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Correlation of Neutron and X-Ray Emission from Plasma Focus with Pre-Ionization

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CORRELATION OF NEUTRON AND X-RAY EMISSION FROM PLASMA FOCUS WITH PRE-IONIZATION

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OUTLINE OF THE TALK

- ***MOTIVATION***
- ***ROLE OF PRE-IONIZATION***
- ***EXPERIMENTAL SETUP***
- ***DIAGNOSTICS***
- ***RESULTS***
- ***CONCLUSION***

MOTIVATION

- **There is growing interest to develop intense neutron sources for different field applications like, well logging, materials research for nuclear fusion reactors, neutron radiography, detection of gold in sand and presence of water, taking the advantage of the penetration and activation properties of the neutral radiation.**

- **X-ray sources of high intensity are required in diverse disciplines like X-ray lithography, X-ray contact microscopy, micro-machining and radiography.**

- Among all the X-ray and neutron generators, Plasma Focus is much attractive due to its simple operation, compact size, lower cost and easy to develop [S. Lee et al. Amer. J. Phys., 56 (1988) 62].

- The Plasma Focus has also high efficiency for X-ray generation as compared to the present day X-ray tubes [X-ray Science and Technology" Michette and Buckley, © IOP Publishing (1993) 49].

- In view of these observations the main motivation behind this work is to develop a Plasma Focus as an efficient X-ray and neutron Source in the presence of pre-ionization produced by α-Source (U^{238}).

ROLE OF PRE-IONIZATION

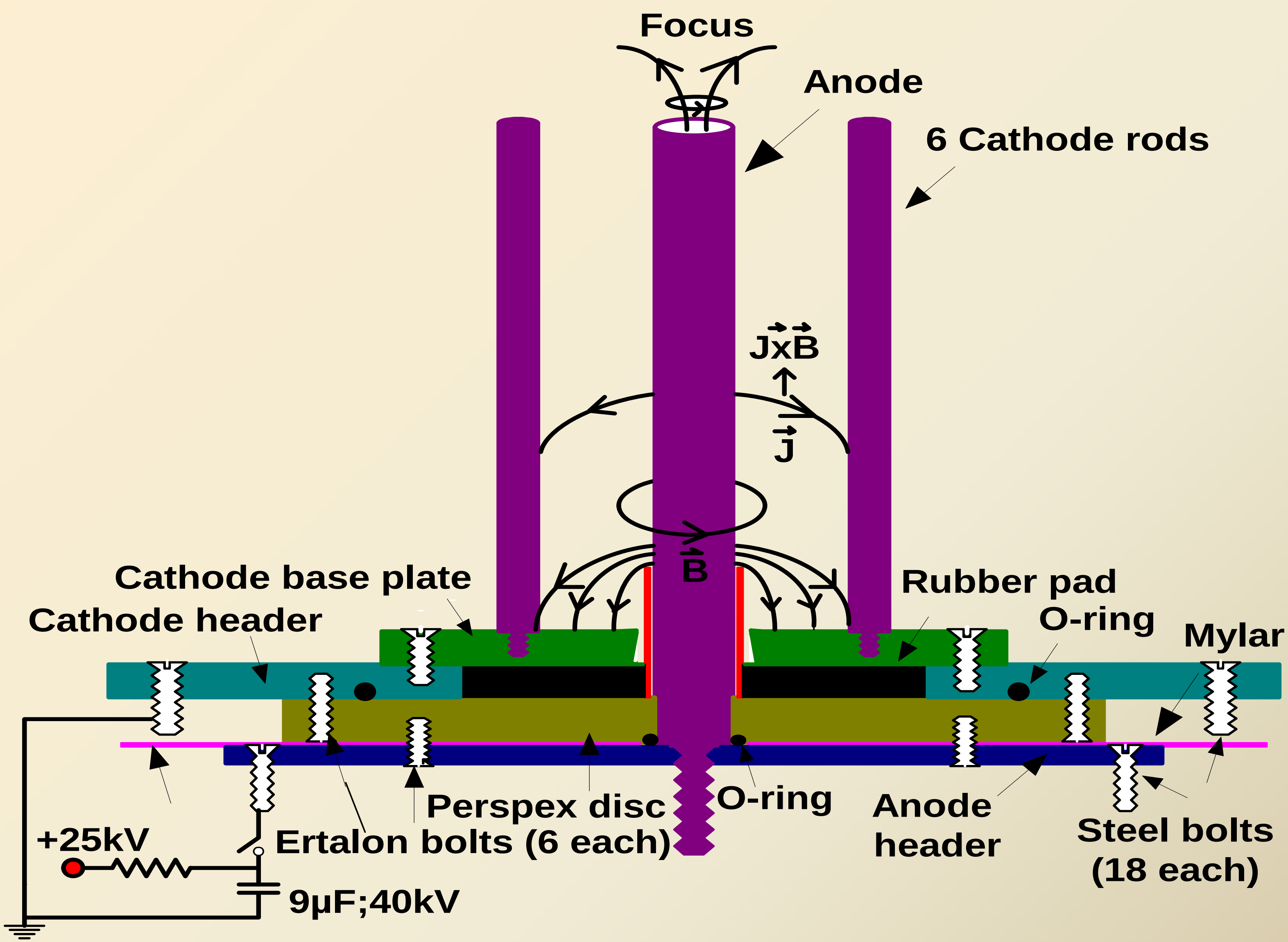
- **In toroidal plasma devices like tokamak, and stellarator, it is normal procedure to assist the start-up of the main discharge by the use of some type of pre-ionization.**

- **The pre-ionization discharges may be produced dependently or independently on the subsequent discharge.**

- **The pre-ionization causes the smooth initiation of the pinch discharge by reducing initial impedance at the gap of the electrodes, and hence stabilizing the pinch discharge.**

- Kies [Plasma phys. & Control. Fusion, 28 (1986)1645] studied the effect of pre-ionization on the initial phase of plasma focus device.
- The several external means were tried such as pulsed low energy discharge (10% of the total bank energy), continuous glow discharge $\leq$1 A, pulsed X-rays (200 keV, 70 nsec) and continuous X-rays (300 keV) for pre-ionization.
- It was found that homogenous current sheath formation and reduction in breakdown delay take place.

