Inertial Electrostatic Confinement (IEC) Based Compact X-ray Source

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Outline

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- Introduction
- Advantages
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- Other modes of operation
- Neutron source
- Comparison
- Summary of Applications
- Conclusions

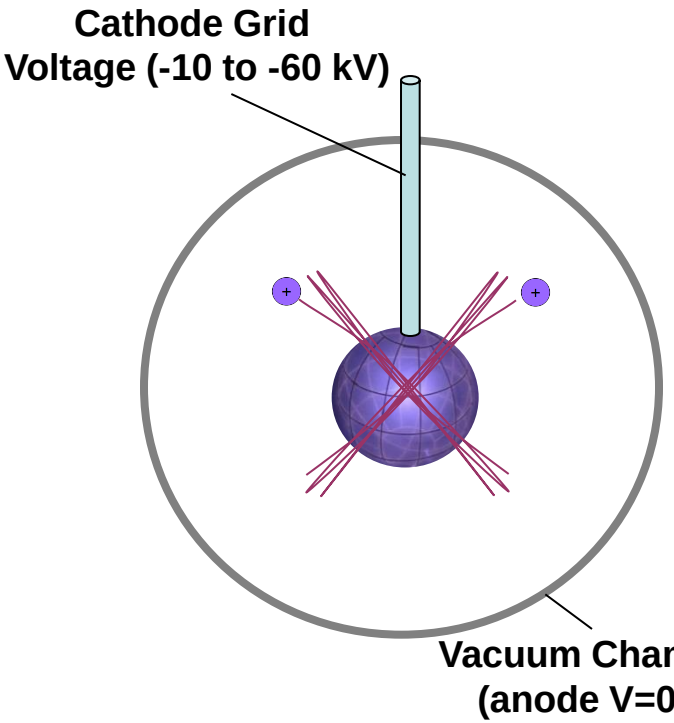
Motivation

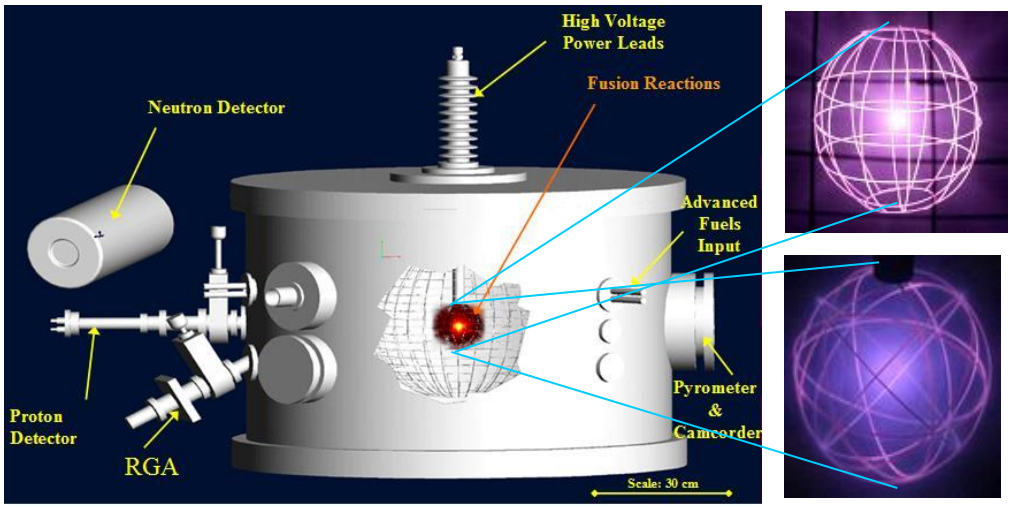
- Although x-ray detectors are already available onboard ISS for cosmic x-ray background measurements, there are no diagnostics available for material characterization.
- Moreover, those that are being scheduled to be used in ISS are principally x-ray sources and none else.
- In every materials research effort x-ray and neutron radiographies are required to cover the entire spectrum of elements. While High Z materials require X-rays, the Low Z materials require neutron radiography for characterization.
- Space systems require low mass, low power systems that are not only durable but also multifunctional when possible (to save space)
- Inertial Electrostatic Confinement (IEC) devices offers some unique features suitable for space applications

What is an IEC device?

