FUSION OF ^{3}HE WITH ^{3}HE INSIDE A MEDIUM ENERGY PLASMA FOCUS DEVICE

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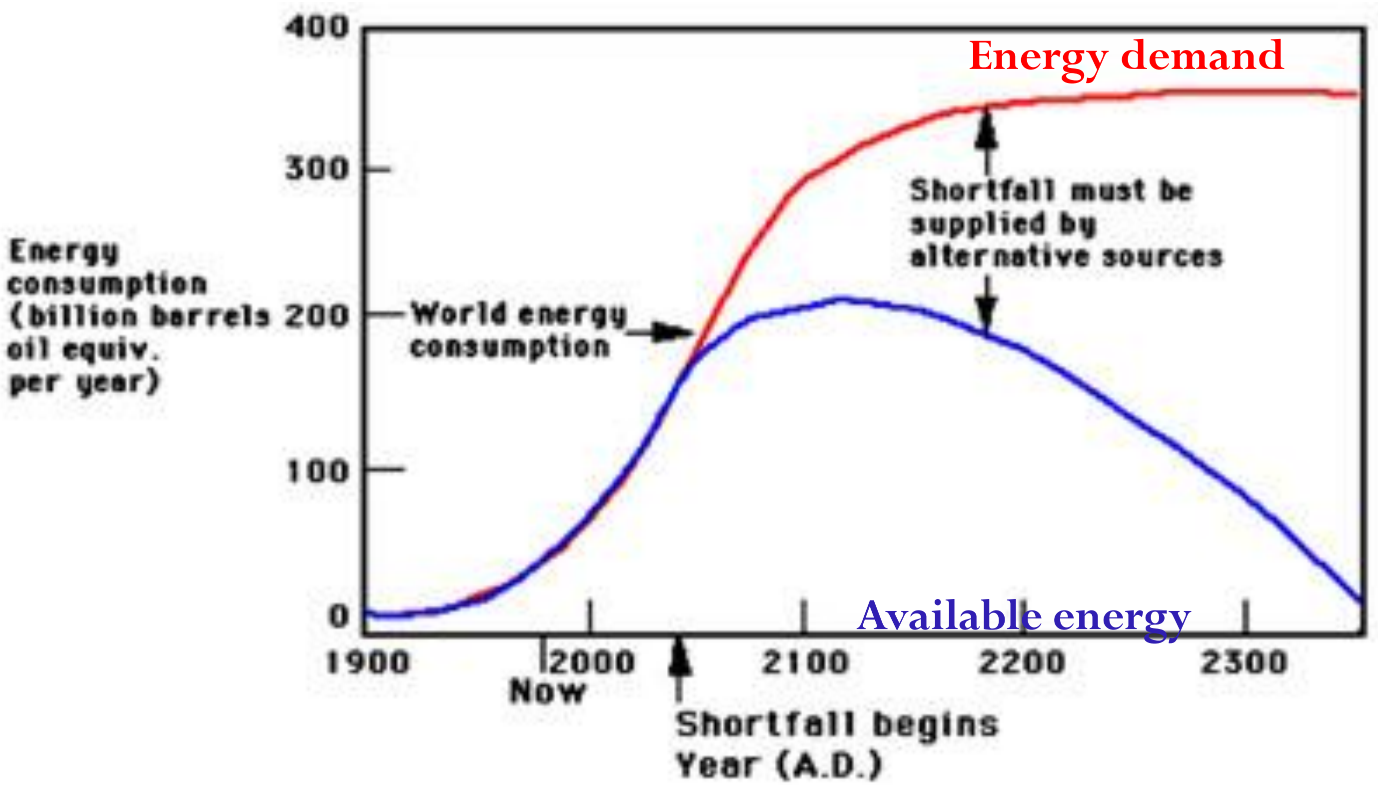
Importance of Fusion Power:



Fusion energy appears to be an alternate source ?

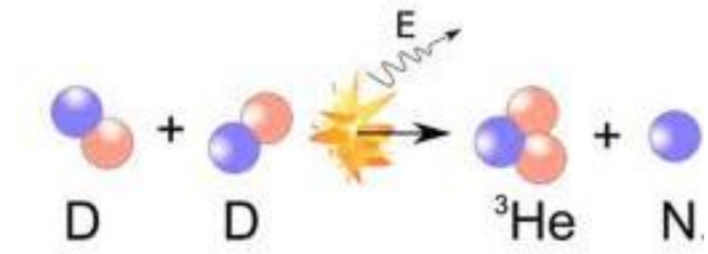
G.L. Kulcinski, "Using Lunar Helium-3 to Generate Nuclear Power Without the Production of Nuclear Waste," May 2001 [20th International Space Development Conference, Albuquerque NM, May 24-28, 2001].