ELECTRODES ASSEMBLY OF DPF



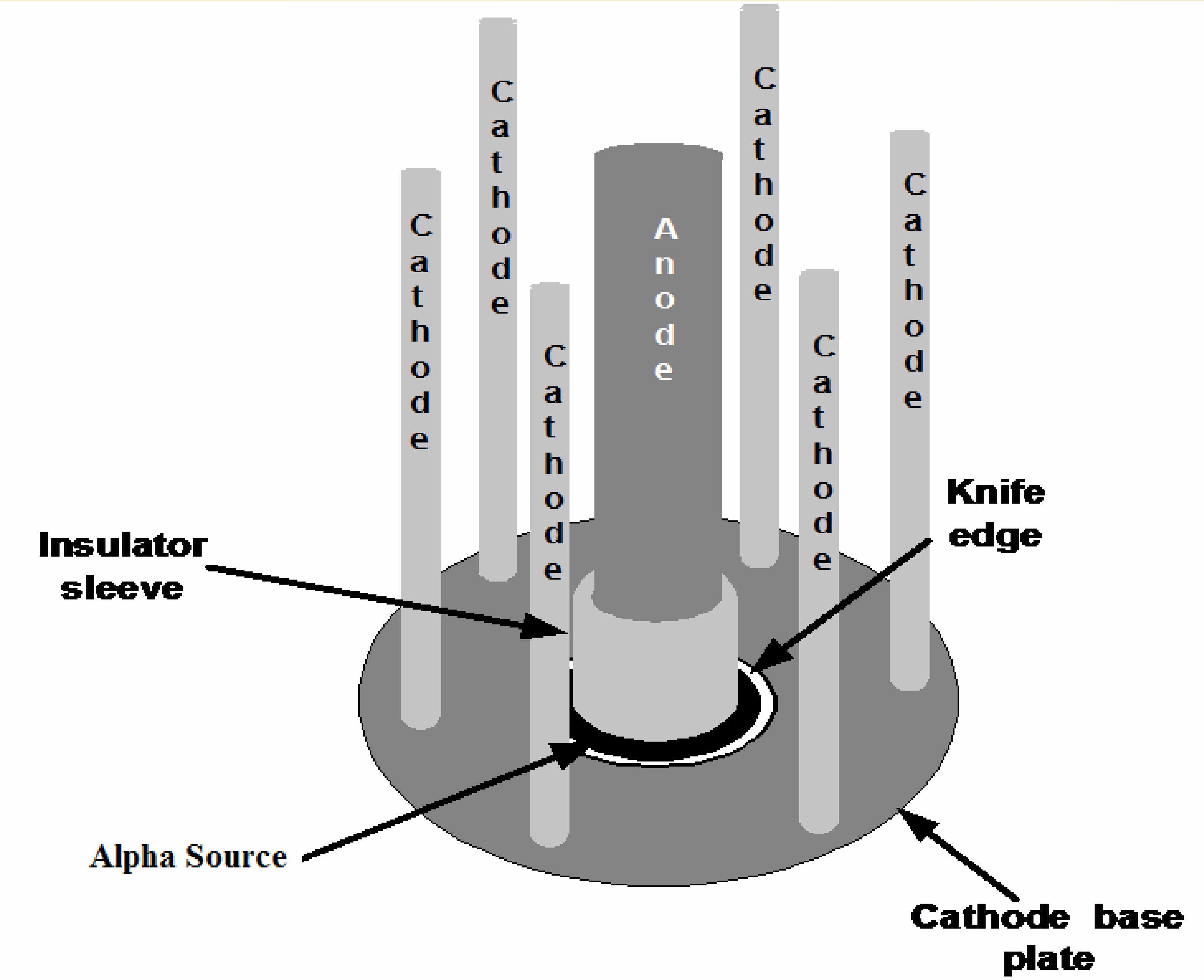
EXPERIMENTAL SETUP

- **The PF system having cylindrical anode of 110 mm in length is powered by a 12.5 μF capacitor, charged at 17 kV (1.8kJ) giving peak discharge current of 170 kA.**
- **For neutron detection the anode is usually engraved from the open end to reduce the interaction of electron beam with the tip of anode but in this experiment we use the anode of flat tip in order to study the line radiation emission also.**
- **A rotary vane pump is used to evacuate the chamber.**

- After 4-5 shots, the previous gas is pumped out to reduce the effects of impurities. Ten shots are recorded at different filling pressures with and with out pre-ionization.

- For pre-ionization a depleted uranium (${}_{92}U^{238}$) ring, having specific activity of about 4.6×10^{7} nuclei/sec is placed symmetrically around the insulator sleeve.

- The energy of α- particles, emitted from depleted uranium is about 4.19 MeV.


Cathode
Cathode
Cathode
Anode
Cathode
Cathode
Cathode
Knife edge
Insulator sleeve
Alpha Source
Cathode base plate

