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Driven Subcritical Assembly Using a Cylindrical Inertial Electrostatic Confinement (IEC) Neutron Source

G. H. Miley, B. Ulmen, L. Wu, H. Momota
University of Illinois, 214 Talbot Laboratory, 104 S. Wright Street, Urbana, IL, 61801 ghmiley@illinois.edu

H. Hora
University of New South Wales, Sydney, Australia, School of Physics, SYDNEY 2052, Australia

P. J. Shrestha
NPL Associates, Inc., 912 W. Armory, Champaign, IL 61821

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illinois.edu

Introduction

- Design basis for a possible near-term driven subcritical assembly for student labs using a cylindrical Inertial Electrostatic Confinement (IEC) fusion neutron source.

- Rebirth of nuclear fission power requires new generation of training facilities for students.

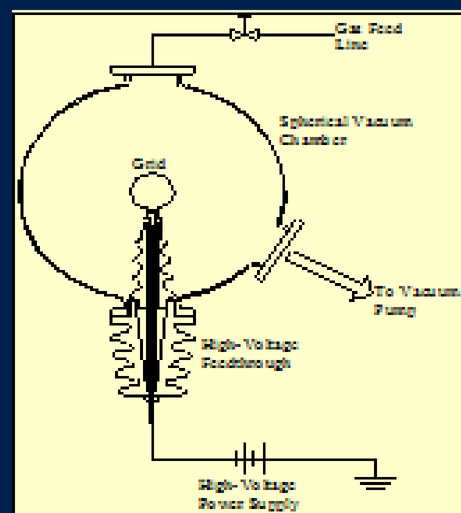
- **The IEC driven subcritical**
  - Very versatile facility for such training.
  - Various neutron wave forms (pulses, sinusoidal ramp ,etc.) by varying the applied voltage.
  - Opens up important class of dynamic experiments for student lab study.
  - Eases regulatory requirements and limitations on core configuration changes
  - Introduces students to fusion-fission reactor concept.

An Accelerator-Driven Sub-Critical Reactor

- Benefits:
  - Important safety advantages for future fission power systems.
  - Small enough to fit within fuel element channels or in a central cavity region of sub-critical assembly.
  - In addition to large power reactors, special low power designs for student subcritical laboratory experiments and research reactors.
  - Allows exploration of a wide variety of fuel element configurations and reactor kinetic dynamic studies not possible with current facilities.
  - Better equip future nuclear engineers for insuring continued safe operations of our nuclear power plants.
  - “Hands-on" introduction to fusion-fission hybrid systems which may become an attractive approach to future power systems.
- Issues:
  - Ability to achieve neutron rates required using small diameter units.
  - Radiation hardening in the high-voltage feed-through design.

Prior Work on the IEC Source

- IEC neutron source units at the University of Illinois at Urbana-Champaign (UIUC) employ a large grid opening spherical or cylindrical design to allow operation in the unique “Star” mode. In this mode, the ion beams formed go through the center of the grid openings, preventing excessive grid erosion by ion bombardment.

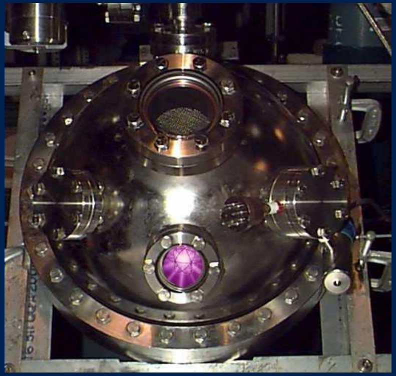


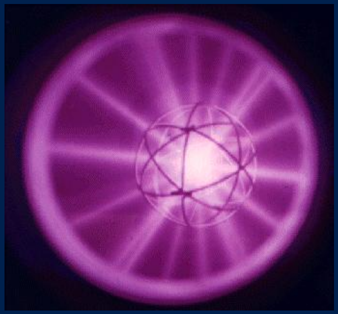
The “Traditional” Spherical Design

Illustration of a spherical IEC. The discharge between the grid and vacuum wall creates an ion source that is extracted and directed towards the center by the highly charged nega

