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The measurements and applications of photoneutrons induced by an e-linac

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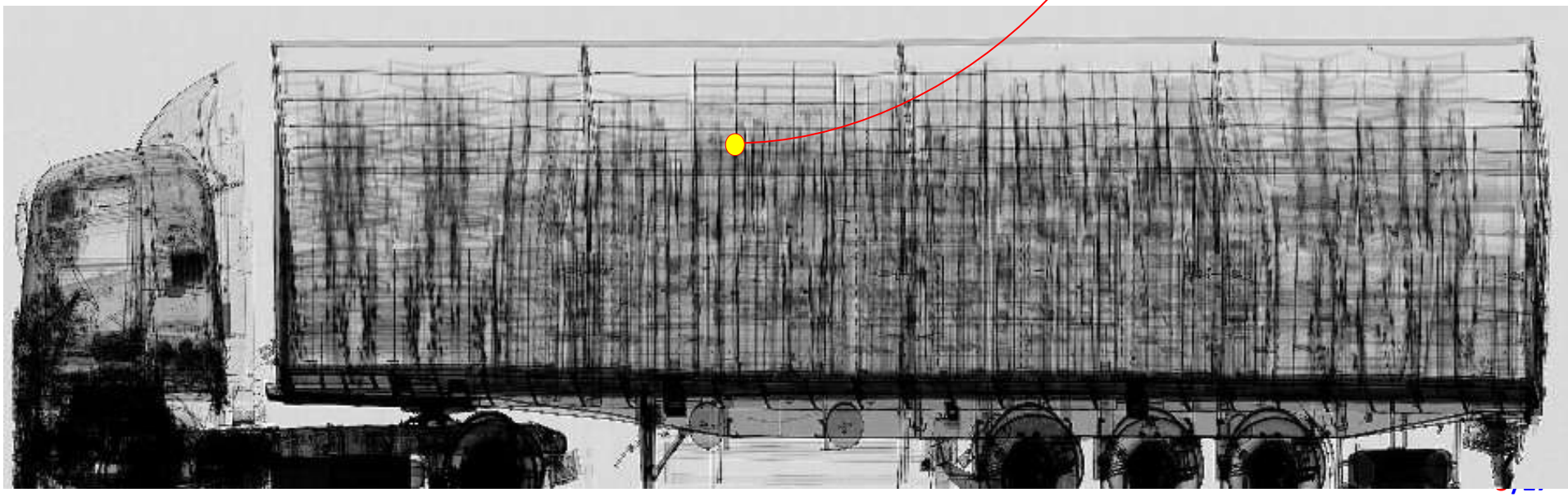
Outline

1. **Research motivation**
2. e-LINAC based materials detection
3. Summary

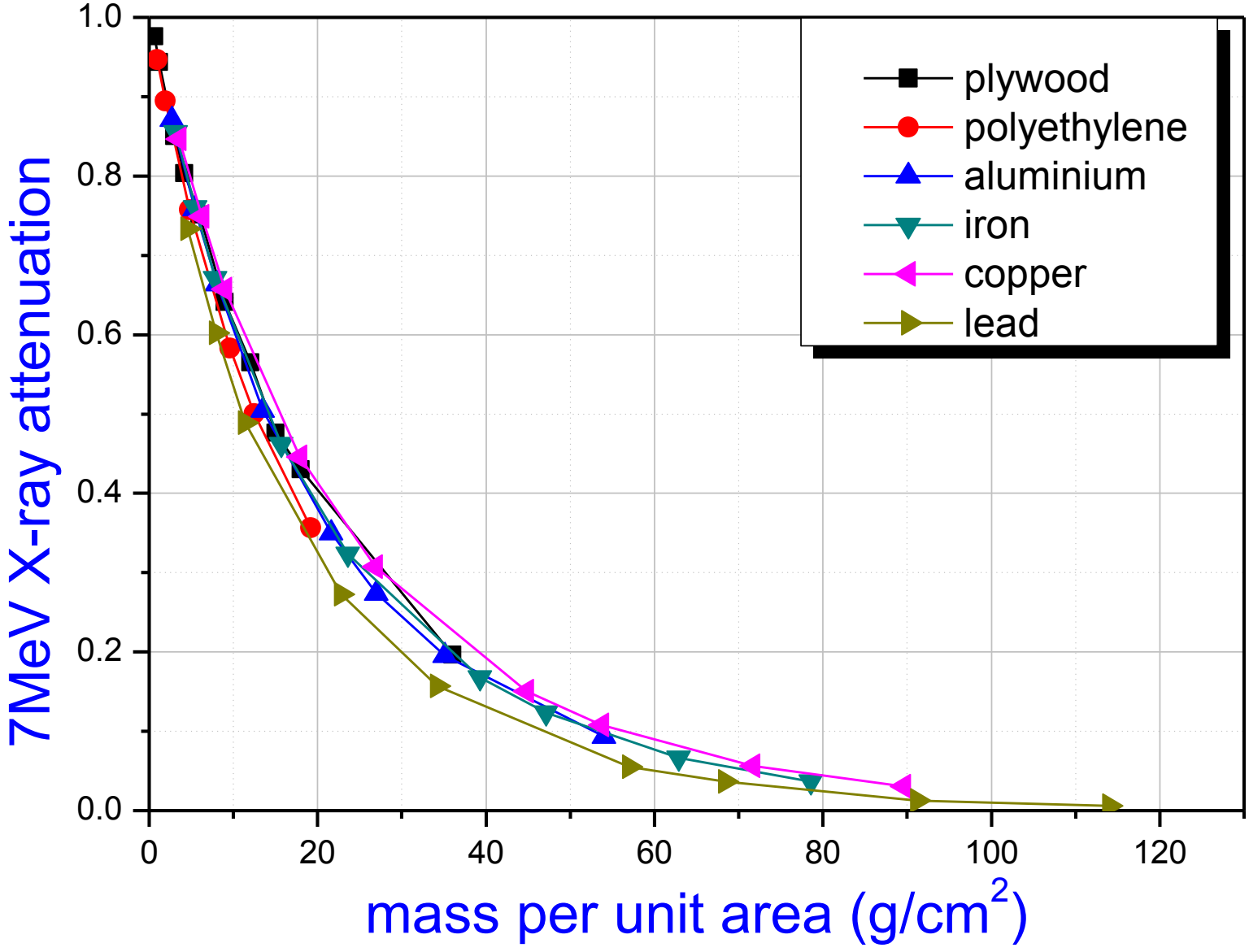
MV X-ray imaging

constant in MeV region for **Compton scattering** is the dominating interaction

$$\ln\left(\frac{I_0}{I_D}\right) = N \cdot \sigma \cdot D = \mu_m \cdot t_m \propto t_m$$



The same mass thickness←→the same attenuation



More information is needed for the contrabands detection

- In the traditional MV X-ray imaging system, **mass-thickness** is the only acquired information, which is not enough to indicate the existence of contrabands.
  - ***Explosives, Drugs, and SNMs (Special Nuclear Materials)***
- **Fusion of different information** of various technologies is needed to locate and identify contrabands.
- **Integrating different physics** within one system can reduce the system complexity.

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② High-Z materials detection with photoneutrons

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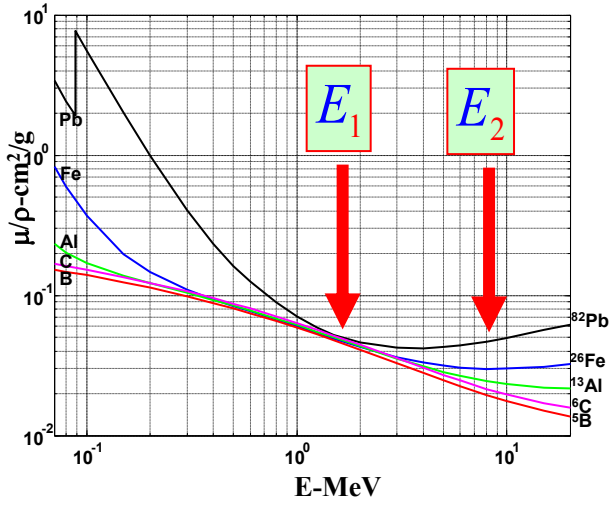
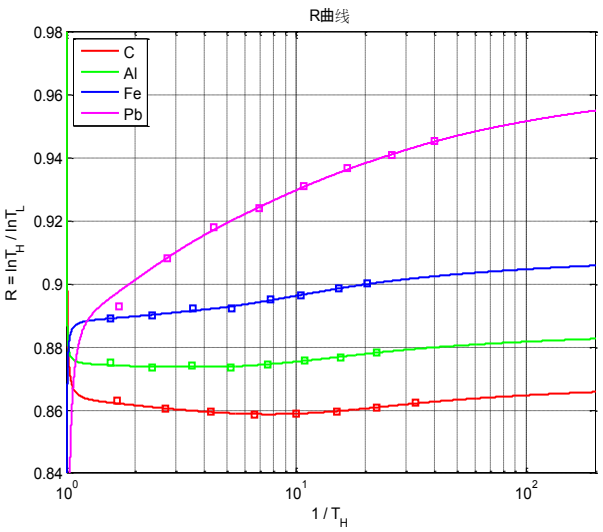
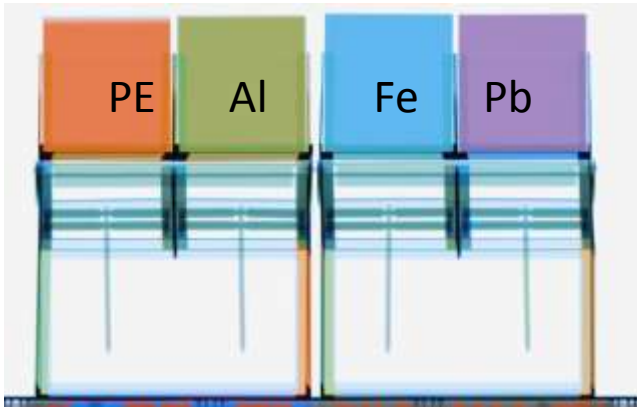
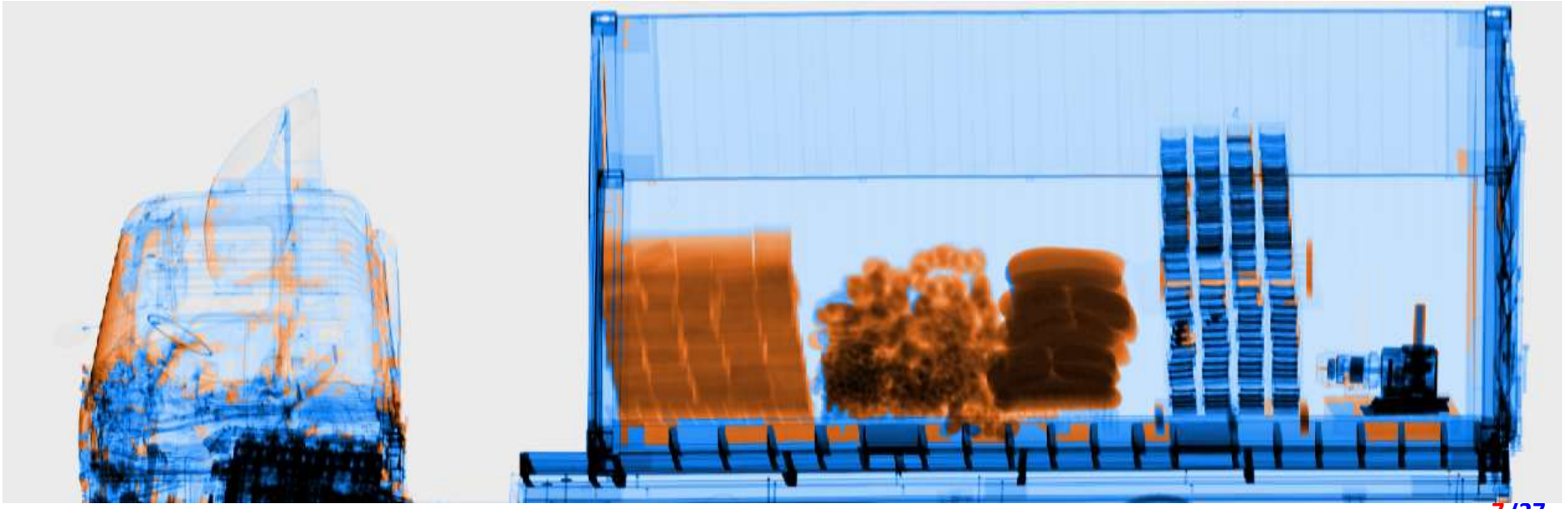
Dual-energy X-ray imaging