IEC Technology

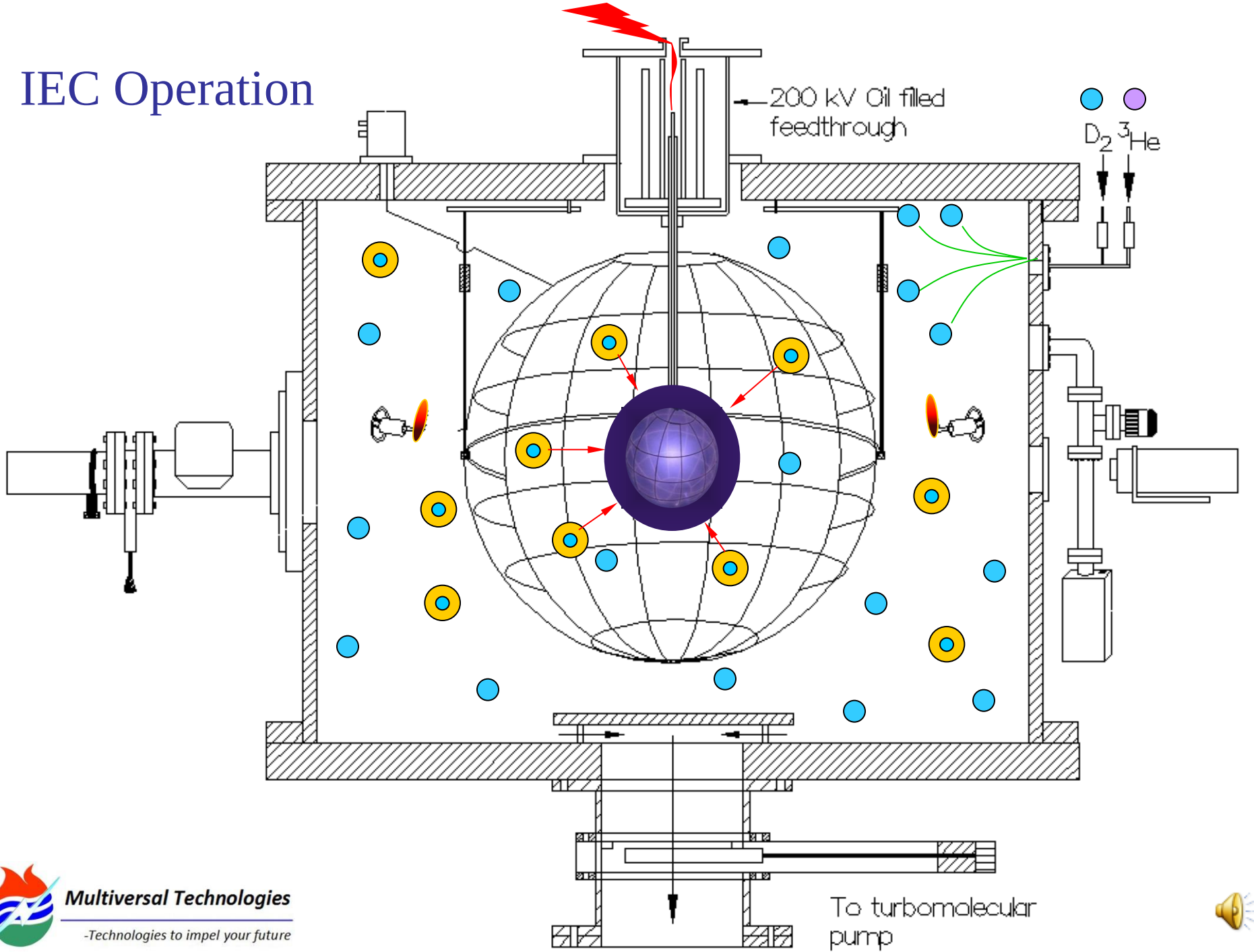
Basic functioning is simple





- IEC stands for
  "Inertial Electrostatic Confinement"
- Simultaneously invented by
  - **Philo Farnsworth (USA) & O. Lavrent'yev (Former USSR) in early 1950s**

IEC Operation



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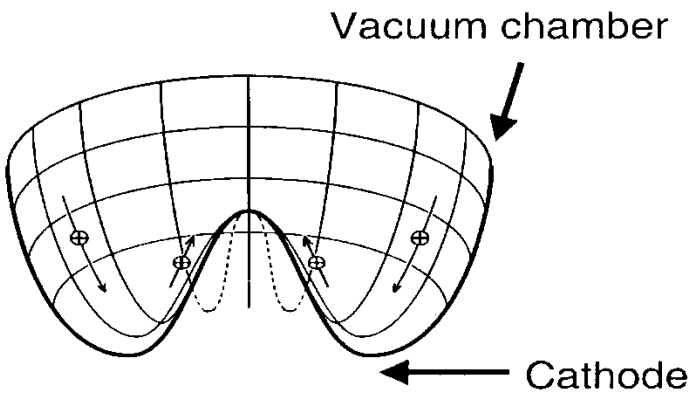
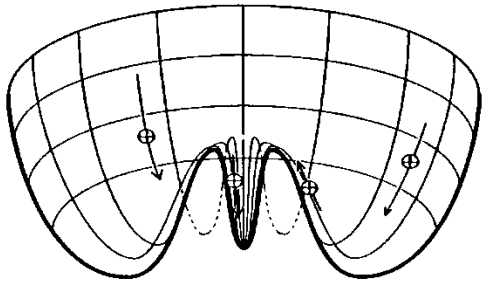
Formation of 'Poissor' Structures