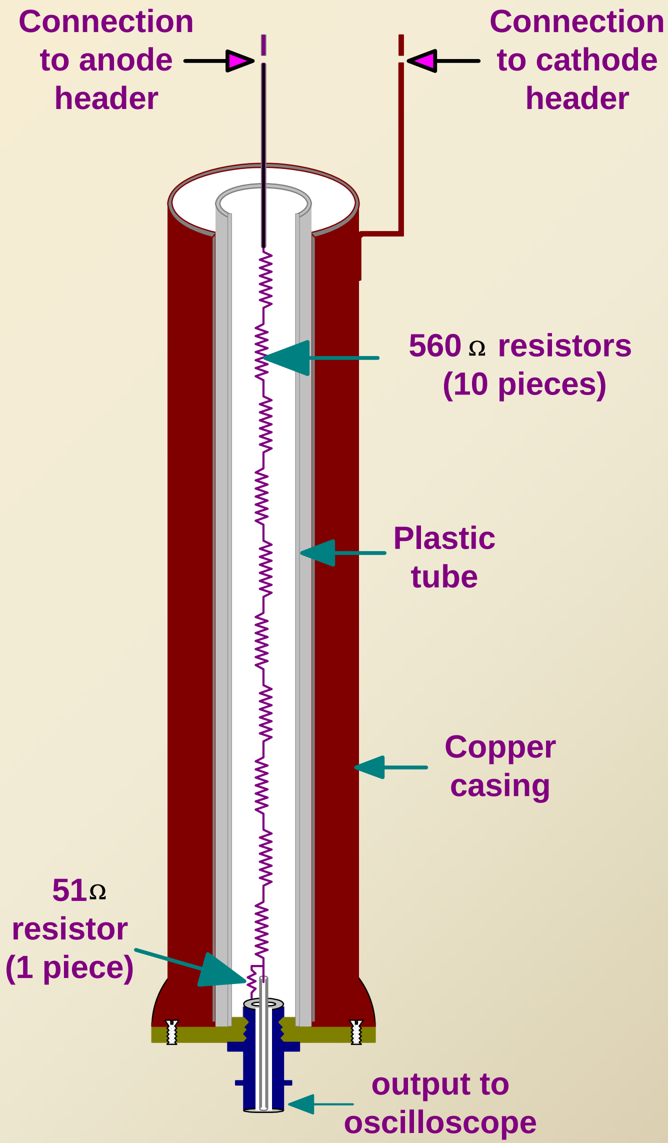
ELECTRICAL DIAGNOSTICS

- Two basic electrical diagnostics are used in experiments. One for the measurement of the voltage and the other one for the discharge current measurements.

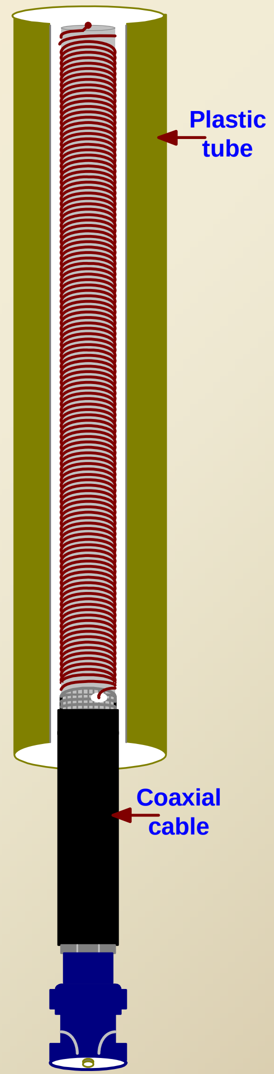
- In PF high voltage is developed due to rapid change in inductance during the radial collapse of the current sheath.

- The voltage developed is few tens of times the charging voltage.

- **To measure the transient high voltage across the focus tube, a high voltage (HV) probe is used.**



- **In PF device high transient current of the order of few hundred kA is passed through the device.**
- **The most simple and effective device commonly used to measure such a high current is Rogowski coil.**