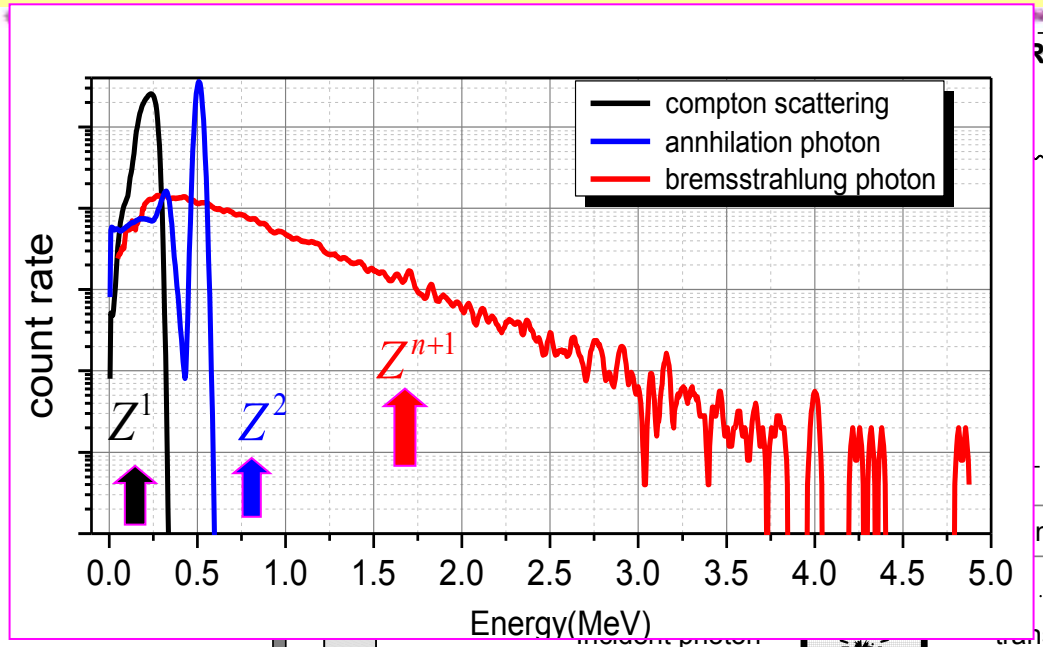


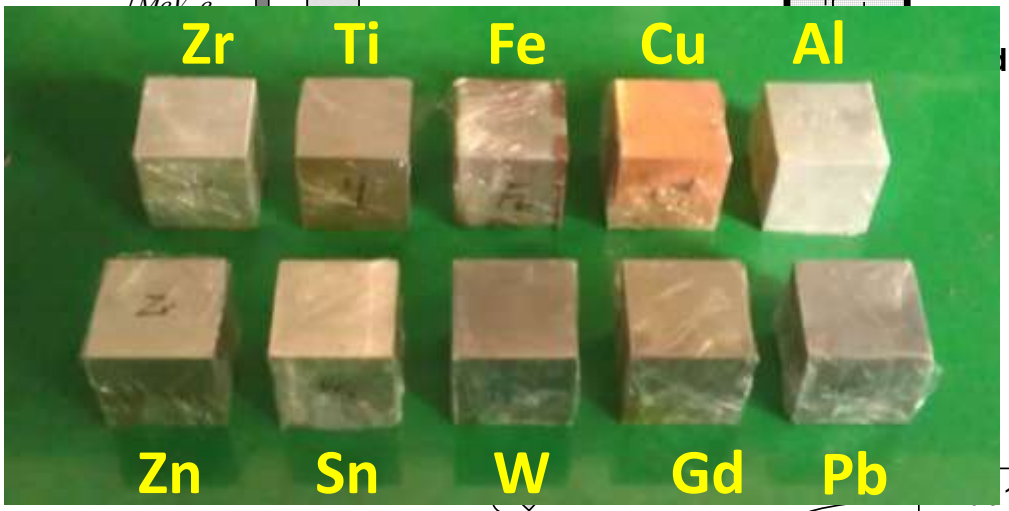


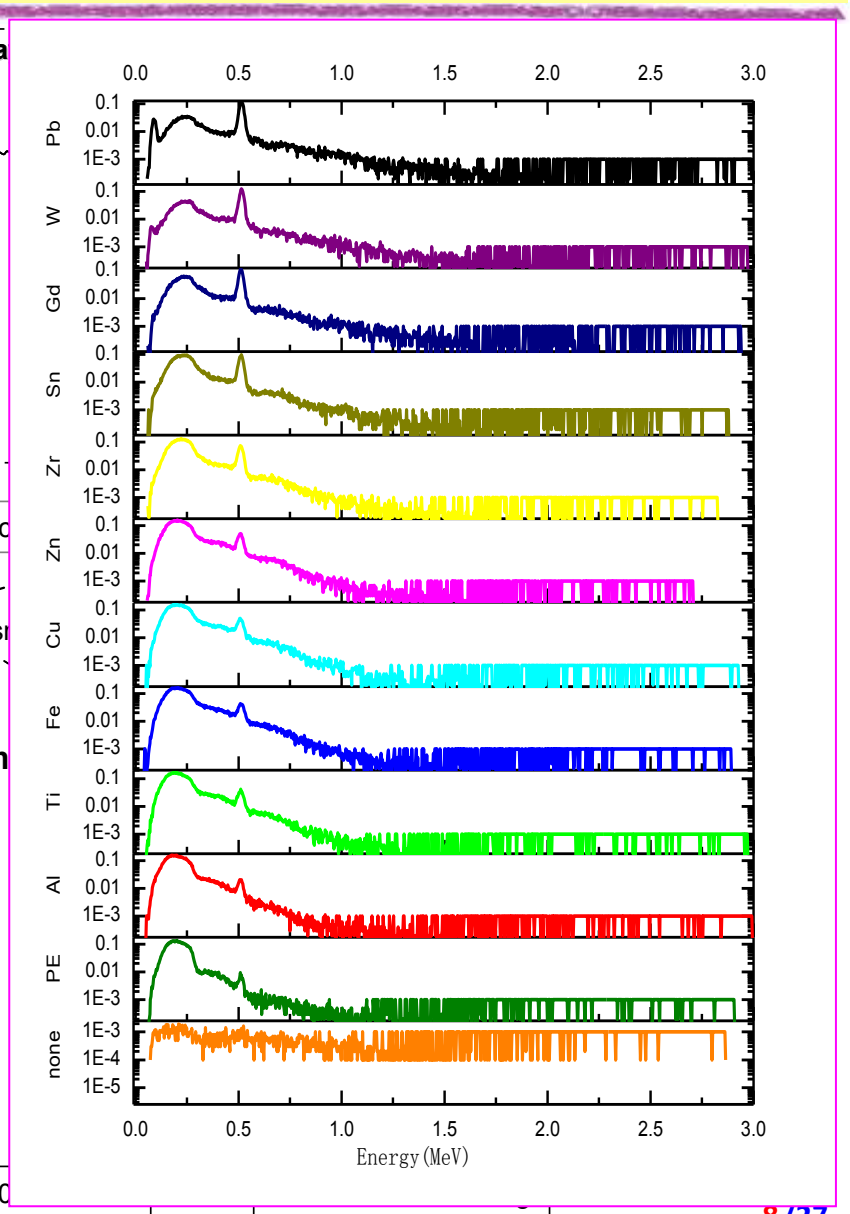




Scattering X-ray analysis

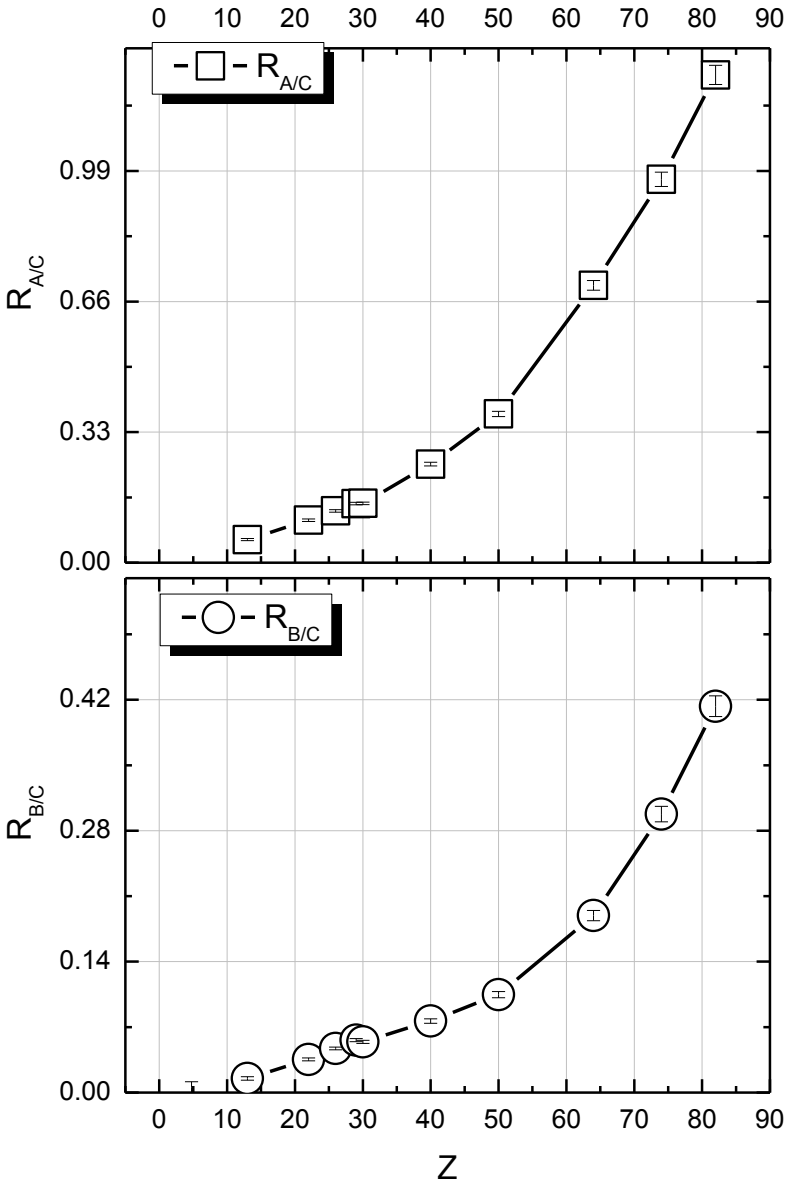




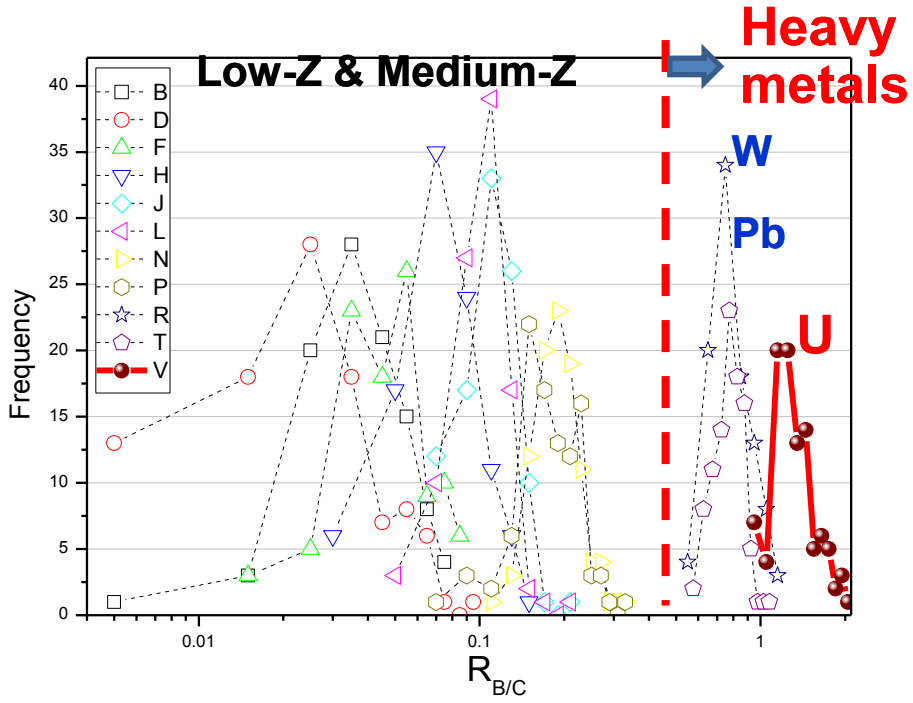


spectra

by analyzing the scattering X-ray spectra, Z information can be acquired



Experimental results of 1 second measurement with a 7 MeV e-LINAC



Yigang.Yang, Weiqi Huang, and Yuanjing Li, "*Measurement of Atomic Number by MV X-Ray Scattering Spectra Analysis*," ***IEEE TRANSACTIONS ON NUCLEAR SCIENCE,*** vol. 60, p. 5, 2013.

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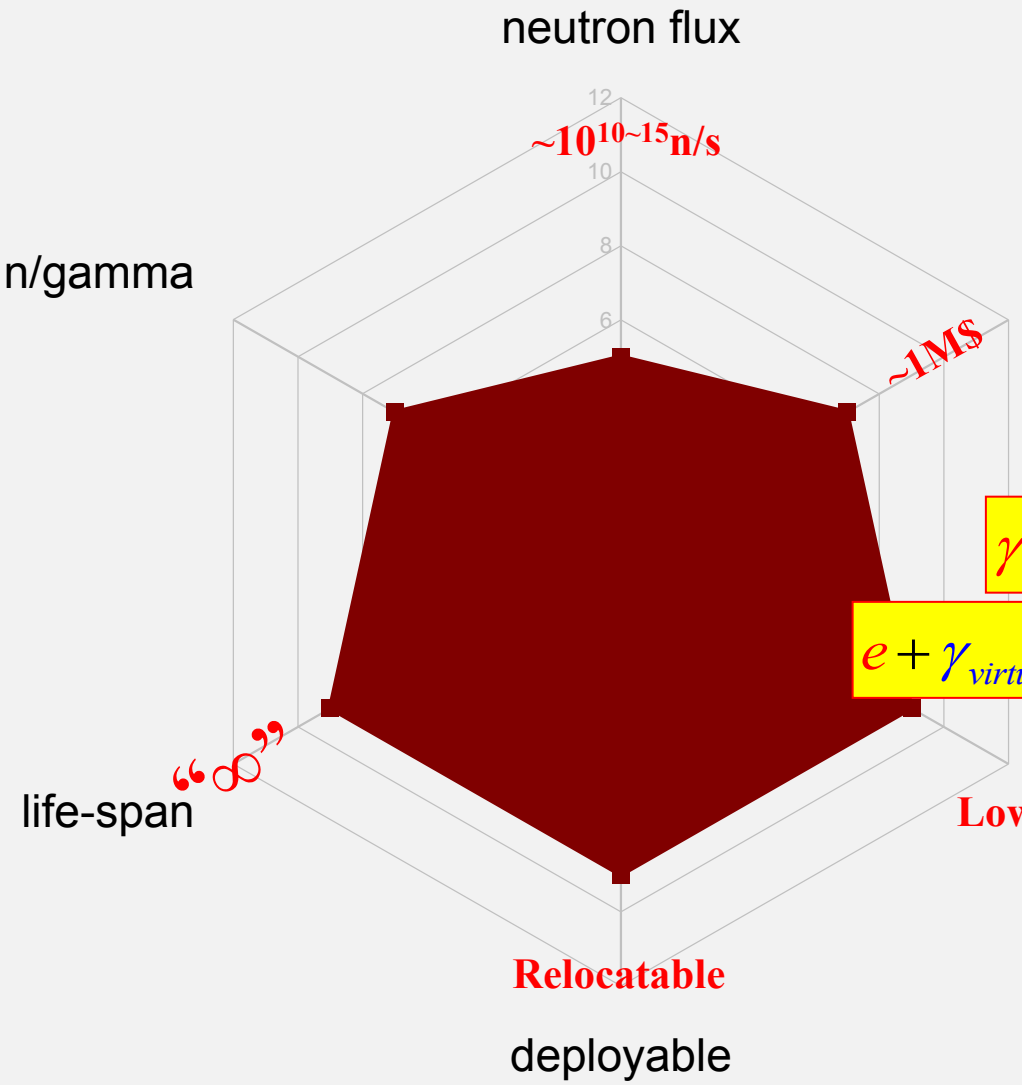