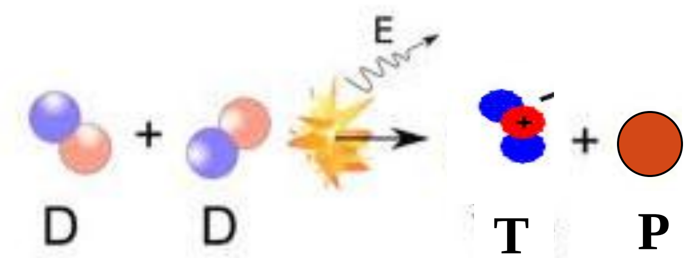
Fusion fuel :

FIRST Generation Fuel :

$${}_1D^2 + {}_1D^2 \rightarrow {}_2He^3\ (0.82MeV) + {}_0n^1\ (2.45MeV) + 3.27MeV$$

$${}_1D^2 + {}_1D^2 \rightarrow {}_1T^3\ (1.01MeV) + {}_1H^1\ (3.02MeV) + 4.03Mev$$

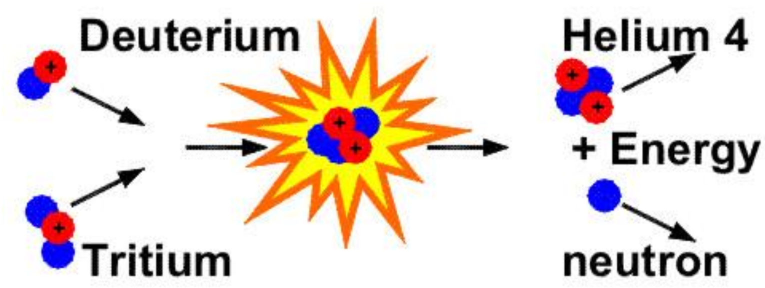




$${}_1D^2 + {}_1T^3 \rightarrow {}_2He^4\ (3.52MeV) + {}_0n^1\ (14.1MeV)$$

Problems:

- Radioactive fuel (T)
- Radioactive reaction products (T)
- Product neutrons and its activation.



Fusion fuel :

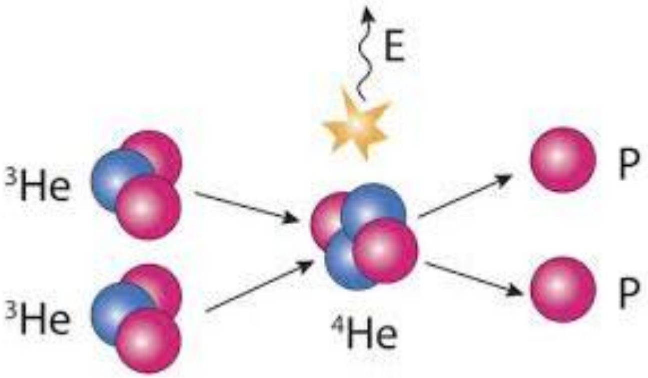
SECOND Generation Fuel :

$_1D^2 + _2He^3 \rightarrow P\ (14.68\ MeV) + _2He^4\ (3.67\ MeV) + 18.35\ MeV$

THIRD Generation Fuel :

$_2He^3 + _2He^3 \rightarrow 2P\ (8.6MeV) + _2He^4\ (4.3MeV) + (12.9MeV)$

- No radioactivity fuel or product.
- ^{3}He fusion is aneutronic in nature.
- The fusion products alpha and proton can be contained using electric and magnetic fields.
- These particles will not induce any radioactivity in components of the reactor vessel.
- The fusion products can directly be used for the electricity generation .
- High efficiency of conversion (>70%) .



$^3He + ^3He \rightarrow ^4He + p + p$

Influential factors for ^{3}He as a fusion fuel :

- 1 ton of ^{3}He can yield = 10 billion watts of electricity.
  =100 million barrels of oil.

- 200 tons of ^{3}He per annum = Power needs of the mankind per annum .