- **The peak value of the current can be calculated from the equation,**

$$I = \frac{\pi C V (1 + f)}{T}$$

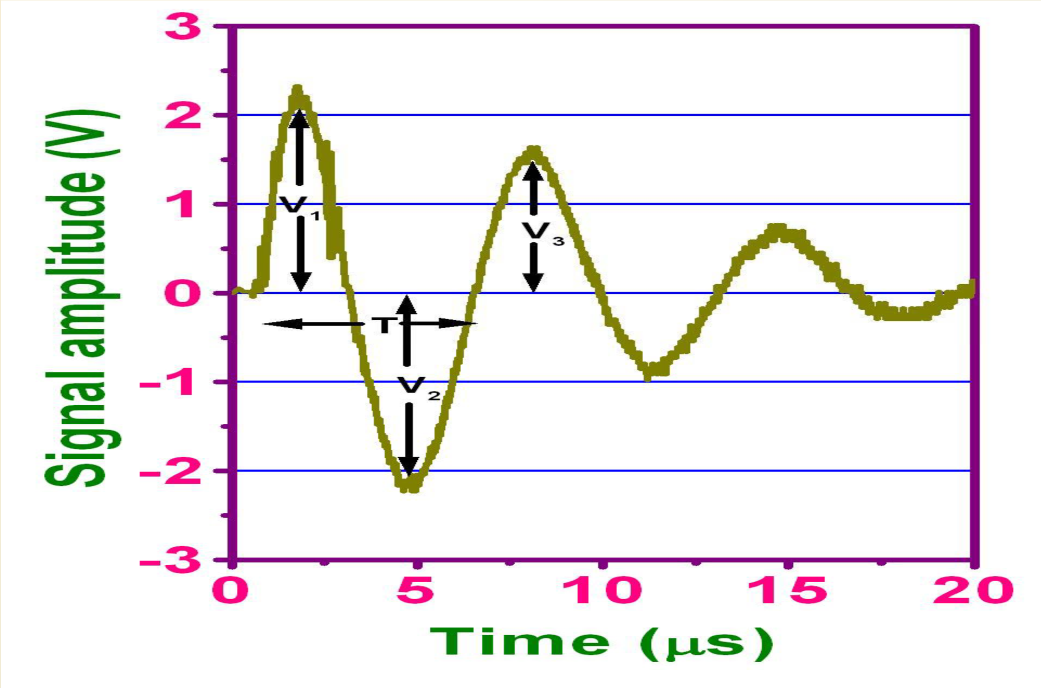
Where

C = Capacitance

V = Charging voltage

f = V_2/V_1 = reversal ratio

T = Time period



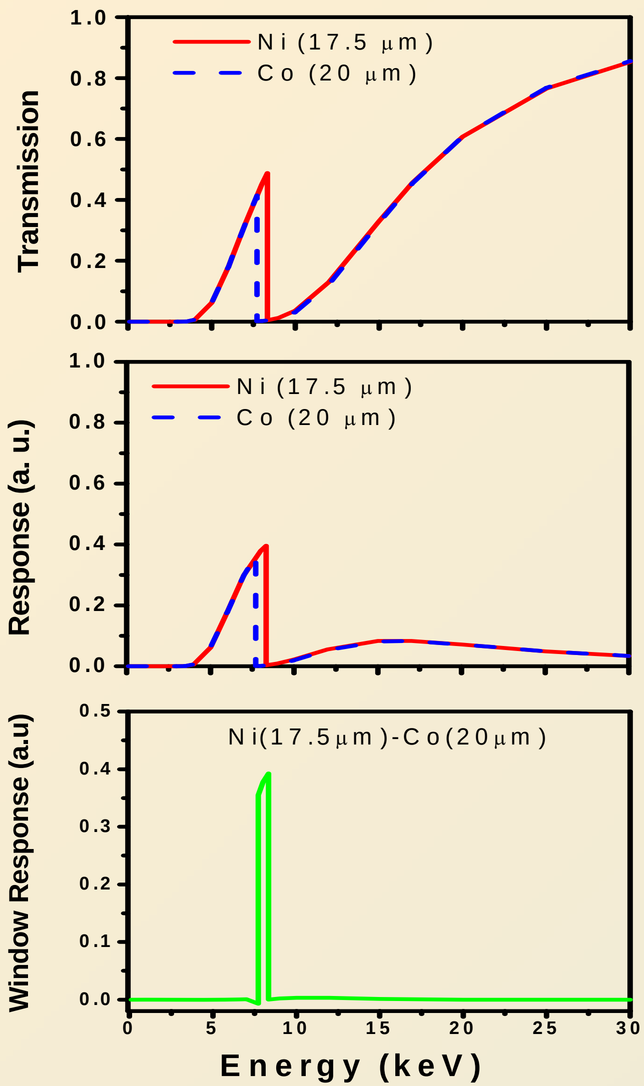
NEUTRON MEASUREMENTS

- For neutron detection both time resolved and time integrated techniques are employed.
- For the time resolved neutron detection, the photomultiplier tubes (XP2020) coupled with fast (50×50) mm^2 cylindrical plastic scintillators (NE102A) are used.
- Two detectors are used simultaneously, both placed at 75 cm from the anode tip, one in end-on direction and other in side-on direction.
- For time integrated neutron measurement a GM counter along with silver foil of thickness 0.5 mm and a paraffin wax block of moderating length 3 cm is used.
- The detector is placed at top of the vacuum chamber in end-on direction at a distance of 21 cm from the anode tip.

- **The GM tube detector is connected to an ORTEC counter through a locally developed preamplifier.**
- **The counter is triggered simultaneously with the application of trigger pulse to operate the plasma focus device.**
- **The GM tube detector is calibrated against standard Am-Be neutron source.**

X-RAY MEASUREMENTS

- **In order to study the X-ray emission from the Plasma Focus, the time resolved two-channel X-ray detector is used.**
- **The detector contains an array of two Quantrad Si PIN-diodes of 125 μm active layer thickness.**
- **The PIN-diodes in the diode X-ray detector are arranged in such a way that each diode could receive almost equal intensity from the pinch region.**
- **These detectors are placed in the side on direction at 17.0 cm from the anode axis, and elevated at 1.5 cm from the anode tip.**
- **In the present work, the PIN-diodes are reverse biased at 175 V.**



(a)

(b)

(c)

(a) **Transmission curves of Ni (17.5 μm) and Co (20 μm).**

(b) **Detector (PIN-diode) response along with corresponding filters.**

(c) **Window response of Ross filters obtained by the subtraction of Co (20 μm) from Ni (17.5 μm) filter, the detector response is included.**

CALCULATION OF X-RAY YIELD

- **To estimate the radiation emission in the specified energy interval, the following empirical relation is used [Zakaullah et al. Plasma sources Sci. Technol. 9 (2000) 592],**

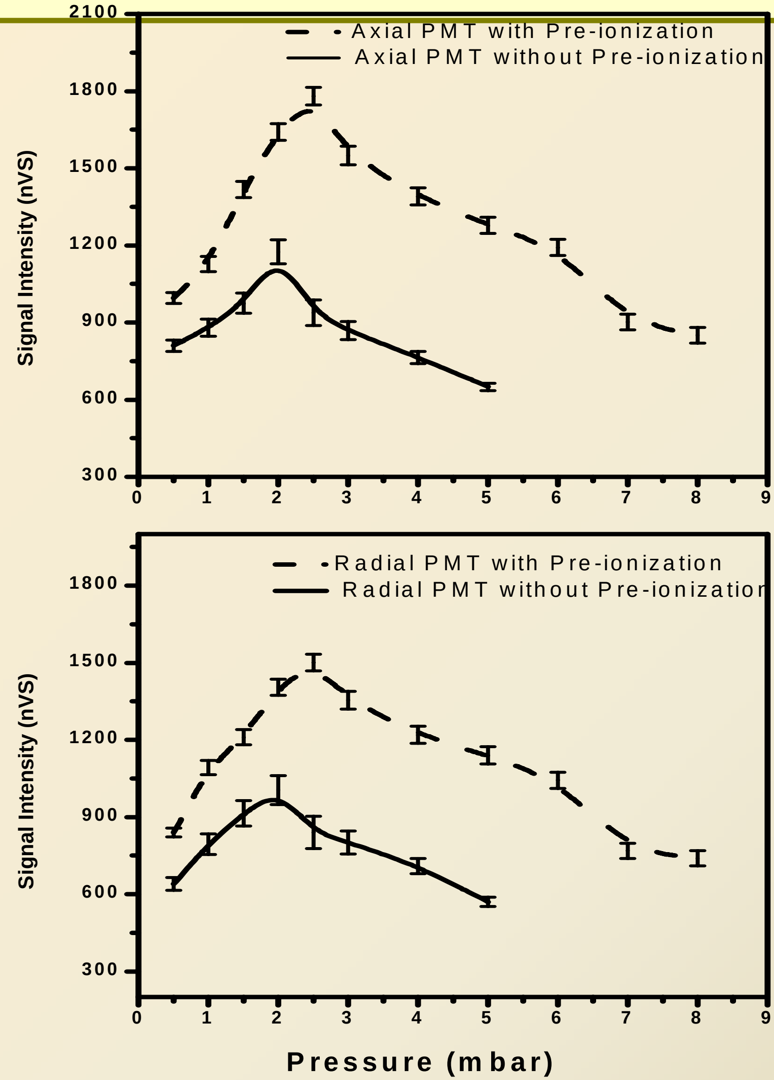
$$Y = \frac{4\pi Q_{\exp}}{d\Omega S(E)T(E)}$$