Fermion and neutral particle

- **Neutron:**
  - Neutral particle: Penetrating capability
  - Fermion: Pauli exclusion principle → **Nuclear Structure**
- **More information** about contrabands can be provided by neutron related reactions.

Why e-linac driven neutron source?



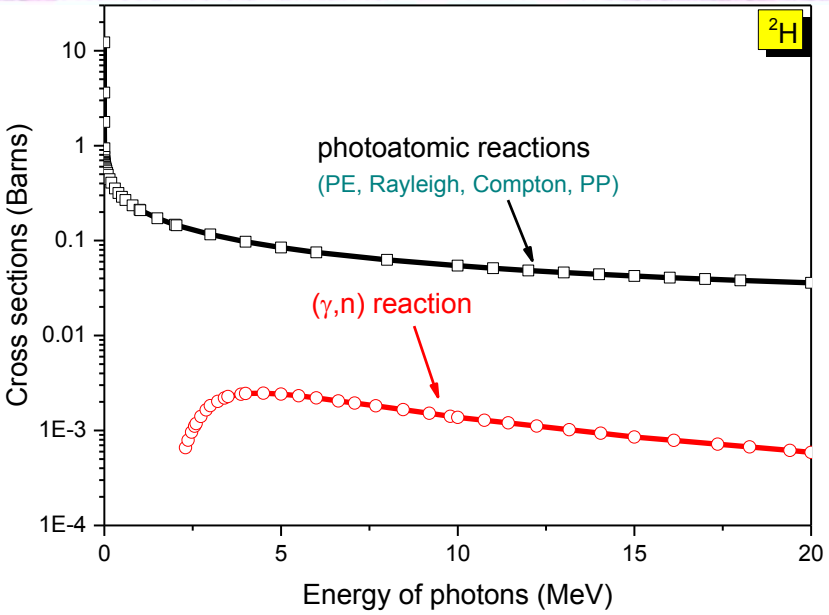
Photoneutron source

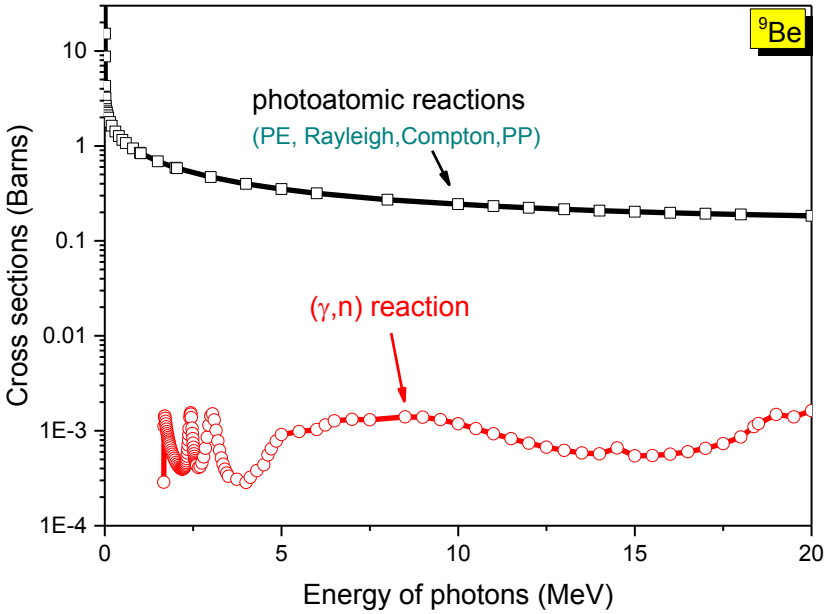
$$e \xrightarrow{bremsstrahlung} \gamma$$

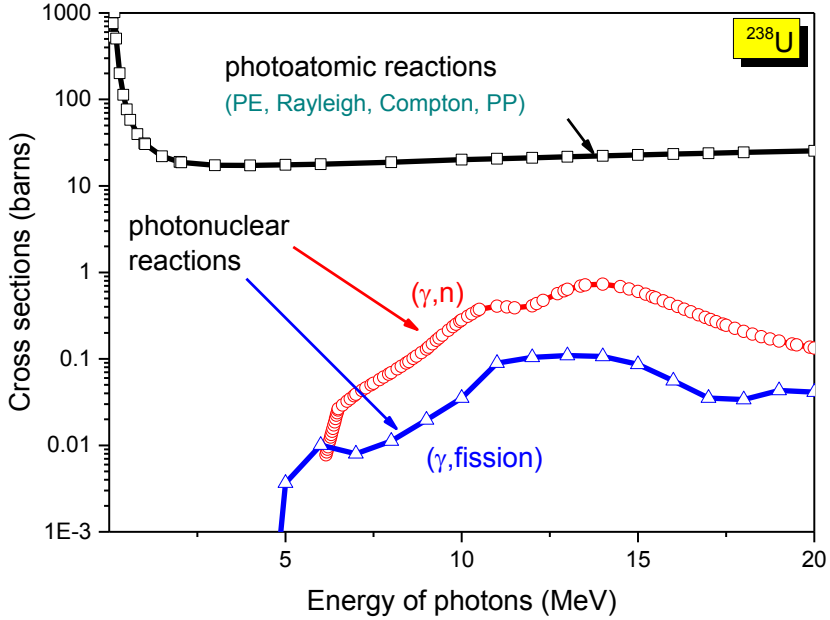
$$\gamma + {}^{A}_{Z}X_{N} \xrightarrow{(\gamma,n)} {}^{A-1}_{Z}X_{N-1} + n$$

$$e + \gamma_{virtual} + {}^{A}_{Z}X_{N} \xrightarrow{(\gamma,n)} {}^{A-1}_{Z}X_{N-1} + n + e$$

