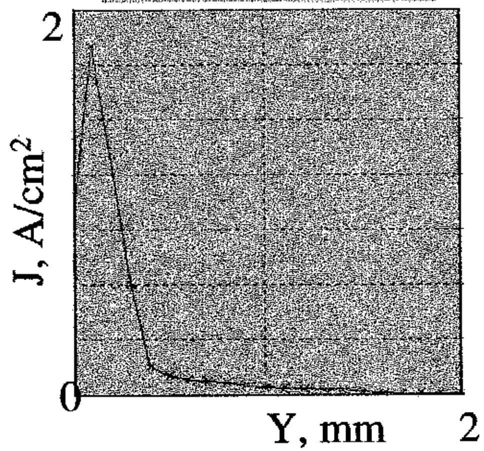
Beam intensity vs discharge current for first version of semiplanotron



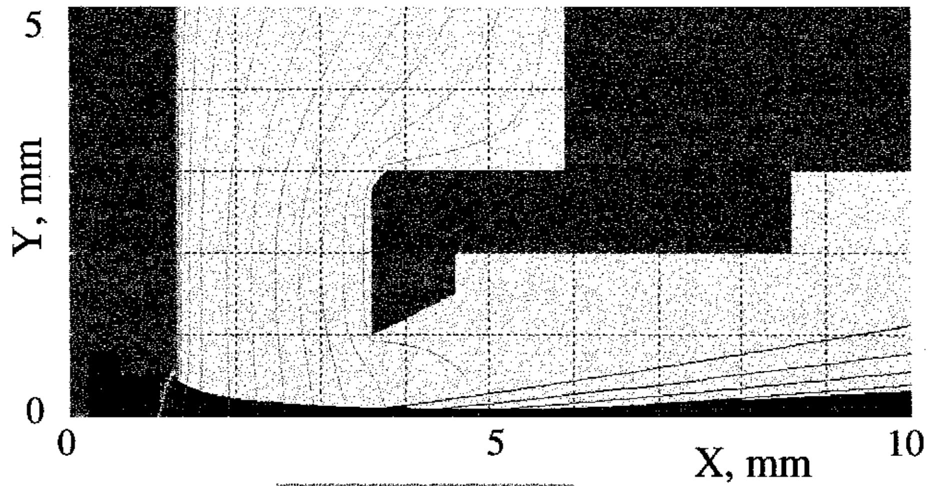
Evolution of H^- beam intensity in ISIS

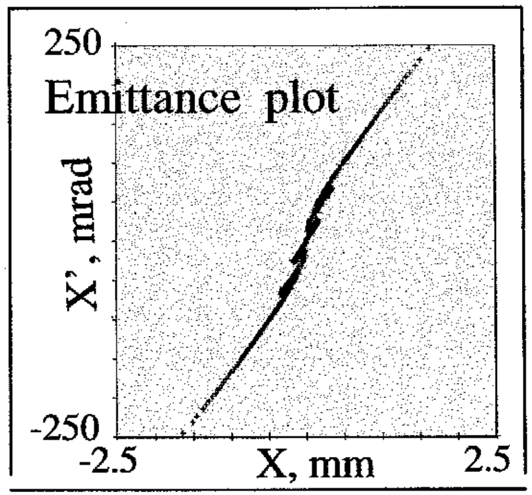
Simulation of H^- Ion Beam Extraction from the Slit Magnetron

Current density



Electrodes trajectories and equipotentials

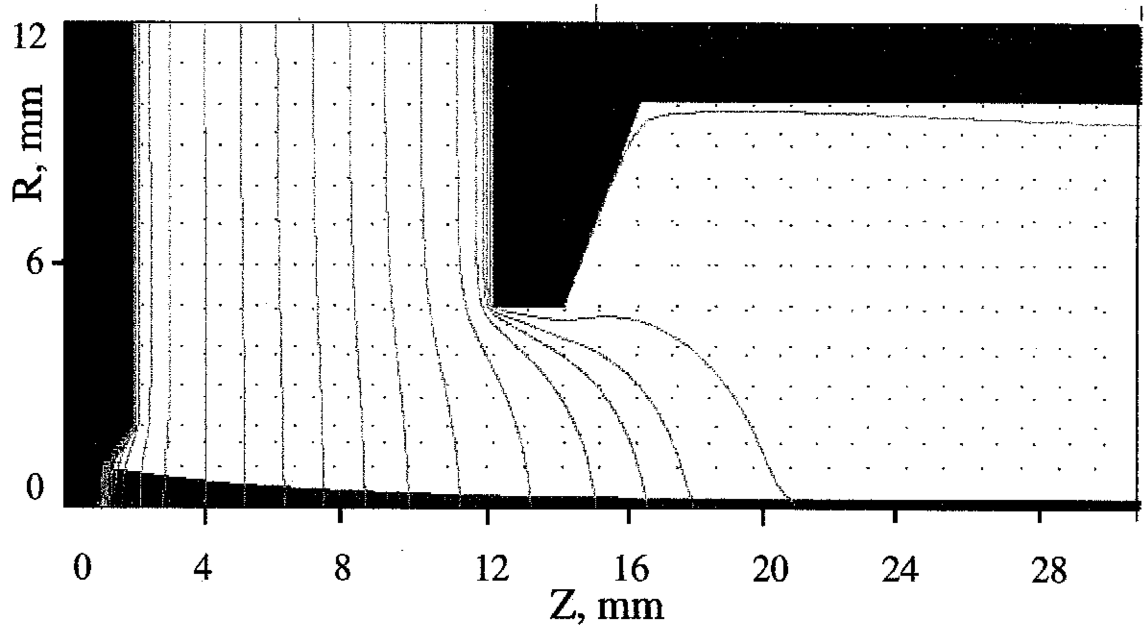




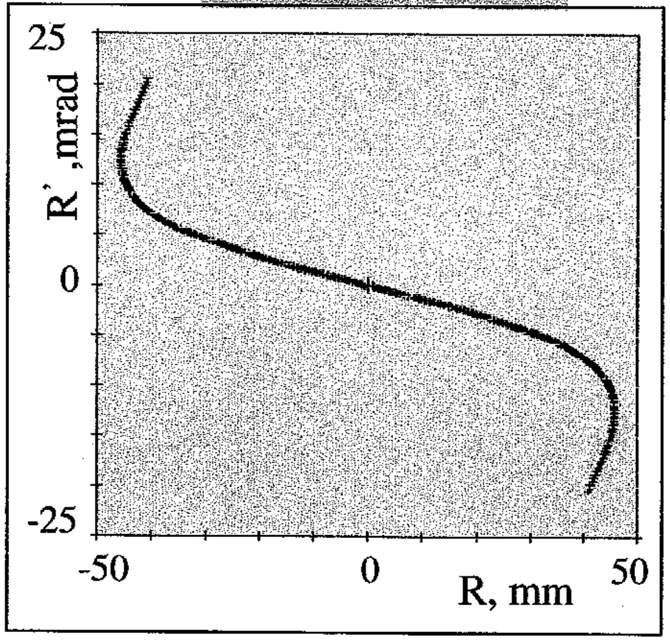
Slit 2x10 mm
I=87 mA
U=21 kV
neutral 95%

