Improving of the Converter Surface Plasma Sources

V. Dudnikov[1,a)], G. Dudnikova[2]

[1] Muons Inc. 552 N. Batavia Ave. Batavia, IL 60510. USA ,

[2]Institute of Computational Mathematics and Mathematical Geophysics SB RAS, Novosibirsk, 630090, RF

a) Corresponding author: dvg43@yahoo.com

NIBS 2020

Outline

- **Introduction**
- **Existing LV SPS with convertor in LANSE**
- **Modified LANSCE converter SPS with a heated cathode Penning discharge and with hollow cathode discharge**
- **SPS with separated functions**
- **Conclusion**

Work of modern negative ion sources is based on Cesiation Effect.

Cesiation effect, a significant enhancement of negative ion emission from gas discharges with decrease of co-extracted electron current below negative ion current, was observed for the first time by location into discharge chamber a compound with one milligram of cesium on July 1, 1971 in Institute of Nuclear Physics (INP), Novosibirsk, Russia *(V. Dudnikov. "Technique for producing negative ions", patent, 411542, filed 10/III,1972, https://inis.iaea.org/search/search.aspx?orig_q=RN:9355182).*

This observation was further developed and understood as a new surface plasma method of negative ion production. In the patent application it was stated: "A method of negative ion production in gas discharges, comprising adding into the discharge an admixture of substance with a low ionization potential such as cesium, for example, for enhancement of negative ion formation".

V. Dudnikov. Development and applications of negative ion sources, Springer, 2019.

В. Дудников. Источники отрицательных ионов, НГУ, Новосибирск, 2018.

V. Dudnikov. Surface plasma method of negative ion beam production, Phys. Uspekhi, 62 1233–1267, 2019.

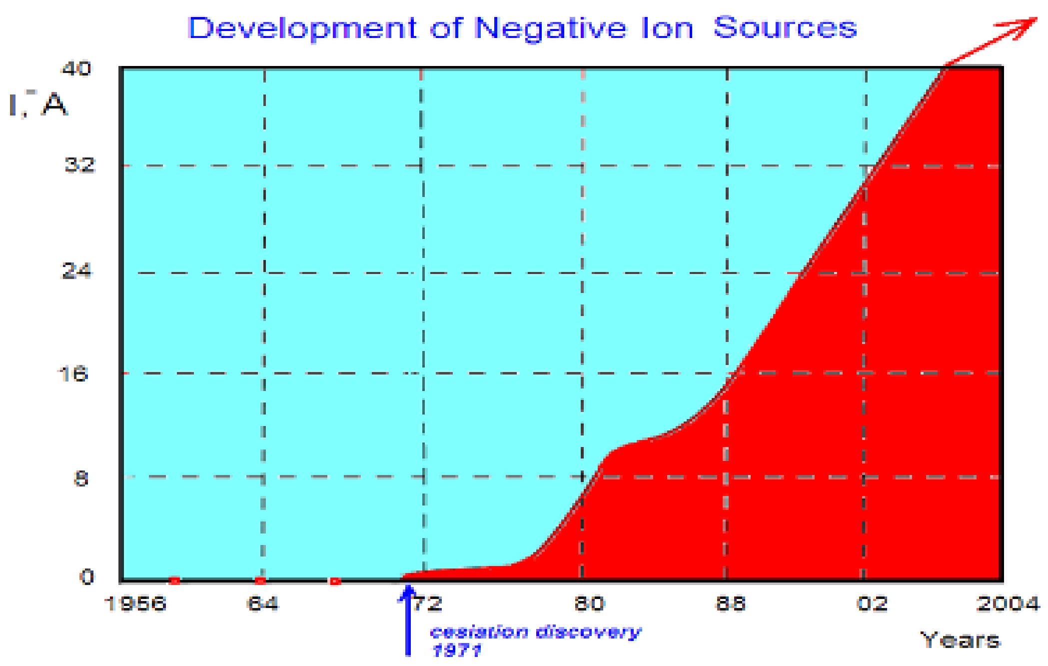
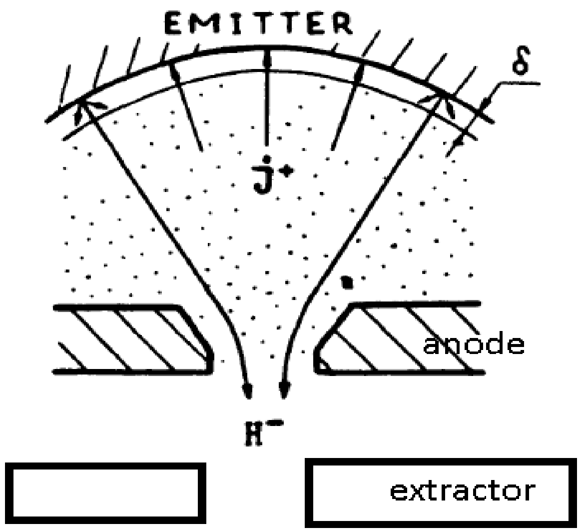


Fig. History of development of negative ion sources. Growth of beam intensity in time.
With cesiation effect H- beam intensity was increased to 10**4 times from 3 mA to >40 A.