photoatomic or photonuclear reactions

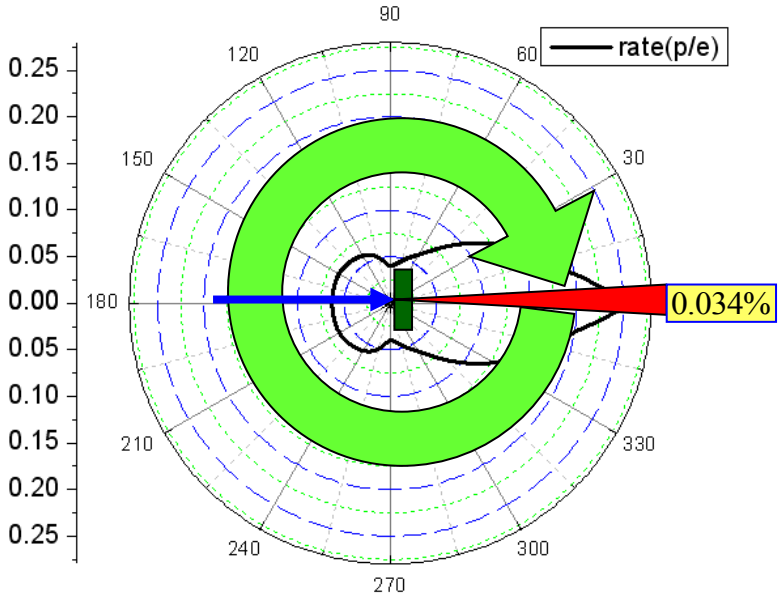


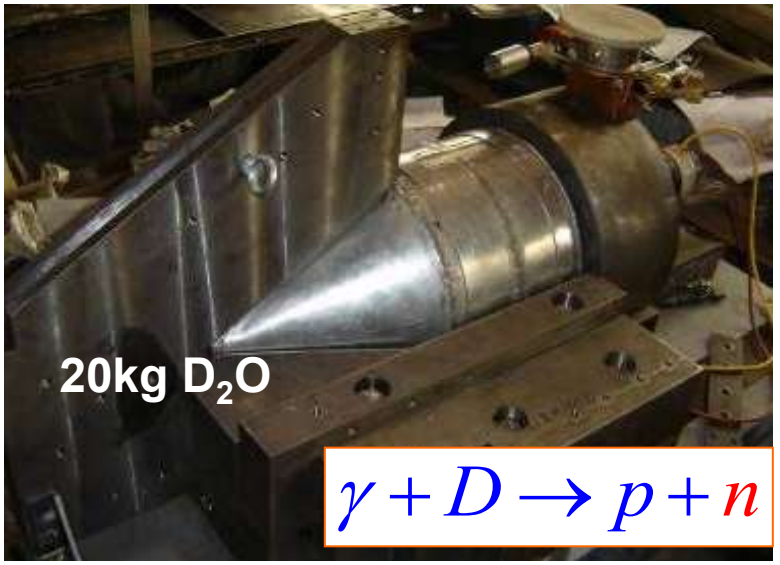


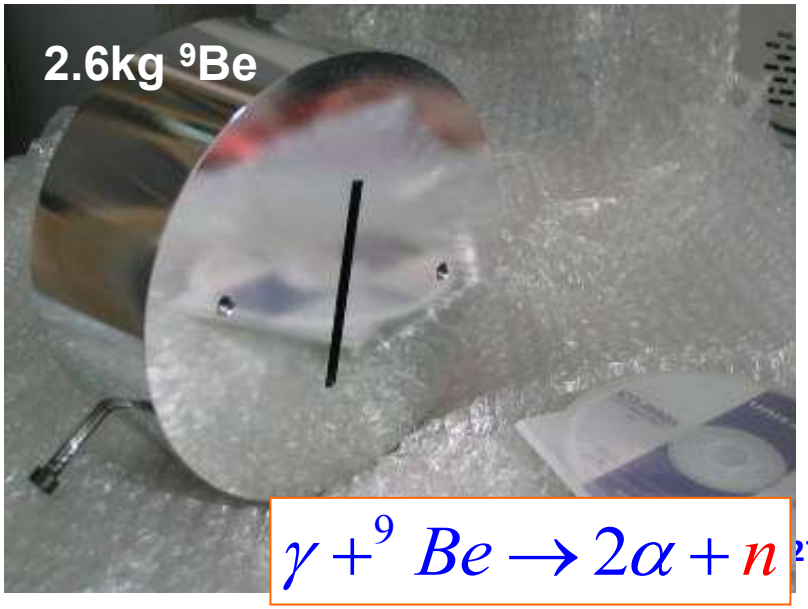


Photons → Neutrons

Angular distribution of X-ray

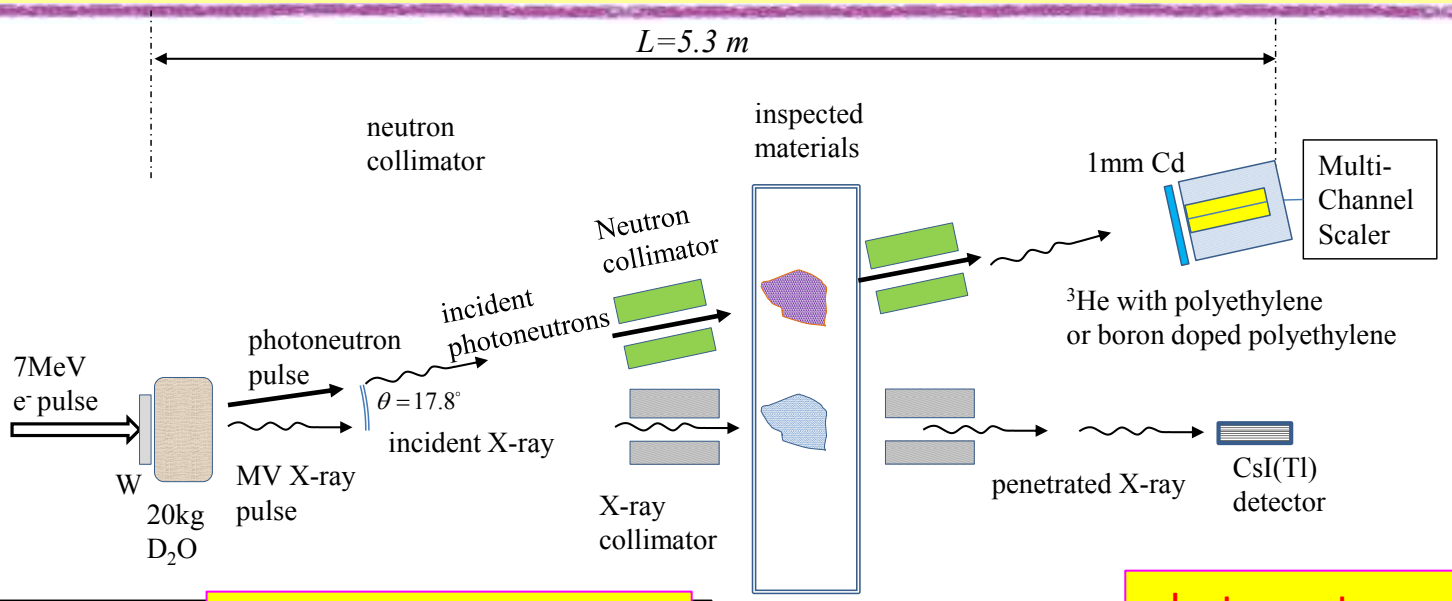


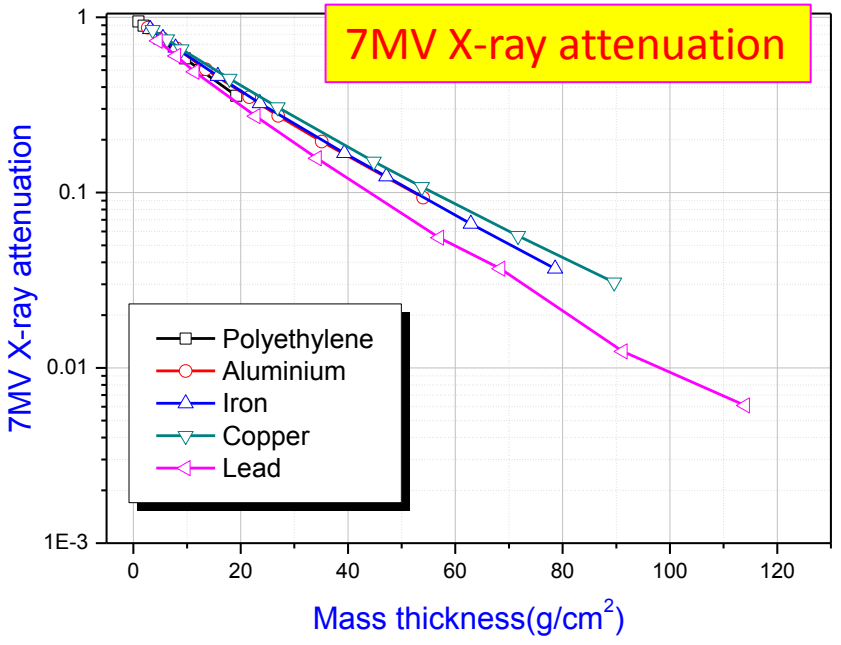


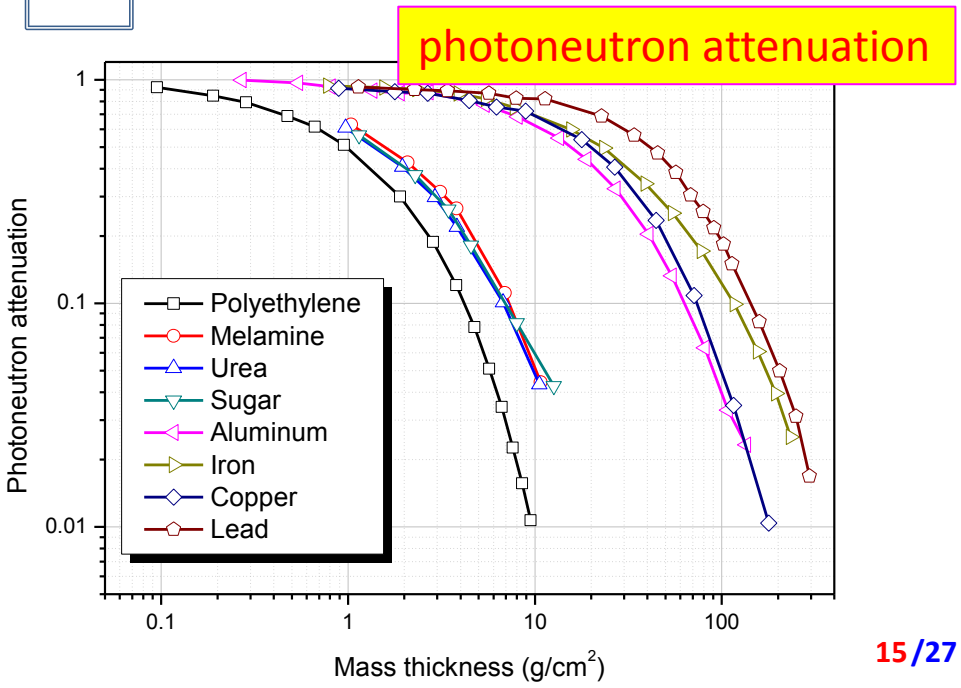


- **Photoneutron yield**
  - 7MeV/100W : **10^{10}n/s**
  - 10MeV/20kW : **6.7×10^{12}n/s**

