

RF Ion Source-Driven IEC Design and Operation

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Abstract

- * ***Portable neutron sources are of strong interest for uses such as industrial neutron activation analysis and various medical research applications. The inertial electrostatic confinement (IEC) device under development at the University of Illinois, Urbana-Champaign (UIUC) is intended for such applications and also provides a tunable x-ray source (requires reverse bias and added electron emitters). The IEC operates as an accelerator plasma-target type device, and when filled with deuterium presently provides $\sim 10^8$ 2.5-MeV D-D fusion neutrons/sec steady state. Use of D-T fill gas gives 14-MeV neutrons, with rates about 100 times that of D-D, but with the added complication of handling low levels of tritium. Research on a higher yield version using an RF ion source now under development is described here.***

Outline

- * **Introduction**
- * **Pulsed Operation**
- * **Goal of the Present Research**
- * **IEC and RF Source Setup**
- * **Neutron Yield Studies**
- * **Multi Beam Mode**
- * **Conclusions**



Introduction

- * The IEC (Inertial Electrostatic Confinement) concept has been demonstrated to offer a very attractive compact MeV neutron source in the 10^8 D-D neutron/sec range for laboratory use.
- * Changes in operation of the same unit can provide protons or intense keV X-rays.
- * An IEC neutron source has already been commercialized for industrial neutron activation analysis of various metallic ores during unloading on a conveyer belt. In this case, the IEC replaced a Cf-252 source to provide “on-off” capability.
- * Increased neutron/proton yields and efficiency will significantly expand the range of potential applications. Use of ion injection represents one factor towards such improvements.



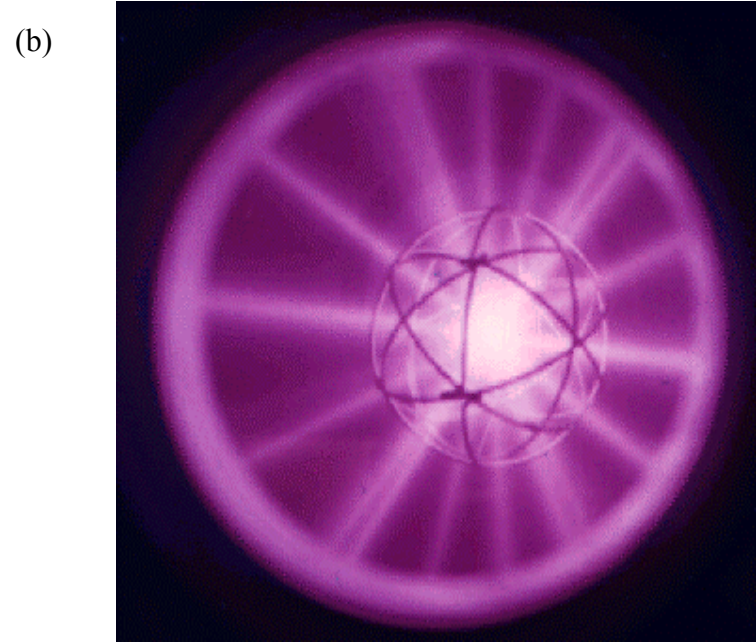
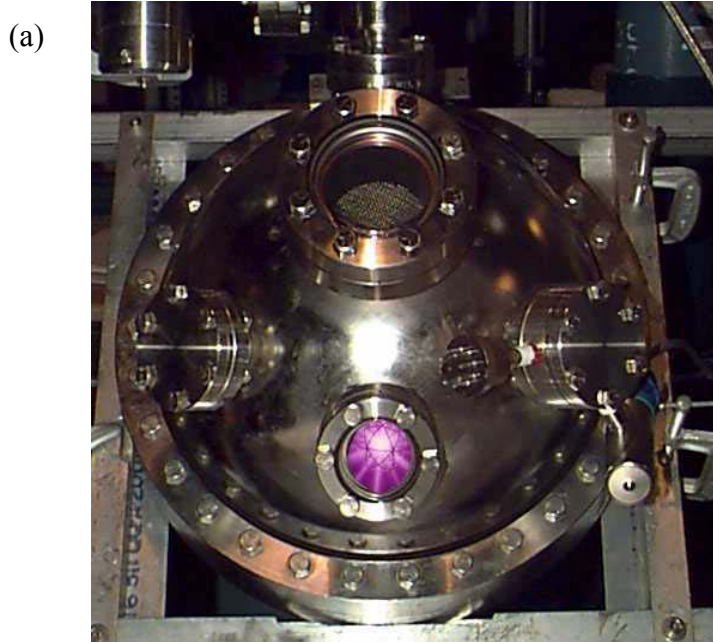


Photo of the “N-Device” IEC with open cage grid. The potential field associated with this type of grid causes the “star mode” ion beams that are clearly visible in the photo.