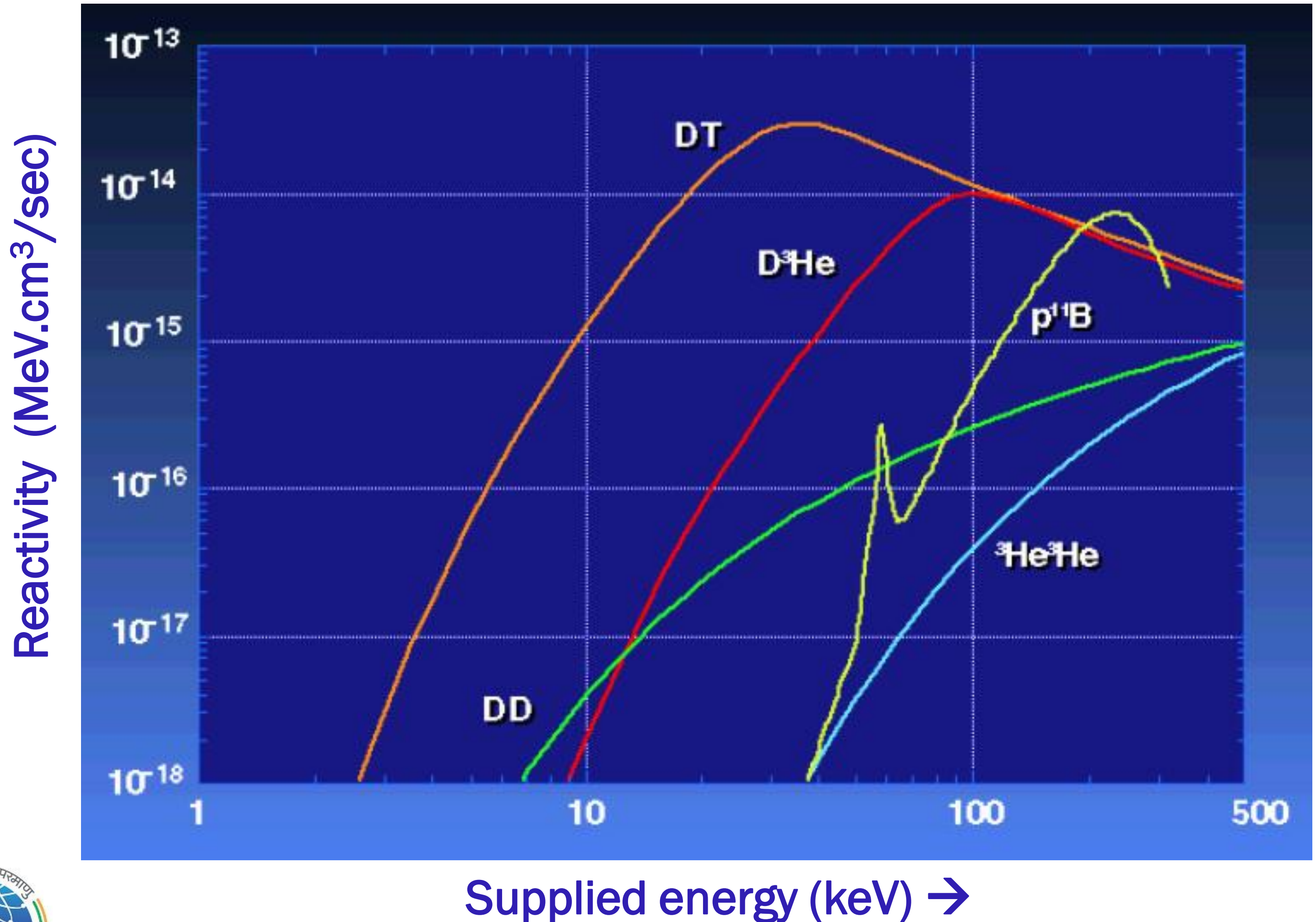
- Although ^{3}He is extremely rare on the earth, it is stored on the moon where it was brought from the sun by the solar wind.

- About 500 million tons of ^{3}He are stored on the lunar surface. This amount is enough to feed the mankind for the next 1000 years.

G.L. Kulcinski, "Using Lunar Helium-3 to Generate Nuclear Power Without the Production of Nuclear Waste," May 2001 [20th International Space Development Conference, Albuquerque NM, May 24-28, 2001].

