Muons, Inc.

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Development of surface plasma method for negative ion beams production

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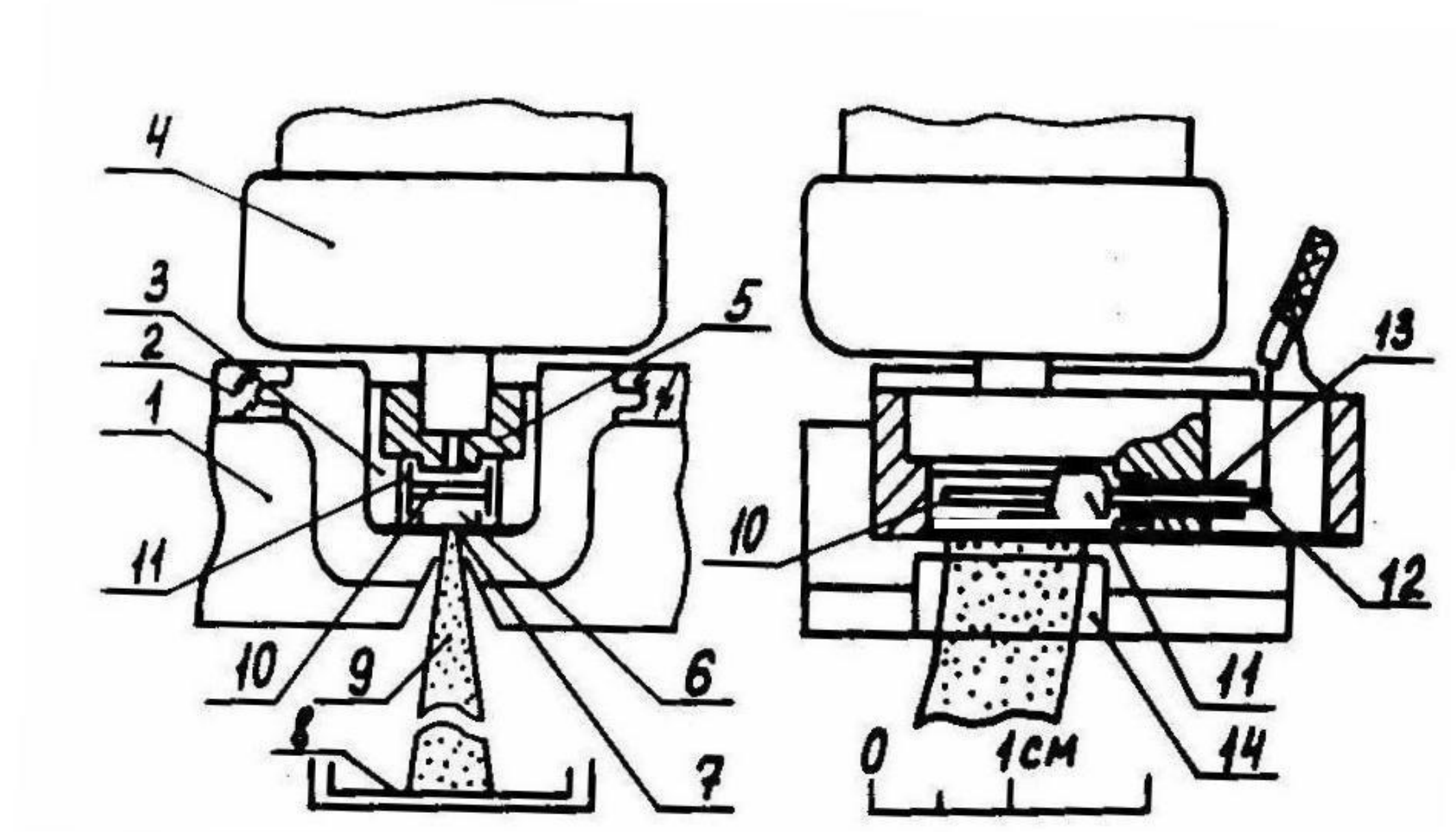
Abstract. **The cesiation effect is a large increase in the emission of negative ions from the discharge with a simultaneous decrease in the flux of accompanying electrons, below that of the negative ions, after adding a small amount of cesium or other substances with a low ionization potential to the discharge.**
Cesiation was discovered 50 years ago, on July 1, 1971, in the Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia. The cesiation effect has opened the door to high-intensity, high-brightness negative ion beam production. The efficiency of generating beams of negative ions has recently been significantly increased due to the invention at BINP of geometric focusing of generated negative ions. Based on the cesiation effect, the surface-plasma method for producing beams of negative ions developed at BINP has provided surface plasma sources of negative ions for accelerators with currents of hundreds of mA and sources for Controlled Nuclear Fusion with currents of tens of A. (the previous intensity record was 5 mA). Surface plasma sources are being developed all over the world in England, France, Germany, Switzerland, Italy, Japan, Korea, China, India, USA, Canada, Sweden, Spain, New Zealand, Russia, Ukraine, Finland with investments equivalent to billions of USD. Specialists in surface plasma sources are trained at the Plasma Physics Department of Novosibirsk State University.