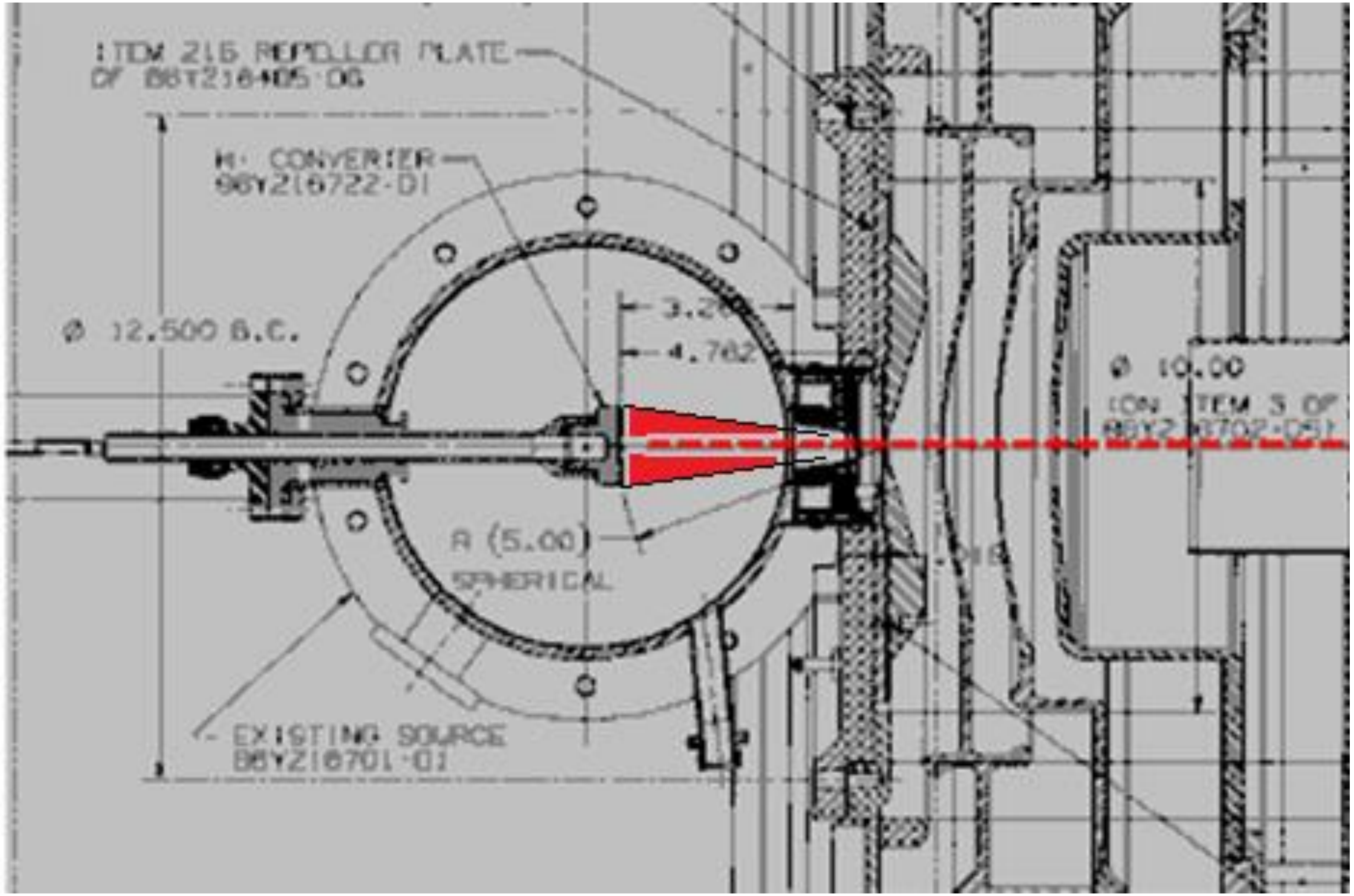


The generation efficiency of negative ions beams could be significantly increased by geometric focusing of the negative ions. The geometric focusing scheme is illustraed in Fig. Negative ions emitted by a cathode are accelerated in the near-cathode potential drop along a normal to the surface. If the surface is cylindrical or spherical, negative ions are focused to the center of curvature.

- On the basis of cesiation effect a large volume surface plasma source with cesiation and geometrical focusing converter was developed in LBL.

- On the basis of this source LV SPS with converter, a smaller version of LV SPS with a converter for the Los Alamos linear accelerator was developed.