^3He and ^3He fusion require more stringent conditions

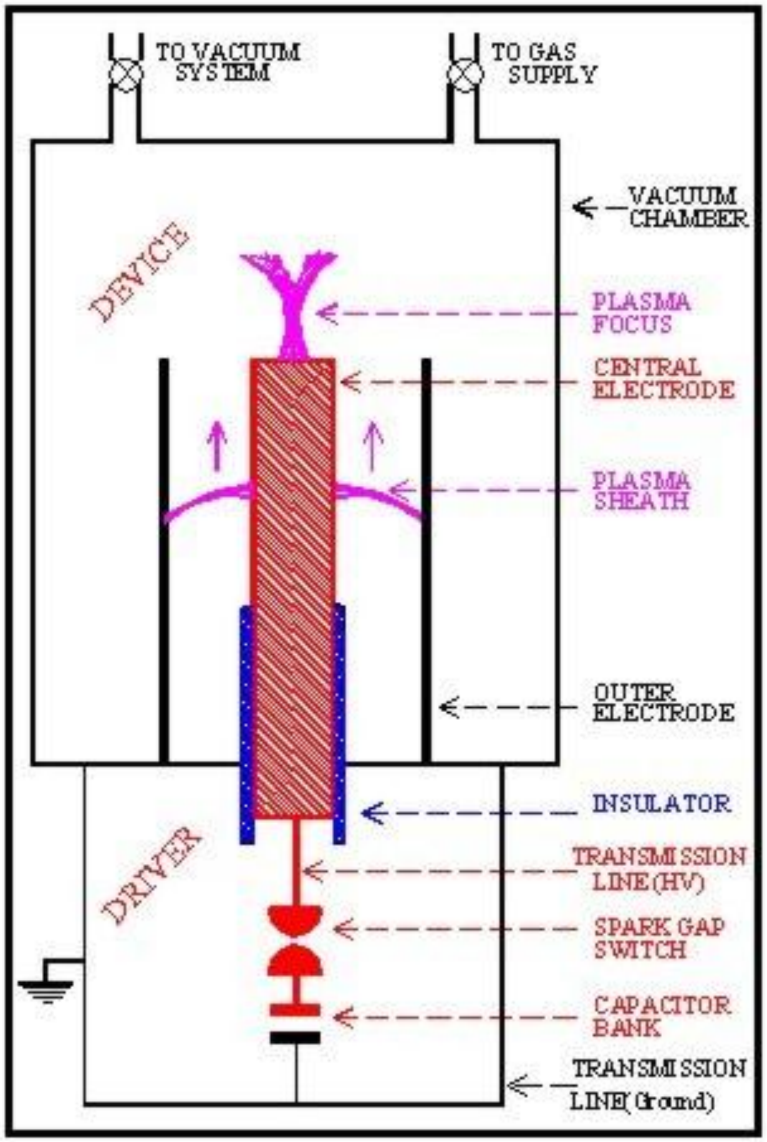
Reaction cross section for fusion reactions :



Ratio of Reactivity (> 100 keV) of D-D to ^3He-^3He < 10

Plasma focus device as a fusion source :

- The plasma focus device is a well known laboratory fusion device.
- Neutrons have been produced due to D-D or D-T fusion reaction.
- Energies of Ions of filling gas have been observed to be few hundreds of keV (even MeV) though charging voltage of a few tens of kV.
- Generated complex and high electric & magnetic field are the cause of ion acceleration.
- Can we cause fusion in ^{3}He



Plasma focus facility for neutron generation

Operation parameters and neutron yield :

Bank energy (kJ)	11.5
Bank capacitance(μF)	40
Bank inductance with PF (nH)	77
Operating voltage(kV)	24
Voltage reversal factor (%)	80
Discharge time period(μS)	11
Peak current (kA)	490
Operating D_2 pressure (mb)	4
Average neutron yield/pulse	$(1.2\pm0.3)\times10^9$
Neutron pulse width (ns)	(46 ± 7)
Neutron energy (MeV)	2.48 ± 0.32