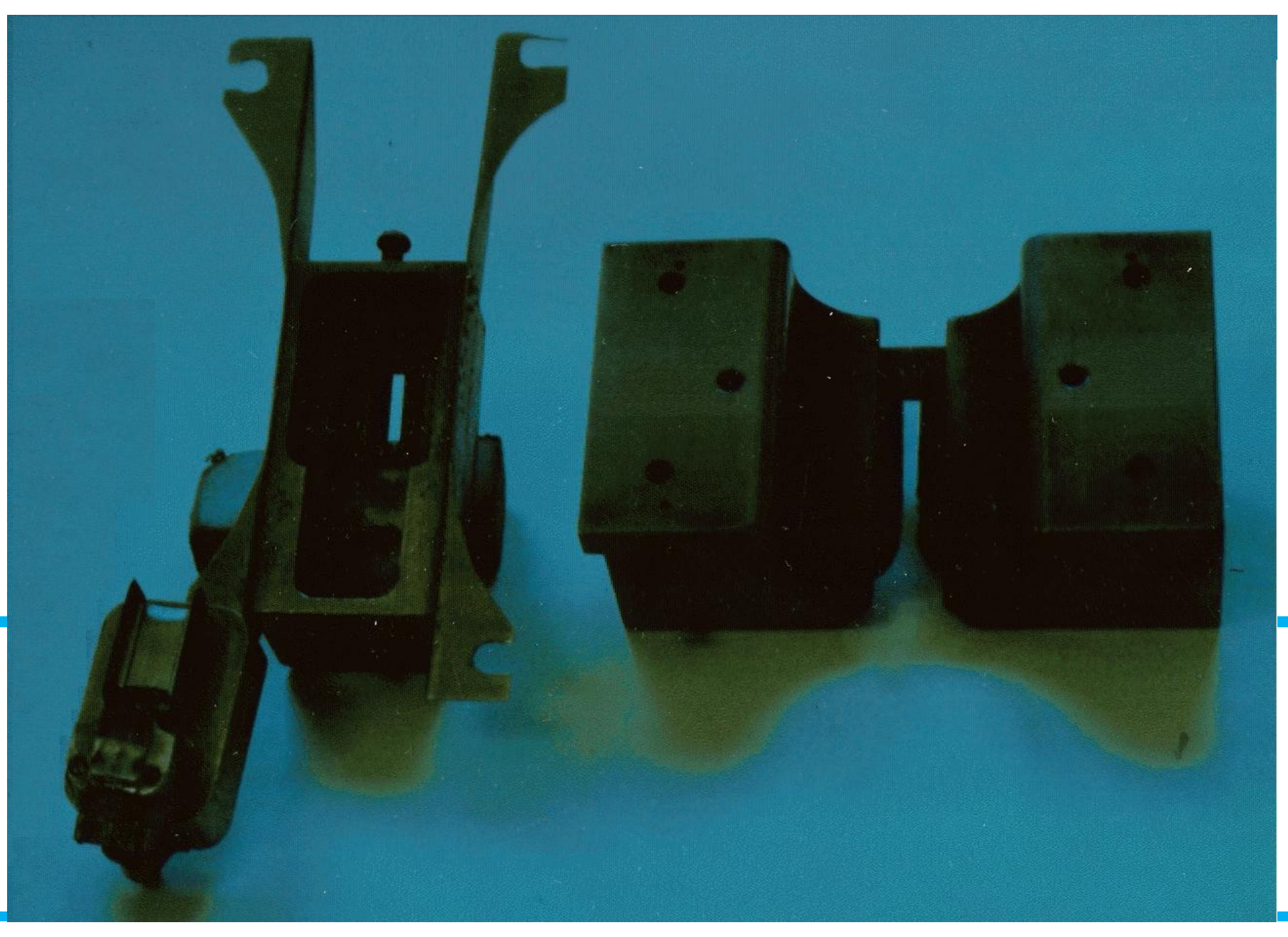
Soviet academician N. Semenov proposed in 1945 to suppress the explosions of nuclear bombs by irradiating them with neutrons. A large accelerator development program was established in the USSR. V. Teplyakov invented the Radio Frequency Quadrupole (Teplyakov Accelerator) within this program, although a similar proposal was put forward by R. Wilson in 1953. After the experimental development of charge exchange injection with the conversion of negative ions into neutrals (my Ph.D. thesis and doctoral dissertation by G.I. Dimov), G. Budker, the director of the Institute of Nuclear Physics (INP, Novosibirsk, Russia), suggested using high-energy neutral beams on space objects to inspect satellites for the presence of nuclear materials or to suppress nuclear explosions.
In the Korolev Space Central Design Bureau (already without Korolev), after the closure of the Soviet lunar program, unused funds remained, and in 1969 a contract was signed with the INP to develop a neutral injector for a 10 mA H- ion beam for 2 M₽ (₽ is the symbol for rubles). For reference, at that time in Novosibirsk, USSR, a nine-story building with 286 apartments cost 1 M₽. The Strategic Defense Initiative using neutral particle beams was established in the USA in 1976. Three groups were then organized in INP, which were engaged in different methods of obtaining negative ion beams. Charge-exchange and plasma sources of negative ions (of the Ehlers type) were developed in Dimov's lab.