Space charge cloud structure - "Poissor" to be formed which enhances the reaction rate



Single well



Double well

- At high enough currents a potential structure (theoretically predicted) forms and could cause an I^3 and eventually an I^5 scaling of fusion rate, Miley et al.
- Several tests have both confirmed the presence or absence of these potential wells.
- More work is needed to establish their presence.
- Even without these poissor structures, this device is still useful.

Advantages of an IEC device

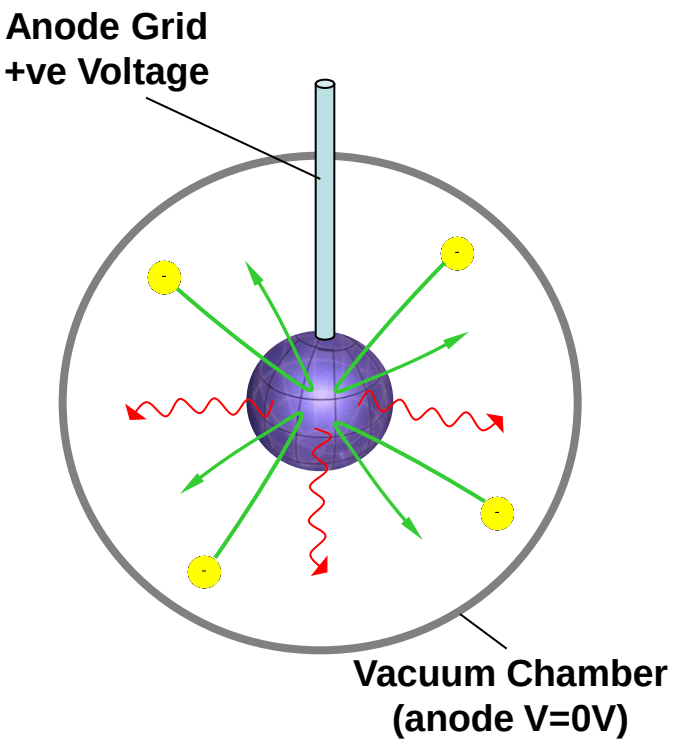
Multitude of applications possible with a single radiation source

- Safe to use
- Robust enough to survive the rattles of the launch vehicle
- Straight forward to fix
- Compact source of multiradiation
  - Neutrons
  - protons
  - x-rays
  - Ions
  - Anions (negative ions)
  - electrons
  - Energetic neutrals
  - charged particles
- Power supply can be made very compact.
- Works in both steady state and pulsed mode.
- Operates in multiple modes
- Consumes less power