- A large gas-discharge chamber with a multipole magnetic wall has a diameter
- of 17.8 cm and a height of 12.8 cm. Two heated cathodes with a diameter of 1.5 mm and a length of 20 cm support a discharge with a voltage of 90 V, up to 40 A, generating a plasma with a density of up to 3×10^{12} cm^{-3} . A cooled converter with a diameter of 5 cm and a potential of up to -300 V, bombarded by positive ions, emits secondary negative ions, accelerates them and focuses in an emission aperture with a diameter of 6.4 mm. From this SPS, up to 18 mA of H^- ions are extracted at a duty cycle of up to 10%. The normalized emittance of this beam is 0.13 π cm mrad.



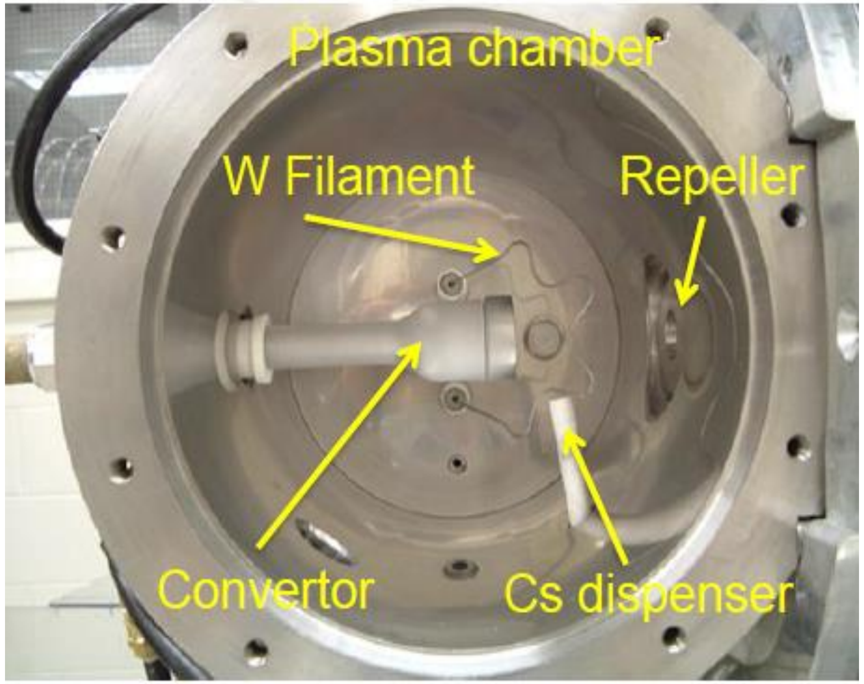


Fig.2.The photograph of source.

Fig.1. The schematic of source.

The dependence of the extracted beam current H- on the discharge power is characterized by strong saturation due to the destruction of H- in a thick layer of the discharge plasma after the converter.