Importance of High Yield Unit

- * If the IEC yield is increased by several orders of magnitude, a number of exciting new applications become practical.
- * These include use as a neutron source, a proton beam source (both of which have a plethora of uses in private industry, medicine, and international security), a power and/or propulsion system for spacecraft, and a small teaching device for plasma physics.
- * The IEC for radioisotope production for medical applications holds promise for commercialization also. A particularly important isotope for medical applications is $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$.
- * A typical proton flux required for isotope production is $\sim 10^{11}$ p/cm²-sec, and this would be achievable from use of fuels such as D-He³ in the IEC.



X – ray Operation

- * Another important advantage of the IEC, especially the smaller laboratory units, is that they can be converted to an attractive tunable x-ray source with minimum alteration of the apparatus.
- * X-ray operation involves reversing electrode polarities and adding electron emitters at the vessel ports.



Pulsed Operation

- * Pulsing the IEC is attractive for higher neutron fluxes since at very high peak currents, the neutron yield scales as the current squared.
- * Pulse lengths of order of 50 μs were employed, slightly exceeding, the ion cathode-anode recirculation time.
- * In this mode, time-average neutron rates of $\sim 10^8$ D-D neutron/s were obtained at about 50 Hz while the extension to even higher yields appears feasible, using the RIDO concept.



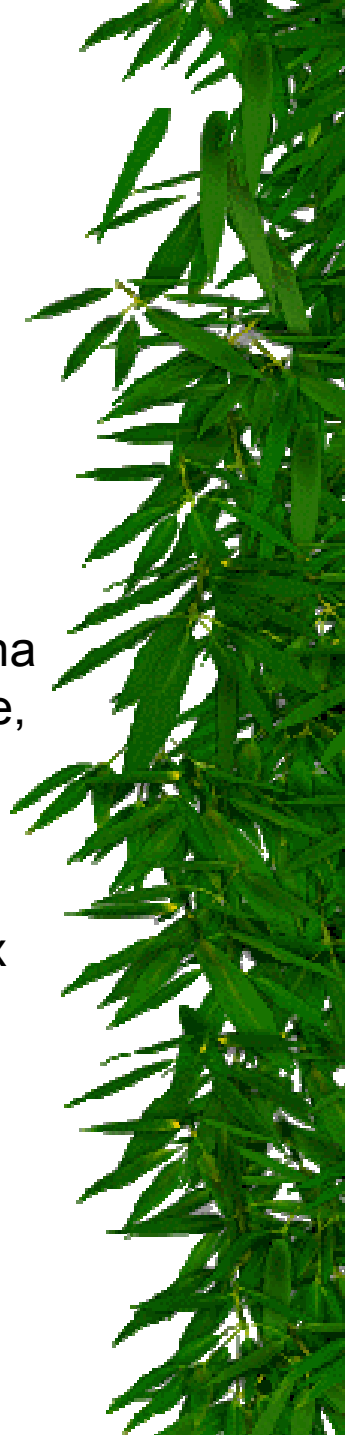
ILLIBS

- * We next review recent progress in IEC research at the UIUC using a unique external ion source, ILLIBS (Illinois Ion Beam Source).



IEC and RF Source Set Up

- * The ILLIBS ion source employs RF power (inductively coupled) to excite a deuterium gas fill (primarily driving electrons).
- * The details of ILLIBS are shown in the following Figure. The antenna is made from ~ 4 meters length of coaxial insulator high voltage wire, wound around a glass tube containing the fill gas.
- * The RF signal (13.56 MHz) is applied to one end of the antenna while the other end is grounded. The oscillating magnetic field created within the coil is directed along its axis and induces a vortex electric field.
- * Then, the negative potential on the IEC grid serves to extract ions from the RF discharge.