Star Mode Operation

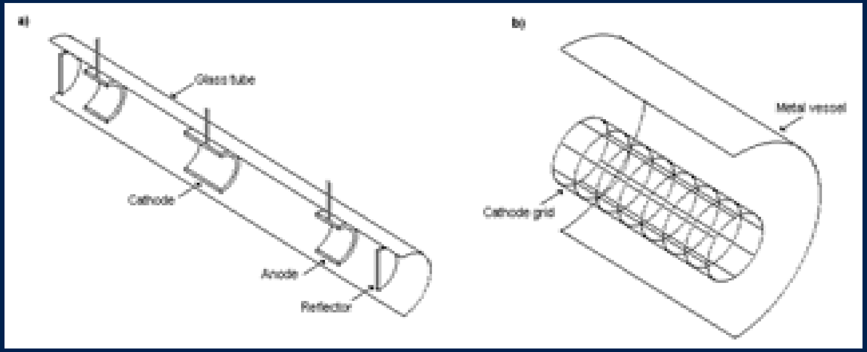
The discharge between the grid and vacuum wall creates an ion source that is extracted and directed towards the center by the highly charged negative grid. Left - photo of a typical IEC chamber. Right - photo of the discharge through the viewport shows the “Star Mode” discharge where ion beams are created that pass through the grid openings.





C-Device

- Cylindrical IECs offer advantages in a variety of practical applications, including the present sub-critical reactor system. Two types shown have been studied:
  - Gridded version (right) is essentially a 2-D version of the "tradition" spherical IEC.
  - C-Device (left) is more like a hollow cathode discharge but with focusing end plates.



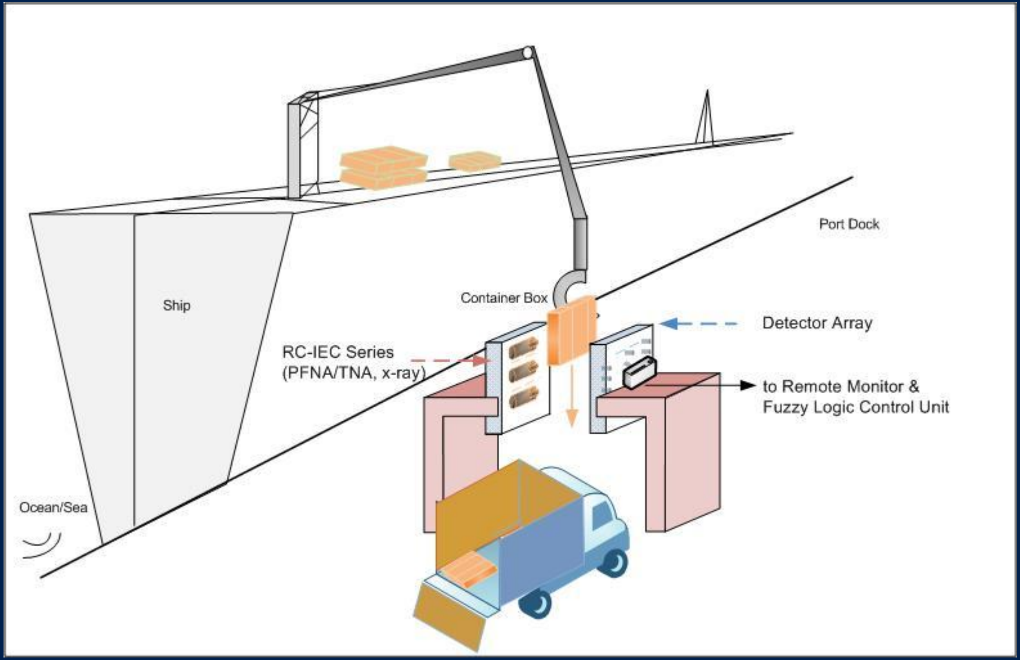
C-Device

- The geometry and size particularly attractive for the driven sub-critical application.