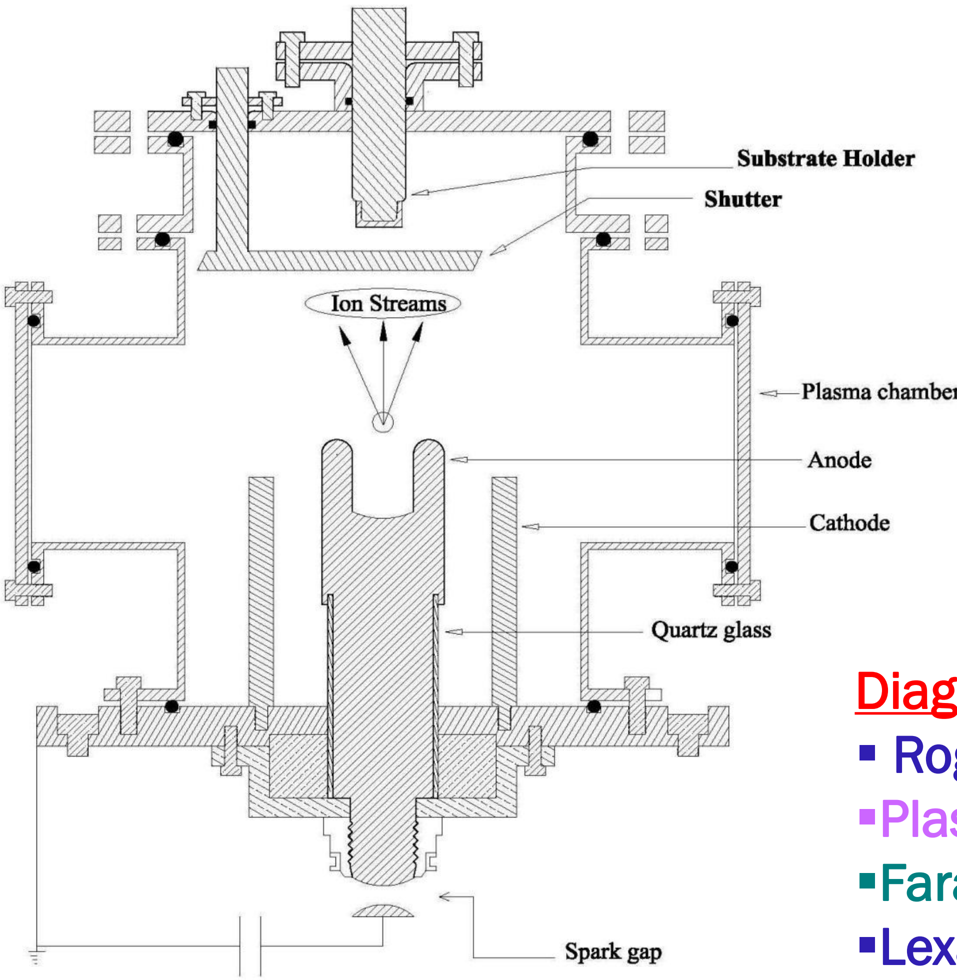
Plasma Chamber with PF device

Rogowsky coil

Capacitor bank

11.5 kJ Plasma Focus Device

Experimental setup for ^{3}He fusion & detection



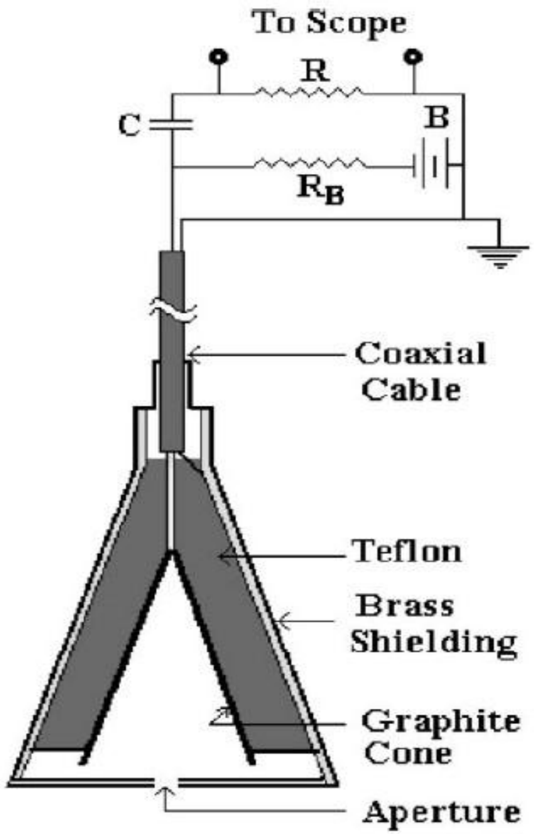
Schematic of experimental setup

Driver:
- Capacitor bank = 40μF
- Operation voltage = 24kV
- Energy = 11.5kJ
- Peak bank current = 490kA

Experimental Chamber:
- Volume = 7.5 ltrs
- Vacuum ≤ 3 x 10^{-5} mbar
- Operation Pressure (^{3}He) = 4mb

Diagnostics:
- Rogowsky coil (for dI/dt).
- Plastic scintillator detector (for X-ray)
- Faraday cup for ions.
- Lexan film (for ^{4}He) at 16 cm.
- CR-39 film with 24 μm Al filter (for P) at 16 cm.

