Characterization of photo-neutrons produced by laser-plasma accelerated electrons impinging on high Z-metallic targets for developing high brightness and pulsed neutron source

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OBJECTIVES

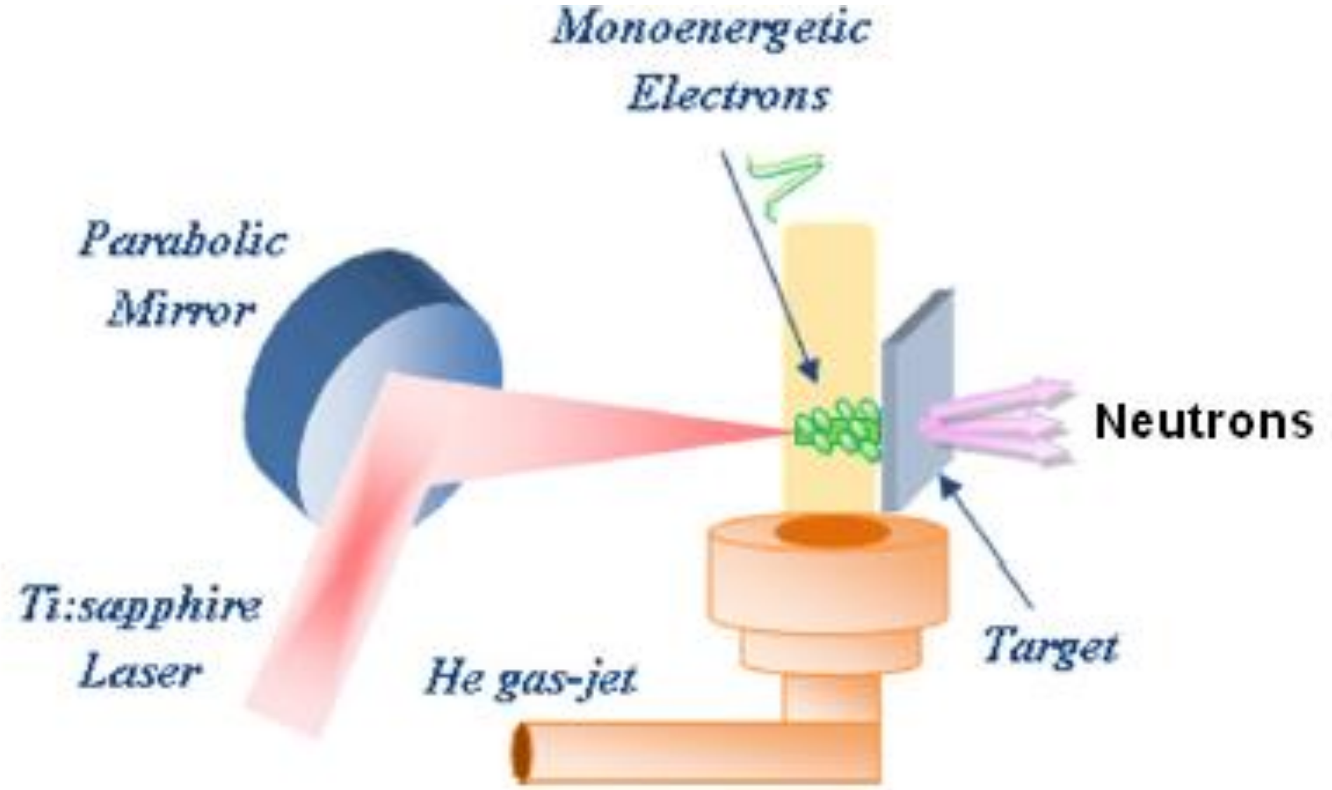
- ♦ Generation of 1.2 GeV and 150 MeV electrons by laser Wakefield acceleration (LWFA).
- ♦ Electron charge measurements
- ♦ Plasma density measurements by plasma interferometer.
- ♦ Generation of pulsed neutrons from 1.2 GeV and 150 MeV electrons by photo-nuclear reaction.
- ♦ MCNP calculations of Neutron yield, Angular distribution, Energy spectrum and Nuclear Temperature

NEUTRON SOURCES

- Fission reaction
- Conventional Accelerators
- Radioactive sources
- Fusion reactions
- Laser plasma accelerators