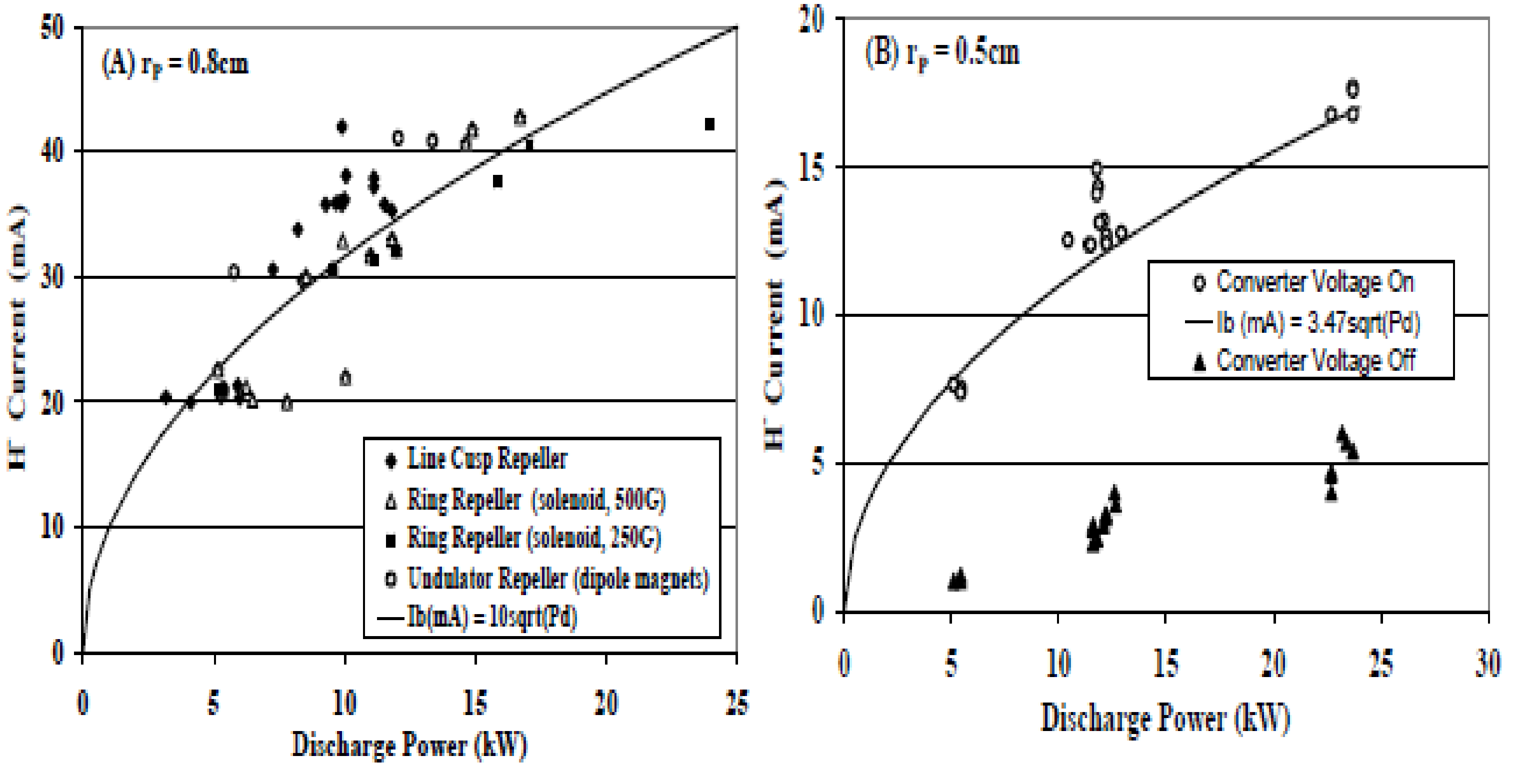


Fig.3. Dependence of H- beam current on discharge power. Left -with emission aperture 0.8 cm, right -with emission aperture 0.5 cm.

Modified LANSCE converter SPS with a heated cathode Penning discharge.

The H- beam intensity, SPS life time and H- generation efficiency can be increased by decrease of plasma layer thickness between converter surface and emission aperture. It is possible to improve beam characteristics by small modification of this converter SPS. A schematic of this modification is shown in Fig. 4. It is proposed to used a thin Penning discharge in front of the converter, shifted to emission aperture. It can be used the same discharge chamber with hot filament, located in front of anode with a slit for electron passing and anticathode for reflection of electrons. Magnetic field for Penning discharge is created by permanent magnets. Decrease of plasma end gas between converter and emission aperture can decrease H- beam loss and increase an extracted beam intensity up to 2 times. H- ion beam is extracted by existent extraction system. A heated tungsten cathode of Penning discharge is shown in Fig. 5.