IEC X-ray Source

IEC X-ray Technology

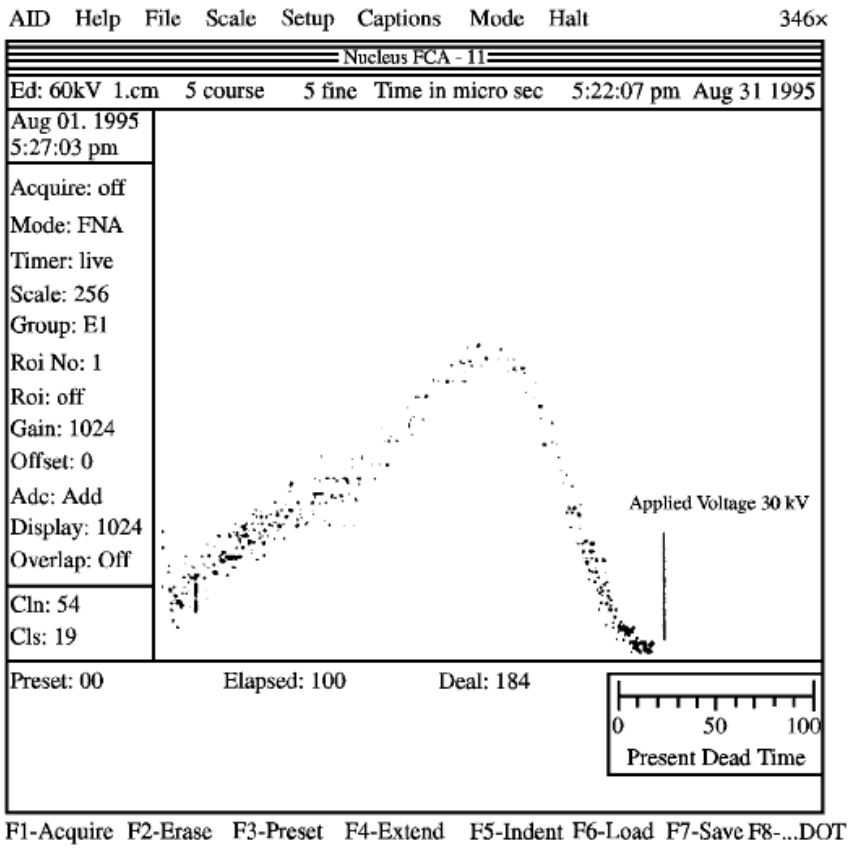
Basic functioning is still simple



- Technology first conceived by Prof. George H. Miley from University of Illinois at Urbana Champaign

Measured X-ray energy Spectrum

X-rays produced all the way up to the applied voltage



- G. H. Miley, Nuclear Instruments and Methods in Physics Research A 422 (1999) 16Ð20

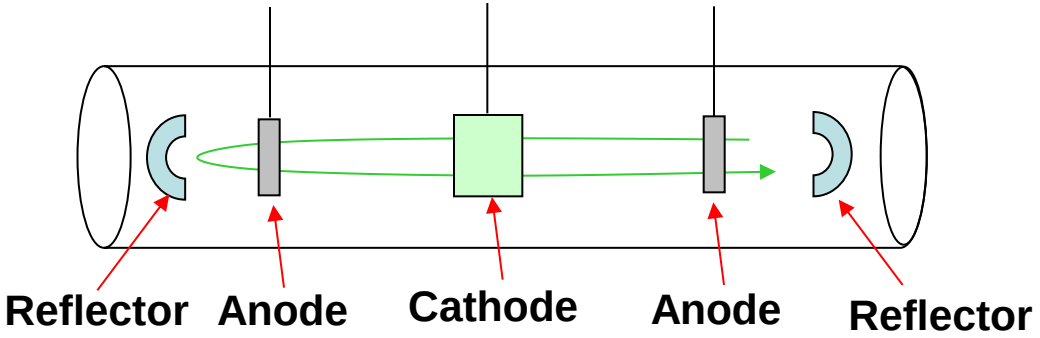
Advantages of an IEC X-ray source

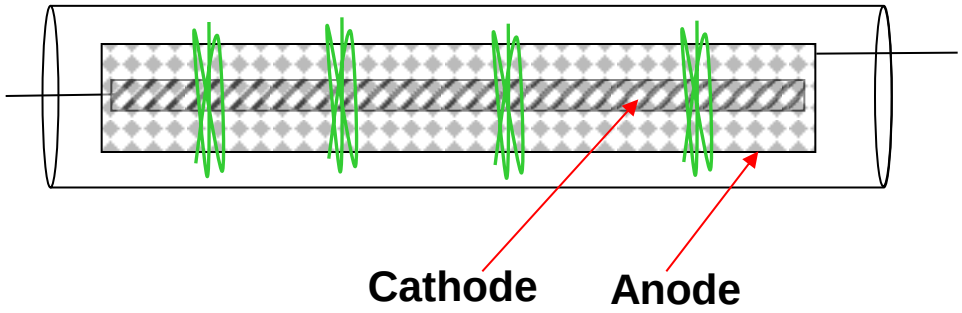
Space saving, multifunctional technology

- The same electrode configuration that earlier produced neutrons can be used to generate x-rays by simply reversing the polarity of the applied voltage.
- The resulting electron Bremmstrahlung radiation has a broad energy spectrum extending up to the applied voltage.
- The hard x-ray generation is limited only by the power source used.
- Since voltage multipliers can easily be created, pulsed hard x-ray sources can be easily created.
- Furthermore, in this mode of operation there is no electrode degradation and hence ensures a long lifetime.
- This makes possible some small-scale laboratory x-ray experiments in any facility that would otherwise necessitate a commute to a synchrotron-type “light” source facility. Not feasible for ISS.
- With instruments available onboard ISS experiments could be conducted at a faster pace ensuring greater productivity
- With such a facility on board ISS new experiments could be planned

Other Device geometries

This device can operate as a point source or as a line source





- An IEC device can take a cylindrical geometry.
- This geometry approximates a line source
- Two such configurations are possible
- First configuration allows ion recirculation along the central axis
- The second configuration promotes radial ion recirculation