where

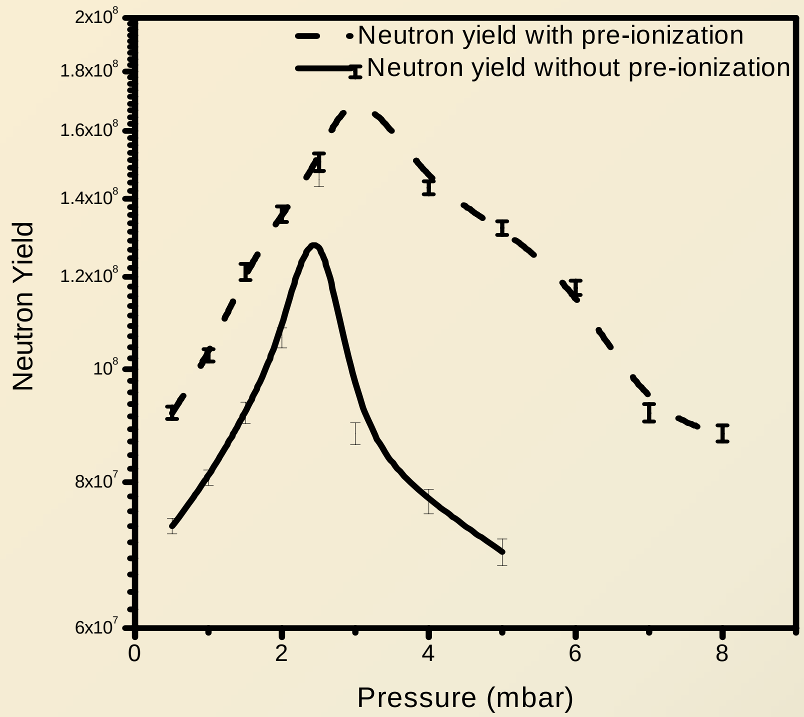
$$Q_{\exp} = \int \frac{Vdt}{R} \quad (coulombs)$$

- $d\Omega$ is the solid angle subtended by the detector at focus region.
- S(E) is the average sensitivity of the detector in the corresponding energy window.
- T(E) is the transmission of the filter in the said energy interval, one may select the FWHM value of the transmission curve.
- R = 50 Ω in our case.

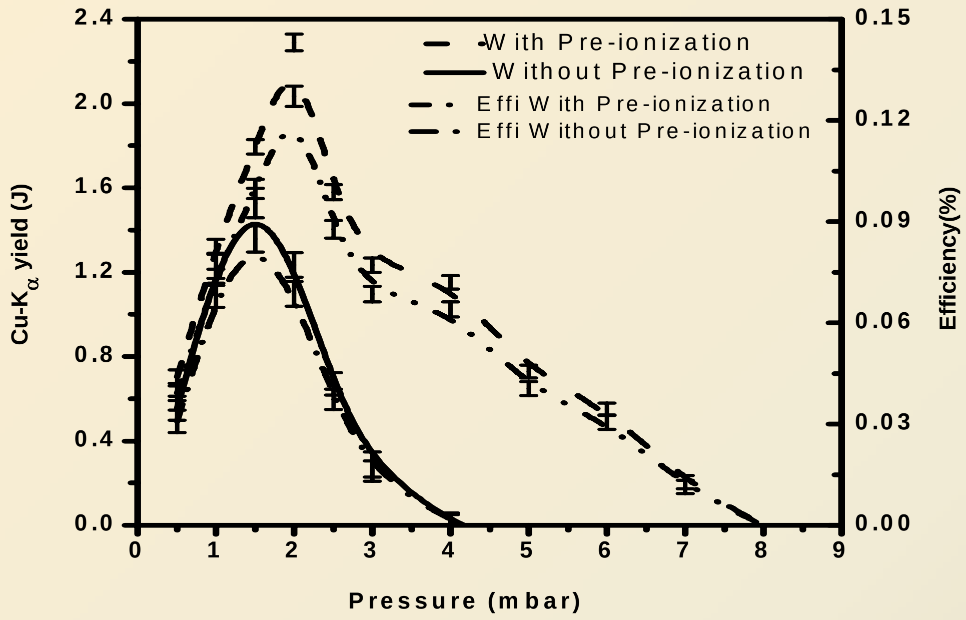
RESULTS



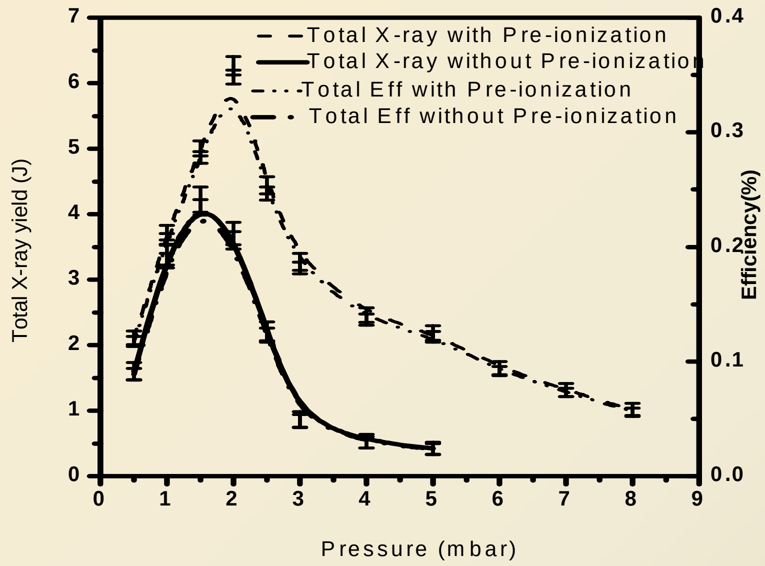
Variation of axial and radial neutron flux (signal intensity) with pressure for pre-ionization and without it.