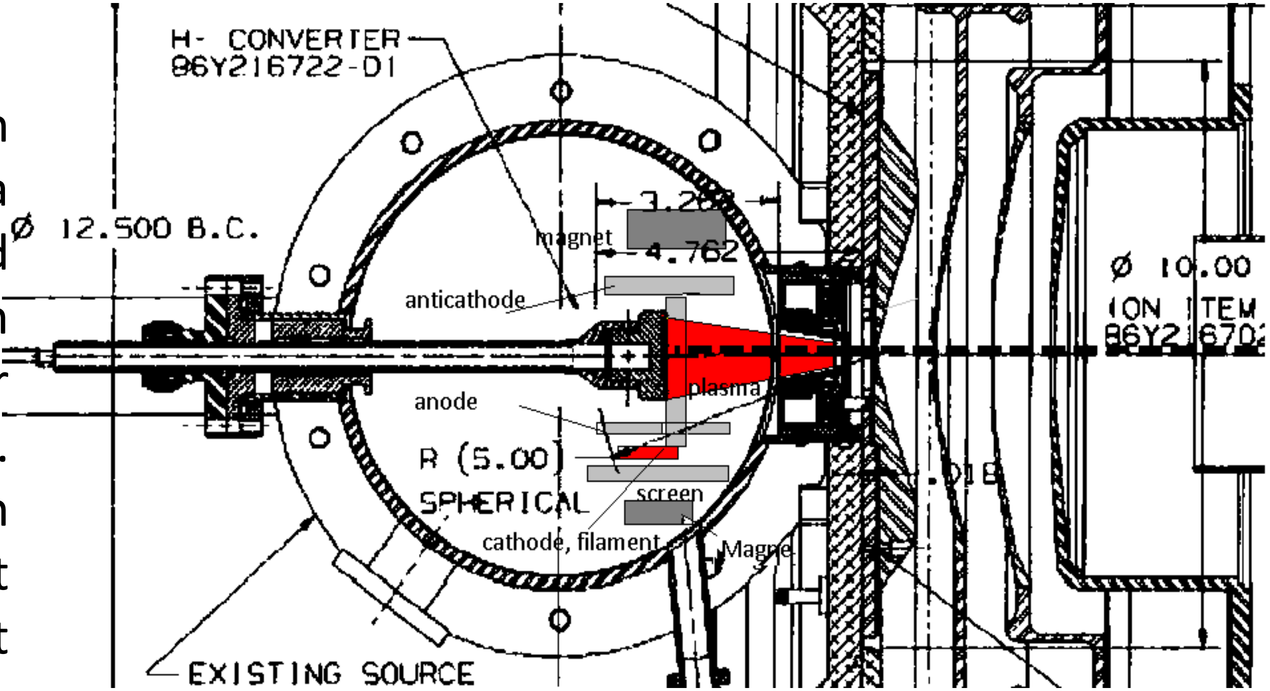


Fig. 4. Modified LANSCE converter SPS with a heated cathode Penning discharge.

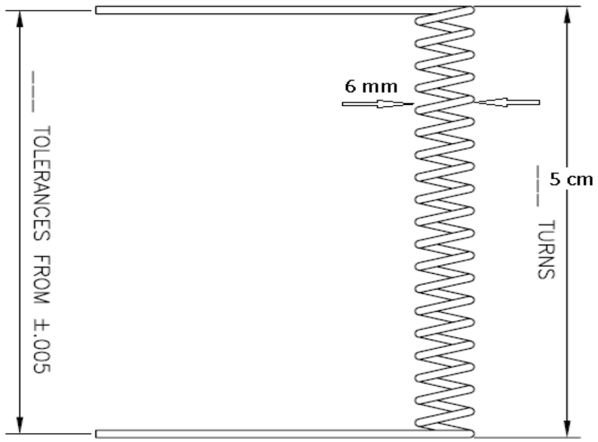


Fig. 5. Heated tungsten cathode of Penning discharge.