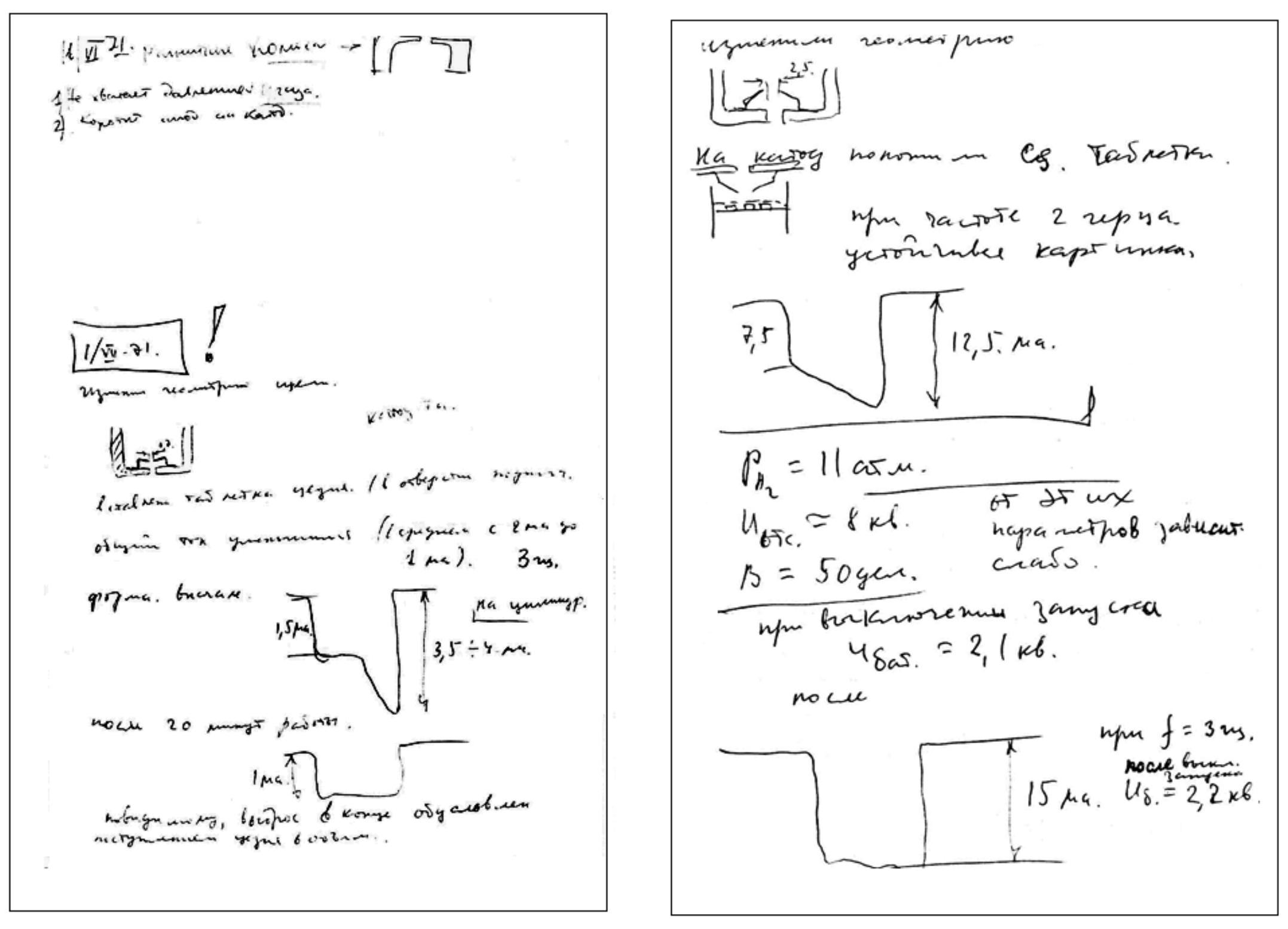
In my first year at Novosibirsk State University, I read Gaponov's textbook "Electronics" and then reread it. In it, I found a mention of the secondary emission of negative ions, little known at that time. I began to study secondary ion-ion emission in more detail. There was a lot of data, but they were very contradictory, everywhere the probabilities of secondary emission were very small, and the theoretical foundations of this phenomenon were absent. It was known that the deposition of alkali metals increases the coefficient of secondary ion-electron emission. The works of Ayukhanov of 1961 and of Kron of 1962 were discovered, in which it was shown that when deposited alkali metals, the coefficient of secondary emission of negative ions also increases, but the resulting currents of H- ions were at a sub-microampere level.
I suggested that Dimov take up the secondary emission method for obtaining negative ions. He enthusiastically accepted this proposal and a group was organized to obtain H- ions by bombarding a surface with cesium ions under his leadership. I took an active part in this work. A stand was set up and rather soon H- beams with currents up to -2.5 mA were obtained, but the brightness of these beams was very low and the service life of these devices was very short. G. Roslyakov's group was engaged in charge exchange sources.
My student Y. Belchenko and I worked on plasma sources. The groups worked intensively, but they were far from reaching the required parameters. Budker gathered weekly meetings where various proposals were discussed, but no solutions were found. By the end of the contract, everyone despaired of the possibility of obtaining the necessary currents and went on vacation for the summer. Yura Belchenko left with a building team in Bilibino in Kolyma (to build the Bilibino nuclear power plant) and took our laboratory assistant with him. The mechanics also went on vacation.
I stayed alone for the summer and continued to work with a plasma source with a planotron geometry. It yielded up to 4.5 mA H- in 1 ms pulses, but with an electron current to the extractor 30 times higher, a discharge current of 100 A, and a discharge voltage of 600 V (a power of 60 kW put into a device with a volume of 1 cm^3). Taking into account the acquired "negative" experience gained after a number of trial experiments, the design of a new source was brought to the form depicted schematically in Figure 1. The body of the plasma cell 3 was fixed on insulators 2 of plexiglass in the gap between the pole pieces 1. The plates of extraction electrode 14 were welded to special protrusions from the pole pieces 1, creating a magnetic field in the high-voltage gap (but not a Penning trap configuration). A pair of pole-pieces with the source was installed between the grounded poles of the electromagnet.