Computer Simulation of H^- Beam Formation
PBGUNS

Electrodes, trajectories and equipotentials

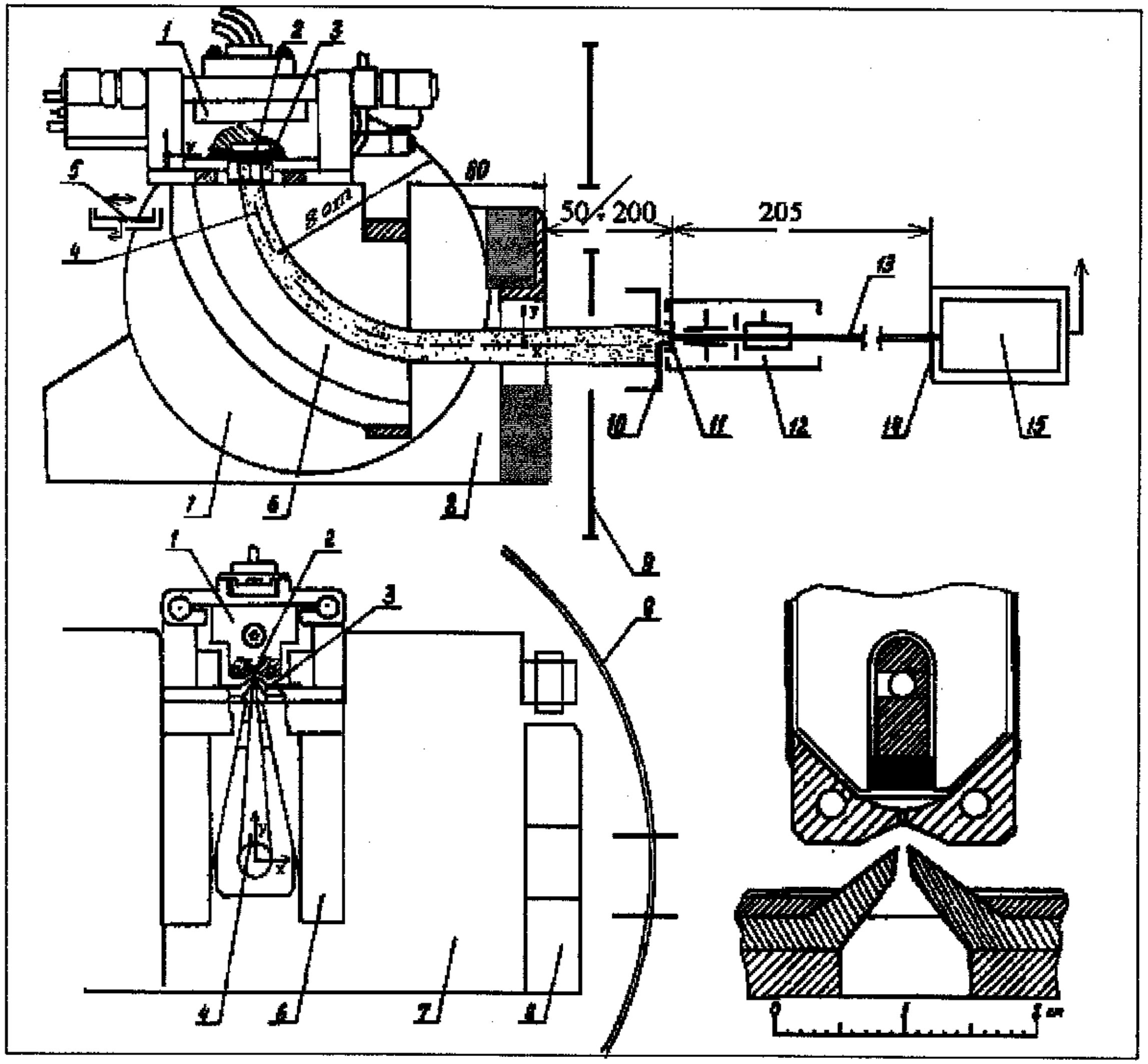


Emittance plot

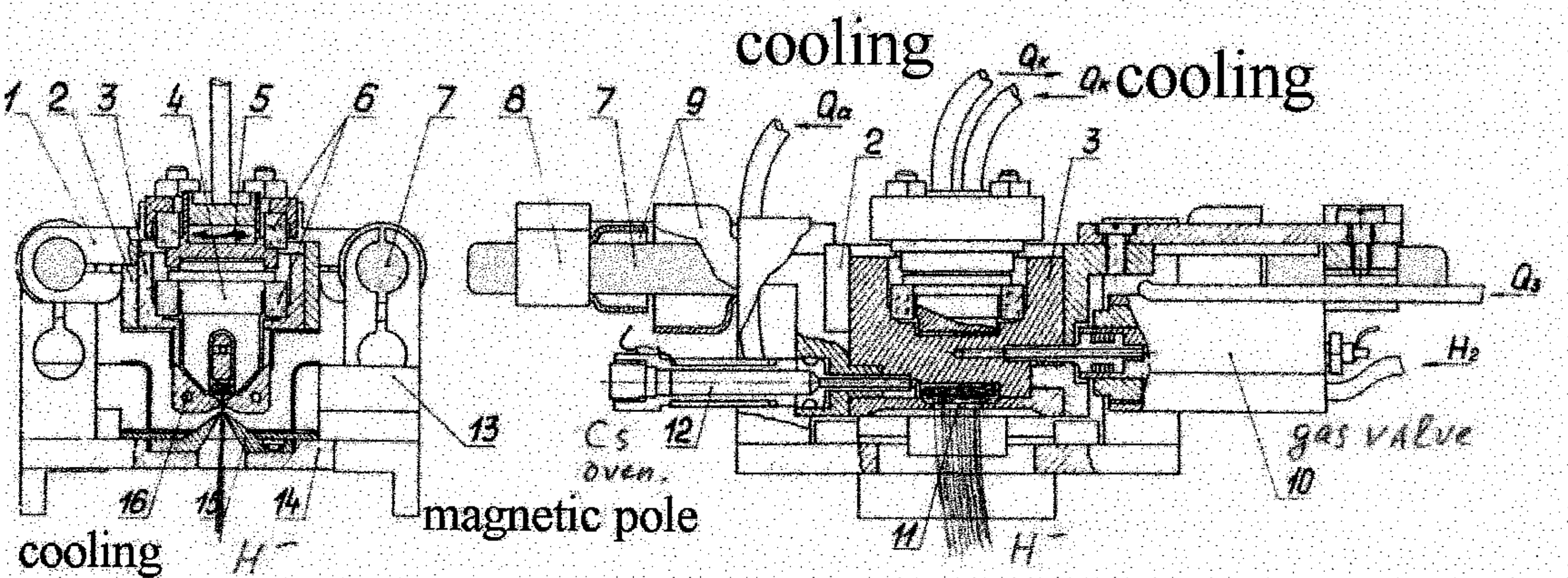


Aperture diameter 0.4 mm, I=1.5 mA

Beam Formation and Diagnostics of SPS with Penning Discharge



Design of SPS with Penning Discharge



Beam current 0.1 (0.15) A,
Extraction 22 kV
Repetition 100 Hz(teste up to 400Hz)
Puls 0.25 ms
discharge volume 6x3.5x15 mm^3
emission slit 0.5x10mm^2

FIG. 8. Surface-plasma negative ion source with Penning discharge (Dudnikov type ion source). (1) support; (2) gas discharge chamber; (3) anode insert; (4) cathode; (5) cathode cooler; (6) cathode insulator; (7) high-voltage insulator; (8) support; (9) insulator screens; (10) gas valve; (11) emission slit; (12) cesium container; (13) magnetic pole; (14) base plate; (15) extractor; (16) cooling channal.

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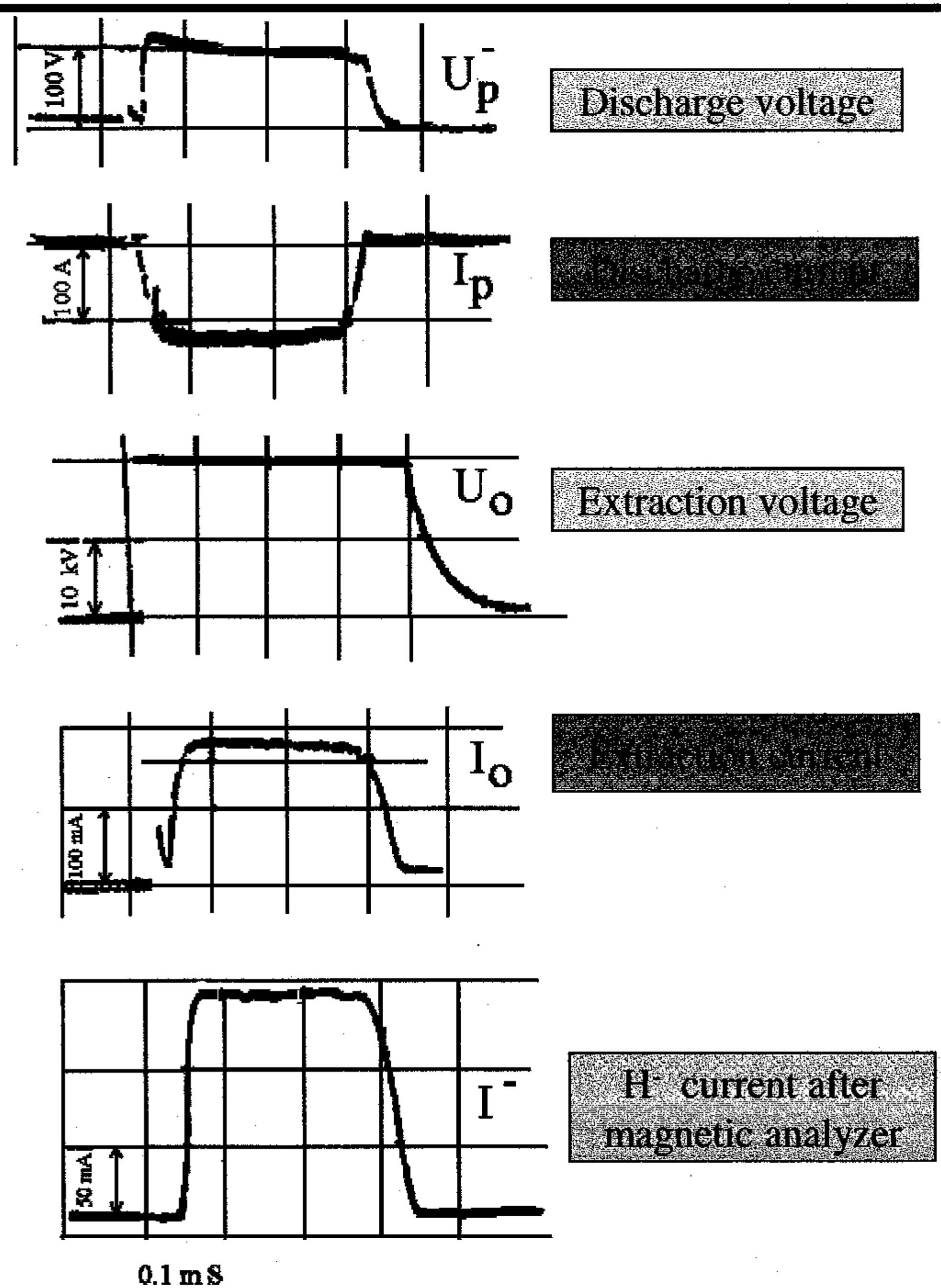
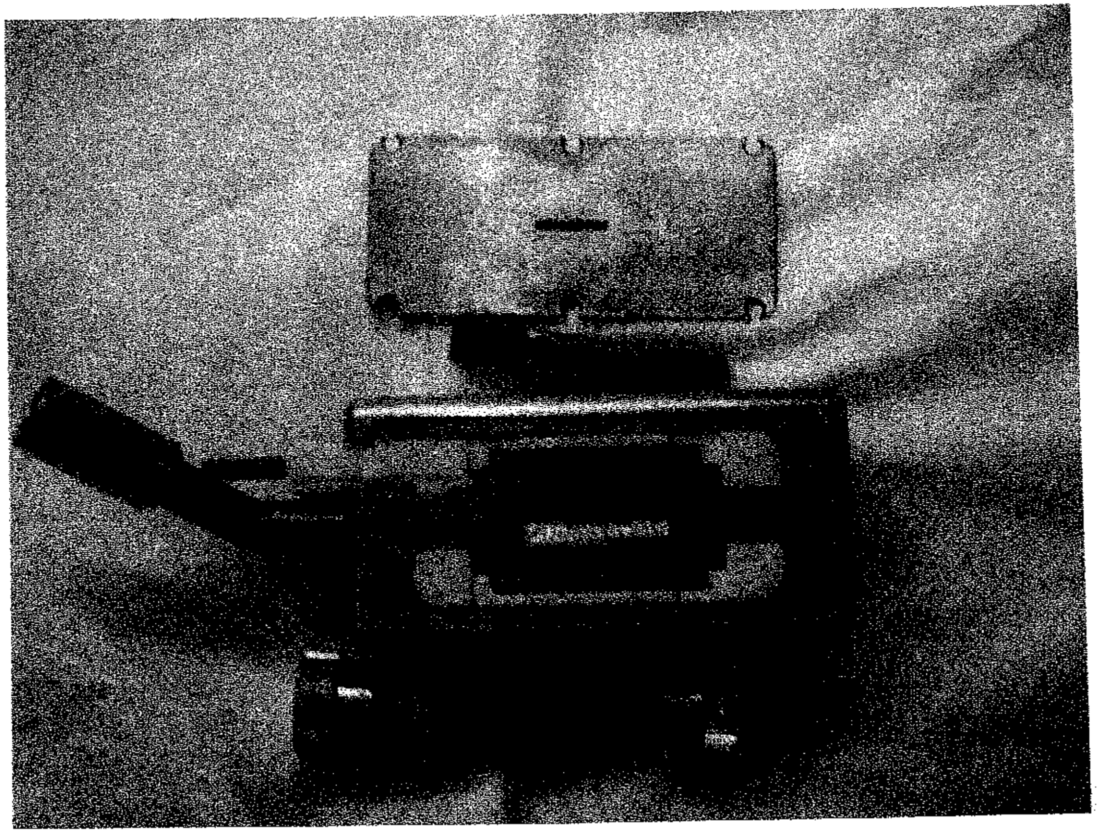