LASER WAKE FIELD ACCELERATION (LWFA)

ultra-intense laser used to excite plasma wave (wake fields)



SHANGHAI JIAO TONG LASER FACILITY

- *a tabletop 200 TW, 10Hz, Ti: Sapphire 30 fs laser*
- 4-mm-long supersonic nozzle gas-jet target *N&He*
- Integrating current transformer (ICT) for electron Charge measurement

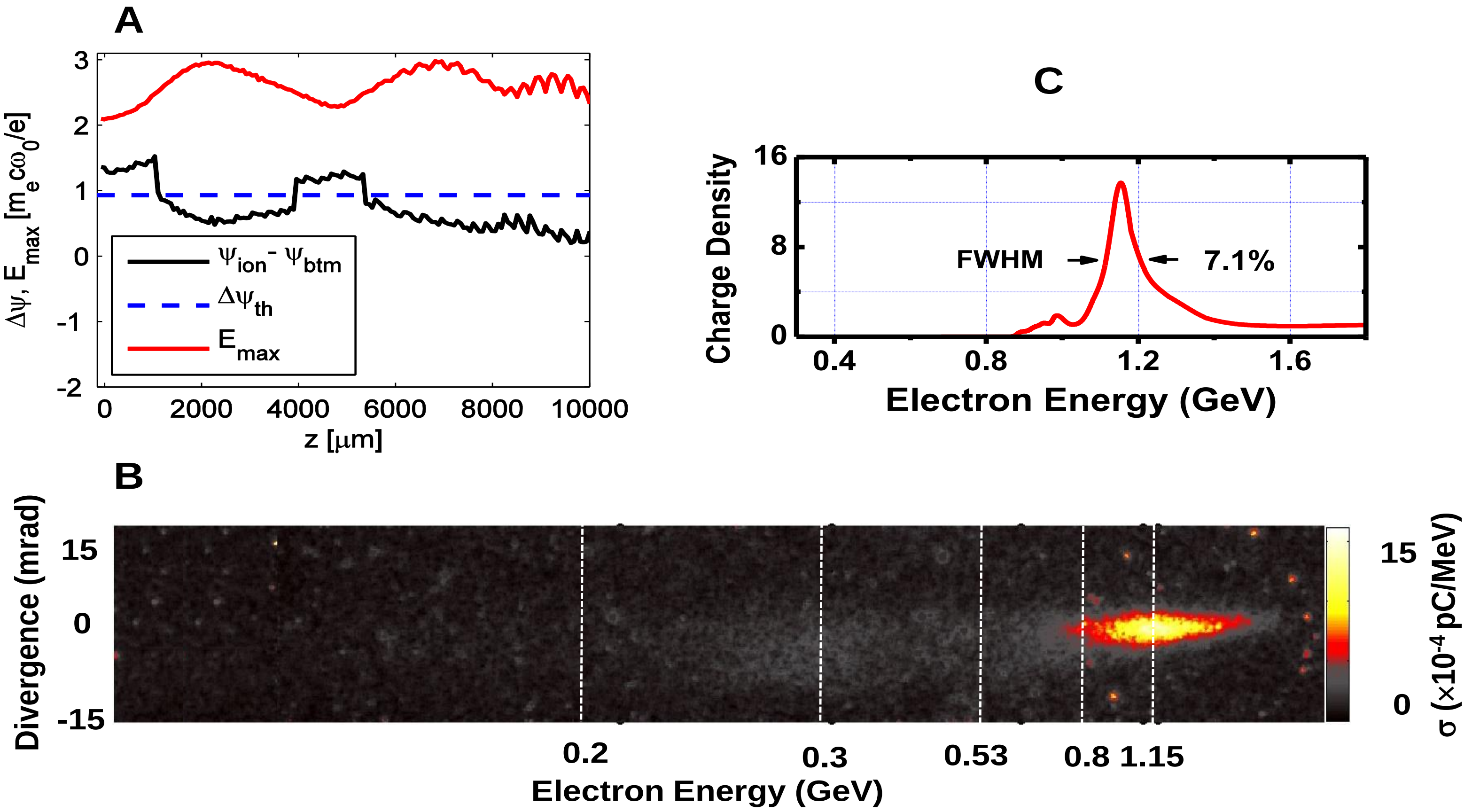
- Fluorescent screen and a 14-bit CCD camera for imaging the spatial profile of the accelerated electron beams

LASER PLASMA EXPERIMENT AT KEY LABORATORY, SHANGHAHI JIAO TONG UNI.