PhotoNeutron X-ray Radiography (PNXR)

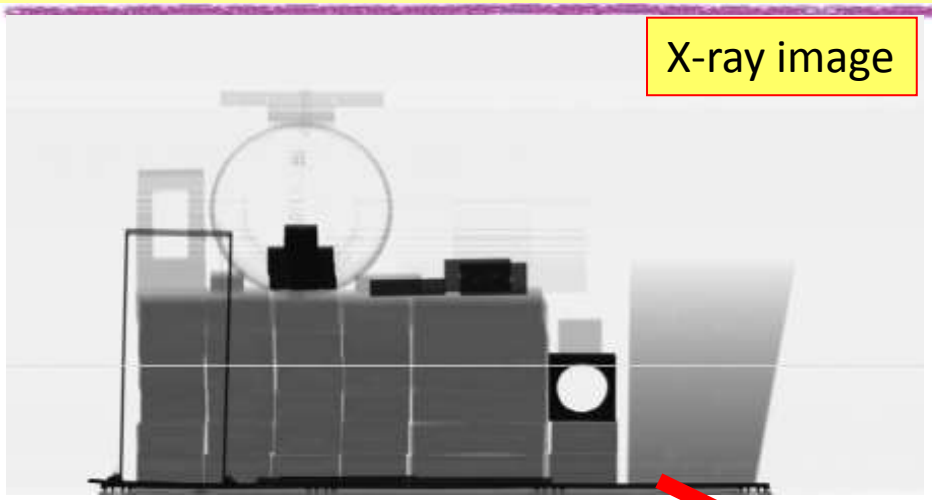




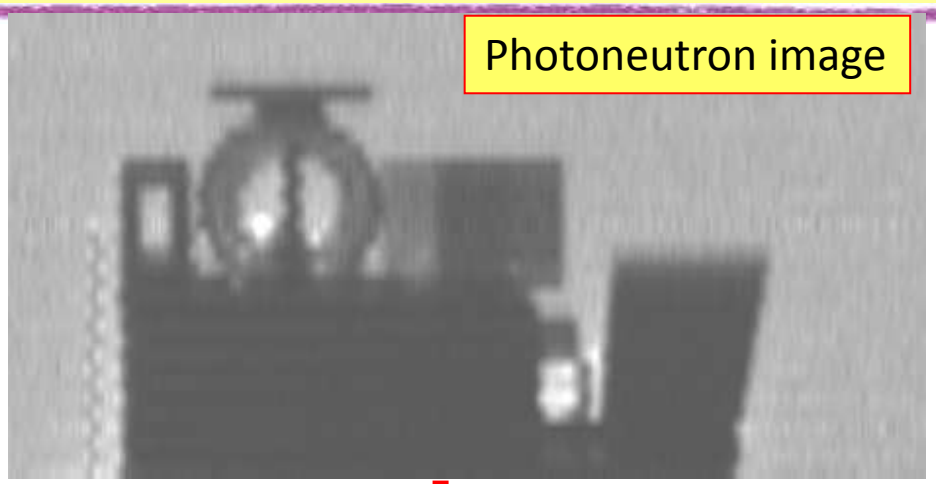


Fused X-ray image and Photoneutron image

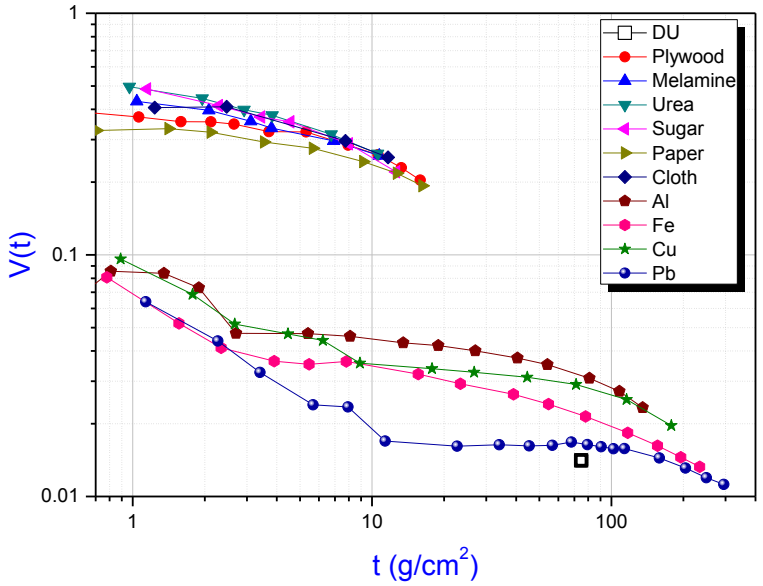
X-ray image



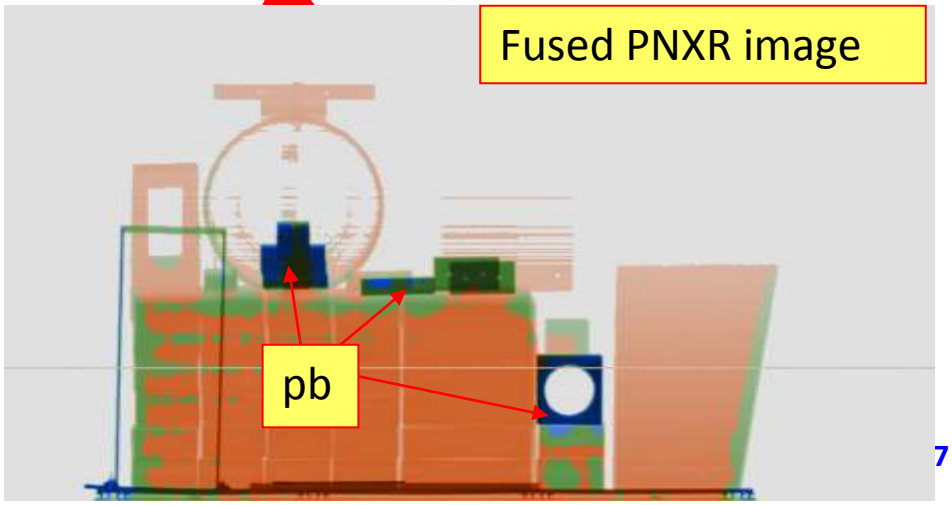
Photoneutron image



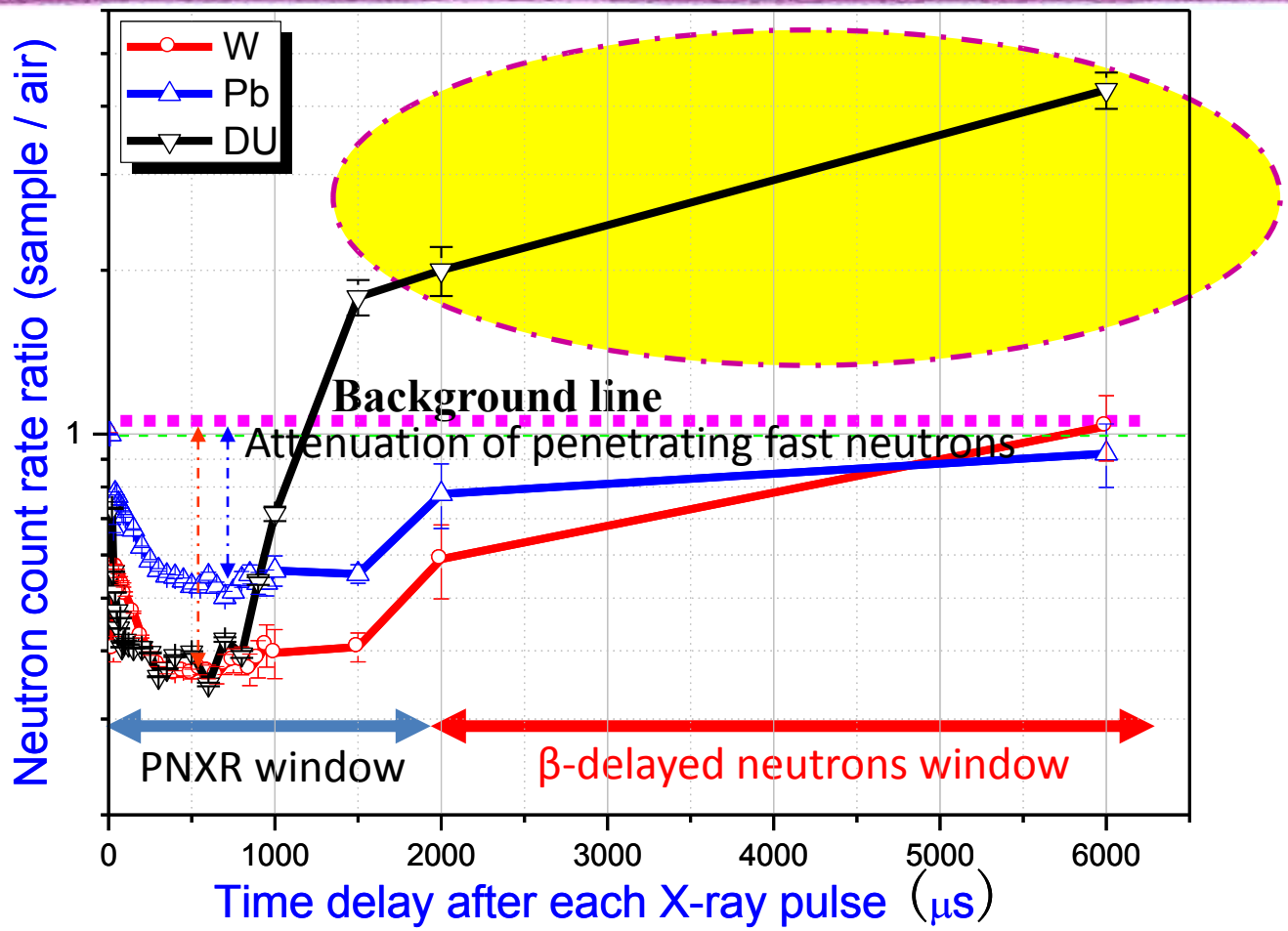
$$V(t) = \frac{\ln\left(\frac{I_n(t)}{I_n(0)}\right)}{\ln\left(\frac{I_X(t)}{I_X(0)}\right)} = \frac{\mu_n(t)\times t}{\mu_X(t)\times t} = \frac{\mu_n(t)}{\mu_X(t)} = \frac{\sigma_n(t)}{\sigma_X(t)}$$

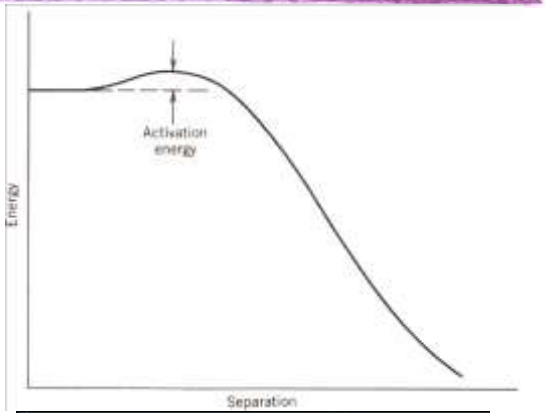


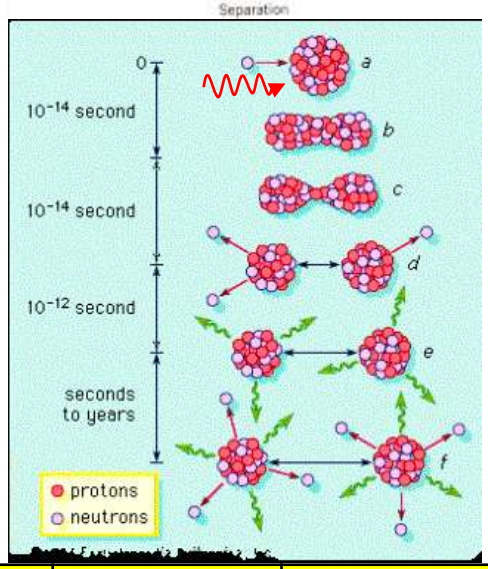
Fused PNXR image



Beta-delayed neutrons after the (γ,fission)