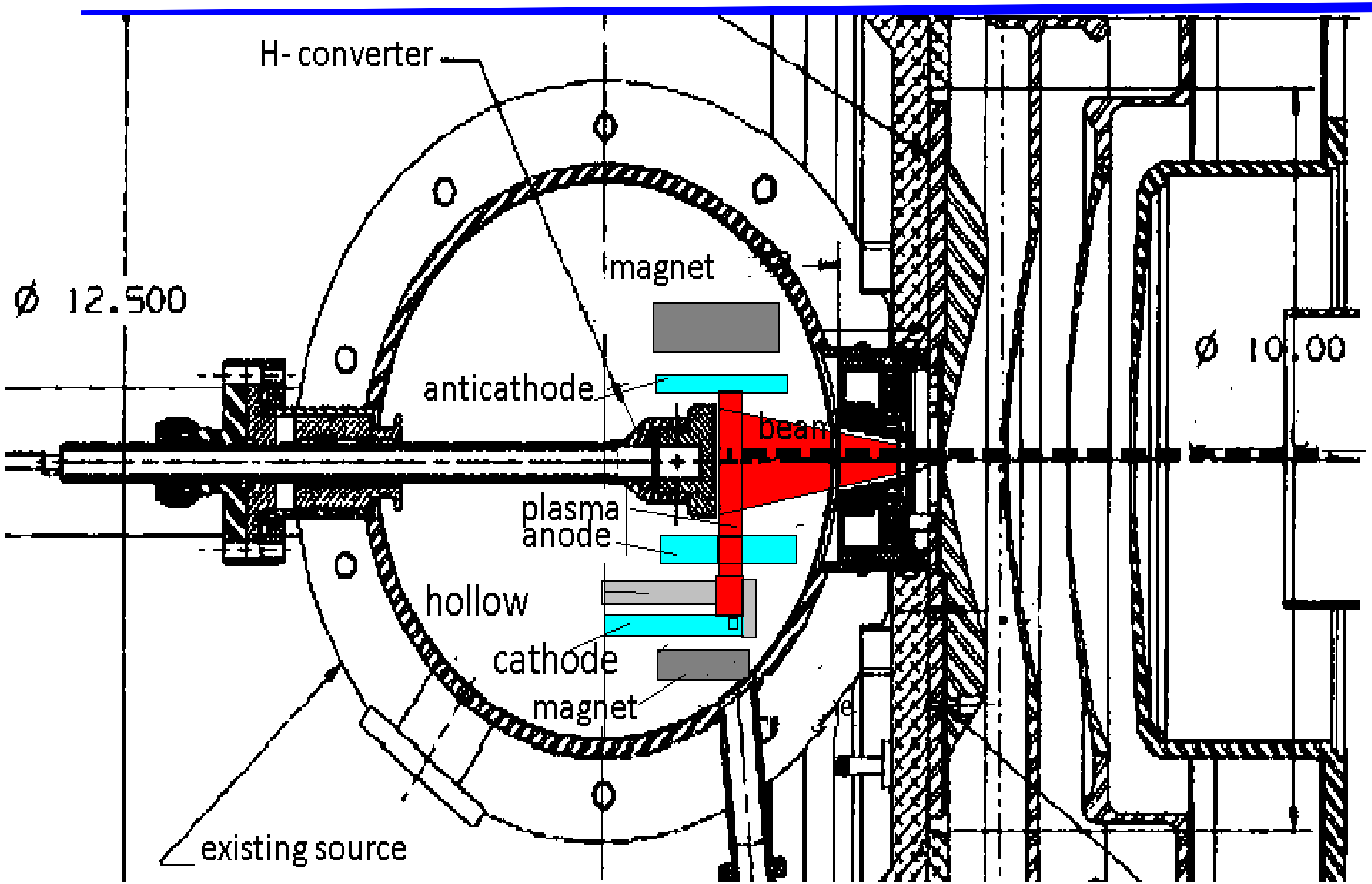


Fig. 6.

Other possibility is used a hollow cathode Penning discharge for generation a thin plasma sheet as shown in Fig. 6.

This discharge was tested in SPS with separated functions.
Hollow cathode have a hole 3x50 mm^2.
H_2 and Cs is delivered through channels in hollow cathode.

SPS with separated functions.

Experiments to optimize the processes considered were attempted in SPS with separated electrode functions.

In these sources, positive ions were generated by an independent discharge with a separate electrode system and a special electrode was used as the H- ion emitter.

The energy of the bombarding particles extracted from the plasma into the emitter was regulated by changing the potential difference between this electrode and the gas discharge plasma.

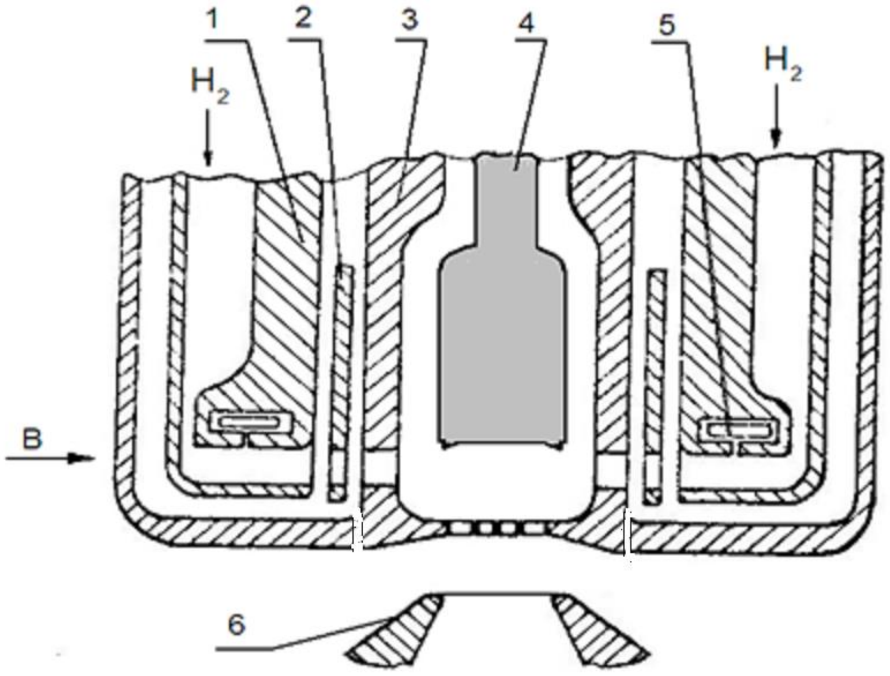


Fig.7. Schematic of SPS with separated functions.

Positive ions are formed in a flat layer of a gas-discharge plasma with transverse dimensions 0.12 × 3 cm^2 formed by establishing a discharge with electron reflexing in a magnetic field between hollow cathodes with cavities in the form of long narrow slits and coaxial anode windows 3. The distance between cathodes in this SPS is 1.2 cm. Hydrogen is supplied by a pulse valve in the cathode cavity. To increase the efficiency of electron emission in the cathode cavity, cesium was released from cesium chromate tablets with titanium in container 5, when heated. The discharge voltage can be regulated over a wide range by changing the cesium release. Stable operation of pulsed discharges obtains up to a discharge current of 450 A. The emitter 4 is installed with an adjustable gap Δ between its working surface and the boundary of the gas-discharge plasma layer (negative values of Δ correspond to its penetration into the plasma). Cesium for the emitter was fed from a container with independent heating. An emission hole with dimensions up to 0.3 x 3 cm^2 is located opposite the emitter working surface. To reduce the flow of accompanying electrons, the emission slit along the magnetic field is divided into three separate narrow slits by a jalousie (a shutter with a row of slats). with transverse dimensions 0.1 x 0.5 mm^2. The gas-discharge chamber is biased negatively at the extraction voltage. The extraction electrode 6 is grounded.