EXP.1
1.2 GeV electron is produced from under dense plasma
Charge 10pC/p
the plasma density (ne) 3.35×10^18 cm -3 (Mach-Zehnder interferometer)
Pulse duration 30 fs
Pulse repetition 10Hz
Energy spread 5%

EXP. 2
150 MeV electron is produced from dense plasma
the plasma density (ne) 4.0×10^19 cm -3

Charge 22pC/p
Pulse duration 30fs
Energy spread 1%



(A) Simulation result using OSIRIS code showing the evolution of the laser pulse electric field (red) and the wake wave's pseudo-potential difference (black). (B) False-color ICCD image of 1.2 GeV electron beam on the florescent screen after a calibrated magnet spectrometer. This electron beam was generated by focusing 120 TW laser pulse on a 1.8 ×1018 cm-3 plasma of helium gas mixed with low traces of nitrogen gas. (c) The deconvoluted energy spectrum of the image in (B).

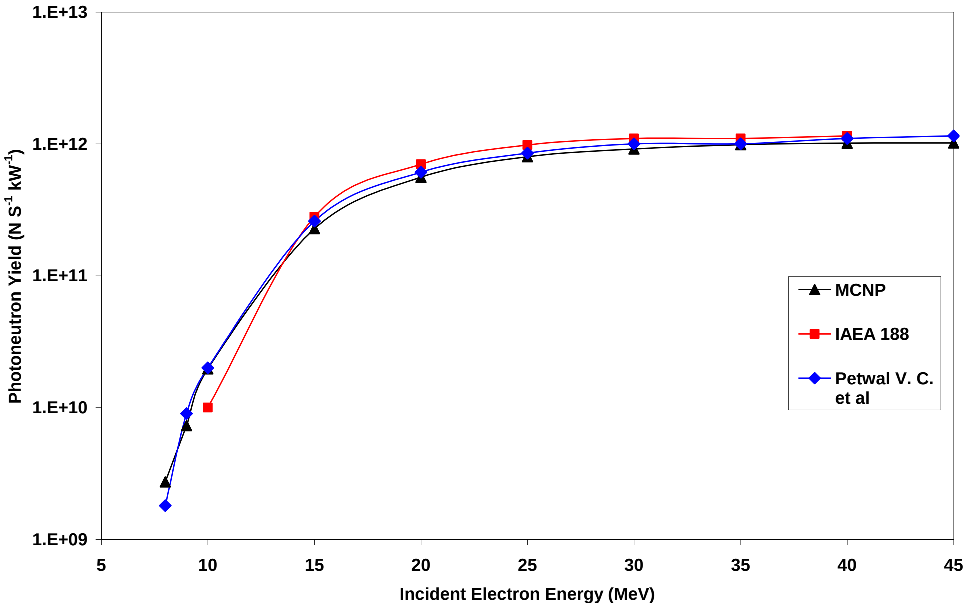
MCNP CODE VALIDATION

♦ Monte Carlo MCNP calculations depend sensitively on the simulation geometry

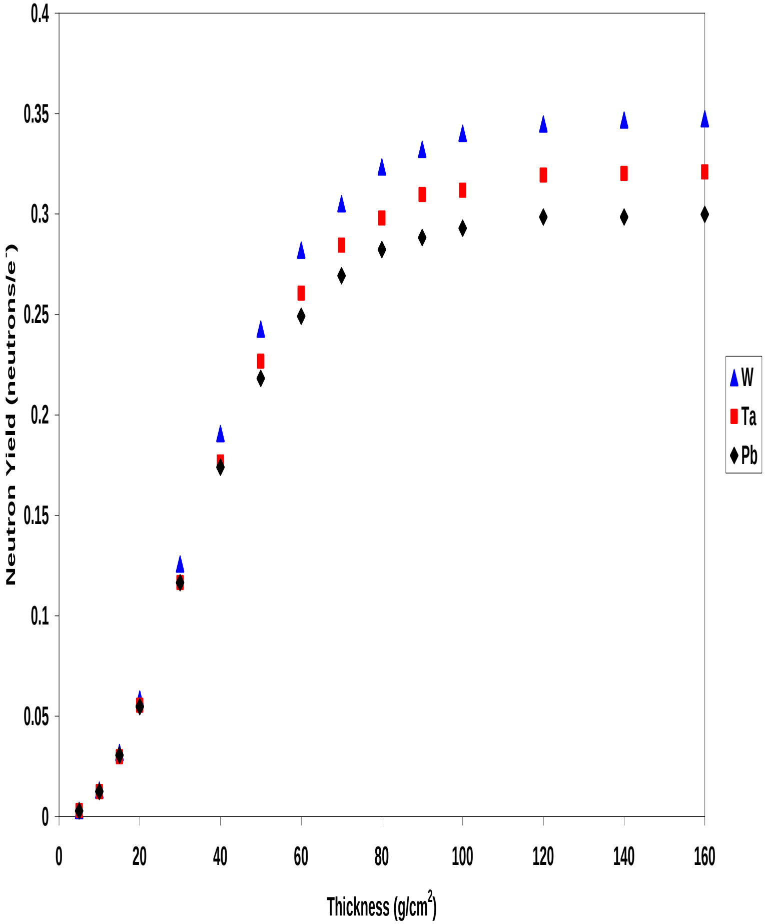
♦ To check the photonuclear physics contained in the code

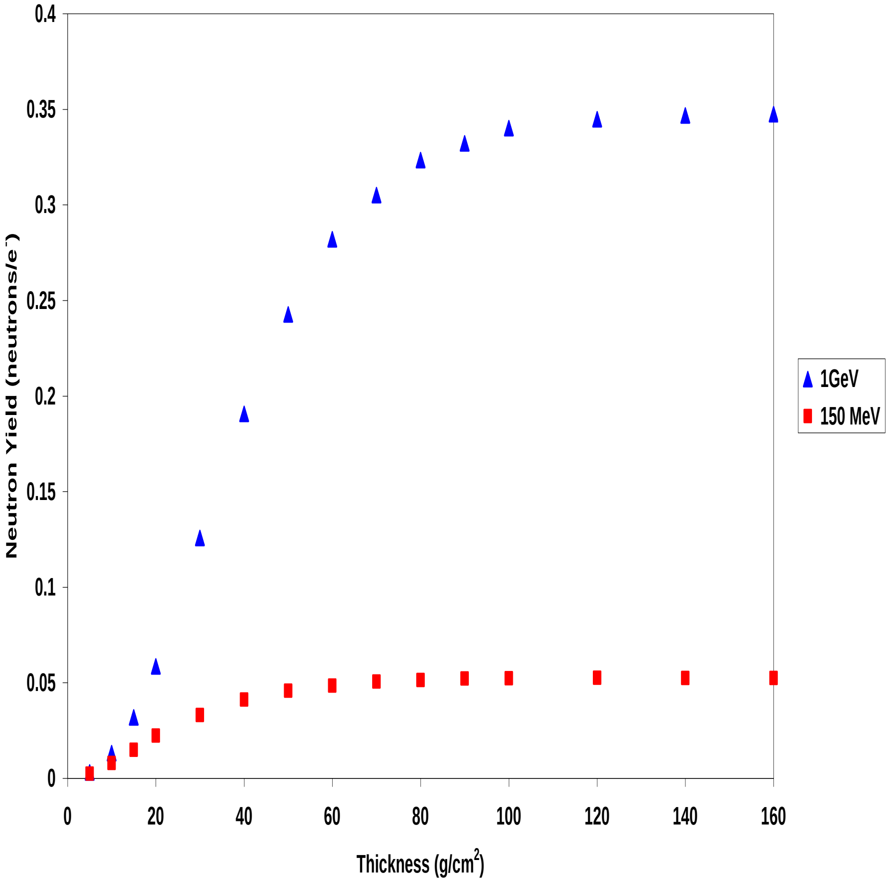
♦Cylindrical lead target (Pb-207) (thickness 1.68 cm and radius 3 cm), for which measured data are available (IAEA TR-188, 1979)