Ion measurement by Faraday cup (at 10 cm from PF anode tip)



Faraday cup signal with dI/dt

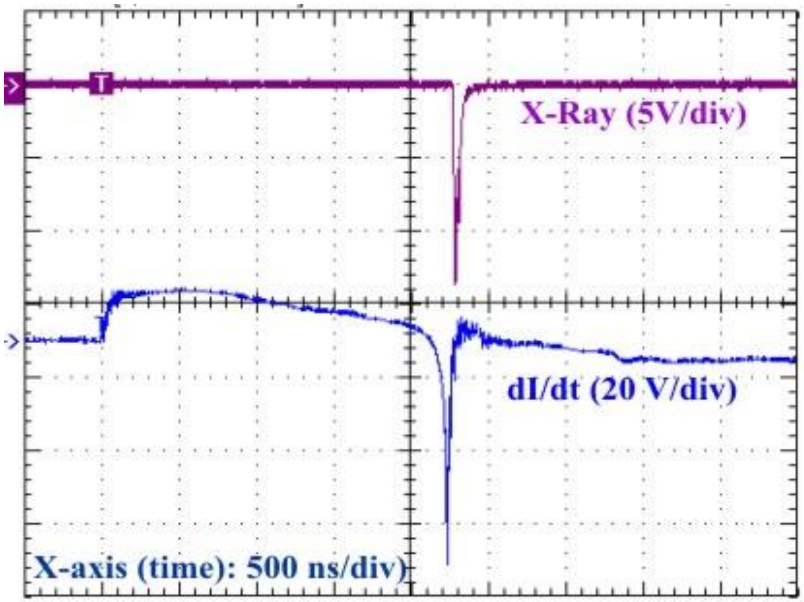
Ion density : $n_i = \frac{V}{RqAv}$

Ion energy : $E = \frac{1}{2}mv^2$

Track development & counting

- The Solid State Nuclear track detector film (Lexan and CR39) of size 2 cm x 2 cm is kept at a distance of 16 cm from the top of the anode in axial direction.
- The lexan film is sensitive only to alpha particles. It is exposed to 6 PF shots.
- The CR-39 film is sensitive to all particles. To detect only protons CR-39 film is covered with 24 μm Al filter, since the range of 4.3 MeV α particles in aluminum is less than 18 μm. The range of relatively low energy accelerated 3He will be much less than 24 μm (filter used). It is exposed to 3 PF shots.
- Five films of each type are exposed in the similar manner, one film at a time. After exposing the film to the desired PF shots, it is removed and is etched off line under the standard conditions (6N KOH at 60^0C) for a period of 4-7 hours to develop visible tracks.
- The tracks are counted using Zeiss axioscope motorised microscope at 100X magnification.