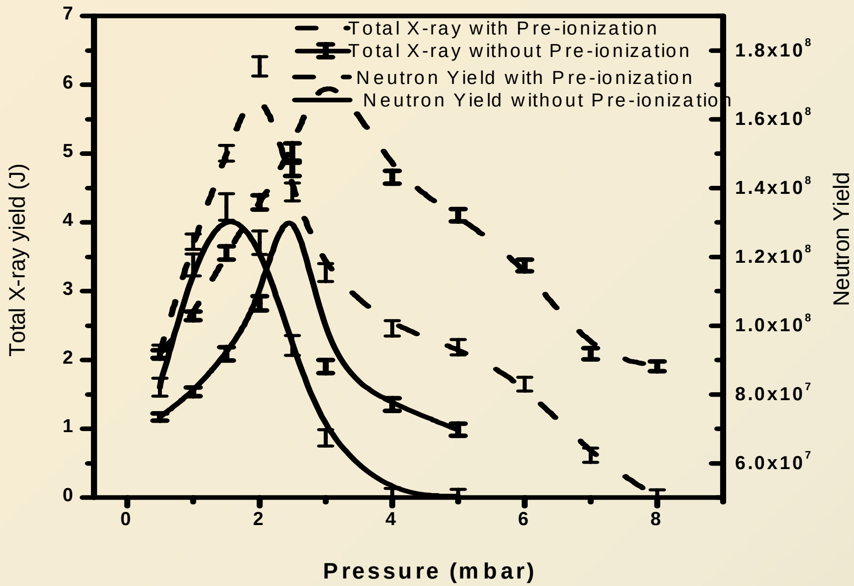
Variation of neutron yield for filling pressure with and without pre-ionization.



Variation of Cu-K$_\alpha$ emission and efficiency with filling gas pressure in 4π-geometry , with and without pre-ionization



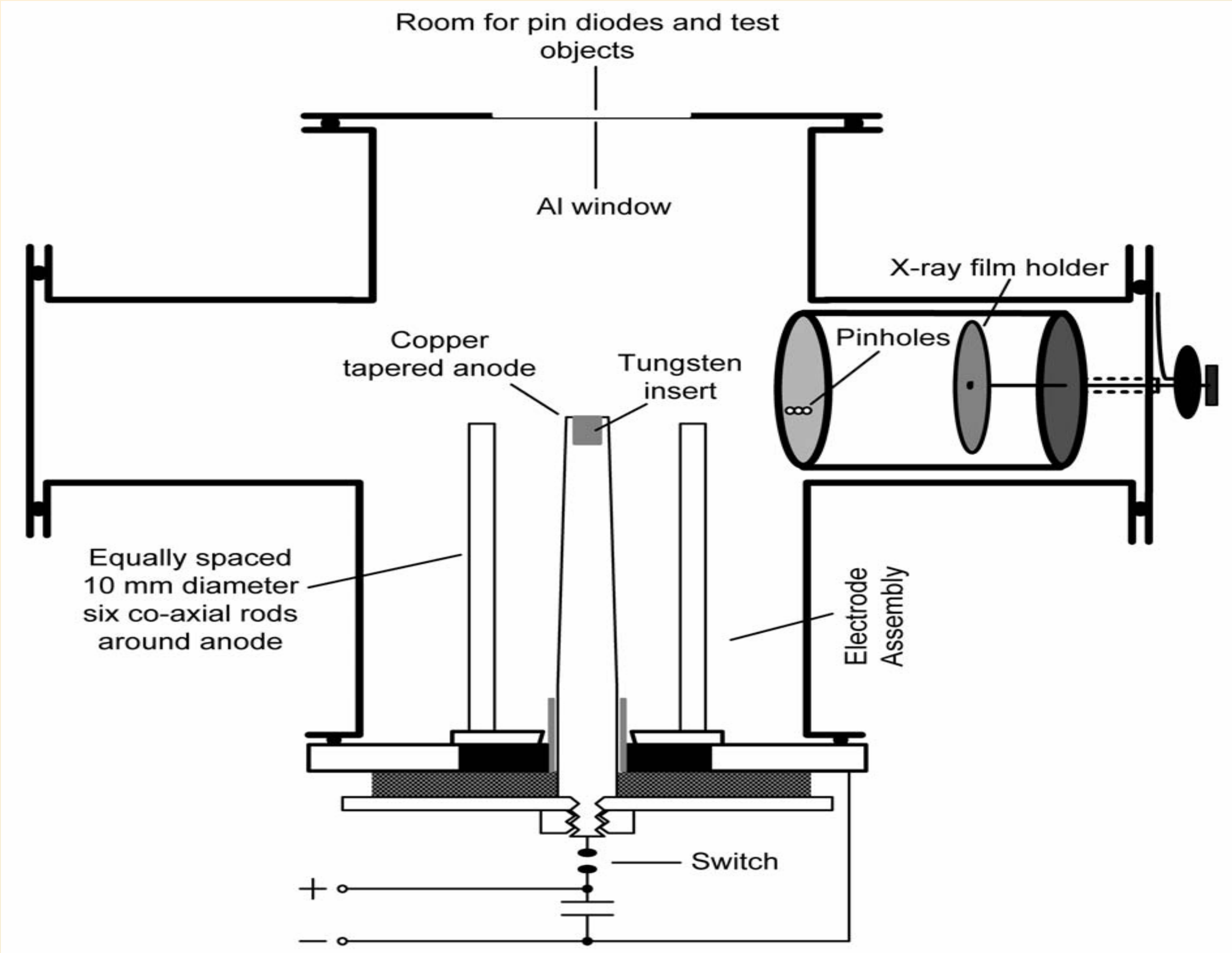
Variation of total X-ray emission and efficiency with filling gas pressure in 4π-geometry with pre-ionization and without it.