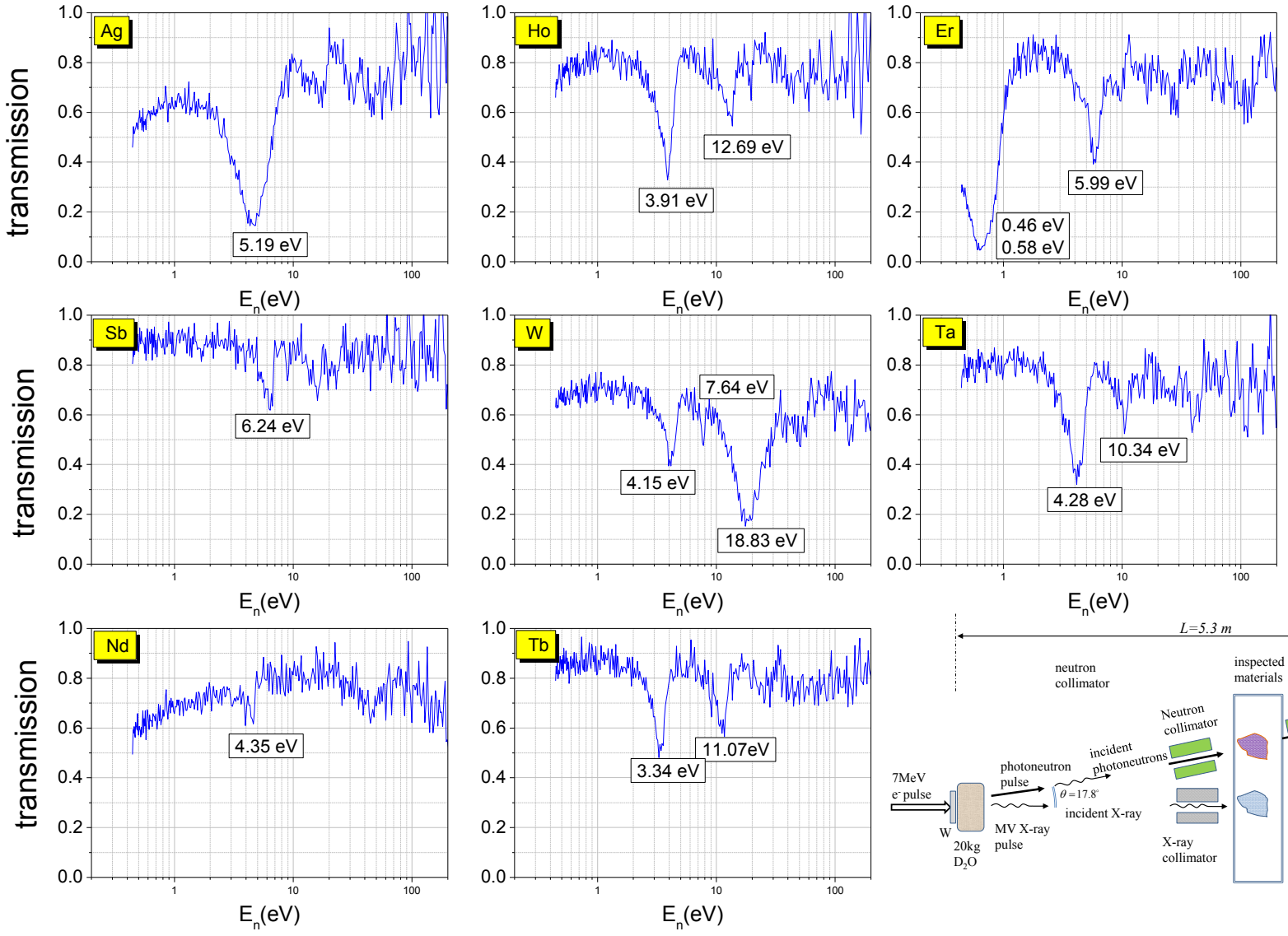


delayed neutrons of U^{235}

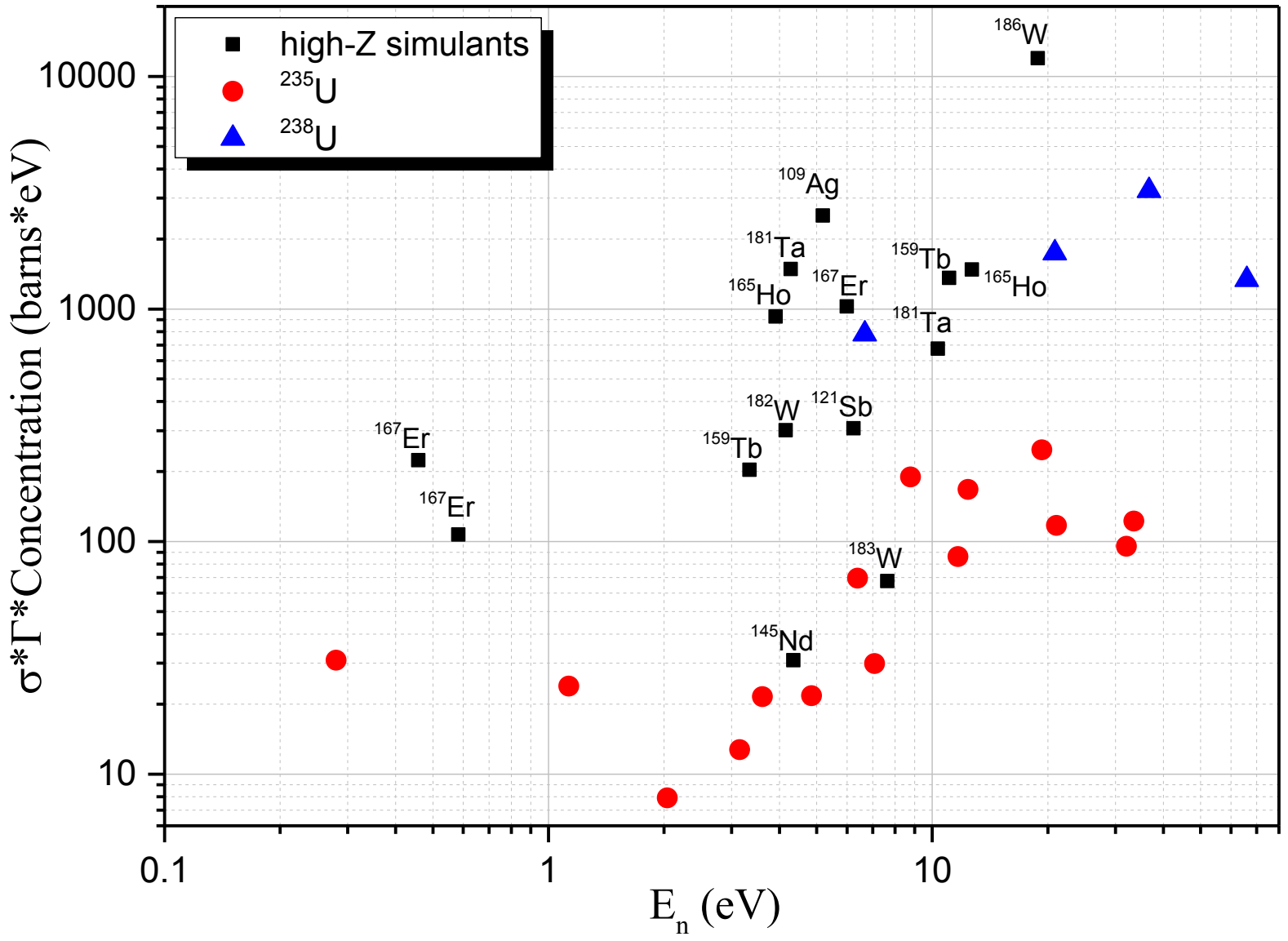
Group	1	2	3	4	5	6
$T_{1/2}$ (s)	55.72 ±1.28	22.72 ±0.71	6.22 ±0.23	2.30 ±0.09	0.610 ±0.083	0.230 ±0.025

W. H. Yigang Yang, Yuanjing Li, "*The integration of Photon and Neutron method for contrabands detection with a 7MeV Linac*," ***2011 IEEE Nuclear Science Symposium Conference Record***, p. 3, 2011.

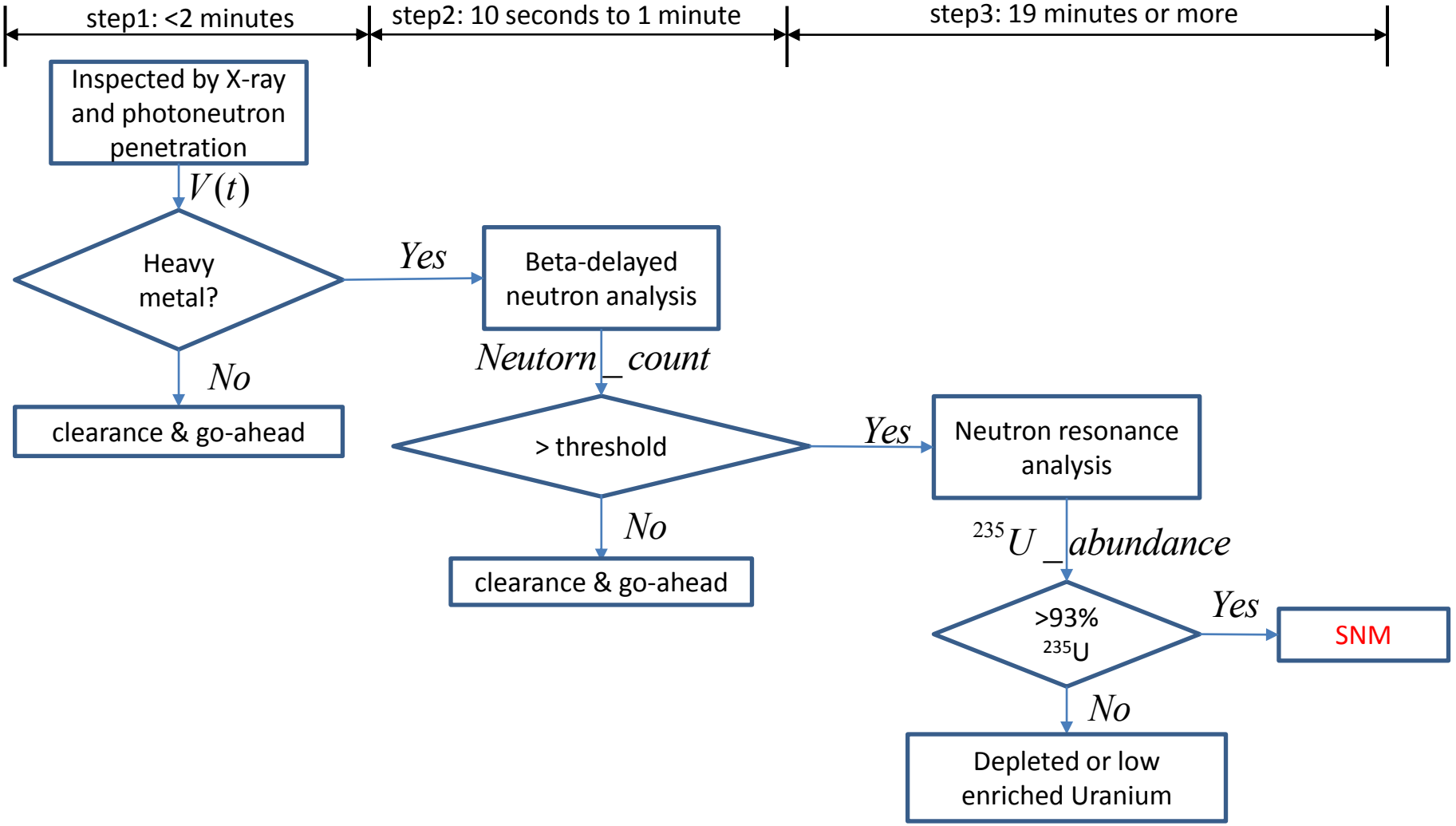
Isotopes identification through photoneutron resonant attenuation