Experimental facility at UW Madison

Ongoing experiments at UW Madison

Other Modes of Operation

Each of the several modes of operation has its own set of applications

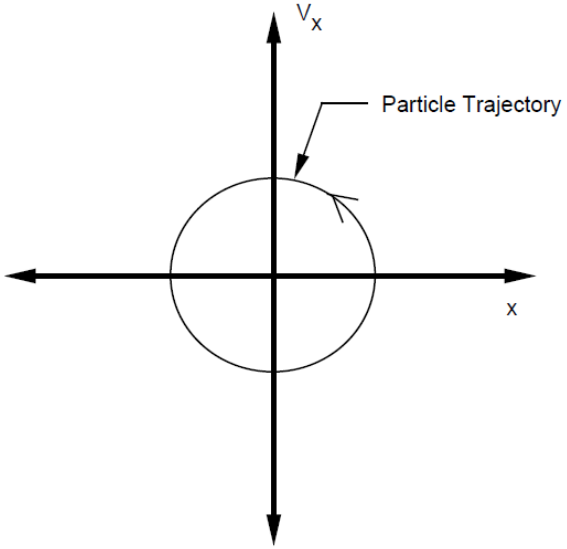
- Pulsed mode operation (highest radiation)
- Stead state mode
  - Impact ionization source
    - Double grid mode
    - Triple grid mode
  - Filament electron source
  - Ion gun source
    - Helicon ion source
    - Ion beam source
  - RF ionization source
- Periodically Oscillating Plasma Sphere

IEC POPS configuration

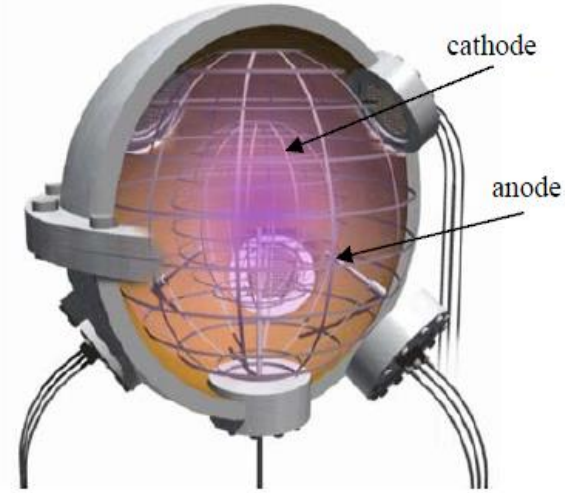
IEC-POPS Description

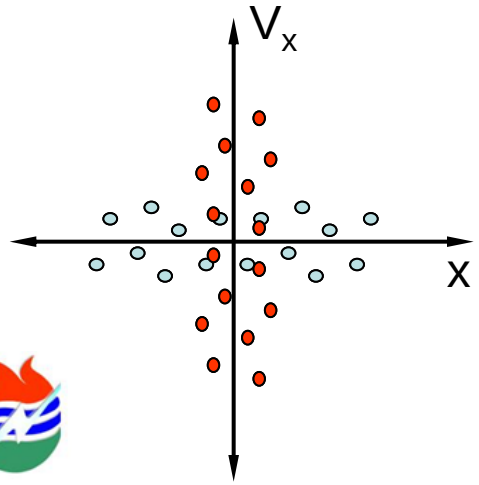
Pulsed device with tuned rotation

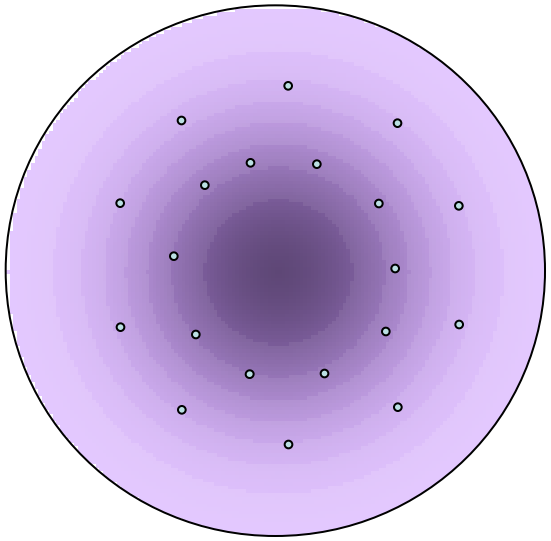
Ion Phase Space Motion in a Harmonic Oscillator



- Distribution functions move like a rigid rotor
- Maxwellian velocity distribution requires a Gaussian density profile
- Density and velocity profiles exchange every quarter period