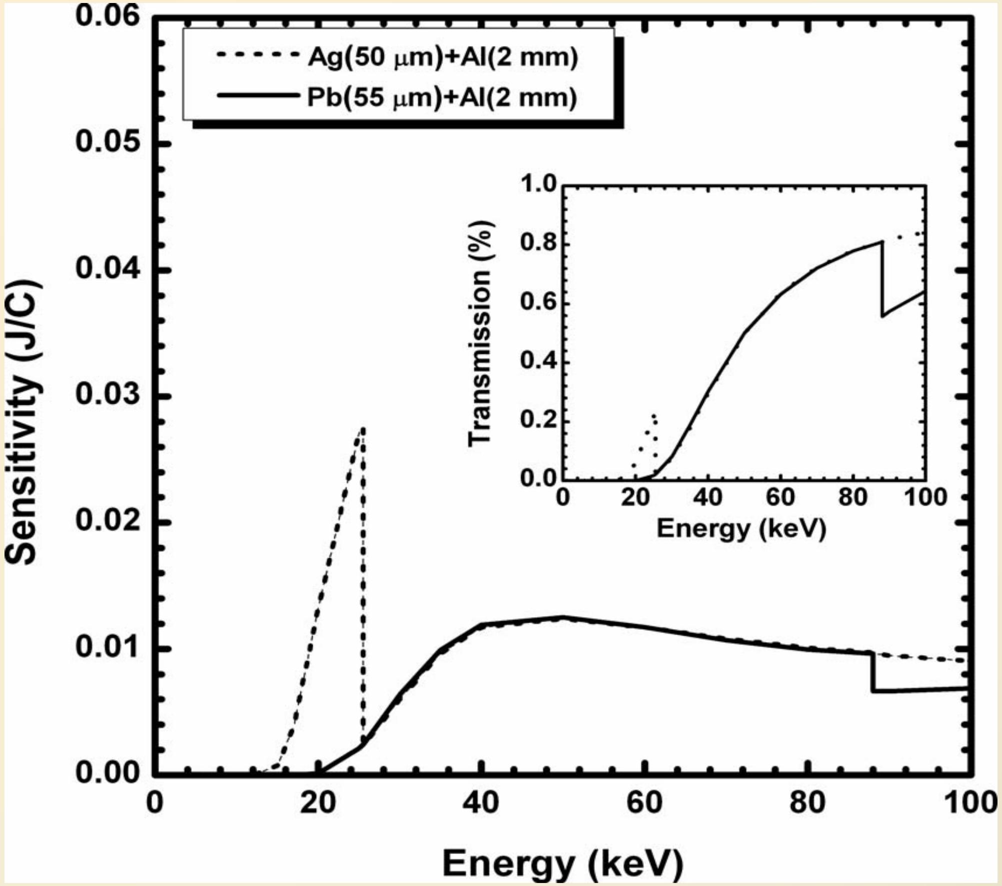
A correlation between the total X-ray emission and the neutron yield for different filling pressures with and without pre-ionization

PLASMA FOCUS AS HARD X-RAY SOURCE

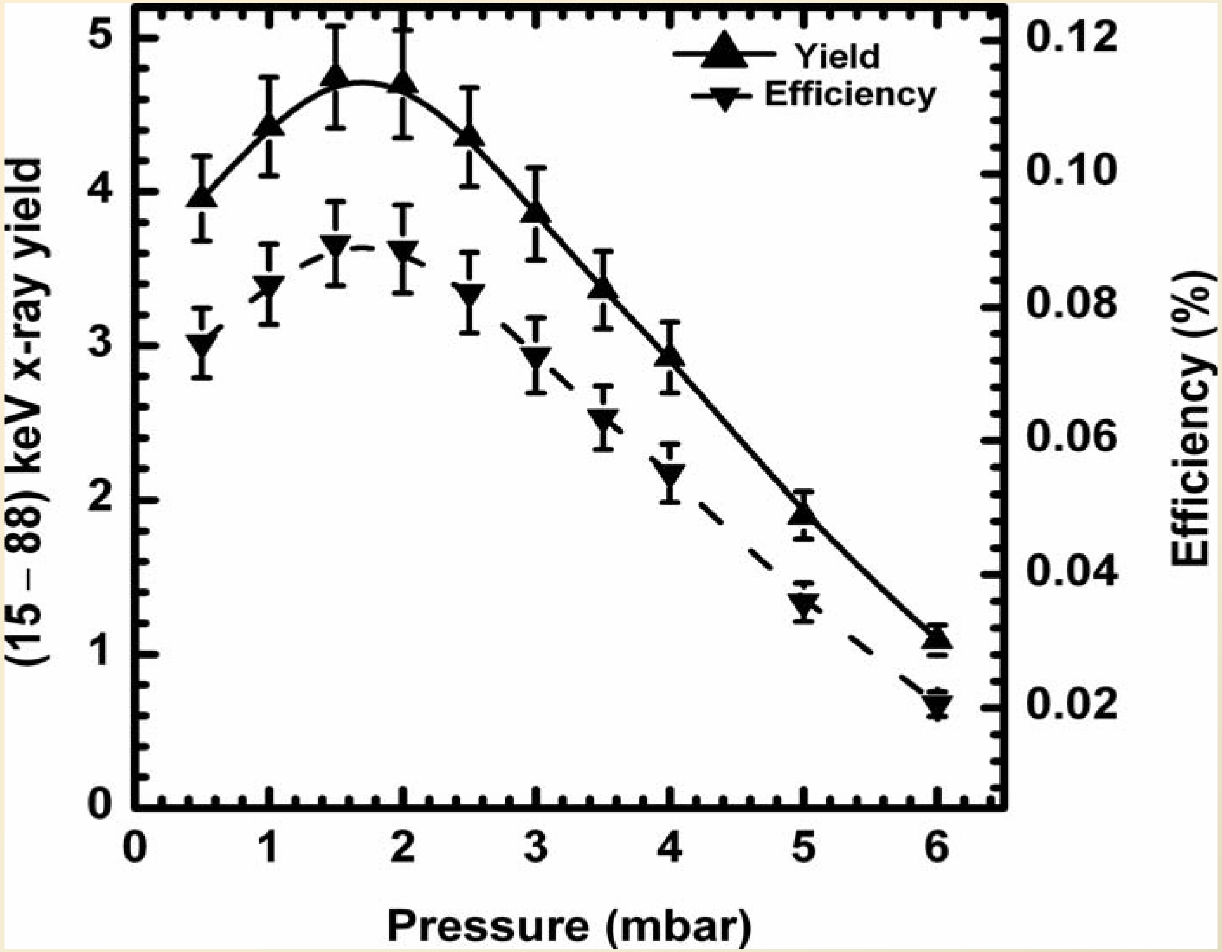
- Plasma foci are well known to produce hard X-ray pulses which are due to the interaction of energetic localized electron beam with anode tip.
- As a hard x-ray generator, the distinctive features of the plasma focus are the small source size, pulses of short duration and high intensity.
- In this Experiment,12.5 μF, 40 kV capacitor, charged at 29 kV (5.3kJ) giving a peak discharge current of about 290 kA, powered the device.