A plasma cell with planotron configuration is formed by the cathode, consisting of the central plate of cathode 10 and cathode side-shields 11, and a cathode-enclosing anode formed by parts of the plasma cell body 3 and anode insert 5. A cathode made of 0.2 mm thick molybdenum foil was attached to tantalum current leads 12 passing through the wall of anode insert 5 and insulated from it by ceramic tubes 13. The volume of the plasma cell was minimized as much as possible. Gaps between the cathode and the anode, in which a discharge should not burn, were reduced to 1 mm. Hydrogen was supplied to the plasma cell through a short channel by a pulsed electromagnetic valve 4. Emission slit 7 with dimensions 0.5 x 10 mm^2 oriented across the magnetic field was cut in the thin-walled body of the plasma cell. From the discharge region, particles could pass to the emission slit through the gap between the anode projections 6 shielding the emission slit from the dense, high-current plasma. A photograph of the first planotron is shown in Figure 2. Old power supply systems were used for pulsed hydrogen gas injection, plasma ignition, to support the discharge, and ion extraction. A beam collector 8 was installed to monitor the beam current 9. The body of the plasma cell was held at the negative-polarity extraction voltage, and the collector was held at low voltage.
On July 1, 1971, I fixed on the anode of the planotron a tablet of cesium chromate with 1 mg of released cesium and turned on the discharge. The emission slit was shielded and an ion current of 1.5 mA was recorded on the collector. After several minutes of operation, a current surge of up to 3 mA appeared at the end of the pulse. After optimizing the gas supply, the current at the end of the pulse increased to 4 mA, but after 20 minutes, the current surge disappeared and the current to the collector became 1 mA again. .Deciding that the current surge was associated ith the release of cesium, I placed several tablets on the cathode, which was heated more strongly, and covered them with a nickel mesh. In this configuration, the collector current quickly increased to 12.5 mA, and after optimizing the gas supply and discharge, a rectangular pulse of 15 mA was obtained. The discharge voltage dropped from 600 V to 100 V. After that, within a week, various configurations of discharges were tested, it was verified that these are mainly H- ions, and the currents of electrons and heavy ions to the collector are small.
After that, I left everything in working order and went on vacation to my village Gunda in Buryatia. After my return, the source worked as it should, the current H- was quickly increased to 100 mA and then to 300 mA, with emission current density up to 4 A/cm^2, then to 0.9 A from a source the size of a lighter.