Ions

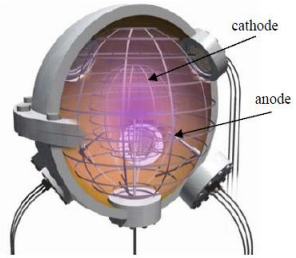
- Execute Simple Harmonic Motion (independent of amplitude)
- All ions with phase-locked period of oscillation arrive simultaneously at the center as the plasma collapses upon itself

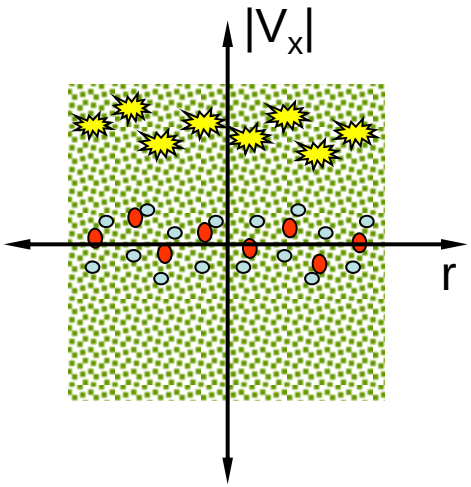
IEC High pressure configuration

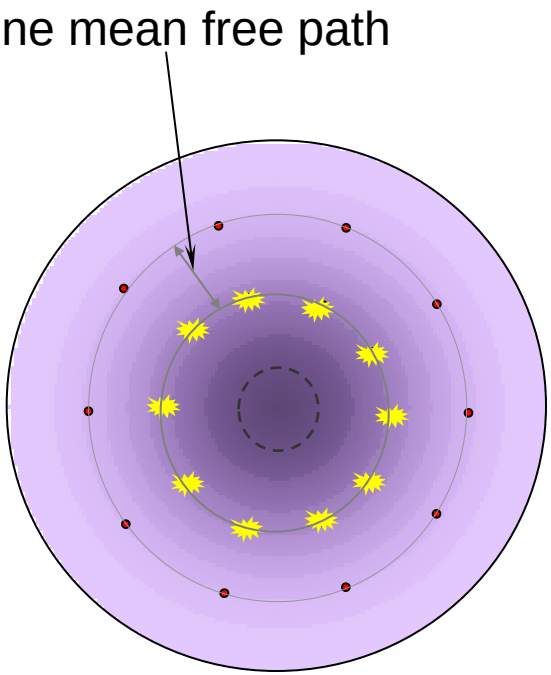
IEC-High Pressure Operation as a Solution (IEF)

Very high voltage Pulsed device at high pressure can provide the answer

High pressure operation of the device allows operation
Practically without the necessity of full confinement







Ions and Neutrals

- Straight forward concept, no complicated circuits, no timers, modulators etc. needed.
- Simpler than POPS concept.
- Equally compact as POPS or better.
- Ions are accelerated within one mean free path to high fusion relevant energies.
- Even the charge exchanged neutrals will continue to cause fusion reactions.
- Ions are not confined, but only accelerated.
- Confinement is imposed only by the neutral density.