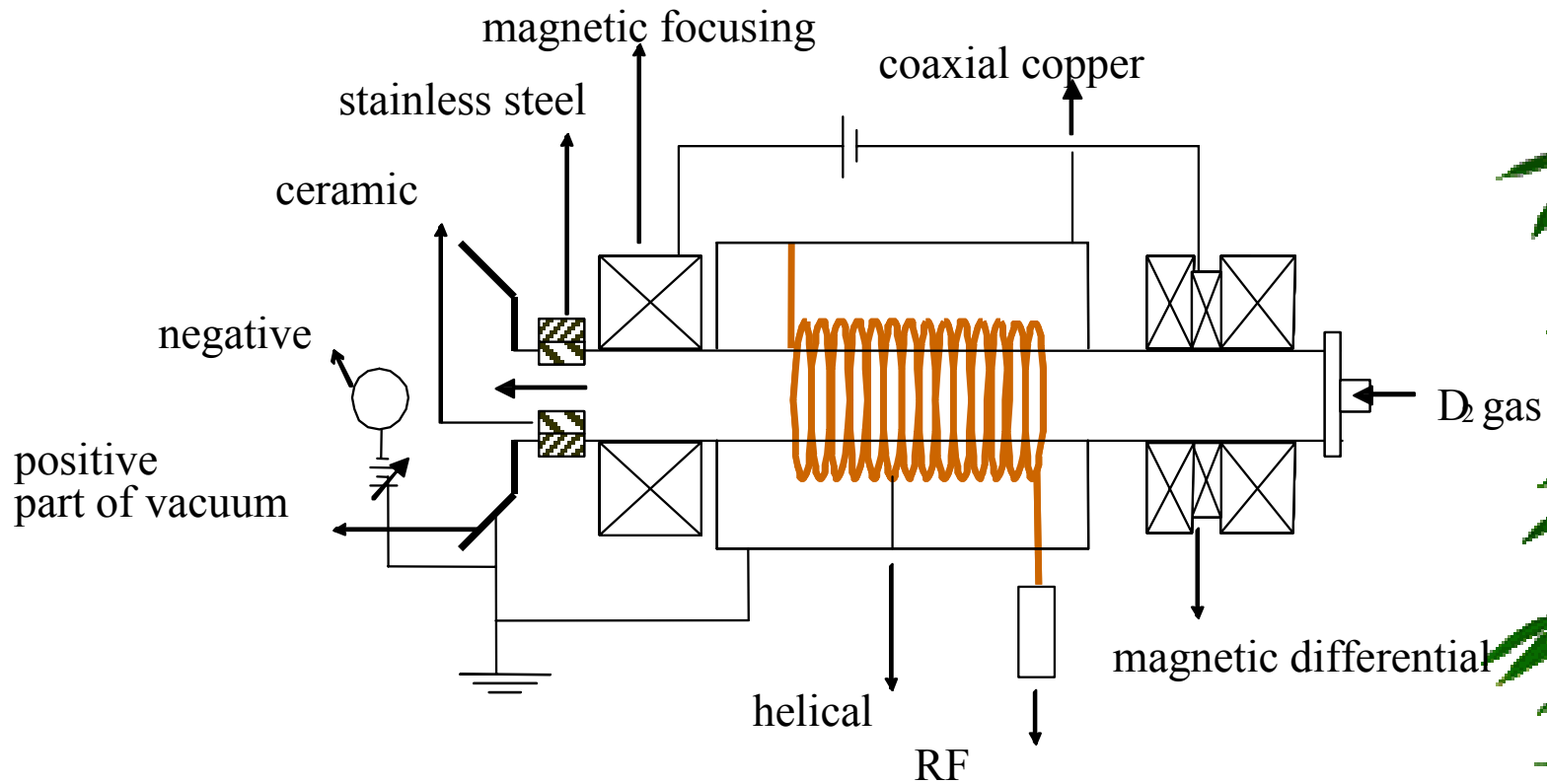
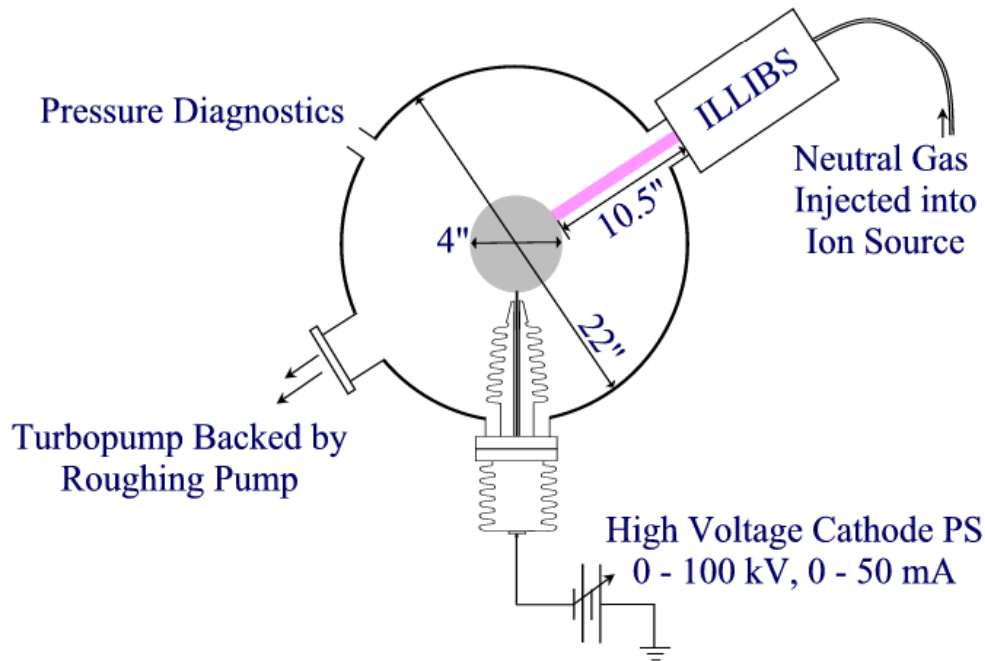
