



The photon and neutron interrogation methods for contrabands realized with an e-linac

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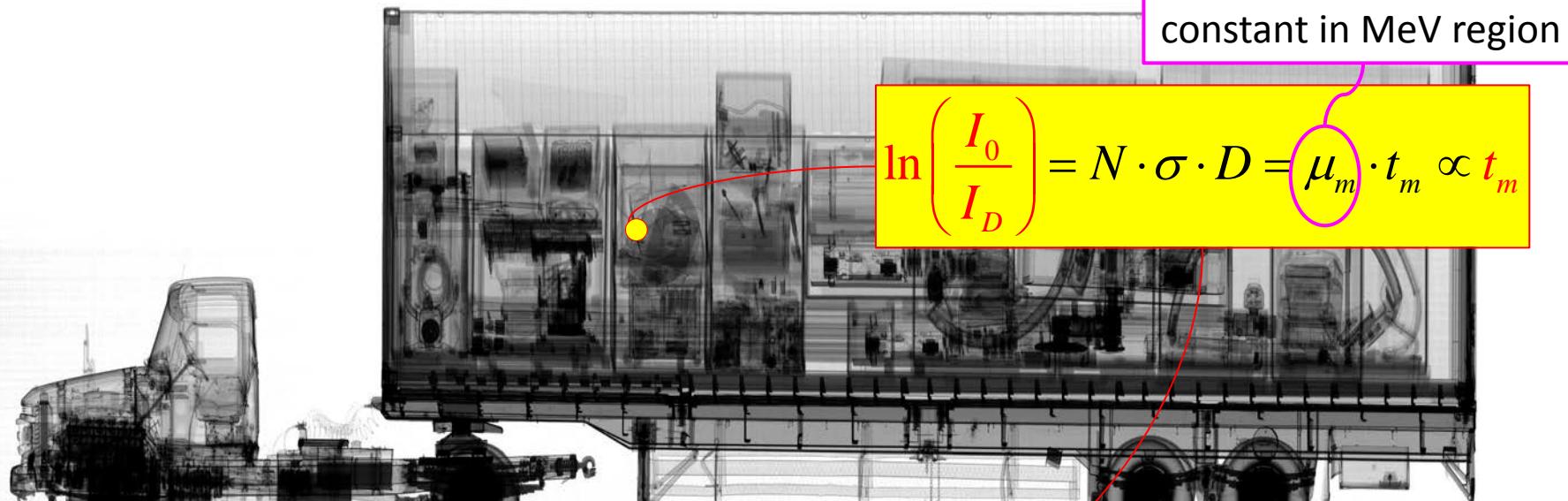
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August 1 2017, Quebec