Neutron Radiography

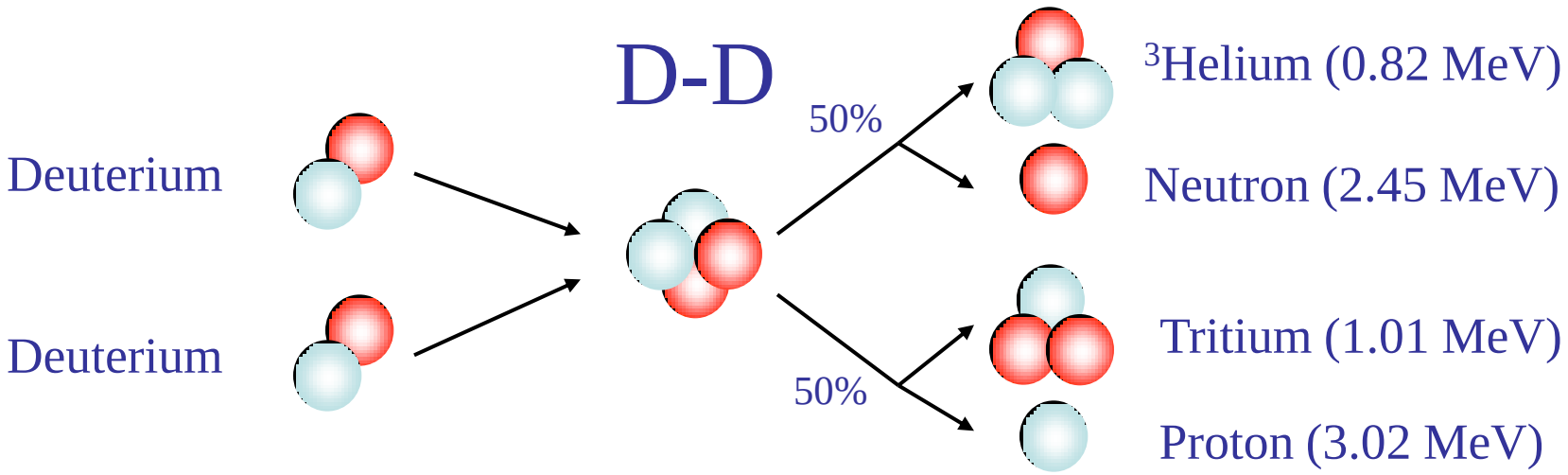
Using the same IEC device

Why IEC neutron source?

- Nuclear reactors are complex and expensive
- Radio isotope sources need heavy shielding when not in use, if ever dispersed or if there is a fire this source would make ISS uninhabitable.
- Neither a nuclear fission reactor nor an isotope source could be turned off completely when not in use
- There are no alternate applications of these neutron sources (cannot be converted into x-ray sources when needed).
- IEC devices are therefore most suitable for space applications.

Generation of neutrons in an IEC device

- Neutrons are generated once the polarity is reversed. The central grid is charged negative (cathode) using the fuel D_2 gas.

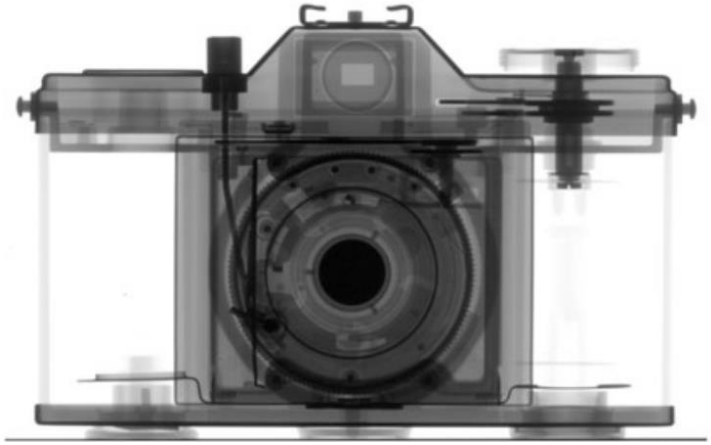


Relevant uses of neutron radiography

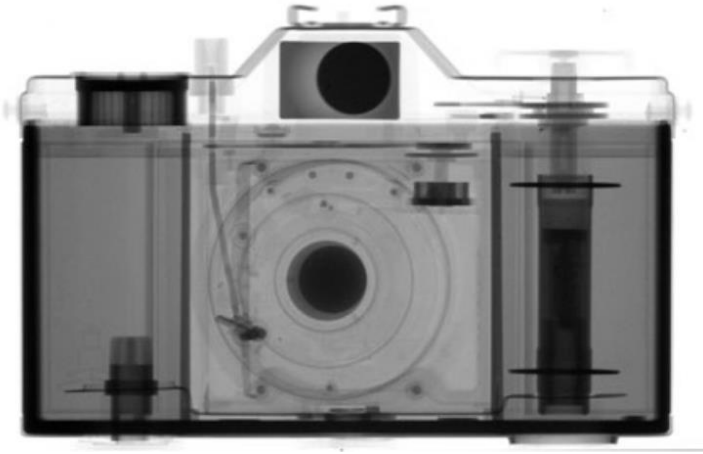
- A neutron detector in tandem with a good neutron source can be used for submicrometer radiography.
- Such an instrument gives insight to the complex interface of inorganic/biological interactions – enhancing the understanding of biological surface interaction and mineral transport.
- Such a neutron source can pierce through heavy steel-encased pressure chambers to reveal the dynamic state of water distribution in the thin membranes aboard ISS.
- Examples are investigations concerning quality tests of soot filters, adhesive joints, lubricated films and in-situ visualization of water management in fuel cells.