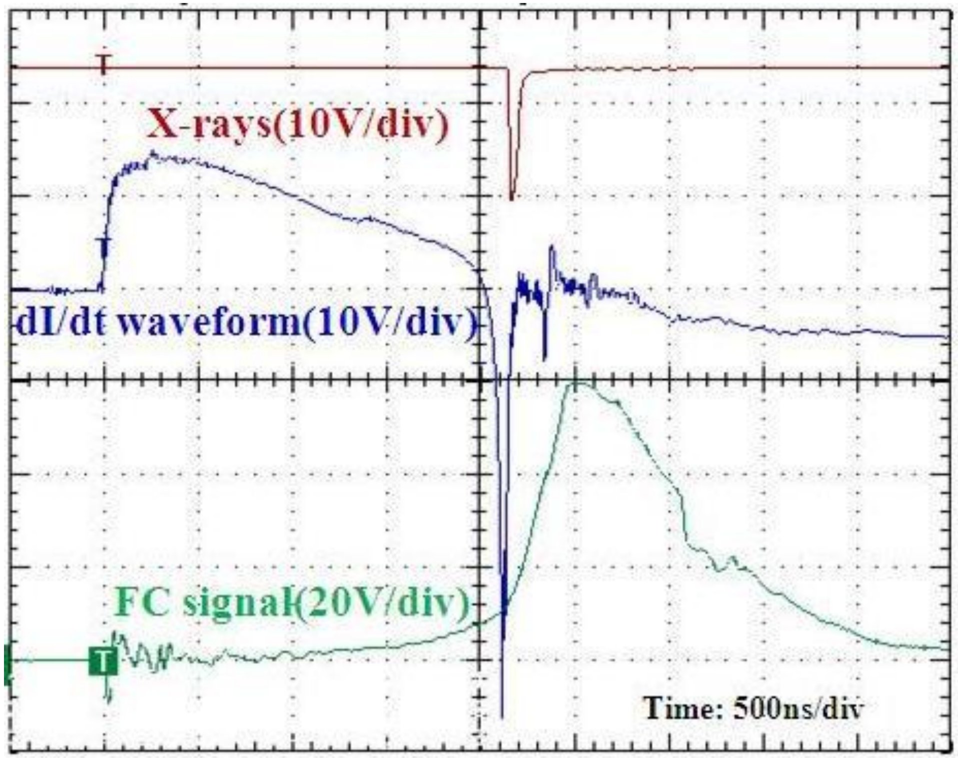
Results from X-Ray measurement



X-Ray signal through Plastic scintillator detector at 2m and dI/dt signal through Rogowsky coil.

- The sharp dip in dI/dt signal suggests maximum compression of plasma due to plasma pinching action.
- The width of hard X-rays is 20 to 30 ns.
- The production of hard X-ray indicates the generation of high energy electrons due to creation of high electric and magnetic fields. It also envisages the production of high energy ions the necessary condition for fusion reaction.

Results from ion measurement through Faraday Cup



Plastic Scintillator Detector (@2m)
X-ray pulse width : 29 nS

Faraday cup @ 10 cm

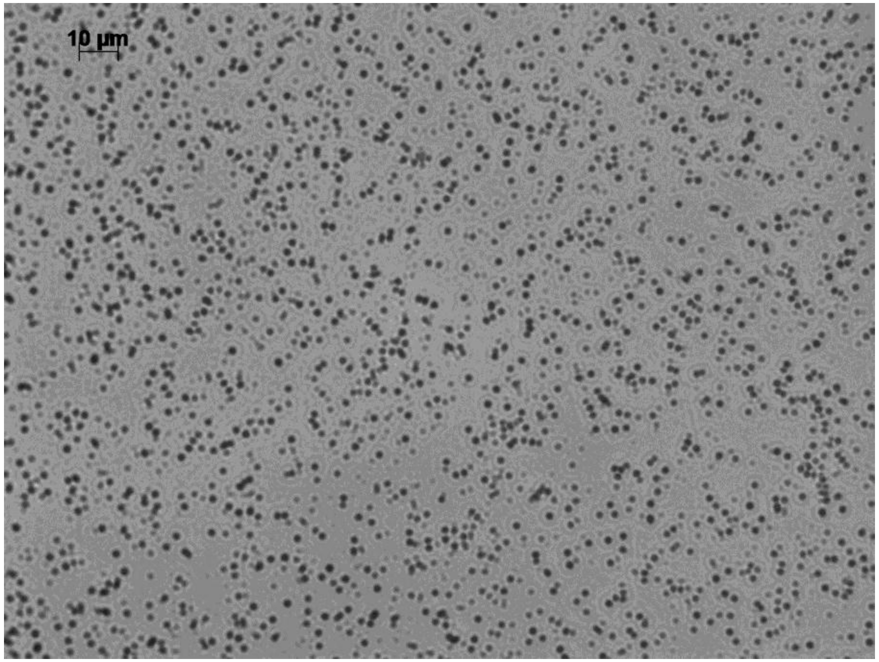
Energy of most of the ions :
a few tens to a few hundred keV.

$$E = \frac{1}{2} m v^2$$

Ion flux = 9.95 x10^{16} ions/m^2

$$n_i = \frac{V}{RqAv}$$

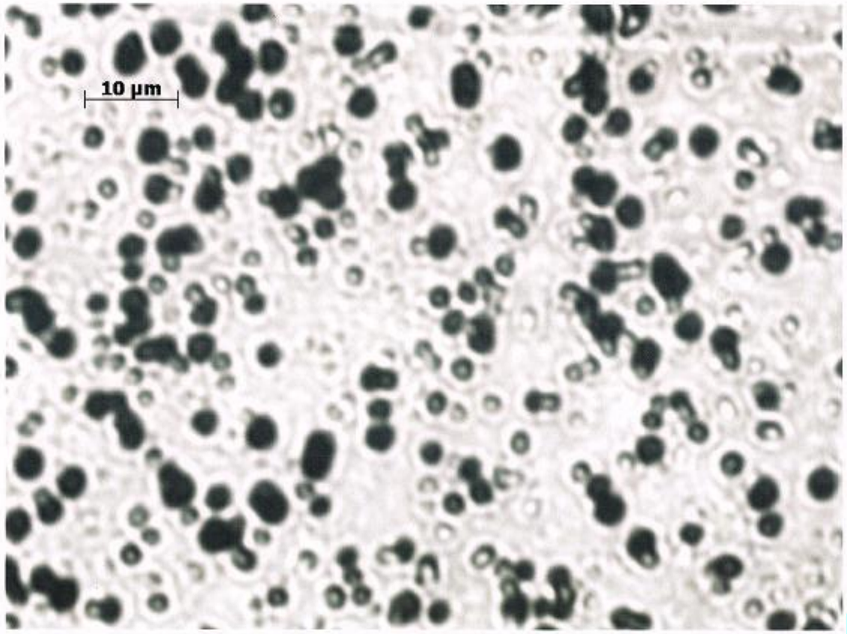
Results from CR39 detector film (with 24 µm Al filter)