♦ Show good agreement with the published data



Neutron Yield



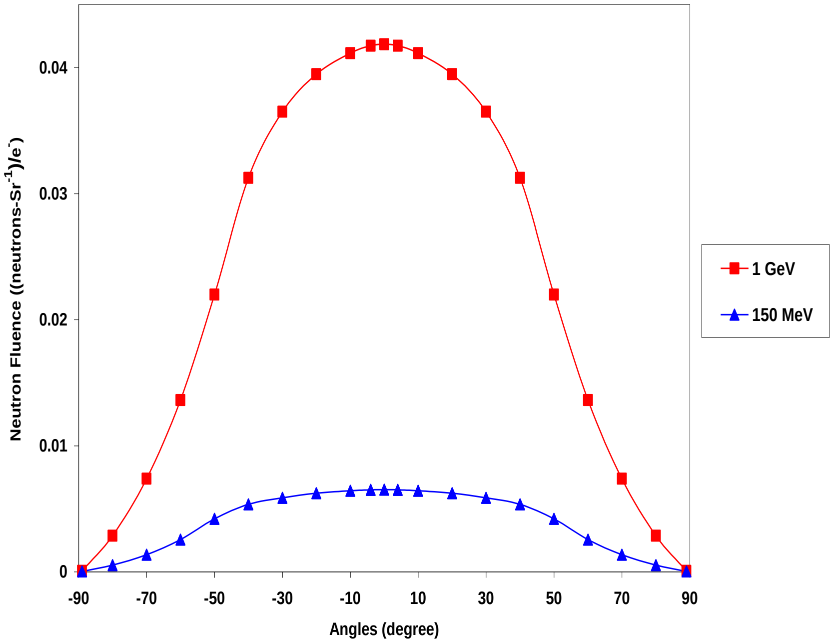


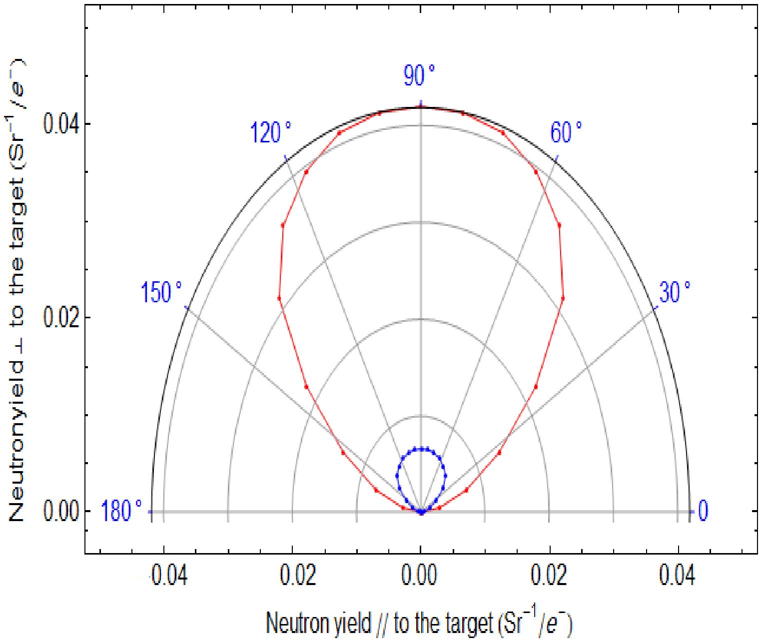
Max. Yields

Target	Electron beam energy	Max. Yield (neutrons/e^{-})	Optimized thickness (g/cm^2)	Optimized thickness (cm)
Tungsten Z=74, D=19.24	1GeV	3.47.10^{-1}	140	7.28
	150MeV	5.23 .10^{-2}	100	5.2
Tantalum Z=73, D=16.4	1GeV	3.2 .10^{-1}	140	8.5
Lead Z=82, D=11.34	1GeV	2.98 .10^{-1}	140	12.35

Accelerator Type	Electron beam energy	electron-neutron conversion factor (photons/e^-)	electron fluence (electrons/s)	Max. Neutrons Yield (neutrons/s)
laser plasma Acc.	1GeV	$3.47.10^{-1}$	$0.624. 10^{9}$	$2.2 . 10^{8}$
	150MeV	$5.23.10^{-2}$	$1.37 . 10^{9}$	$0.72 . 10^{8}$