- Uses hollow cylindrical anodes (held at ground potential) at either end, the hollow cylindrical cathode in the center is biased to a high negative potential. Deuterium gas introduced at the end is ionized in the resulting discharge, creating an ion source. These ions are accelerated back and forth along the axis, where they collide and fuse. The prototype C-device used a cylindrical glass vacuum chamber of ~6" diameter and ~50" long and was run at a positive potential of about +80kV. Positive ions formed in the plasma between the electrodes are accelerated toward the center cathode. Because the anodes and cathode are hollow, most ions and electrons pass through them without colliding with the structure, giving an effective transparency of ~100%. The electrodes at the ends of the chamber, called reflector dishes, are solid concave steel surfaces held at ground potential. The curvature of these dishes is selected to “reflect” and focus electrons toward the center of the anodes where they pass through and recirculate in a manner similar to the ions. The ion density peaks in the beam path, significantly enhancing the fusion rate along an extended beam-background reaction volume around the center line, giving the observed line-type neutron source. Experiments showed the C-device gives neutron yields comparable with a spherical device under similar conditions of voltage and current.

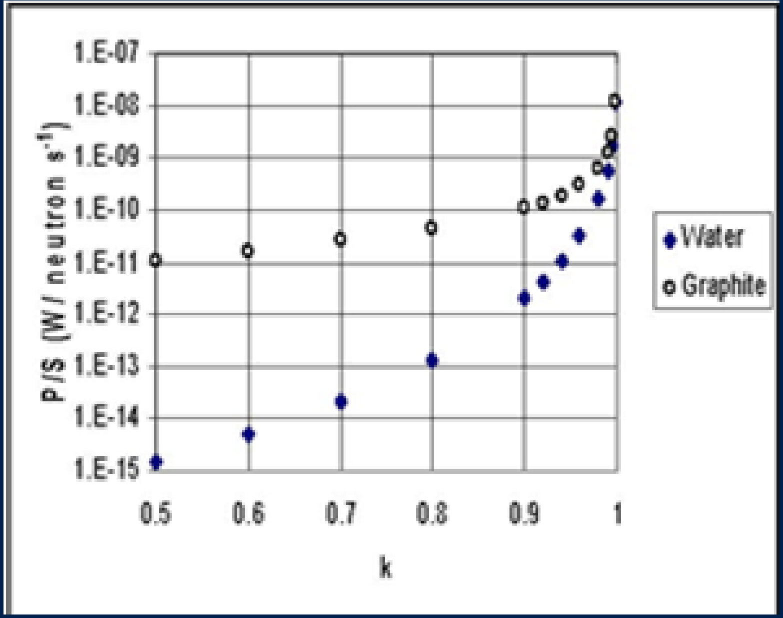
C-device in operation

C-device offers broad area coverage neutron source for NAA applications such as homeland security for cargo ship docks.



Use in Student Subcriticals

- The first use of IEC driven fission systems could well be for application to low-power student laboratory subcritical assemblies in universities.
- Neutron source strength required is modest, near that obtained with present IEC devices.



Power level per unit source (P/S) as a function as a function of k_{eff} for two different moderators

Use in Student Subcriticals

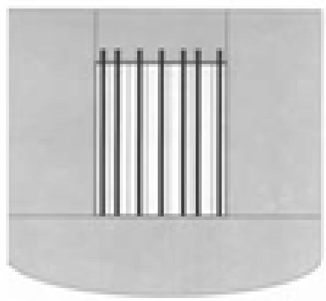
- Since existing experimental IEC devices have already achieved ~10^9 D-D n/s or 10^{11} D-T n/s equivalent, the increased gain needed for the system in Table 1 appears feasible in the near term.

Parameters for a 1 kW graphite- moderated sub-critical system

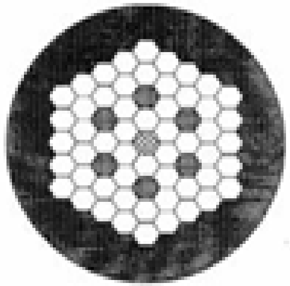
Fuel	**UO_2 (0.5% U-235)**
Moderator material Graphite Moderator volume fraction	**95%**
Multiplication factor	**0.99**
Radius (cm); Height (cm)	**30; 50**
# of C-devices/yield per device(n/s)	**7/1.5x10^{11}**
Subcritical Power (kW)	**1.2**

IEC for the Driven Power Reactor

- Designed to ensure safety against criticality and loss-of-cooling accidents as is proposed in the accelerator-target driven reactor concepts.
  - Simple temperature sensitive fuse in the in-core electrical circuit to shut down the high-voltage needed to maintain neutron generation. A melt type rupture disk on the IEC wall could be added to spoil the IEC vacuum.