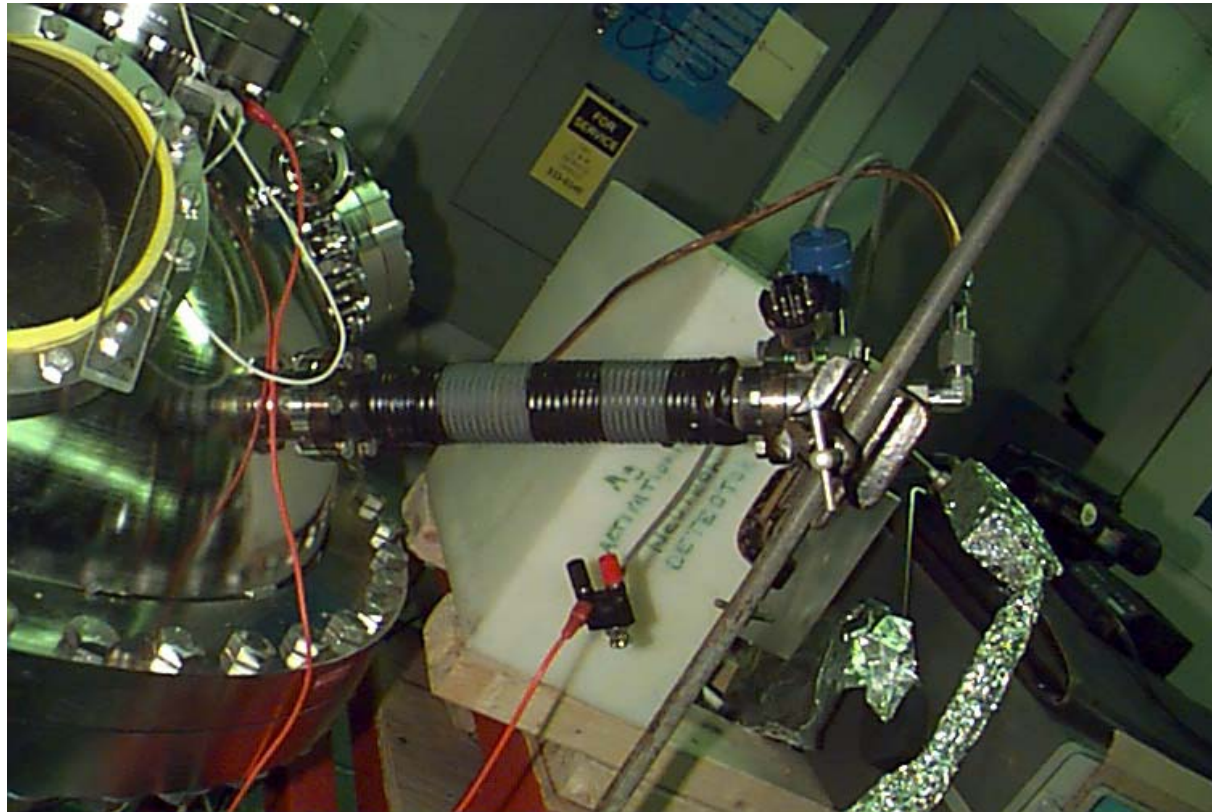