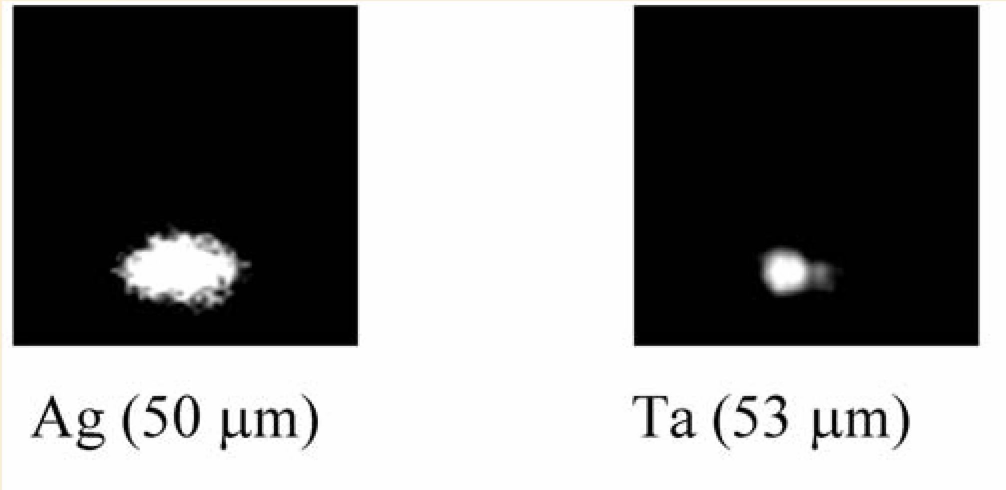
A schematic of the plasma focus facility and diagnostics.



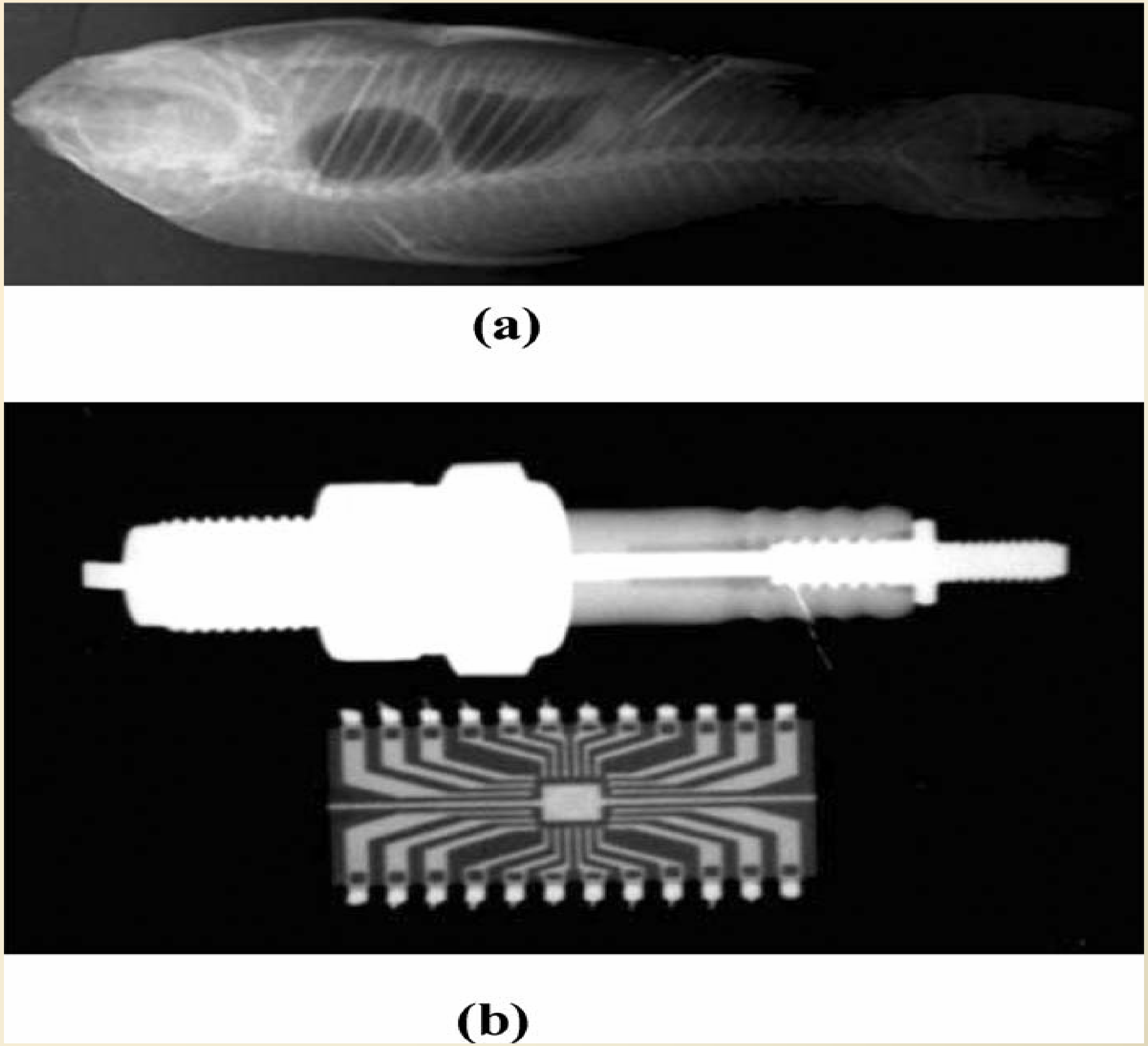
The transmission curves and the detectors' sensitivity for 50 μm Ag plus 2 mm Al and 55 μm Pb plus 2 mm Al Ross filter pair



The variation of hard x-ray yield and corresponding efficiency as a function of argon filling pressure.



Pinhole images of the x-ray emission zones obtained with 200 μm diameter pinholes masked by Ag 50 μm and Ta 53 μm filters.



(a) Radiograph of a fish (b) a motorbike spark plug and an integrated circuit

CONCLUSIONS

- Pre-ionization induced by depleted uranium ($_{92}U^{238}$) enhanced total X-ray yield about 30 % while neutron emission is increased up to 25%.
- It is found that pre-ionization also broadened the pressure range of the high X-ray and neutron yield
- The shot to shot reproducibility of the system is much improved in the presence of pre-ionization.
- In second experiment, the hard x-rays having pulse duration of 15–20 ns and a source size 1 mm is found to be efficient for imaging of thick objects made of various materials.

THANKS FOR ATTENTION