Noiseless operation

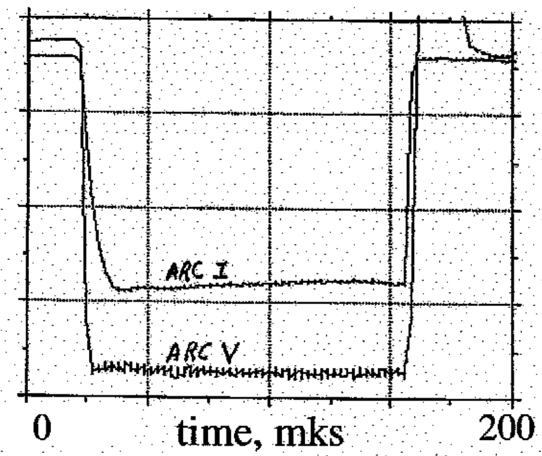
100 Hz

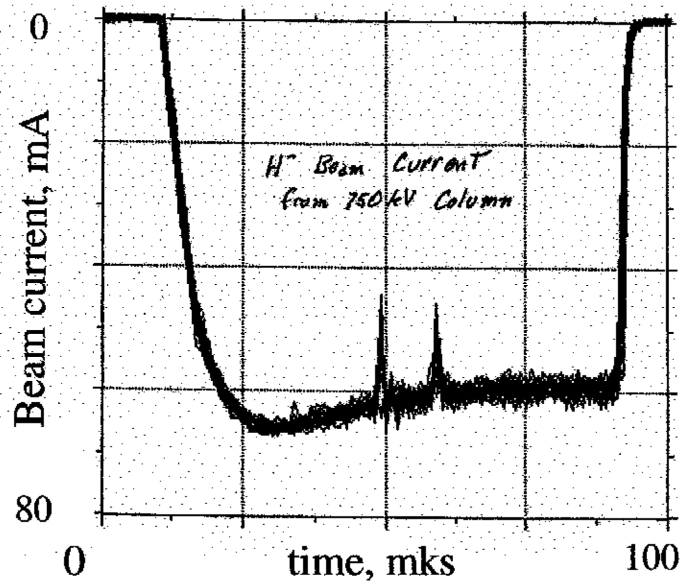
Tested for 300 hs of continuous operation