Illustration of the Illinois Ion Beam Source, ILLIBS. The main components are: magnetic-index dc coils, coaxial cooper shielding, antenna, front magnetic focus coil, and floating exit nozzle. The three back coils are connected in series.

Arrangement of the “N-Device” IEC with the ILLIBS ion source attached.



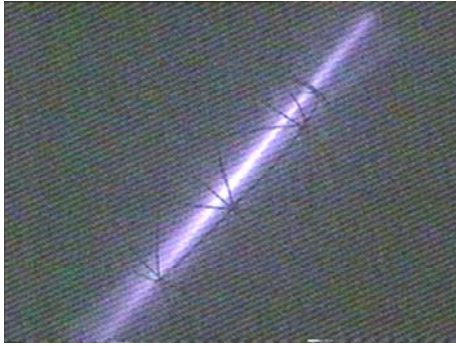
ICRF Ion Source Experimental Setup



The ILLIBS ion source is modest in size.

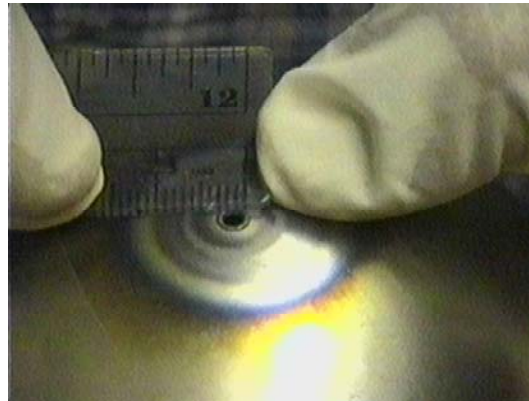


Single and Multi Ion Beams Generated in IEC Below Break Down Pressure



Photos of ion beam tracing inside IEC chamber, single ion beam (left) at 1.2 mTorr, 50 kV, and 0.015 Tesla, and multi-ion beam components (right) at 1.2 mtorr, 60 kV, and 0.03 Tesla. The multi-ion beam is generated above 50 kV, at pressure greater than 1 mTorr, and with magnetic field equal to or greater than 0.015 Tesla. The ion beam is generated from the upper part of these photos. However the orientation of the video camera was changed during the experiments and therefore the ion beam exit is either shown upper-left or upper-right.





Ion beam tracing at 2 mTorr 10 kV (top-left) and 13 kV (top-right).

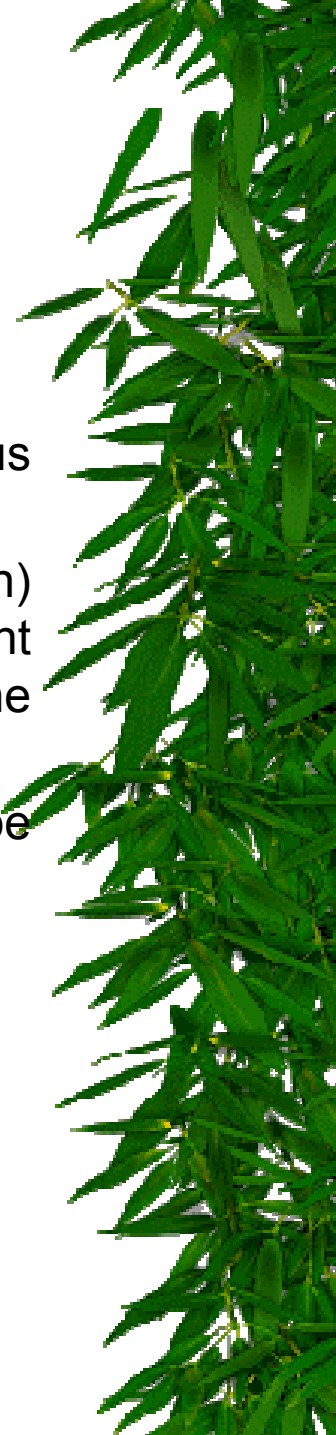
The ions were extracted at a distance of 26.6 cm. Effective ion beam diameter (bottom), the diameter of the hole, was measured to be 2.89 ± 0.01 mm (actually measured by digital caliper). The extracted voltage at this pressure is 13 kV, with corresponding current of 65 mA.