Vertical cross-section of the core showing cylindrical IEC modules (Dark vertical lines)



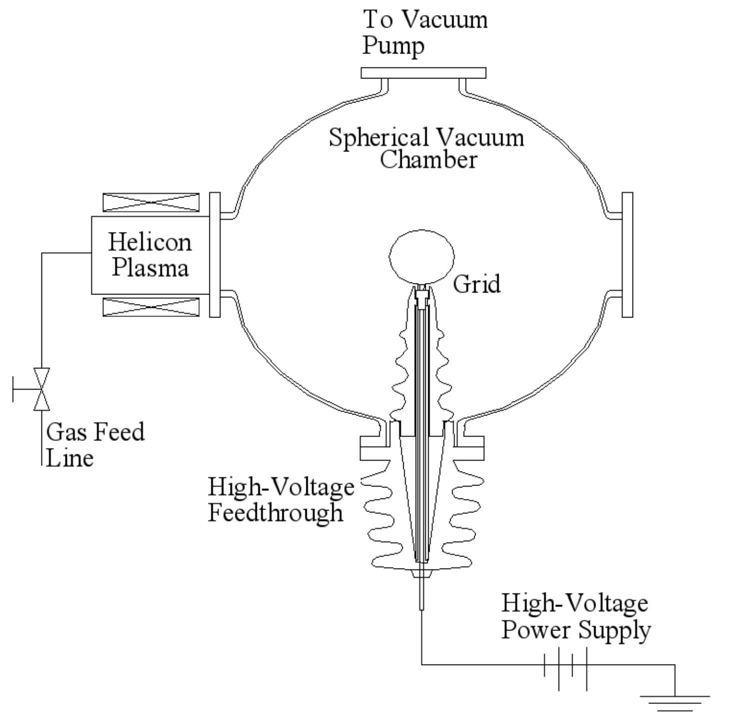
Cross-section view of the reactor core showing the IEC modules (cross-hatched channels).

RF Ion Injector for IECs

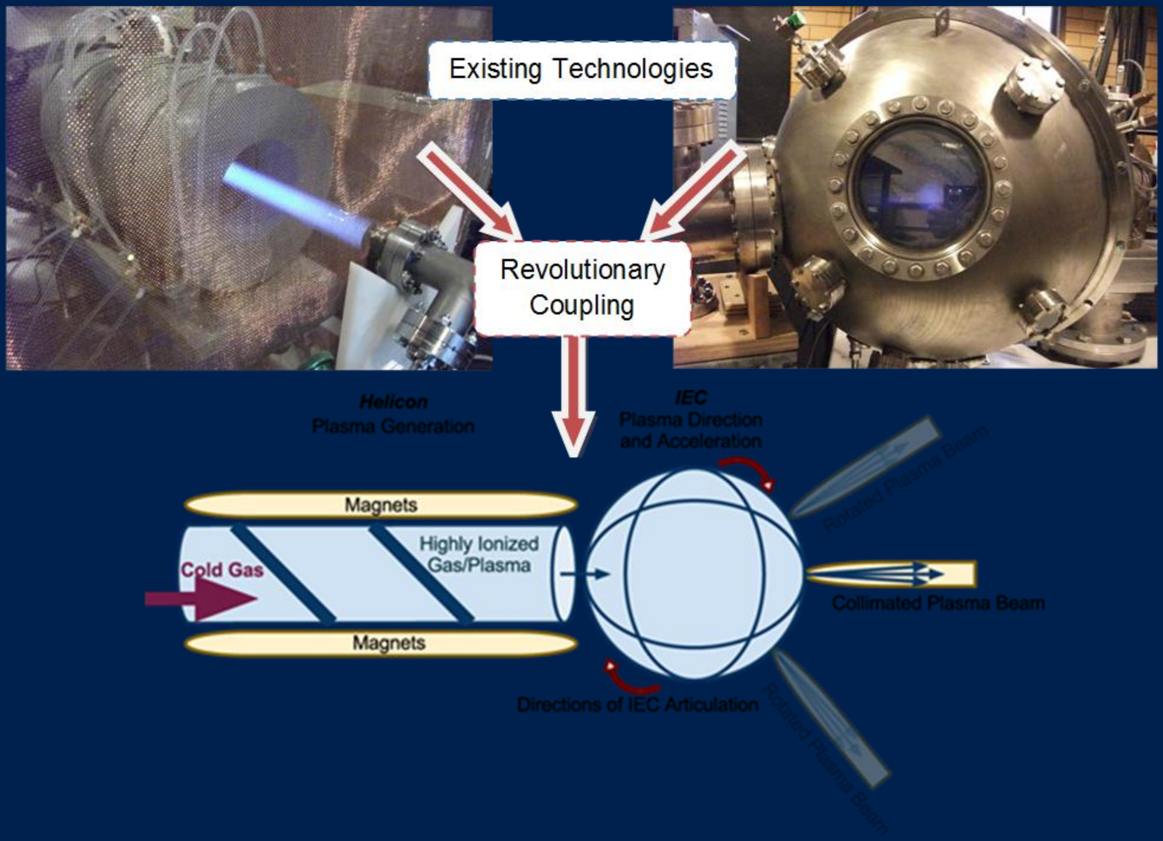
- A possible high current that could mate well in size to the C-Device is the ILLIBS (Illinois Ion Beam Source) which was previously studied for use on a spherical IEC.