Sensitivity & energy range



Steps for locating and identifying SNMs



Yigang Yang*， Zhi Zhang， Huaibi Chen， Yulan Li， Yuanjing Li. "*Identification of high-Z materials with photoneutrons driven by a low-energy electron linear accelerator*". ***IEEE Transactions on Nuclear Science***
Volume: 64, Issue: 7, July 2017, 1719 - 1724

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① High-Z materials detection with photons

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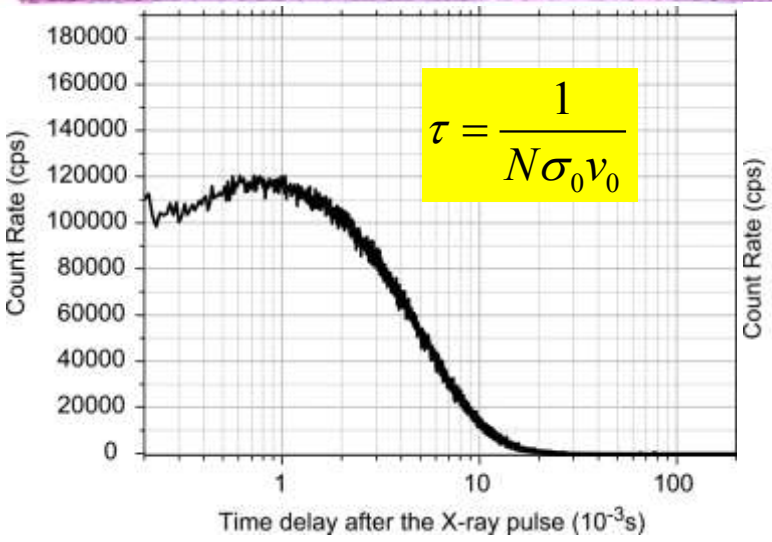
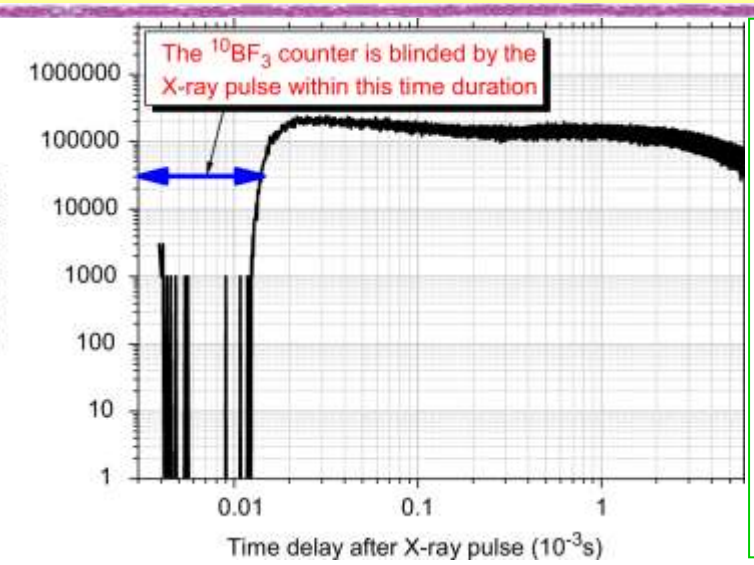
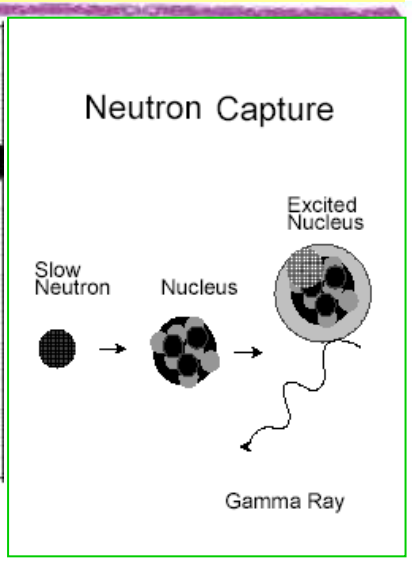
3. Summary