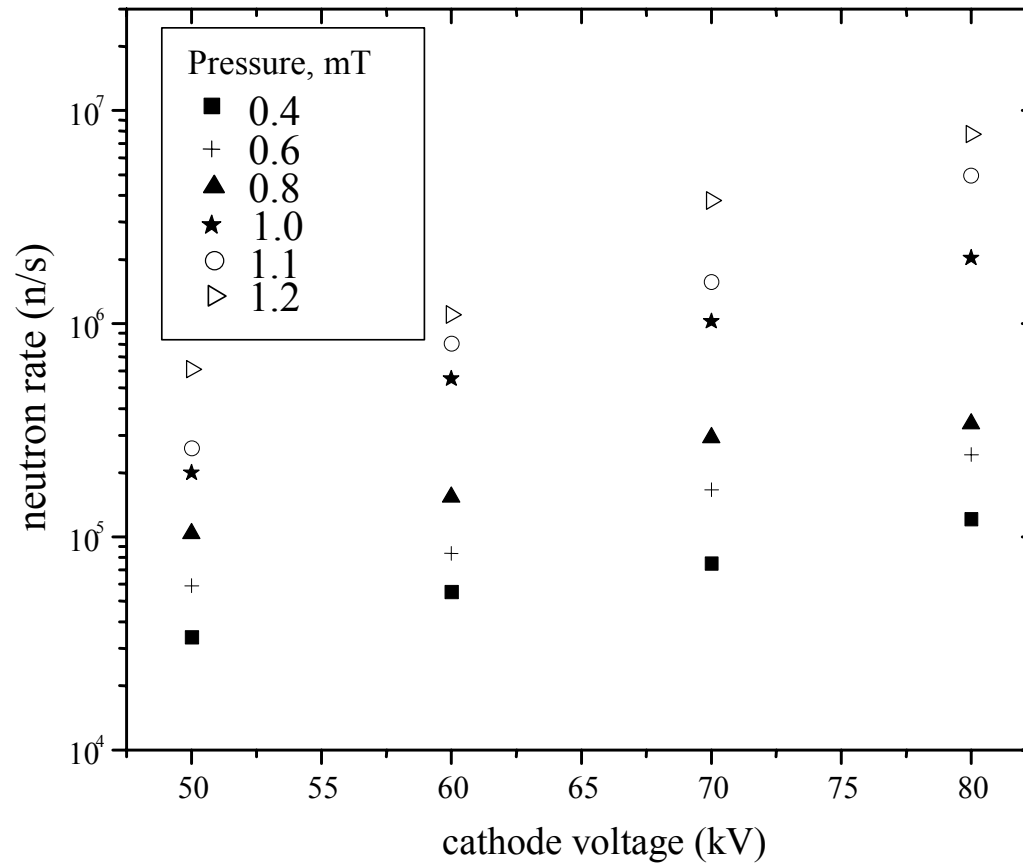
It is shown in the figure the elliptical diameter of the Gaussian beam, shown dark grayish with semimajor axis 21 mm and semiminor axis 17 mm. No peak current was obtained in this experiment (due to limitation of used equipment).



Measured Neutron Rate

- * The measured neutron rate is plotted in the graph that follows versus the cathode voltage for different pressures.
- * The net cathode current (total current reading with ion gun on) increases with an increase of the cathode voltage at constant pressure, and with an increase of IEC chamber pressure at the constant voltage.
- * At full gun operation a D-D neutron yield, of 2×10^8 n/sec would be achievable at 150 mA with cathode voltage at 75 kV.