First version of Planotron (Plain Magnetron) SPS, INP, 1971,

Beam current up to 230 mA, 1.5x10 mm^2, J=1.5 A/cm^2 with Cs





Pages from the laboratory log book for July 1, 1971, describing the evolution of intensity of the negative ion beam when cesium is added to the discharge.

This result was not published because was recognised as a "top secret" without permeation for publication. After strong effort of Gennadii Dimov it was permeated only application for patent (Author sertificat): Vadim Dudnikov, "The Method for Negative Ion Production", SU patent, C1.H013/04, No 411542, Appl. 3/10/72.

Invention formula:

"Method of negative ion production comprising admixture into the discharge a substance with a low ionization potential, such as cesium".

There is big difference between "surface production" and "surface plasma production", because without plasma it is possible to have only microAmpers of negative ions as in sputtering type (Middleton) sources.

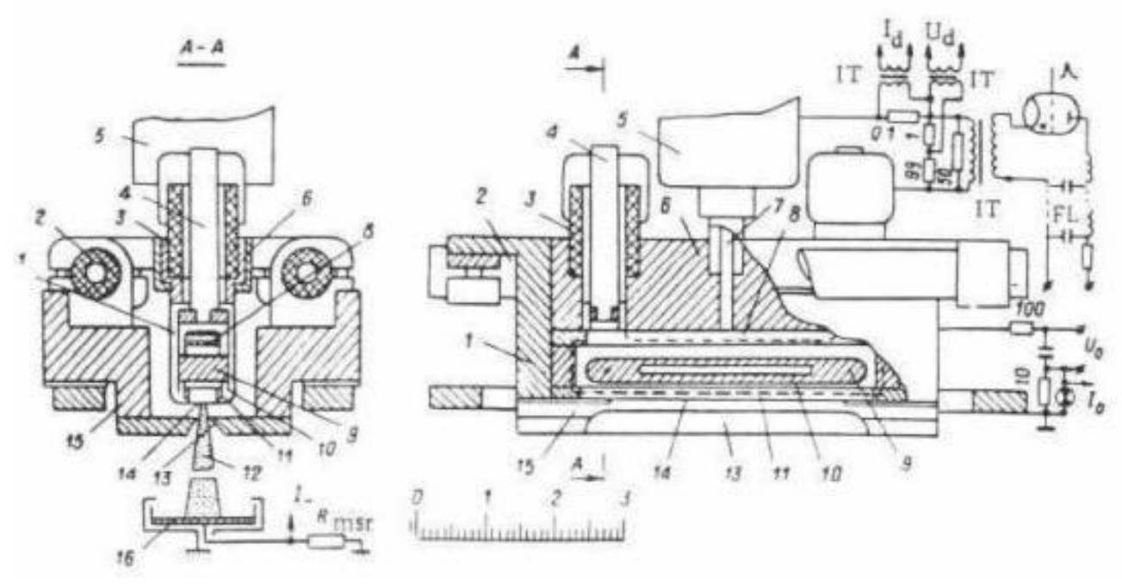
Further development of SPS was conducted by Belchenko, Dimov, Dudnikov in INP and many teams in many laboratories around the World.
**First International publication was permeated in 1974 when H- beam current was increased up to 0.9 A :
BELCHENKO Y.I., DIMOV G.I., DUDNIKOV V.G., "POWEFUL INJECTOR OF NEUTRAL S WITH SURFACE PLASMA SOURCE OF NEGATIVE IONS", NUCLEAR FUSION Volume: 14 Issue: 1 Pages: 113-114 , 1974**