Angular distribution



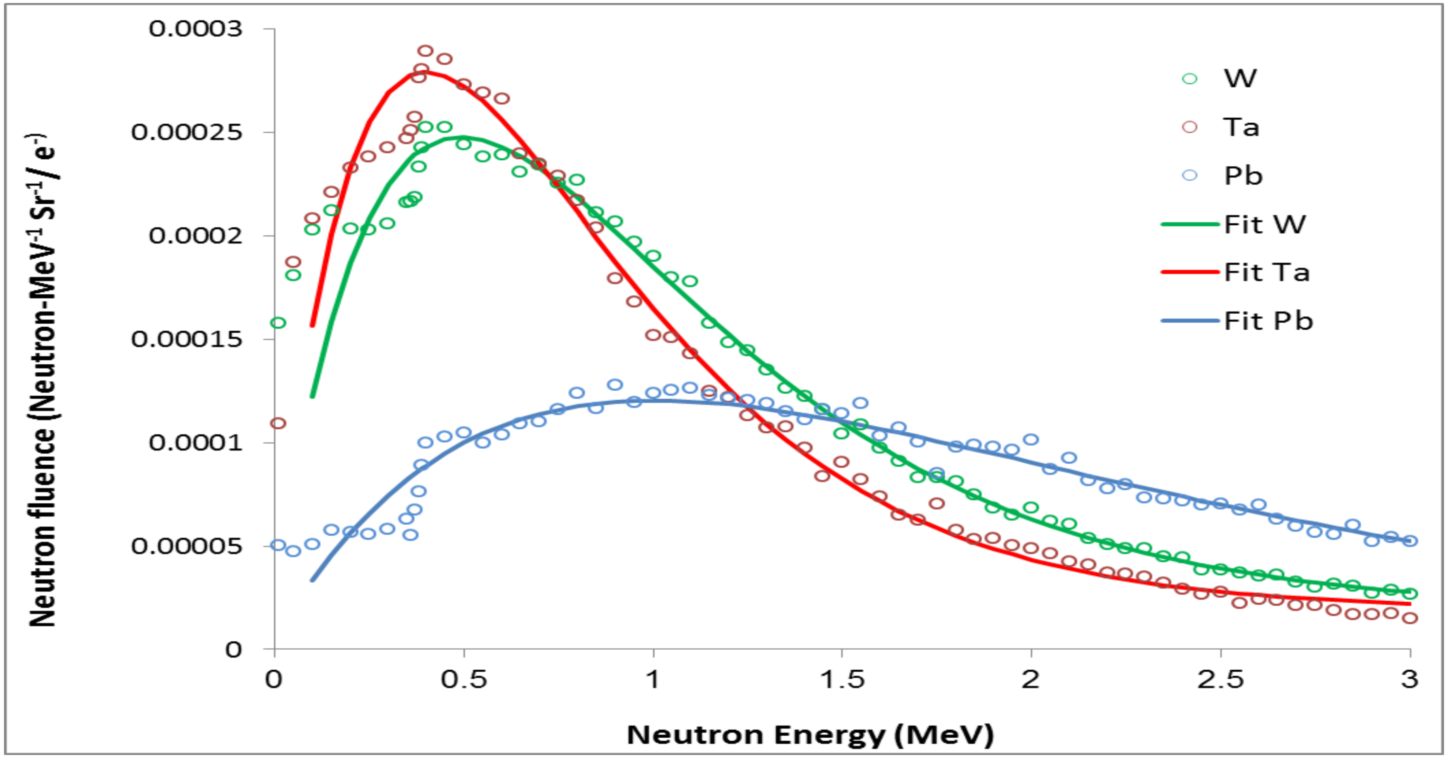


♦ **Giant dipole resonance (GDR), neutrons are produced by photons with energies from threshold energy to 30 MeV**