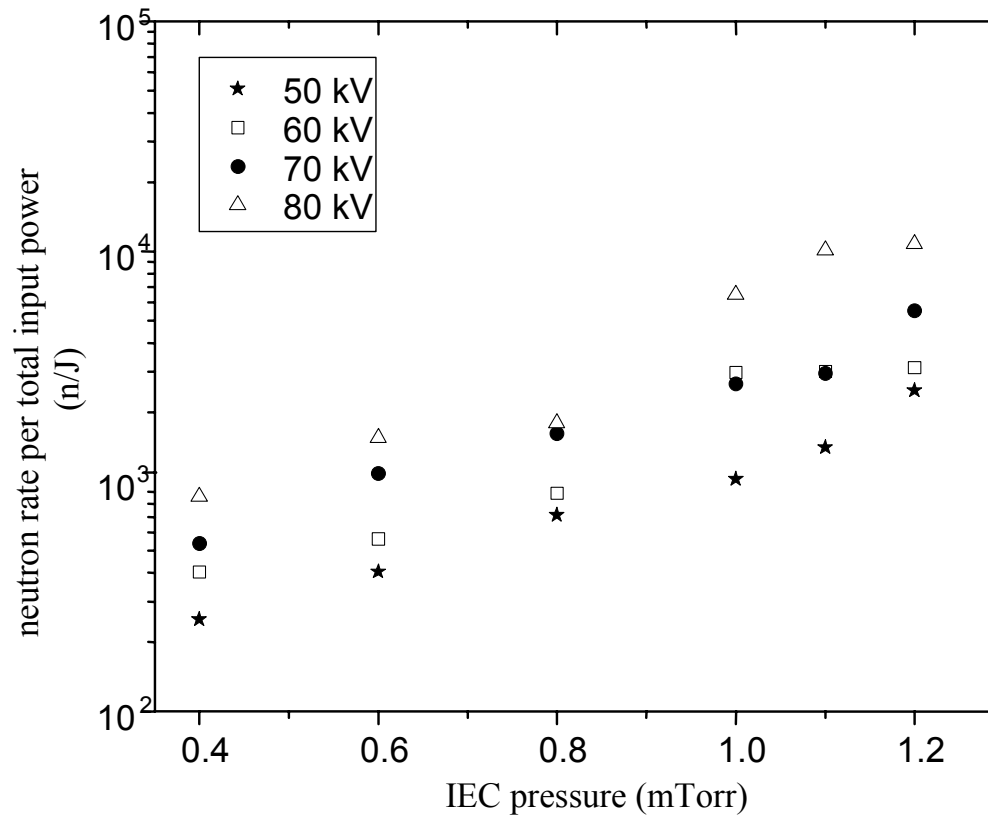
Variation of neutron rate with cathode voltage at different pressures. The RF transmitted power and the magnetic field were fixed at 91 W and 21 W (0.015 Tesla) respectively.