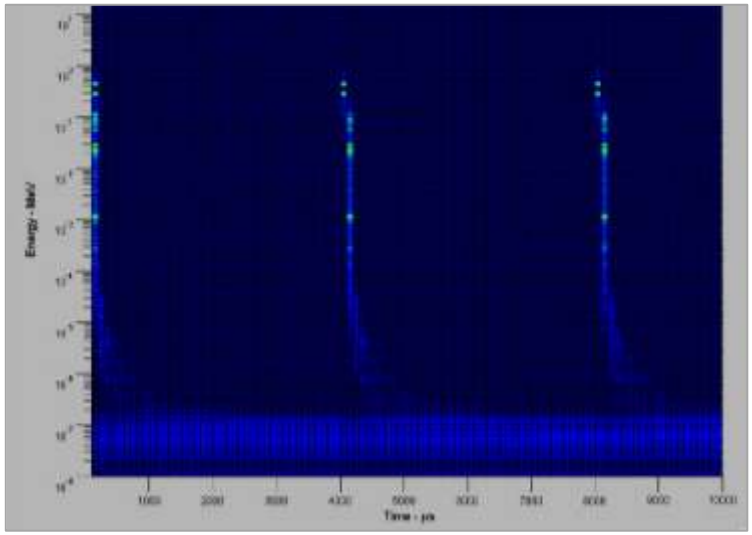
(n, γ) analysis for explosives or drugs

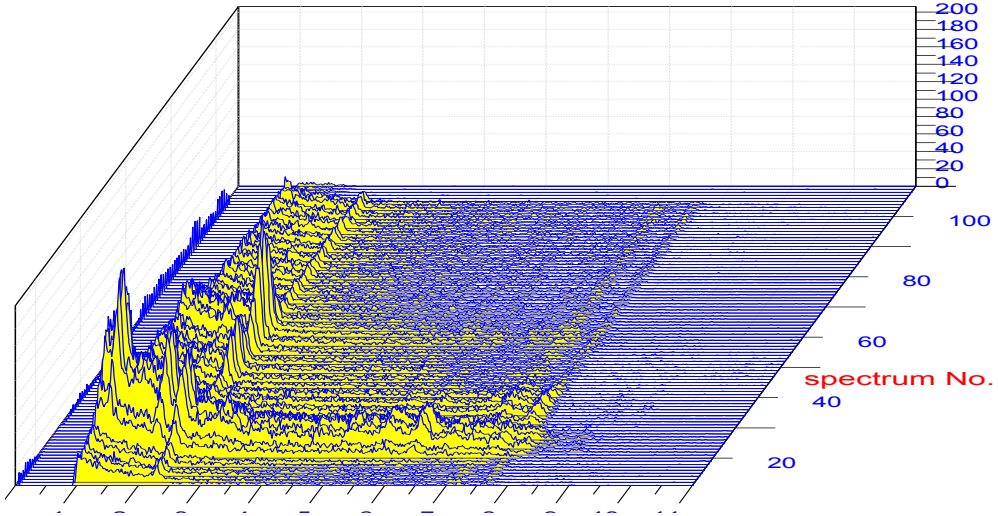


$$\tau = \frac{1}{N\sigma_0 v_0}$$



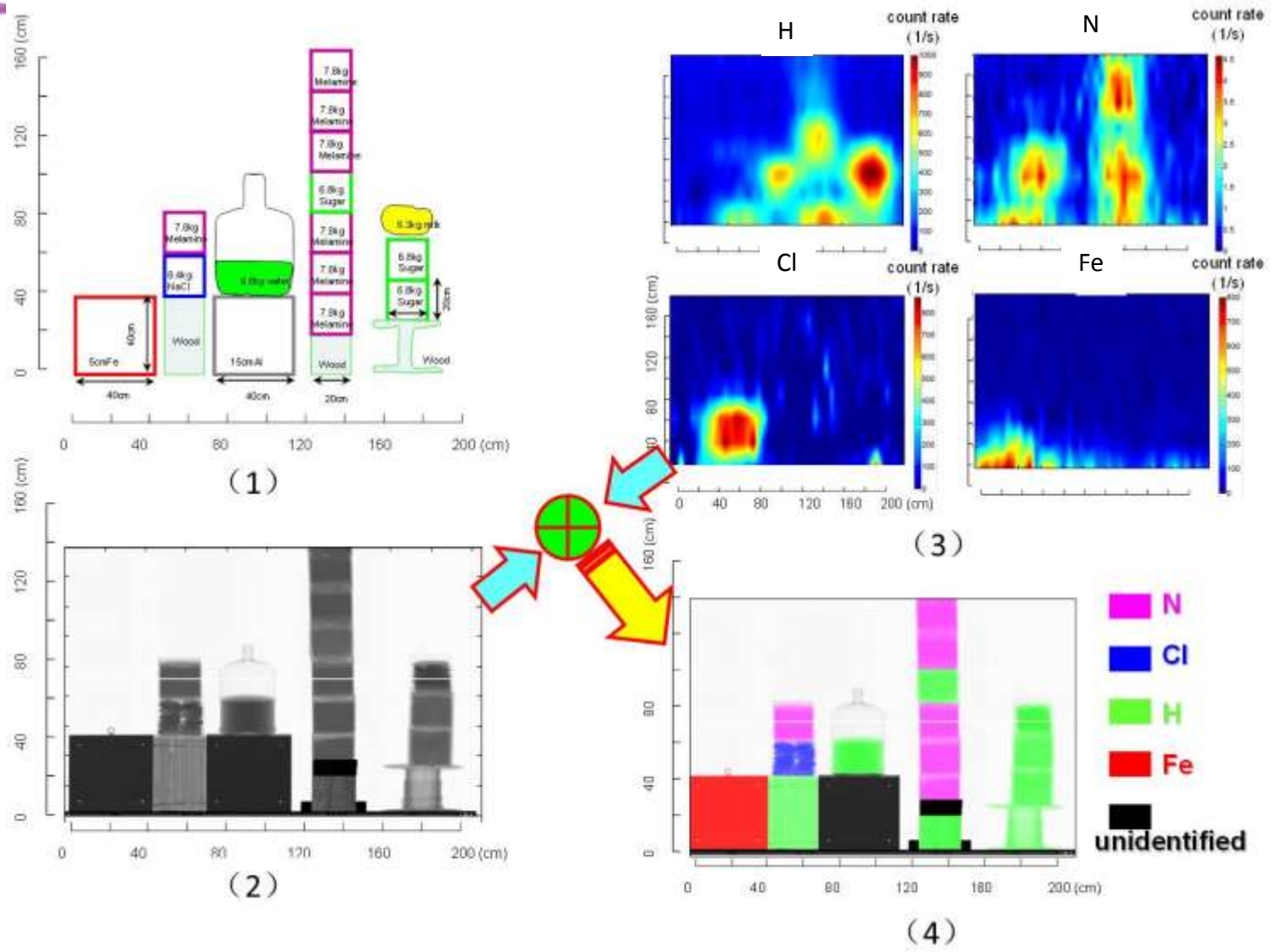






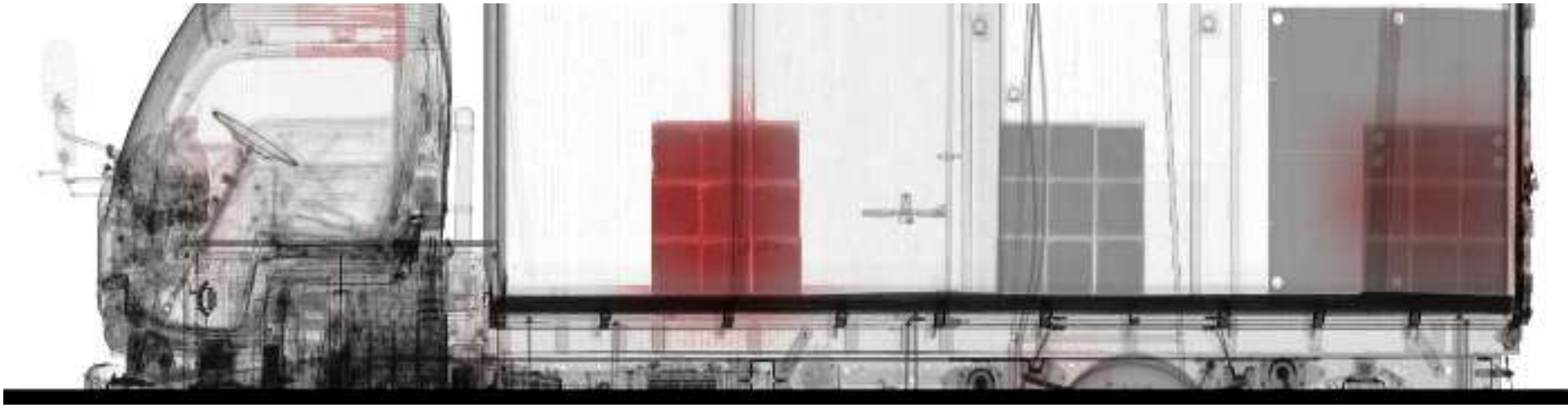
Y. Yigang, L. Yuanjing, W. Haidong, L. Tiezhu, and W. Bin, "*Explosives detection using photoneutrons produced by X-rays*," ***Nuclear Inst. and Methods in Physics Research, A,*** vol. 579 (2007), pp. 400-403

Fusion of X-ray image and elemental concentration distribution



Yigang Yang, Jianbo Yang and Yuanjing Li, "*Fusion of X-ray Imaging and Photoneutron Induced Gamma Analysis for Contrabands Detection*," ***IEEE TRANSACTIONS ON NUCLEAR SCIENCE***, vol. 60, p. 6, 2013.

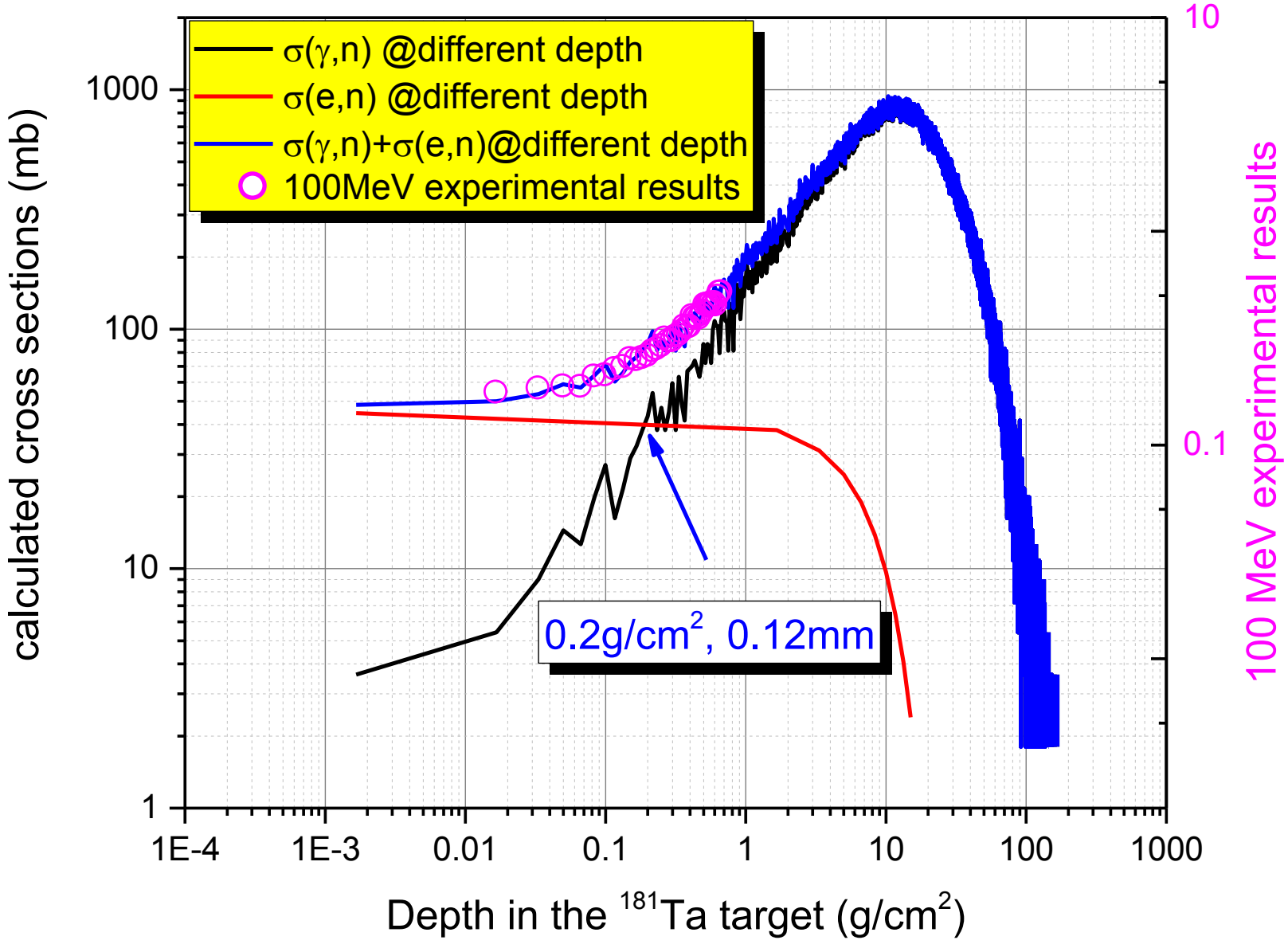
Drugs or explosives detection system



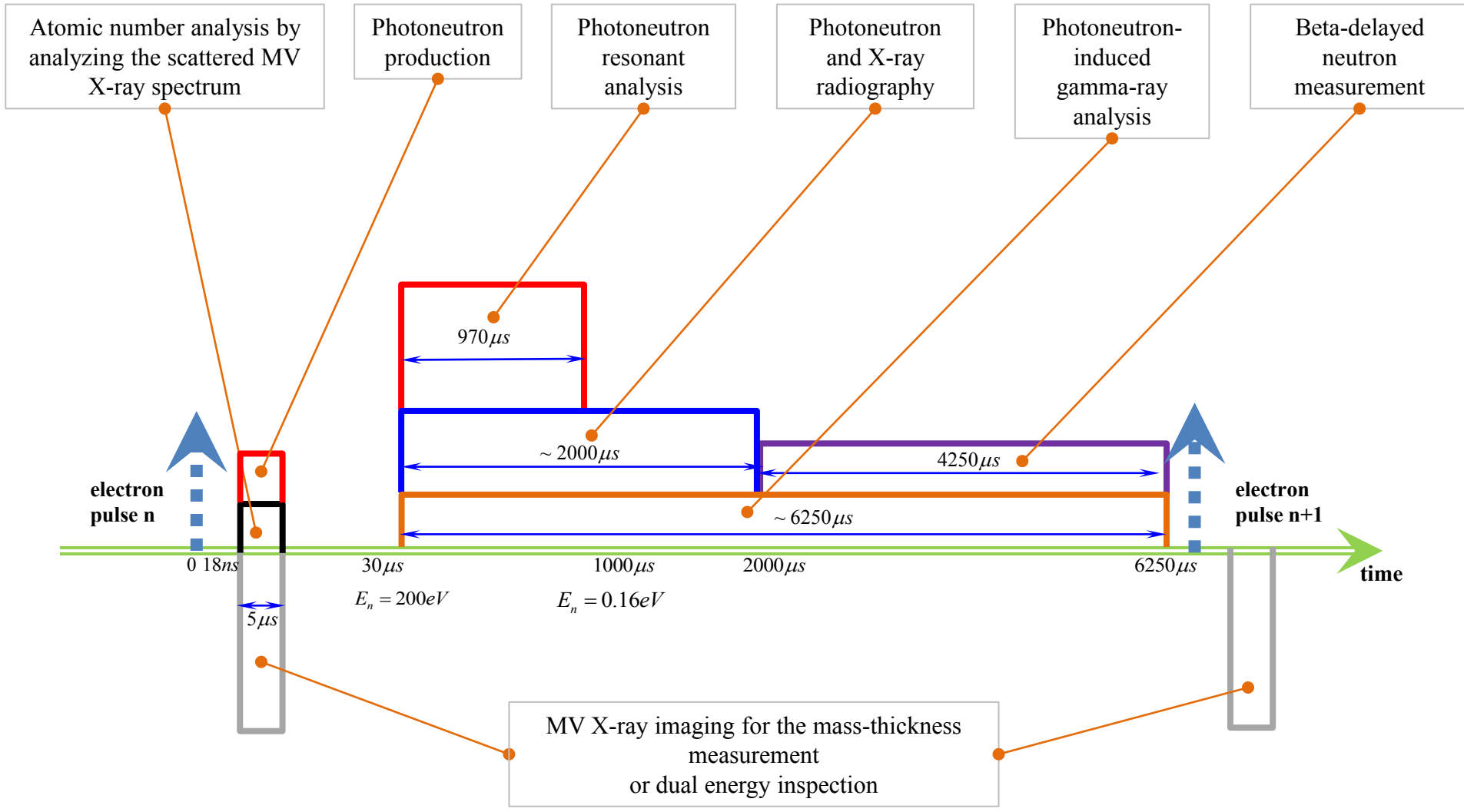
3.Summary

- An e-LINAC can produce both X-rays and photoneutrons simultaneously.
- Properties of the photoneutron source:
  - **High neutron yield**
  - **Long life-span & Robustness**
  - **Relocatable** and suitable for the **field use**
  - **Pulsed mode**, enabling the energy selective methods
- The philosophy of "**one-source, two-radiation, multi-physics**" can be supported by the e-LINAC driven photoneutron source to enhance the contrabands detection capability.
- Coulomb excitation of high energy electrons may result in interesting interactions and should be investigated.

100MeV e- *vs* ^{181}Ta



“one-source, two-radiation, multi-physics” for the contrabands detection



Thanks for your attention

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Questions please