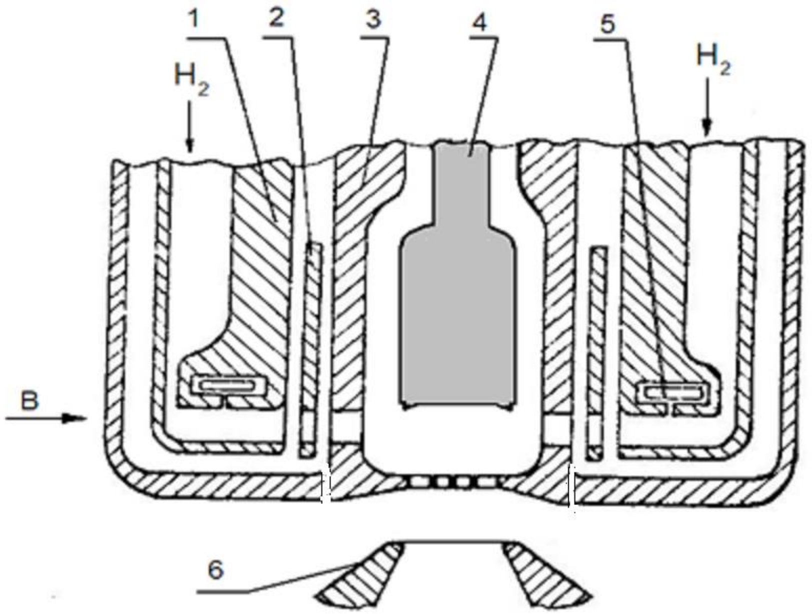


Fig. 7. Schematic of an SPS with separated functions. 1 – Cathodes of the plasma generation system, 2 – bounding diaphragms, 3 – anode, 4 – independent emitter, 5 – cavities for cesium, 6 – extraction electrode.

The above concepts were also confirmed when working with this SPS. Without the emitter and with a positive potential on the emitter, comparatively intense H- ion beams were extracted from the source with emission density up to 2 A/cm^2 by formation of H- ions at the electrodes near the emission slit.

With increase in the potential of emitter 4 up to -100 V relative to the plasma, the H- intensity increased by a factor of two ($\Delta \sim 0.1$ mm).

The dependence of the H^- ion current density on the voltage of the independent emitter for different emitter positions relative to the plasma is shown in Fig.8. In high current mode, H^- ion beams with emission density up to 5.4 A/cm^2 were obtained by optimizing the emission properties of the emitter and the energy of bombarding particles.

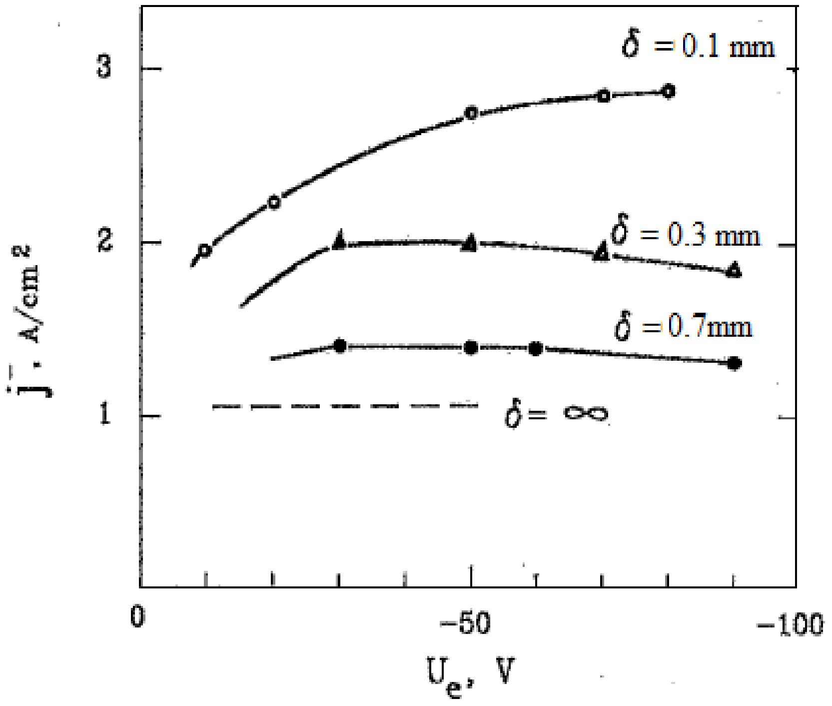


Fig. 8. Dependence on the voltage of an independent emitter of the current density of ions H^- for different positions of the emitter relative to the plasma.

Conclusion

- A new modification of converter SPS with cesiation and Penning discharge is proposed.

- It can improve negative ion production and increase SPS life time substantially.