Dudnikov V, Method of negative ion obtaining, USSR Patent 411542, 10/III. 1972; http://www.findpatent.ru/patent/41/411542.html, **Dudnikov, V.G., Technique for producing negative ions,** https://inis.iaea.org/search/search.aspx?orig_q=RN:9355182

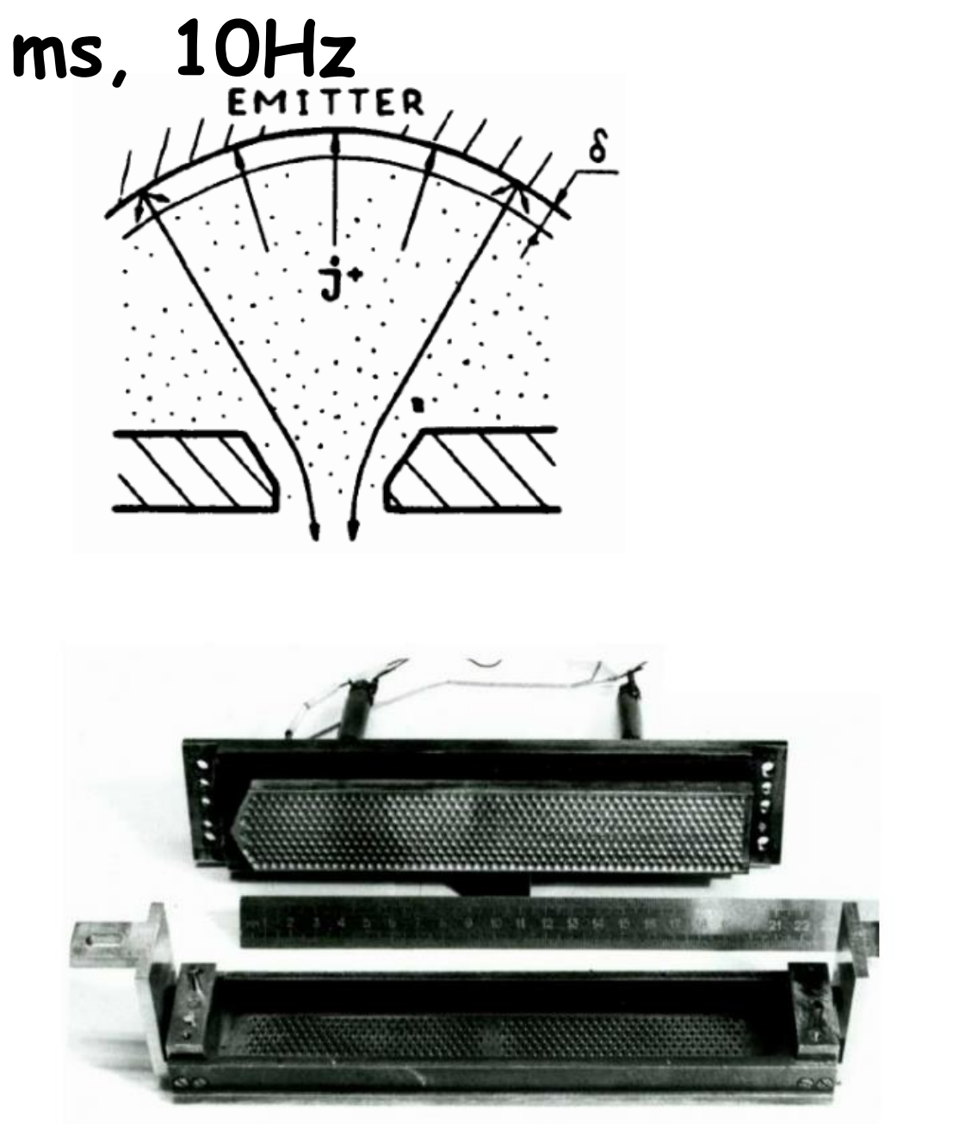
At 1977 in USA was started similar program involving all National Laboratories and European cooperation. BNL Symposiums were established sponsored by DOD and Strategic Defence Commander. Fortunately,
DEVELOPMENT OF NEGATIVE ION SOURCES BECOME PEACEFUL DIRECTION AND BECOME A FIELD FOR INTERNATIONAL

COOPERATION.