Efficiency

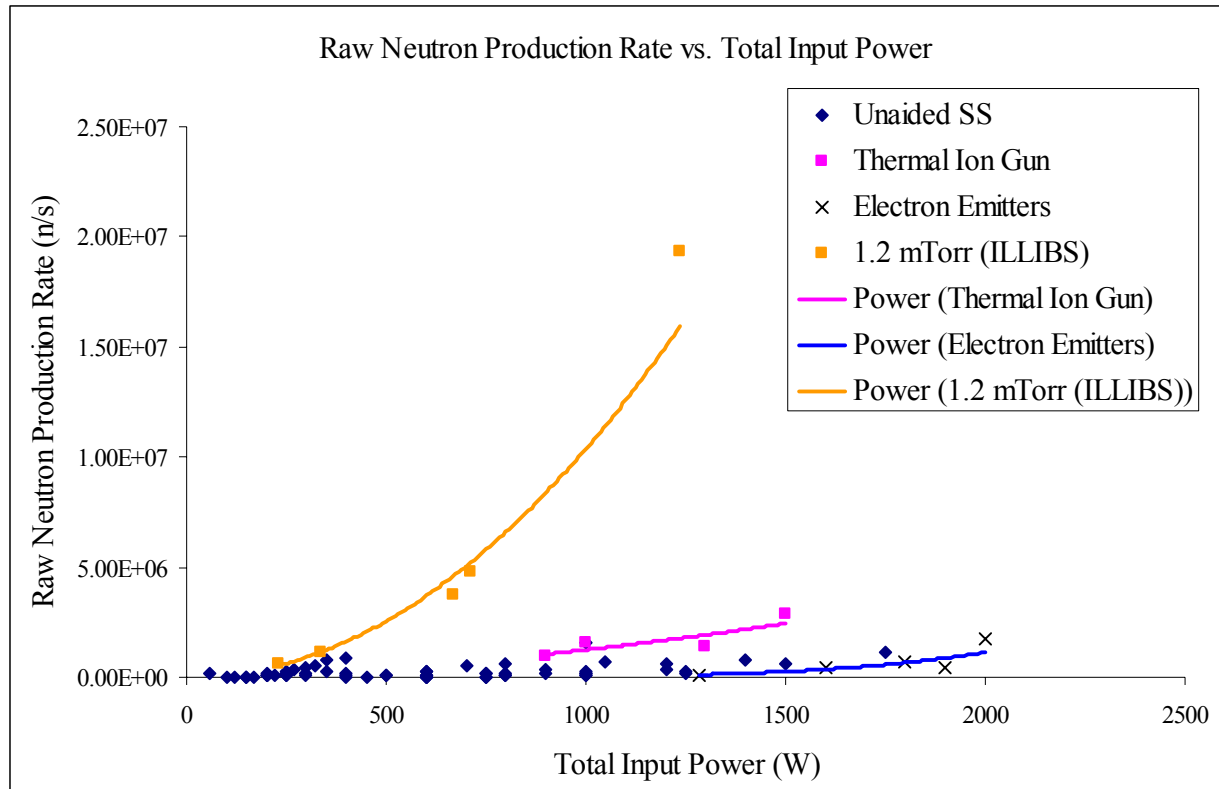
- * Maximum efficiencies of order of 10^4 n/J were obtained. The fact that this occurs at higher pressures is deceptive since the ion currents were low, and beam background fusion still dominated.
- * At very high currents, where beam-beam fusion dominates, lower pressures would be used, but the next graph does not include this region.





Neutrons production efficiency as a function of pressure for different voltages. The power input is the sum of the RF power, the inductive coupling power (91 W), the power supplied to the magnets (21 W, giving 0.015 Tesla) and the product of VI on the grid.





This graph shows the comparison of neutron production rate for various ion source modes. The ILLIBS offers the highest efficiency, particularly at higher input power. The benefits of RF ion injection are further illustrated in this Figure, where RF is compared to other plasma generation methods. As shown, the neutron yield at a given power input (neutron production efficiency) is significantly higher with RF ion injection as other modes of IEC operation Such as electron emitters and thermal ion guns. The ILLIBS gun enables IEC operation over a wide range of deuterium pressures that had not been previously studied.

Multiple Guns Needed

- * For optimum operation, sufficiently high ion currents are needed to create beams within all grid holes, simulating Star mode operation. For the present setup, it is estimated that such operation would require six RF guns of the type used here.
- * These guns would be located symmetrically around the IEC similar to the configuration Hirsch employed in early experiments.



Discussion and Conclusion

The ILLIBS RF ion source described here was found to be well suited for injection into the IEC..

Then when ions are injected into the vessel from the ion gun, a discharge immediately forms with the major microchannel aligned with the axis of the gun. Once the gun is turned off, this driven discharge is extinguished.

As these results illustrate, the use of ILLIBS greatly enhances the reaction efficiency for the IEC, one of the main goals of this research.

Thus, a “next-step” IEC with neutron yields $> 10^{12}$ n/sec from D-T fusion reactions appears promising provided a higher current ILLIBS can be built, and/or more ILLIBS units are used.

The gun-injected IEC opens the route to significantly higher neutron yields. If achieved, this would further expand the potential areas for application for IEC-based neutron sources. New applications such as medical isotope production would then become attractive since these units could provide localized isotope facilities near the medical facilities using them.



Thank You for your Attention

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