Fermilab Magnetron with a Slit Extraction

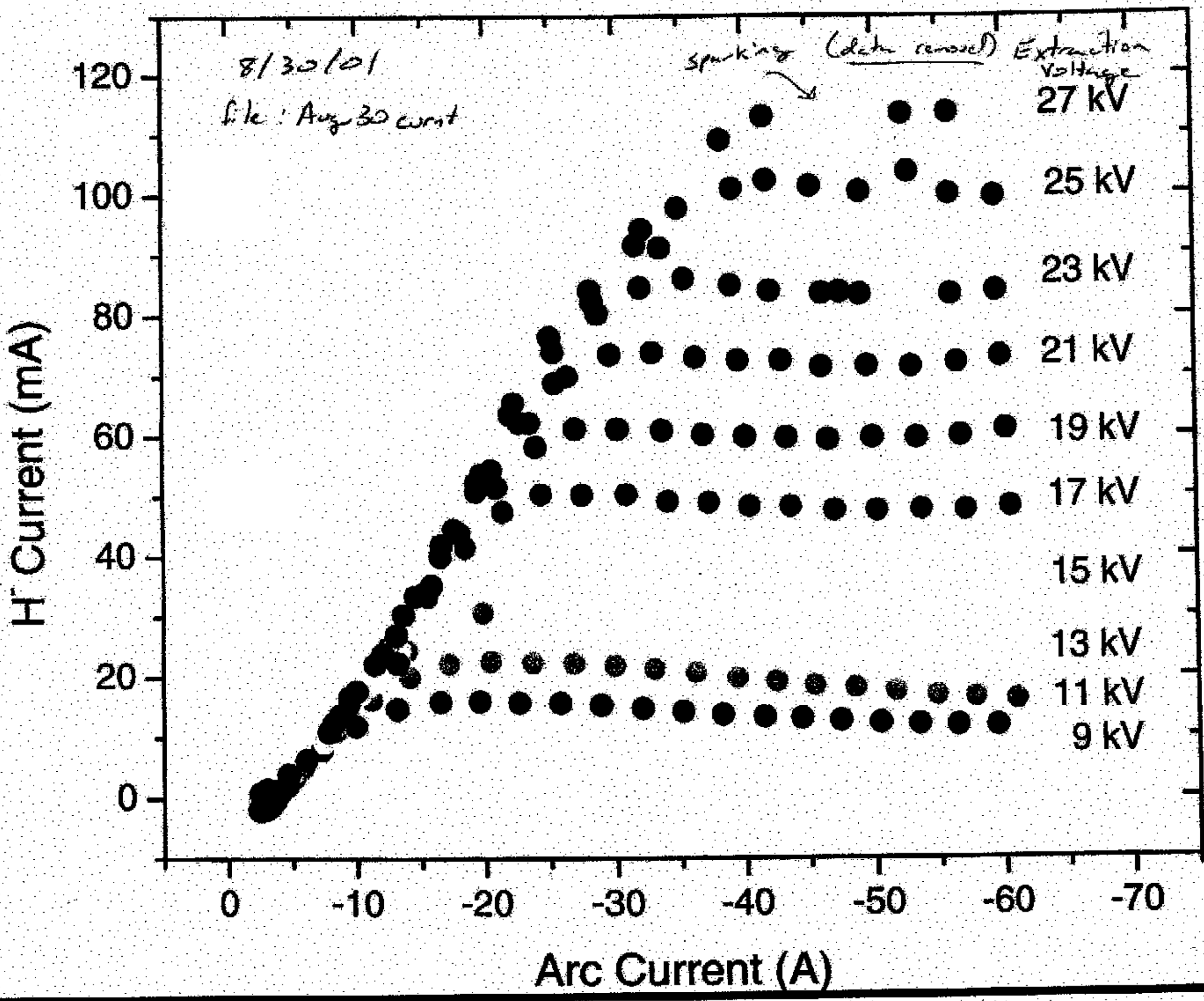


Discharge Parameters and Beam Intensity in Fermilab Magnetron

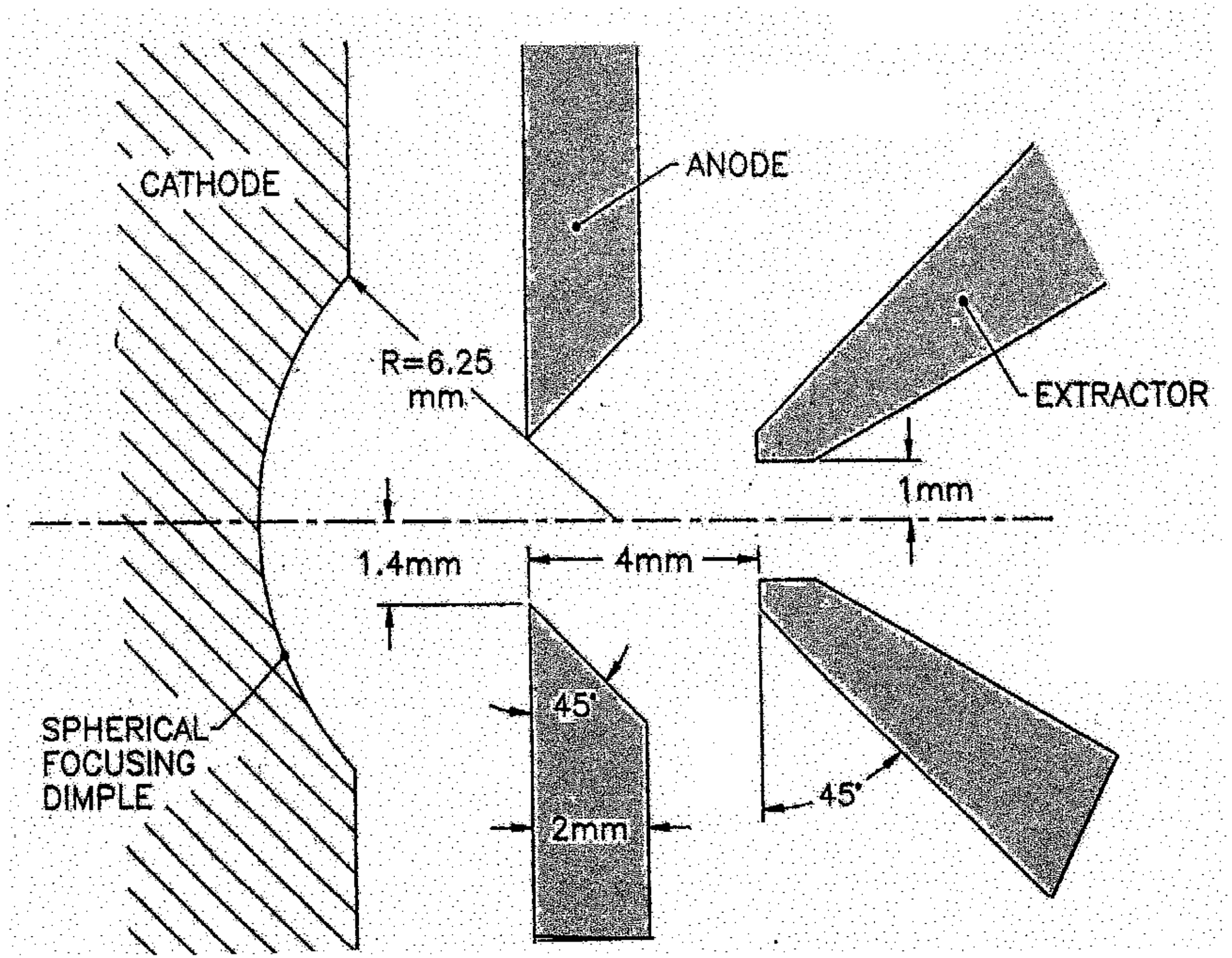




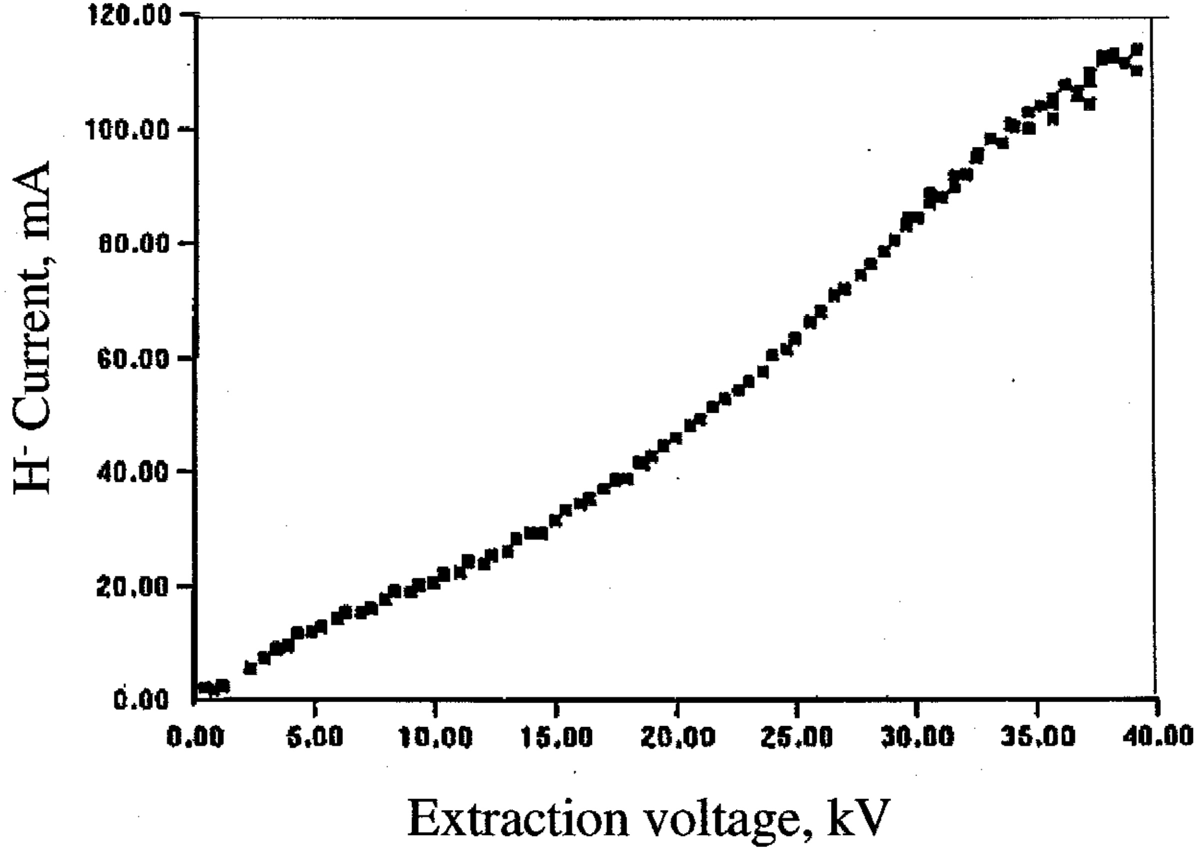
Beam Intensity vs Discharge Current and Extraction Voltage in Fermilab Magnetron



Extraction System of BNL Magnetron

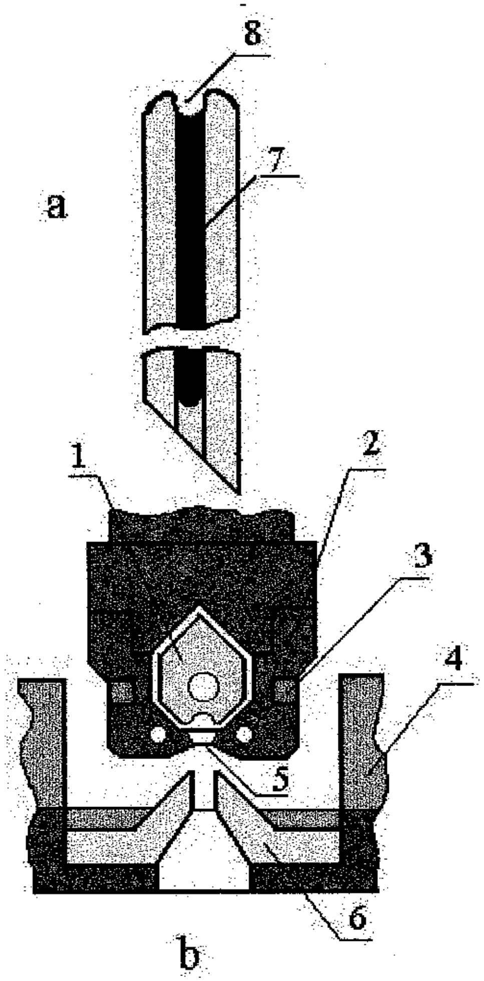


H^- Current vs Extraction Voltage for Magnetron



Design of the first Version of Semiplanotron SPS

V. Dudnikov, INP, 1976



1- Cathode 5cm long;

2- Anode -discharge chamber;

3- Magnetic insert;

4- Magnetic poles;

5-emission slit, d=0.5 mm;

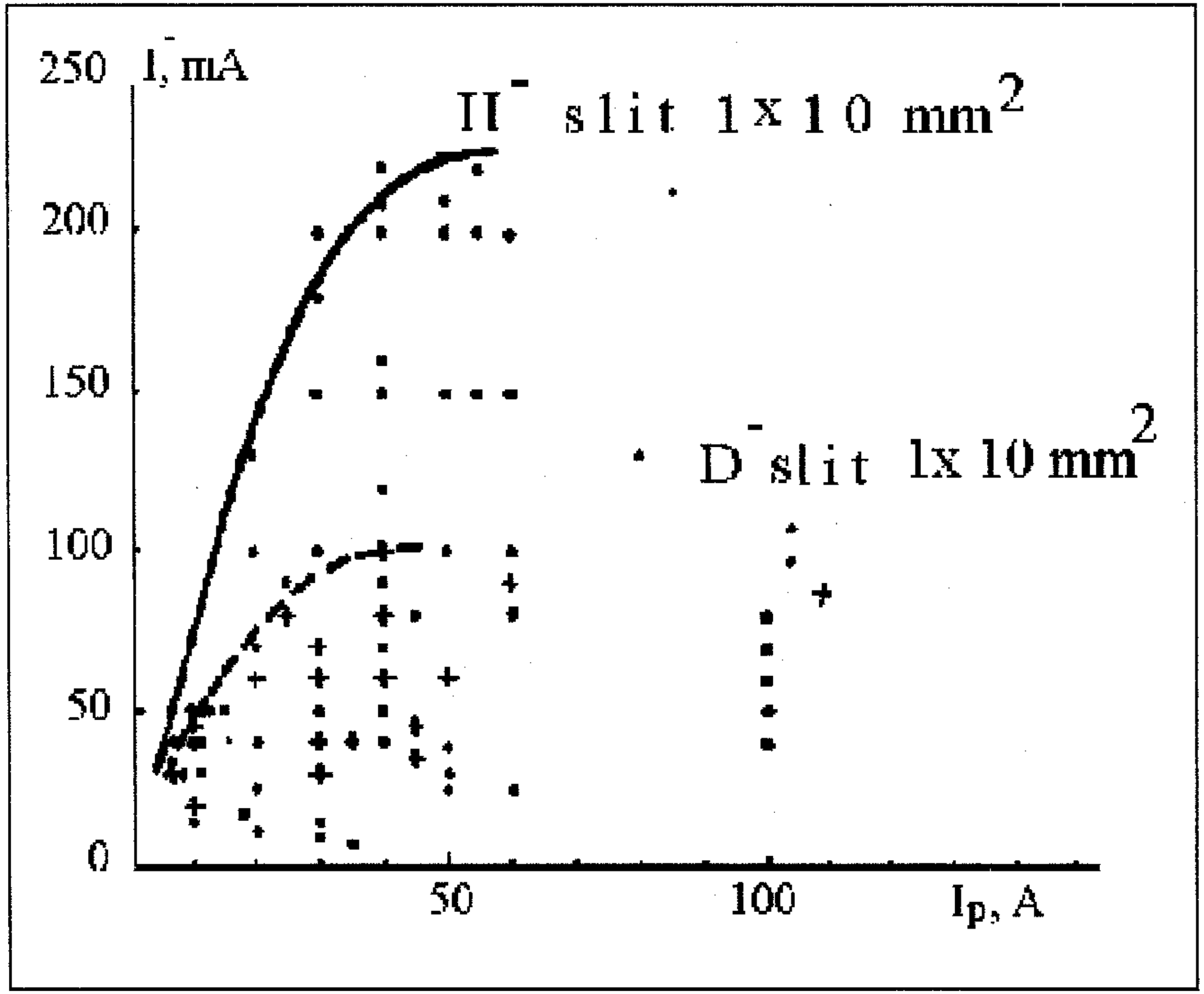
6- Extractor;