Proton tracks in CR39 film (24µm Al filter)

- The displayed film was exposed to 3 PF discharges at 16 cm from anode tip.
- The average proton track density estimated from the five exposed films is : $(16.3 \pm 2.1) \times 10^5$ ion tracks/cm^2/shot.
- .

Results from Lexan detector film



^{4}He tracks in Lexan film

- This film shows the accumulated tracks for exposure to 6 PF discharges at 16 cm from anode tip.

- The lexan film is insensitive to high energy ^{3}He and protons. This was verified by exposing the film to PF shots at 11.5 kJ with deuterium gas at 4 mb pressure . No track was observed.

$${}_1D^2 + {}_1D^2 \rightarrow {}_2He^3 \ (0.82\text{MeV}) + {}_0n^1 \ (2.45\text{MeV})$$

$${}_1D^2 + {}_1D^2 \rightarrow {}_1T^3 \ (1.01\text{MeV}) + {}_1H^1 \ (3.02\text{MeV})$$

- **The average track density estimated from the exposed five films = $(9.1 \pm 1.1) \times 10^5$ ion tracks/cm^2/shot.**

Detection of protons and alpha particles confirm fusion of ^{3}He
Number of protons are about twice number of alpha particles

Estimation of Fusion reaction

The beam-target yield for a PF device can be estimated from the formula

(S. Lee and S. H. Saw, Plasma focus ion beam fluence and flux-scaling with stored energy, Phys. Plasma.19,112703,2012)

$$\text{Yield} = Y_{bt} = C_n n_i I_p^{\,2} Z_p^{\,2} (\ln(b/r_p))\sigma/U^{1/2}$$

n_i: Pinch ion density, I_p: Pinch current, r_p : Pinch radius, Z_p : Pinch length, b: Cathode radius,
σ: D-D fusion reaction cross section for neutron branch, U: Maximum disruption voltage, C_n : A constant.

Using Lee five phase radiative plasma focus model (RADPF (http://www.plasmafocus.net) for our 11.5kJ PF device and using above relation :

Input parameters : L= 77nH, C=40μF, b=5.5cm, a=3.0cm, r_0= 5mΩ, V_0=24kV, p=4 mb, etc.

Outputs : Ip=286 kA, r_p= 0.44 cm, z_p=4.7 cm, τ= 40.6 ns, V=35 kV

Neutron yield: measured = (1.2±0.3)x 10^9 /shot; from Code = 1.05x10^9 /shot

Neutron pulse width: measured = (46±5) ns; from code = 40.6 ns

$${}_1D^2 + {}_1D^2 \rightarrow {}_2He^3 + {}_0n^1$$
$${}_1D^2 + {}_1D^2 \rightarrow {}_1T^3 + {}_1H^1$$

Estimated Beam-target neutron yield= 1.05x10^9 /shot

Measured neutron yield= (1.2±0.3)x 10^9 neutrons/shot

Estimated No. of fusion reaction = 2x1.05x10^9 = 2.1x10^9per shot.

CONCLUSIONS

- It is shown here for the first time, the possibility of fusion of ^{3}He with ^{3}He in a compact plasma focus device operated at 11.5 kJ of bank energy with pure ^{3}He as filling gas.

- Observation of hard X-ray during the fusion process indicates the presence of high energy electrons. This also envisages the presence of high energy ^{3}He ions, which is required for fusion.

- The estimated ratio of fusion products proton to ^{4}He recorded through SSNTDs is 1.8. It is close to the expected ratio of 2.0.

- The fusion products ^{4}He and proton are recorded quite convincingly.

THANK YOU