V. Dudnikov, patent, “Technique for producing negative ions”, 411542, filed 10/III,1972, https://inis.iaea.org/search/search.aspx?orig_q=RN:9355182).
V. G. Dudnikov, “Surface Plasma Method of Negative Ion Production”, Dissertation for doctor of Fis-Mat. nauk, IYaF SORAN, Novosibirsk 1976.
Yu. Belchenko, G. Dimov and V. Dudnikov, Nuclear Fusion, 14(1),113-114 (1974).
Yu Belchenko, G. Dimov, V. Dudnikov, “Physical principles of surface plasma source operation”, Symposium on the Production and Neutralization of Negative Hydrogen Ions and Beams, Brookhaven, 1977 (Brookhaven National Laboratory (BNL), Upton, NY, 1977), pp. 79–96;
V. Dudnikov, Development and applications of negative ion sources, Springer, Switzerland, 2019.
V. Dudnikov, Yu. Belchenko, Journal de Physique, 40, 477, (1979).
Yu. I. Belchenko, V. G. Dudnikov, “ Surface plasma source with increased efficiency of H- generation”, Preprint IYaF 80-30, Novosibirsk, 1980, Proc. XV International conference on phenomena in ionized gases, Minsk, p. II, p. 1504 (1981).
K. N. Leung and K. W. Ehlers, “Self-extraction negative ion source”, Rev. Sci. 53, 803 (1982).
R. L. York and Ralph R. Stevens, Jr., “A cusped field H- ion source for LAMPF”, IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, (1983).
J. Sherman et. al., ‘Physical Insights and Test Stand Results for the LANSCE H− Surface Converter Source’, LA-UR-04-(6O55), LANSCE Division, Los Alamos National Laboratory, Los Alamos, NM87545, 2005.
Benjamin A. Prichard, Jr., and Ralph R. Stevens, Jr., "Status of the SPSS if Ion Source Development Program", Los Alamos National Lab Report LA-UR-02-547 (2002) .
G. Rouleau, E. Chacon-Golcher, E. G. Jacobson, et al., "H' Surface Converter Source Development at Los Alamos", Proceedings of the 2003 Particle Accelerator Conference (Portland, Oregon), IEEE Catalog Number 03CH37423C, 73 (2003) .
G. E. Derevyankin, V. G. Dudnikov, and P. A. Zhuravlev, “ Electromagnetic shutter for a pused gas inlet into vacuum units”, Pribory i Tekhnika Eksperimenta, 5, 168 (1975).

Other possibility is used a hollow cathode Penning discharge for generation a thin plasma sheet as shown in Fig. 6. This discharge was tested in SPS with separated functions. Hollow cathode have a hole 3x50 mm^2. H_2 and Cs is delivered through channels in hollow cathode.

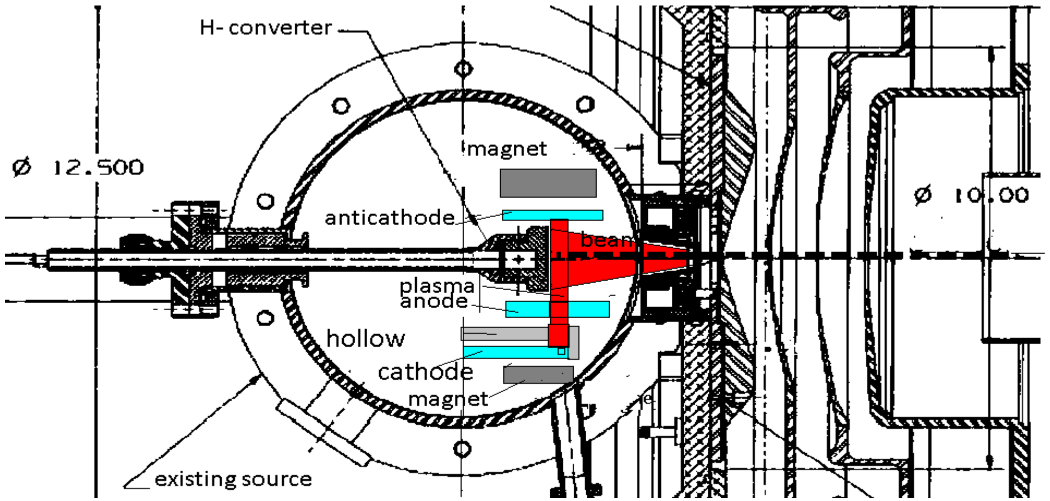


Fig. 6. Modified LANSCE converter SPS with a hollow cathode Penning discharge

SPS with separated functions

Schematic of an SPS with separated functions is shown in Fig. 7. Experiments to optimize the processes considered were attempted in an SPS with separated electrode functions. In these sources, positive ions were generated by an independent discharge with a separate electrode system and a special electrode was used as the H^- ion emitter of. The energy of the bombarding particles extracted from the plasma into the emitter was regulated by changing the potential difference between this electrode and the gas discharge plasma.