7- cylindrical grove for plasma confinement;

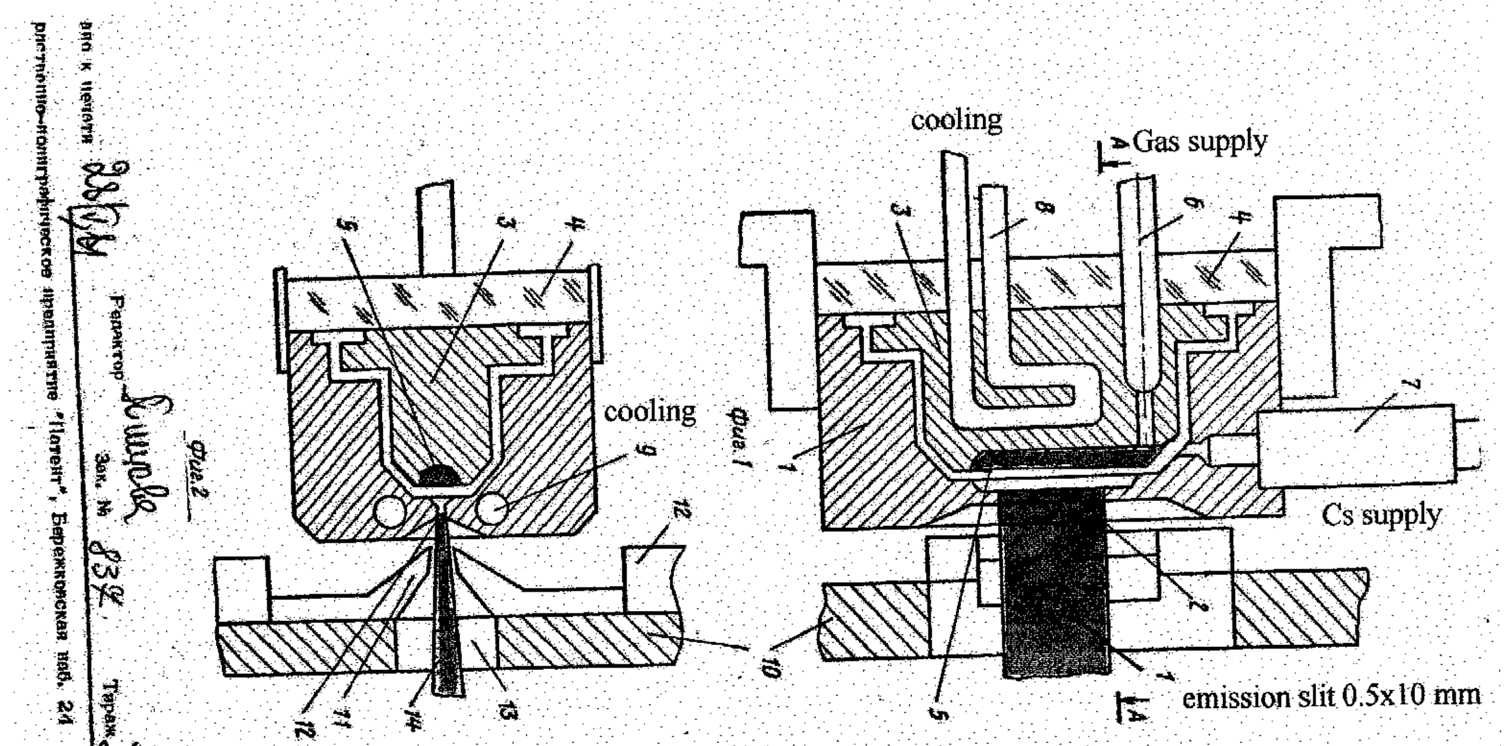
8- plasma trap for discharge triggering.

H^- Beam up to 0.9 A, 1 ms, 10 Hz, slit 0.7x45 mm^2 ; 0.22 A, slit 1x10 mm^2 .