Photo of ILLIBS connected to the spherical IEC. The main parts are: magnetic-index dc coils, coaxial cooper shielding, antenna, front magnetic focus coil, and floating exit nozzle. As shown, it is a very compact unit, about 4" diameter and 25" long.

Schematics of an IEC device with helicon plasma injection. This offers a high injection rate of nearly fully ionized plasma – giving a high neutron yield neutron source such as needed for driven power reactors.



HIIEC facility at Illinois



Helicon Injected IEC (HIIEC) facility at Illinois

- The helicon plasma system at the University of Illinois is an m=+1 helical antenna using a 13.56 MHz radio frequency source to produce an inductively coupled plasma. It has magnetic field coils producing up to 1200 Gauss to propagate the helicon mode. The IEC vacuum vessel is a 24 inch spherical stainless steel chamber with a central grid mounted on a high voltage feed through. The current power supply for the grid can operate up to 1 kW with a maximum voltage of 50 kV and a maximum current of 50 mA. The main vacuum system has been assembled and has been proven to work properly. The entire system reaches a base pressure in the microTorr range. The basic power supplies have been tested and first plasma has already been achieved.

Development Issues

- Geometric and construction modifications (slightly smaller diameter and ceramic vs. glass construction) are needed for robust units for the graphite subcritical described.
  - Construction of an actual prototype device and demonstrate its operation.
  - Technology concerns such as incorporation of high-voltage stand-offs that are "radiation hardened" against the nuclear radiation levels encountered.
  - Economics of retrofitting existing subcriticals in this fashion. It is estimated that such a system using seven devices sharing subcomponents plus controls would be less than $100,000 US, exclusive of design, installation and licensing costs.

Conclusions

- IEC source strength already near level required for driving student subcritical assemblies and concept for retrofitting existing assemblies appears feasible.
- Some more R&D is needed to design a robust C-Device and address engineering issues such as radiation hardening of the voltage holding components.
- Application would be quite advantageous since training for students on reactor dynamics and safety issues would help meet the educational and research needs facing the nuclear community.
- Could be a forerunner to using IECs as an approach to the fusion-fission hybrids driven reactors such as others propose with an accelerator-spallation target.
- Unique flexibility whereby the source could be in a central location or distributed across a number of fuel channels.
- The key issue is how to scale the IEC up to the high yields needed for such use, and a route using the RF ion injector ILLIBS or an Helicon were briefly discussed.

Thanks for your attention

- For more information, contact

George H. Miley
ghmiley@illinois.edu
217-3333772

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