♦ **Quasi-deuteron effect (QD) 30 < E < 140 MeV**

♦ **Photo-pion production above 140 MeV**

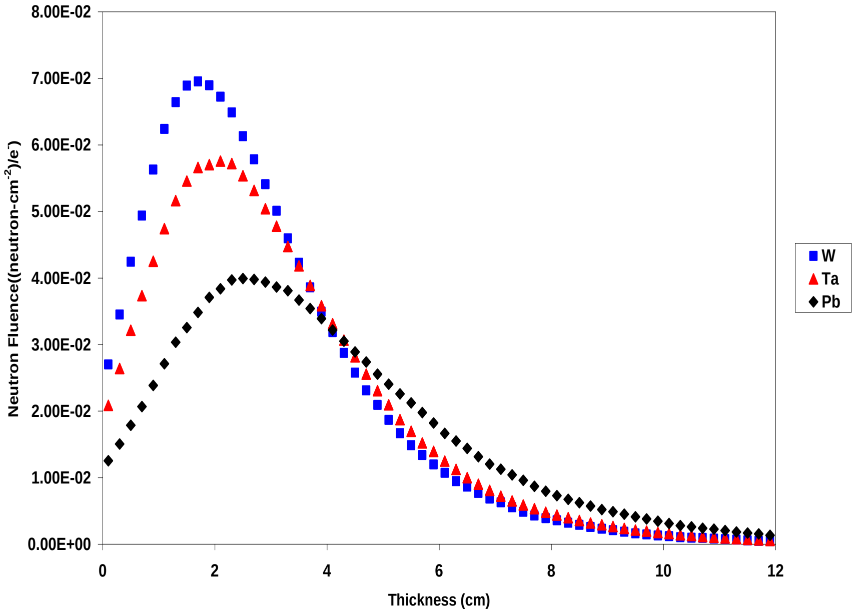
Energy Spectrum

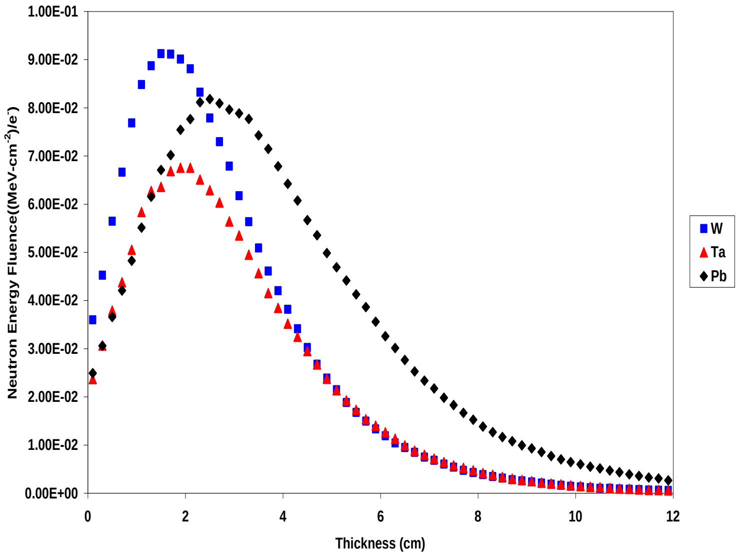


Energy distribution of neutrons produced from 1 GeV electrons incidents on 60g/cm2 thickness of different targets; circles represent simulation data while solid lines represent fittings of such data using Eq

$$\frac{dN}{dE_n} = \frac{E_n}{T^2}\exp\left(\frac{-E_n}{T}\right)$$

Mean energy of neutrons





target	Electron beam energy	neutron Mean energy (MeV)
Tungsten (W) Z=74, D=19.24	1GeV	1.64
	150MeV	1.58
Tantalum (Ta) Z=73, D=16.4	1GeV	1.41
Lead (Pb) Z=82, D=11.34	1GeV	2.24

Calculated Nuclear Temperature T.

Target	Nuclear Temperature T (MeV)
Tungsten (W)	0.44
Tantalum (Ta)	0.57
Lead (Pb)	0.98

Conclusion

♦ GeV class Plasma accelerators can deliver pulsed Neutrons higher than 150 MeV electrons (2.2 X 10 ^{8}) neutrons/s.

♦ Tungsten (W) is the best target for neutron production.

♦ Neutrons mean energy ranged from 1.4 - 2.24 MeV

♦ Over 23% in forward direction from the peaked forward angular distribution

♦ The Ultra Short Pulsed Neutrons (tens femto second) can be used in lab scale TOF for elemental and isotopic identification with minimum signal to noise Ratio

♦The peak forward angular distribution can support linear design of TOF unit

Thanks