NI Beam intensity as function of discharge current in the Semiplanotron SPS

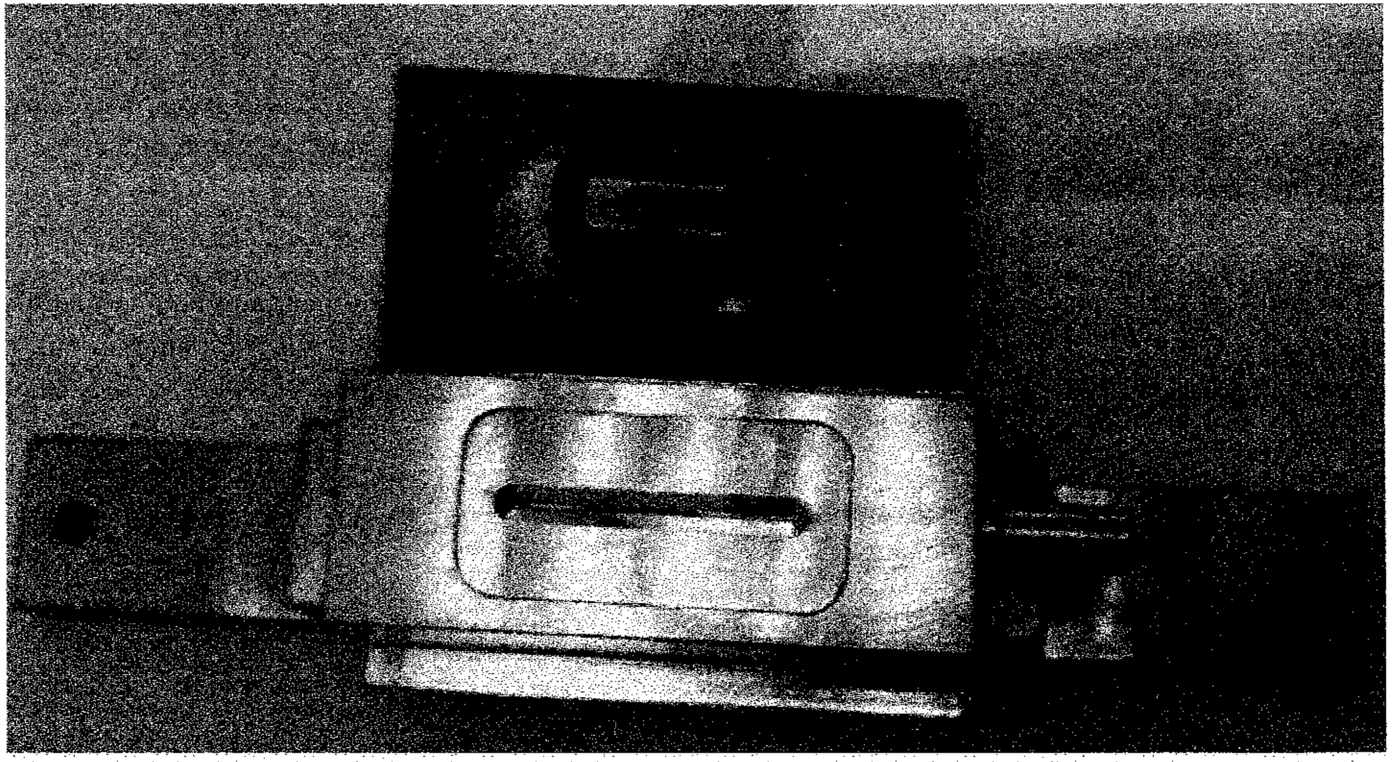


Design of a Semiplanotron SPS for accelerators

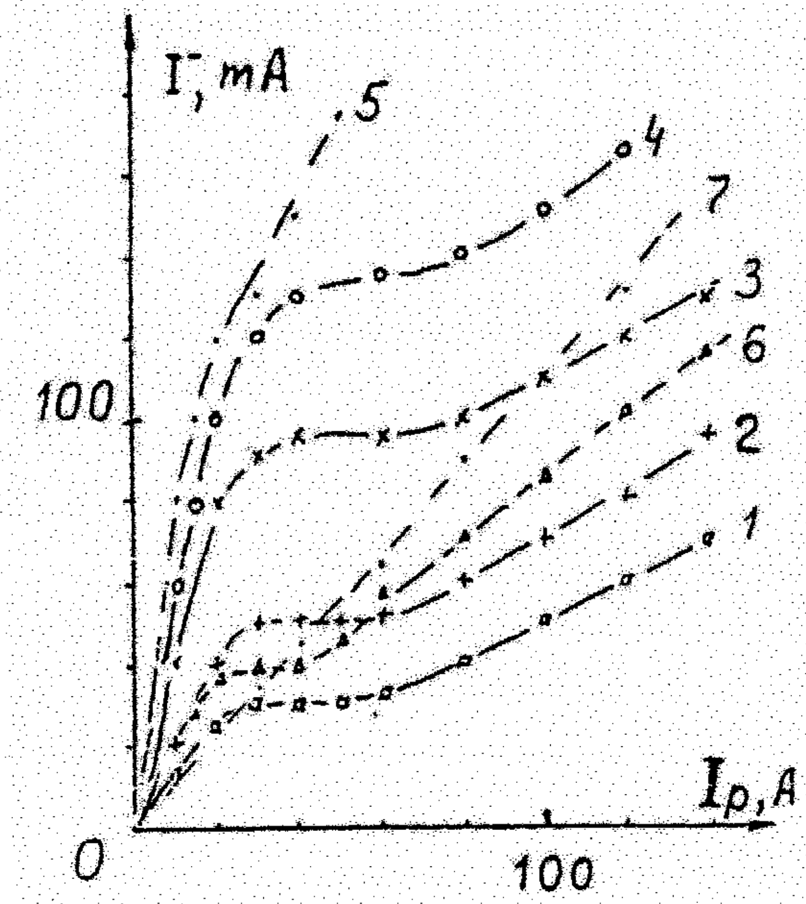


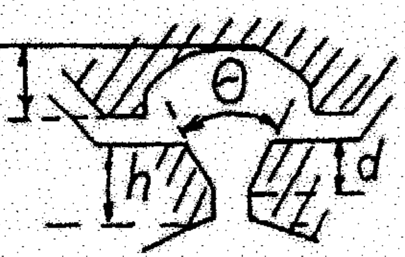
Design of semiplanotron SPS

Semiplanotron SPS with a Slit Extraction



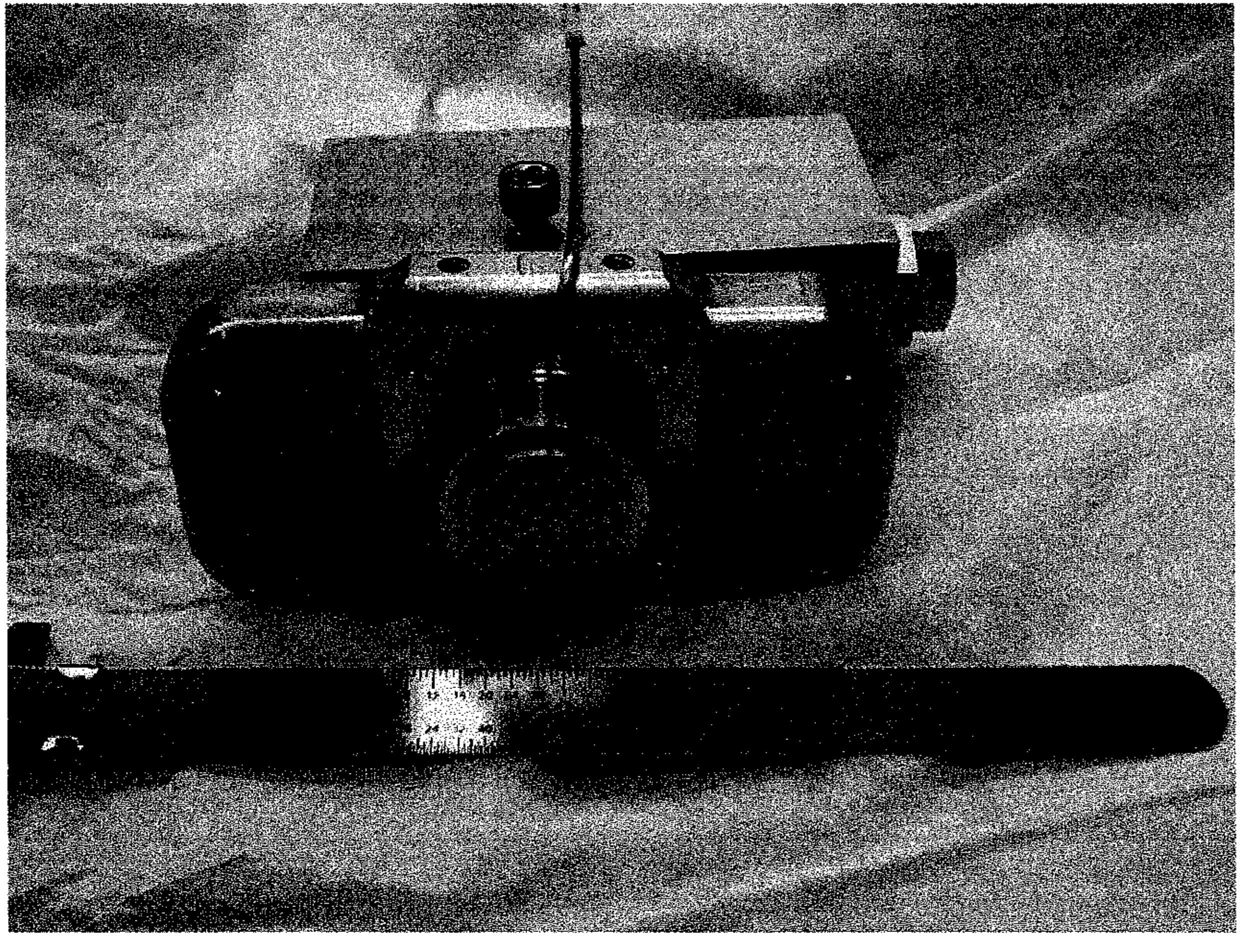
Beam Current vs an Arc Current for Different Slit Geometry in the Semiplanotron



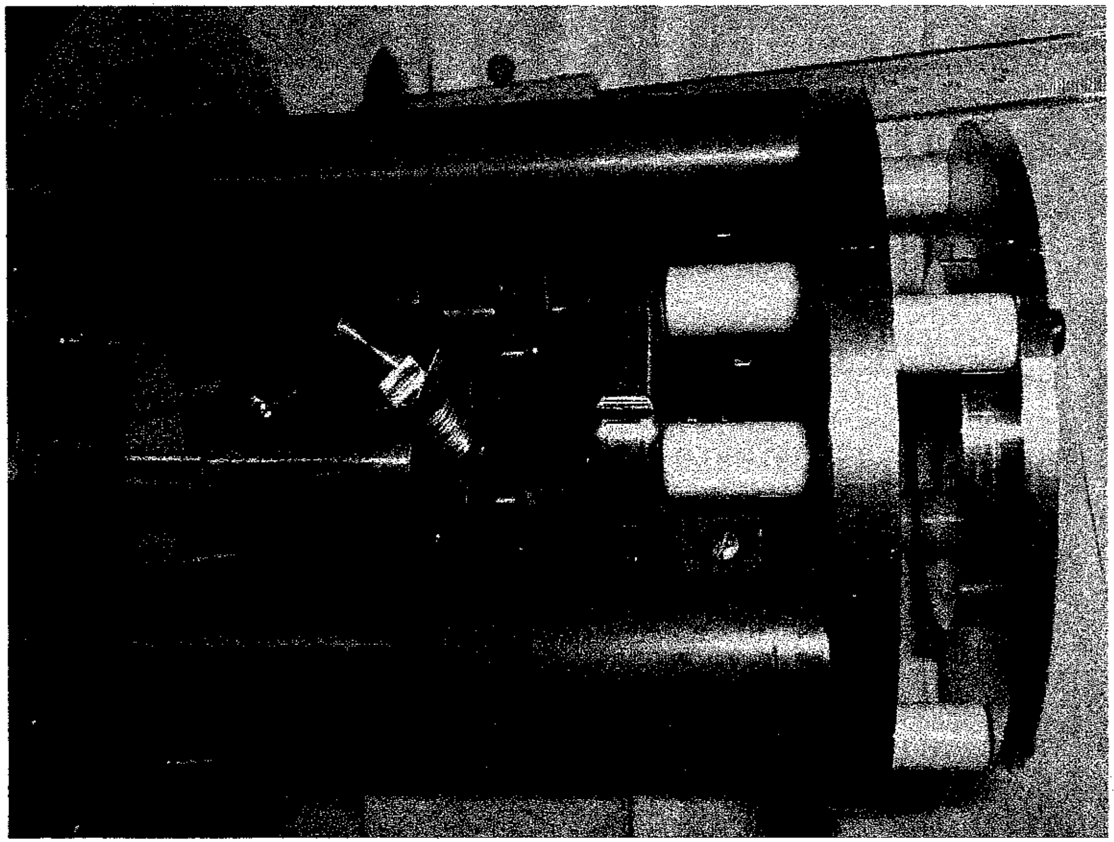


	Θ°	d	h	t
1	0	2	2	1
2	60	1	2	1
3	30	1,8	2	1
4	60	1,8	2	1
5	60	0,8	1	1
6	30	1,5	2	2,5