X-ray Vs Neutron radiography

X-ray radiography



Neutron radiography

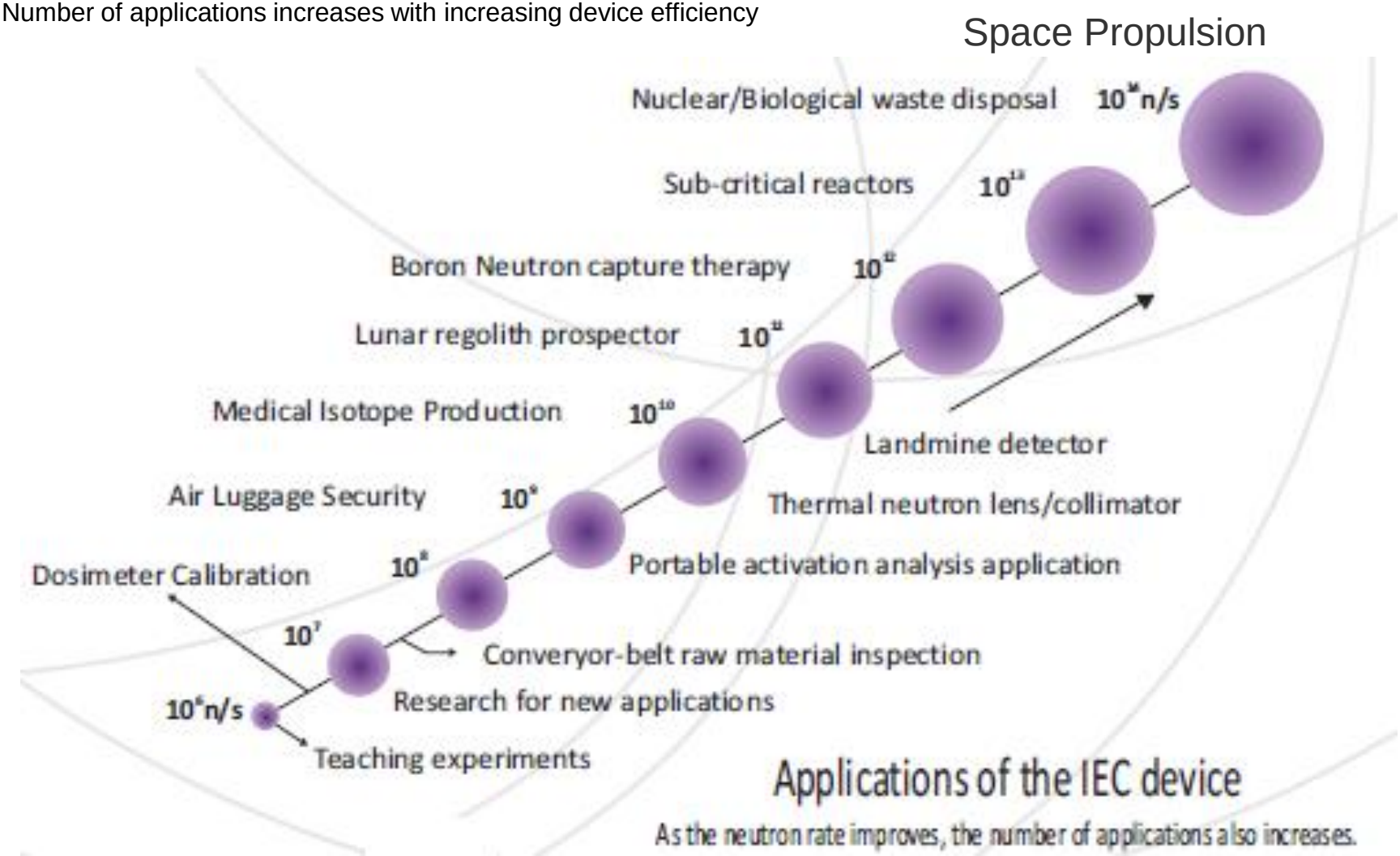


- Features visible using x-rays are not visible using neutrons and vice versa. Comparison of the two radiographies allows more detailed recognition of features.
- Hence using both would give a good perspective understanding of the components, and the associated defects.

Ref: http://michal.rawlik.pl/2013/04/neutron-radiography.html

Other Applications

Number of applications increases with increasing device efficiency



Conclusions

An IEC device

- Could operate as a multi radiation source aboard ISS
- Could facilitate inspace material analysis
- Is compact, light weight and consumes less power
- Provides capabilities that are otherwise not possible through other means
- Given that this system can produce tunable x-rays, it would function like a compact synchrotron radiataion source
- Could double up as a radiation source on a spaceship for medical applications in the future
- A device like this could be very useful on the international space station to conduct experiments (X-ray or neutron radiography, Activation analysis etc)

- We are now developing compact multi-radiation sources for ISS and other space related applications (space propulsion) at our lab and are open to collaboration, please contact multiversal9@gmail.com with questions and enquiries.

Questions?

Contact information

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