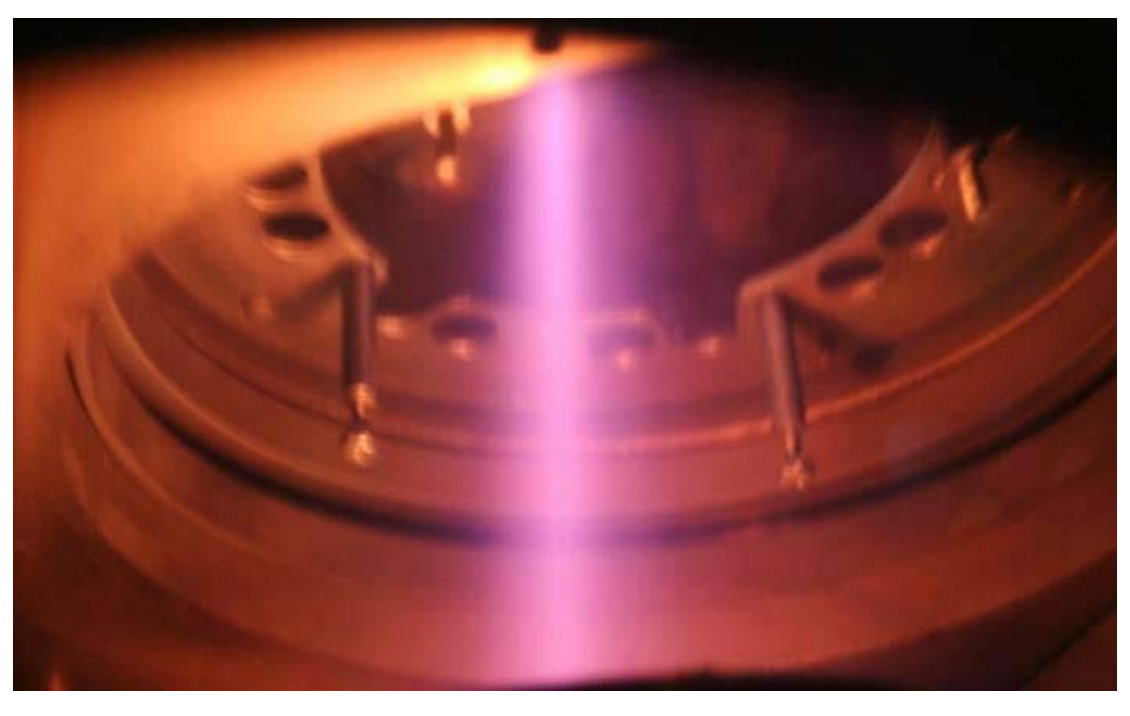
What were changed from 7.1.71 ?
Staff working for development and use Surface Plasma Sources with cesiation was increased to > thousand high qualified scientist, engineers, technicians, workers, administrators,...having excellent jobs.
Negative ion beam intensity were increased ~104 times from record 3 mA to >40 A.**
Cost of SPS was increased from ~1k$ to ~ M$.
SPS with cesiation become "Sources of life and Working horces" for big installations such as SNS, LANSCE, BNL, Fermilab, ISIS, KEK,...JT 60, LHD...
Under development SPS for LHC and for ITER