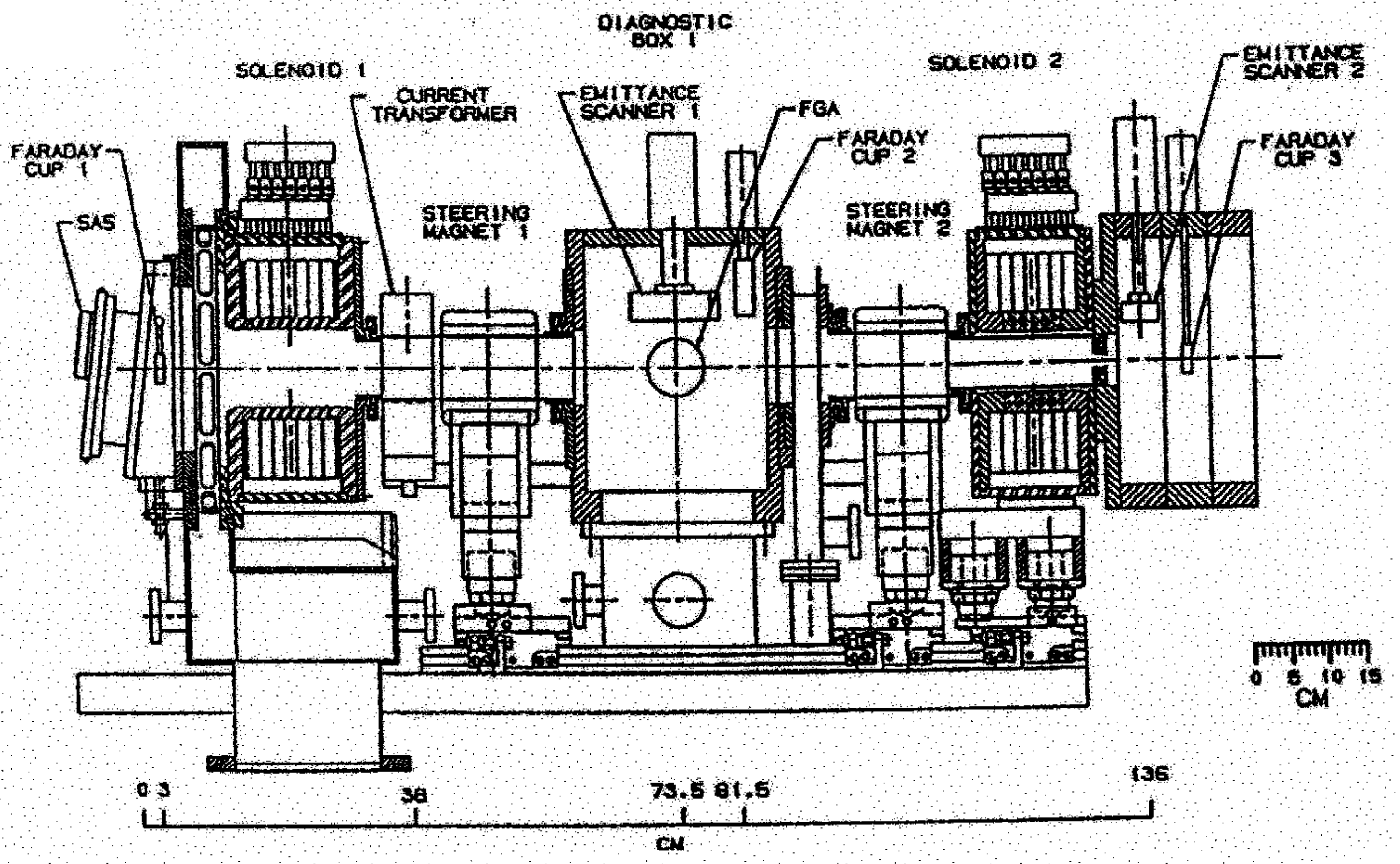
DC SPS
with a High Emission Current Density



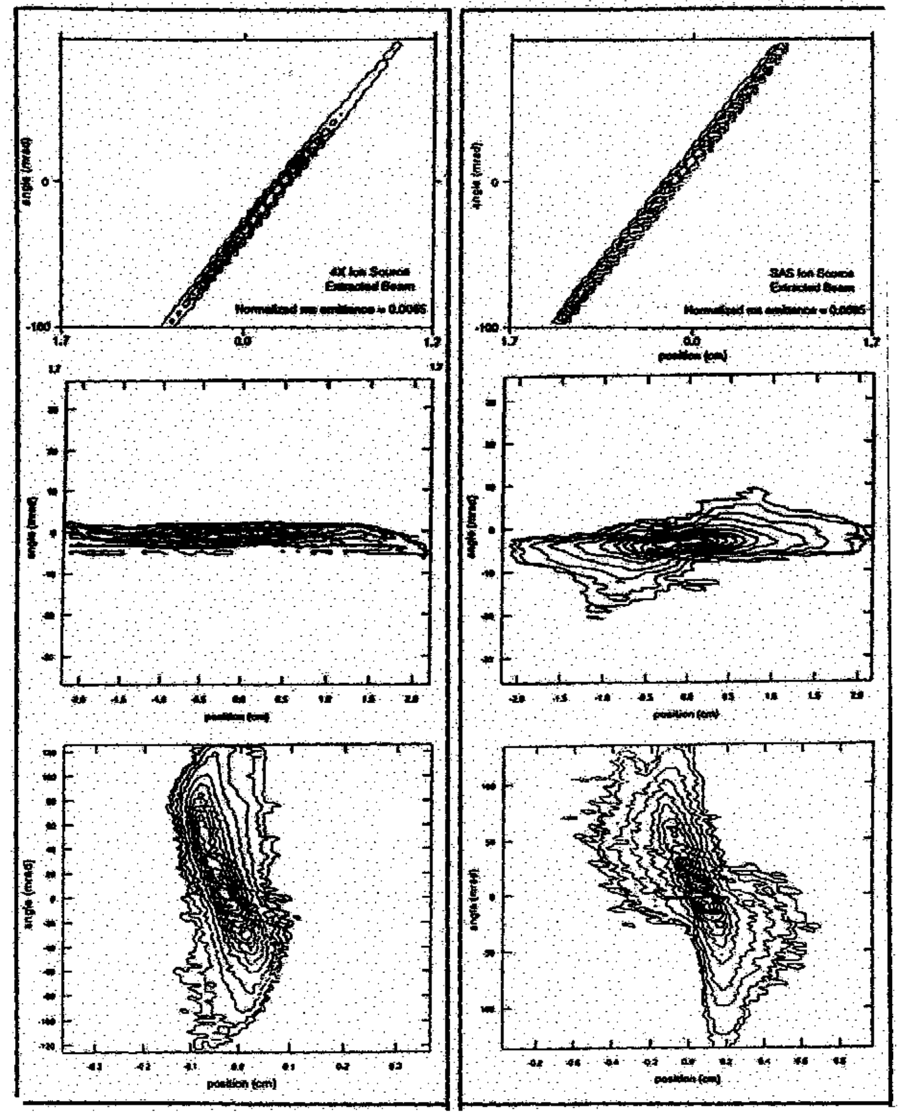
Typical Assembling of CSPS on the Vacuum Flange



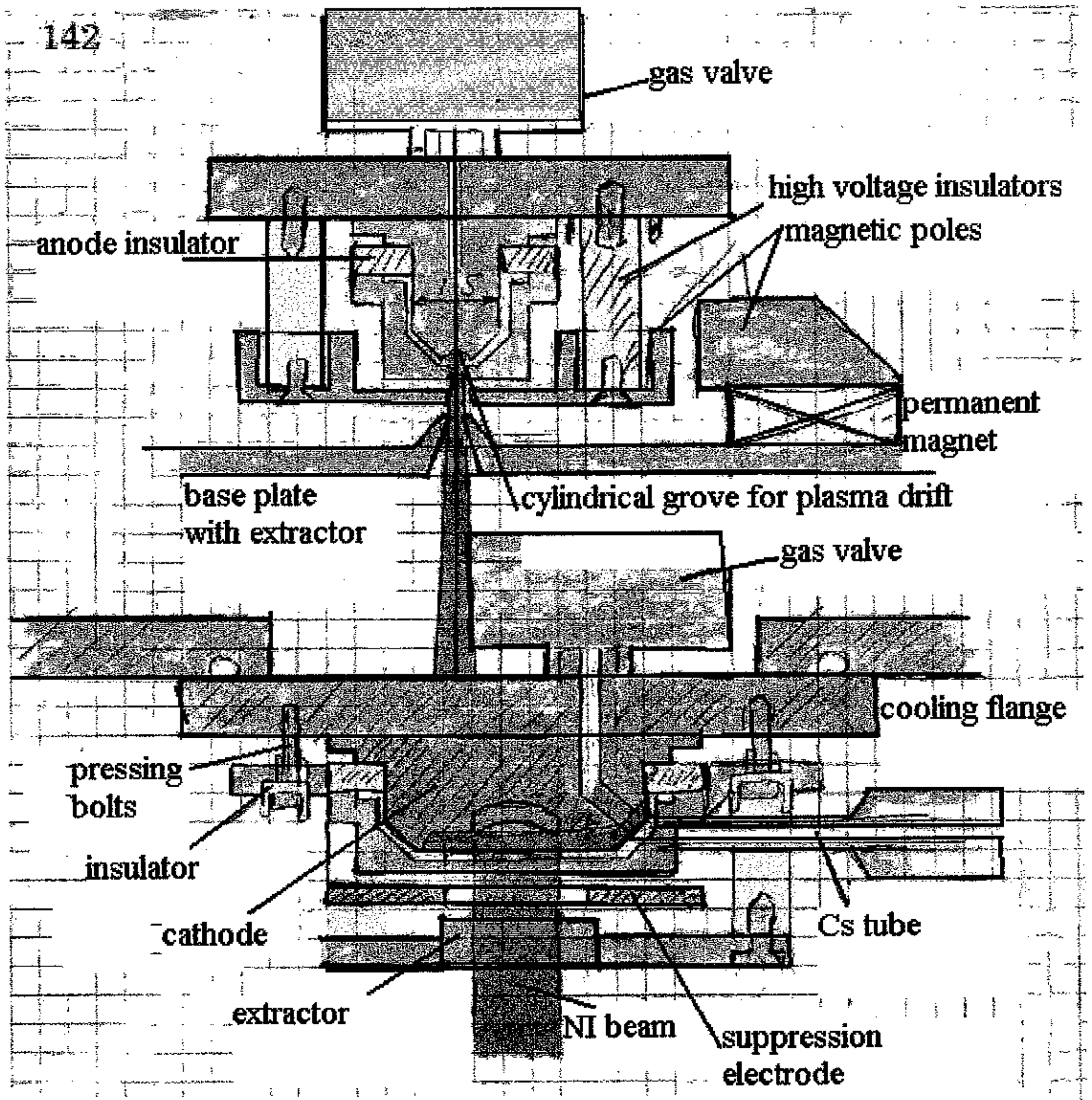
LEBT with Solenoidal Focusing
(BNL, LANL)



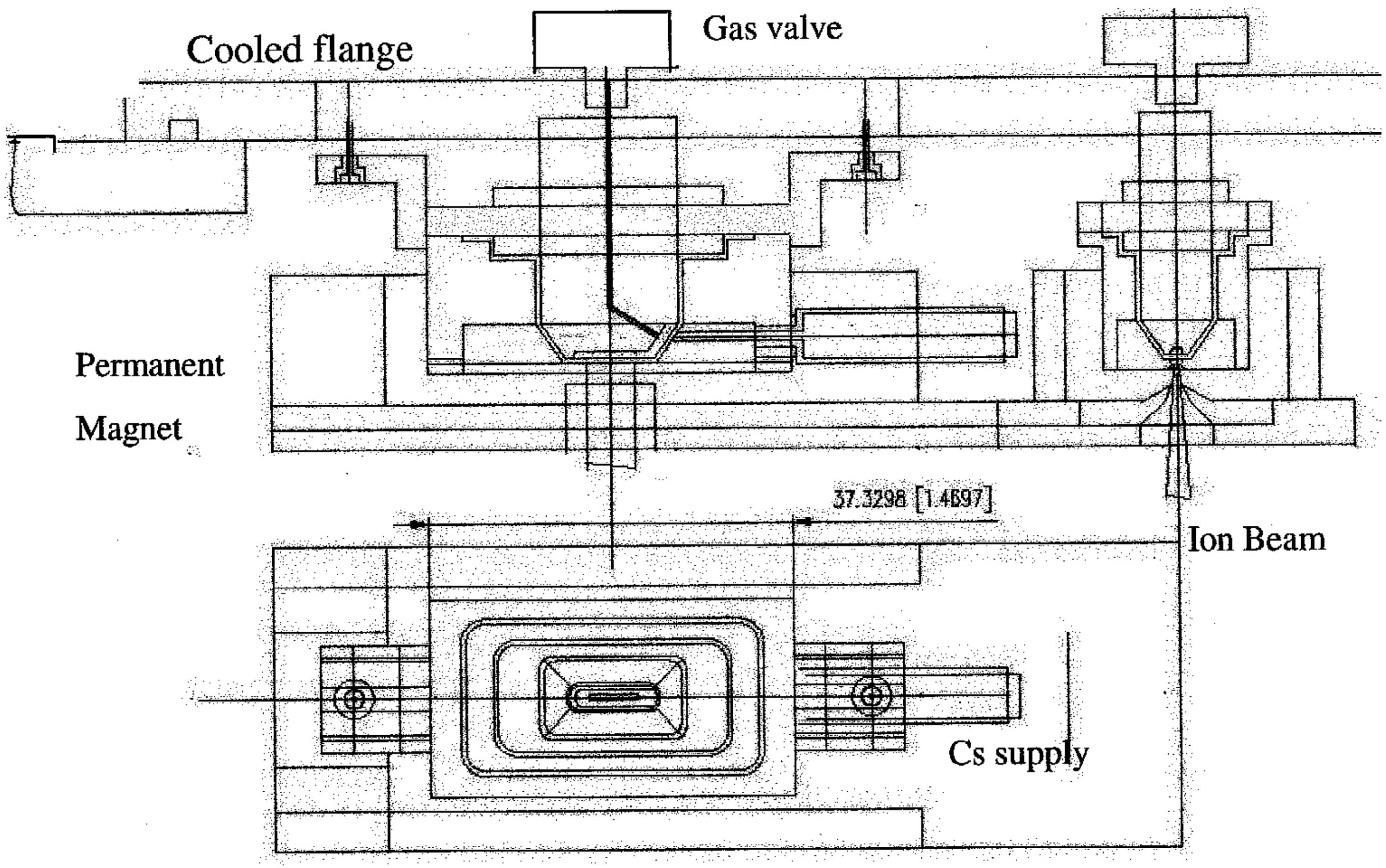
Emittance Plots after Magnetic LEBT



Semiplanotron SPS with Slit Extraction for High Intense NI Beam Production

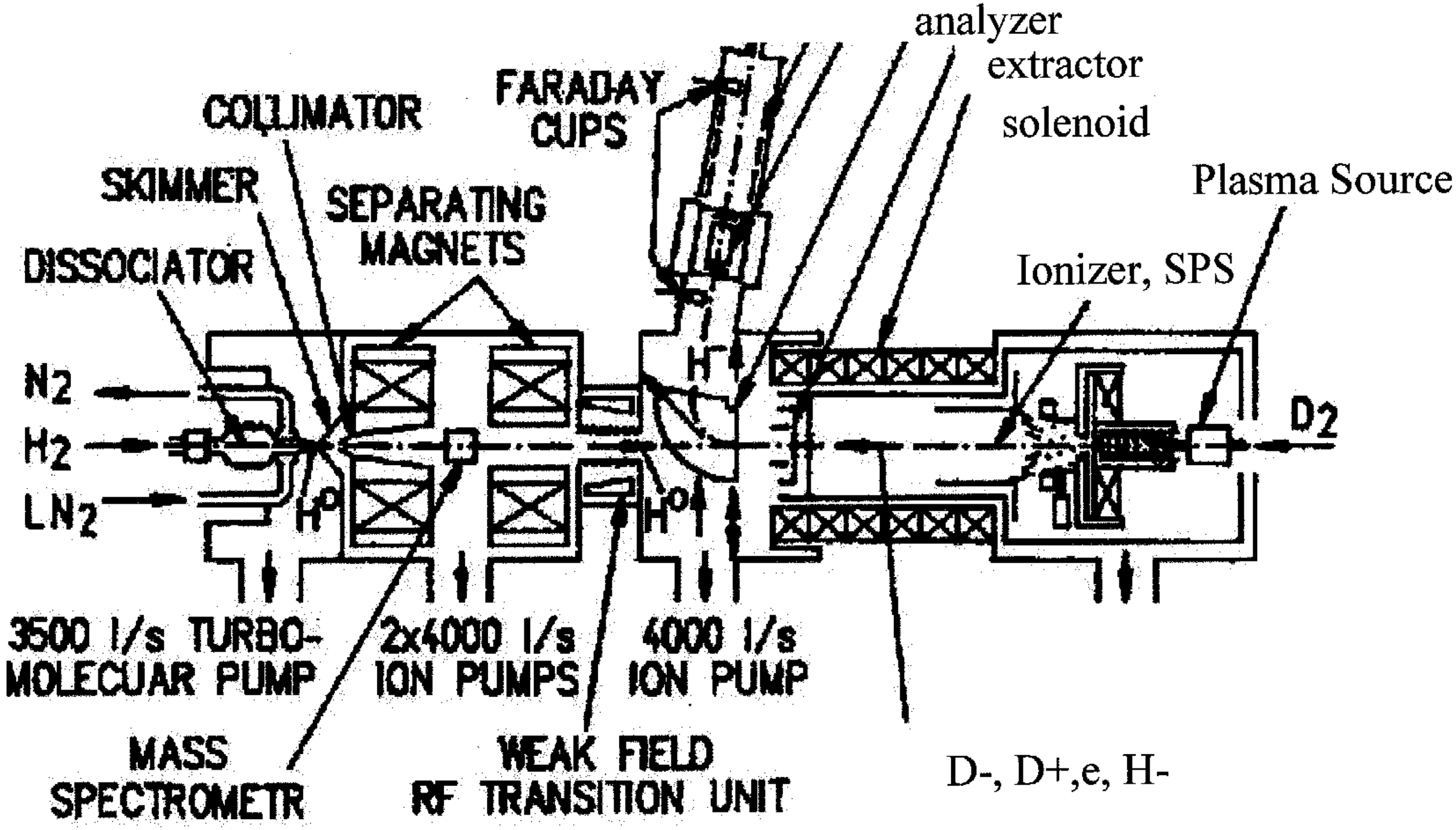


Drawing of Semiplanotron SPS with an Optimized Cooling



Polarized Negative Ion Source with a Resonance Ionizer

A.Belov,V. Dudnikov, et. al.



Summary

- Through the development of charge-exchange injection were improved dramatically the possibility for the accumulation of a high brightness proton beam in circular accelerators.
- Intensity and quality of negative ion beams were improved dramatically after discovery of a cesium enhancement of negative ion formation in gas discharges. A small admixture of cesium into the gas discharge is increase a negative ion beam production in the plasma-surface interaction and suppress an escort electron extraction.
- With development of Compact Surface-Plasma Sources (CSPS) for charge-exchange injection has been reached a record intensity of circulating beams and during 25 years an H^- beam parameters was good enough for support an operation of large scale accelerator complexes without significant modification. With using the SPS an intensity of polarized negative ion beam was increased dramatically.
- Features of compact surface-plasma sources (CSPS) are a high plasma density and emission current density ($j>1$ A/cm^2) of negative ions. They are very simple and effective, have a high brightness in noiseless mode of operation, and high pulsed gas efficiency. The CSPS are very good for pulsed operation and continues operation during many months has been achieved. In accelerators up to now used an SPS with noisy discharge.
- Now is a time for further improvement of ion source parameters. SPS has a significant potential for further improving of the beam characteristics.
- Noiseless discharge, optimized charge-exchange cooling of H^- below 1 eV, optimization of high brightness beam extraction, formation, transportation, space charge neutralization, brightness preservation instability dumping will improve SPS characteristic up to needs of all new challenger applications.
- Accumulated experience in practical aspects of SPS design, simulation and operation, cooling, gas and cesium admixture control, lifetime enhancement of operating SPS is a good basis for development of SPS with a high duty factor.

Acknowledgment

The author is grateful for the contribution into the Surface-Plasma Sources development many ion sources groups in many laboratories around the World.
Thanks for my wife Galina for help in computer simulations and presentation preparation.