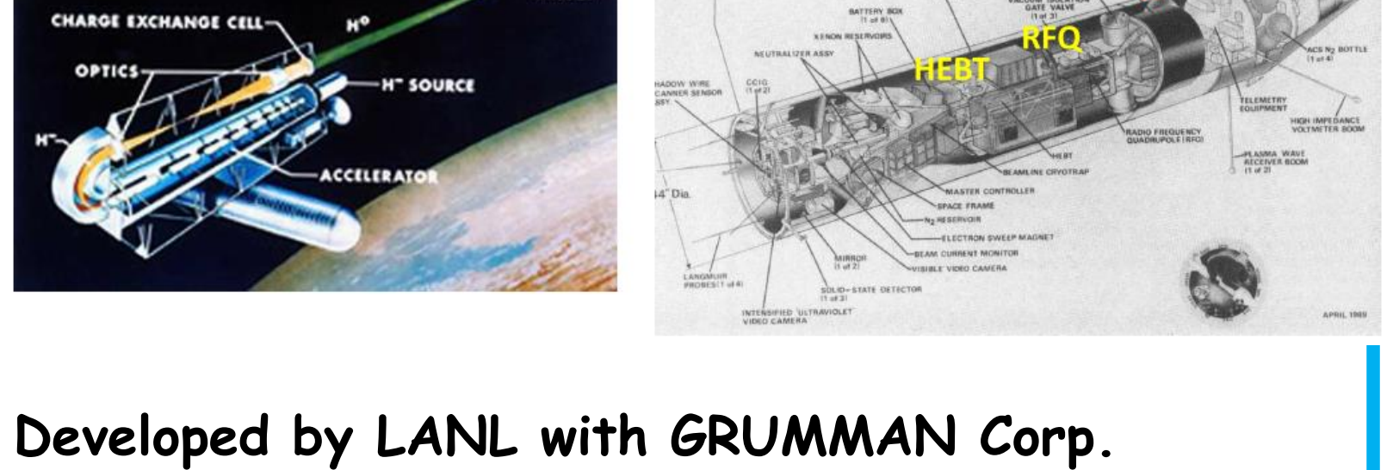
Cross sections of Planotron (Magnetron) SPS of second generation: 1x30 mm2; 0.9 A, 1ms, 10Hz



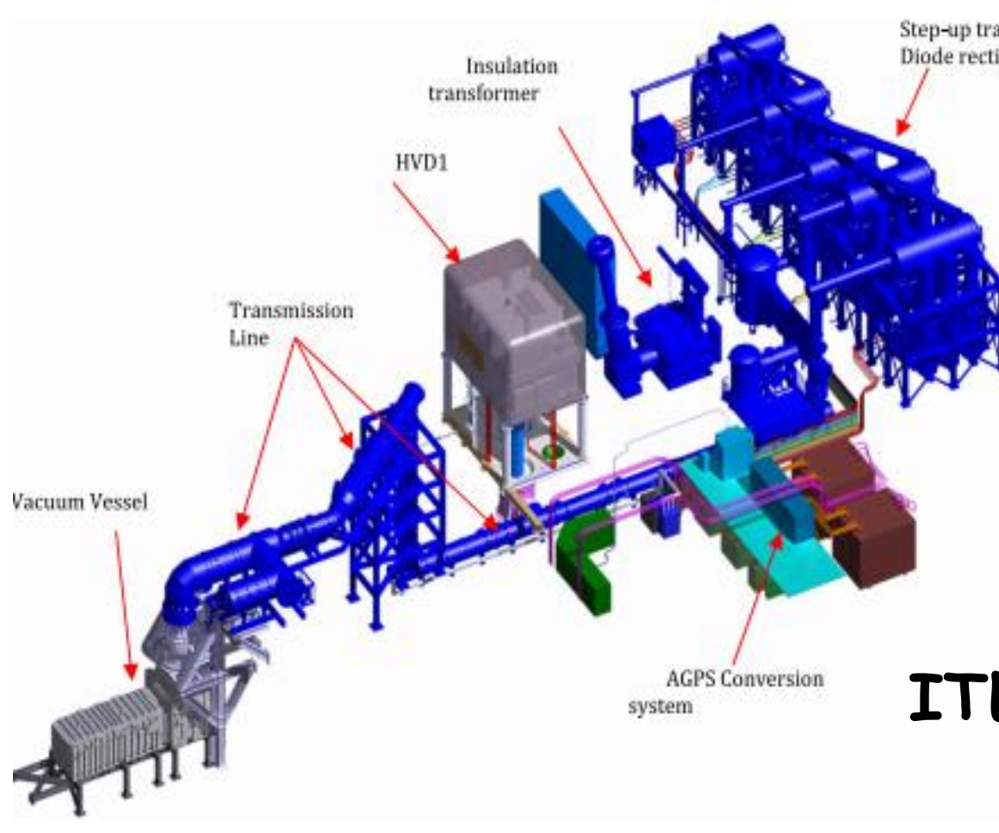
Spherical focusing multiaperture semiplanotron Ib=12 A



DC H- beam of 25 mA from Penning SPS with cesiation



Developed by LANL with GRUMMAN Corp.
Cost of experiment is 794 M$



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