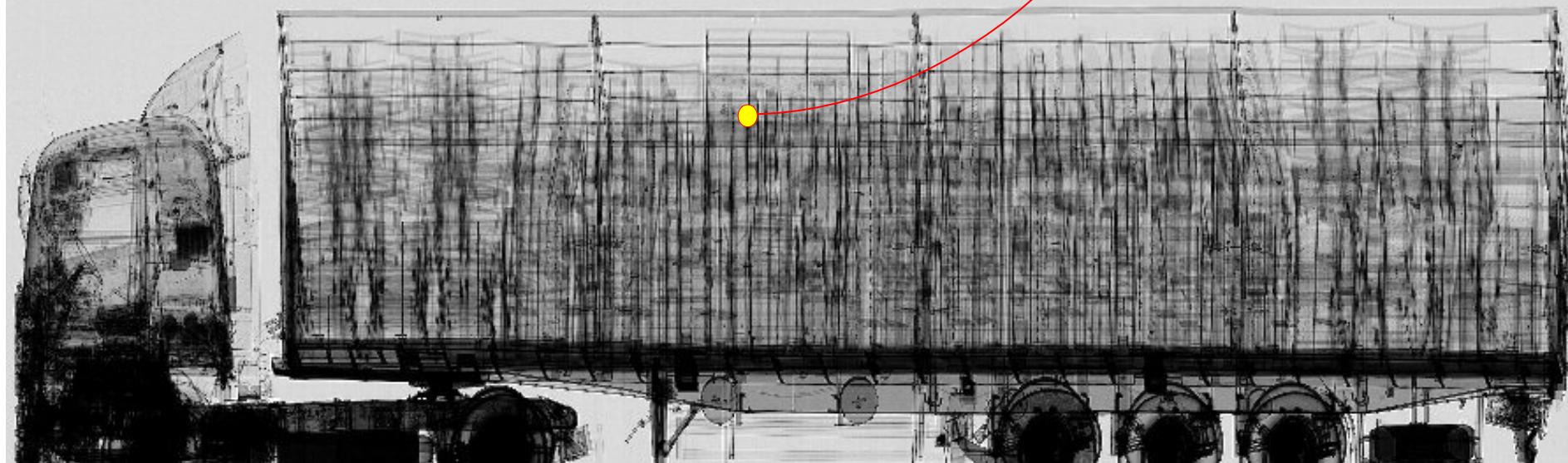
Outline

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

MV X-ray images



constant in MeV region



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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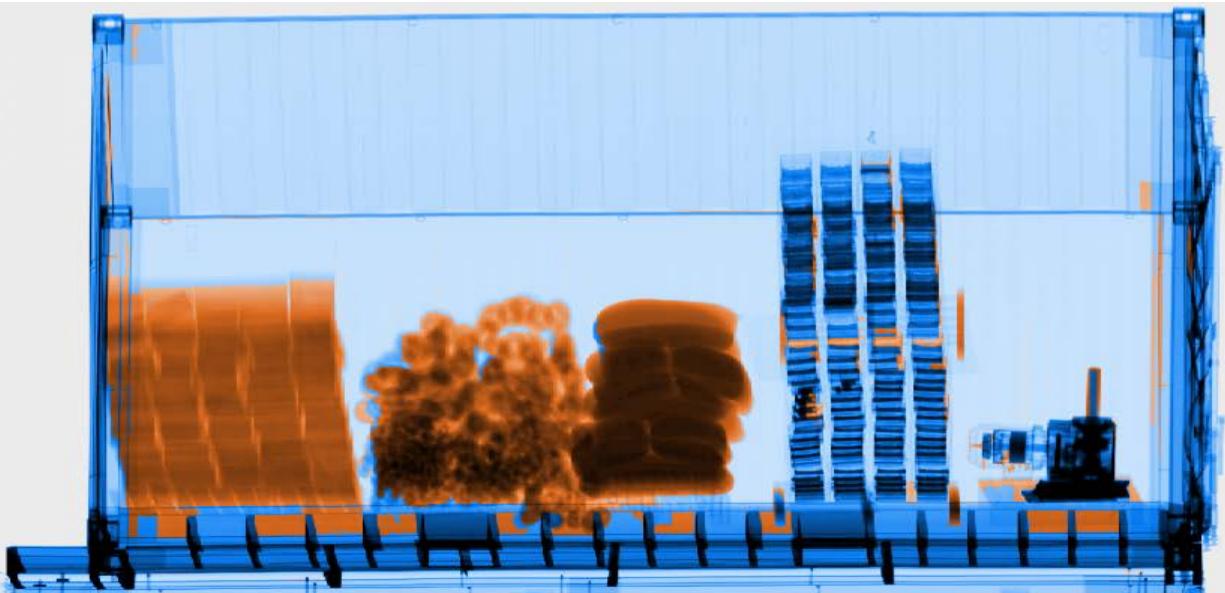
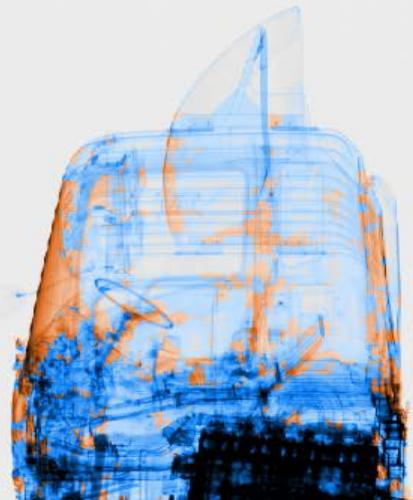
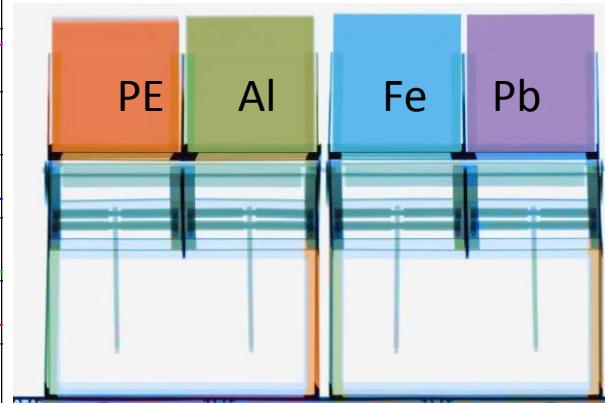
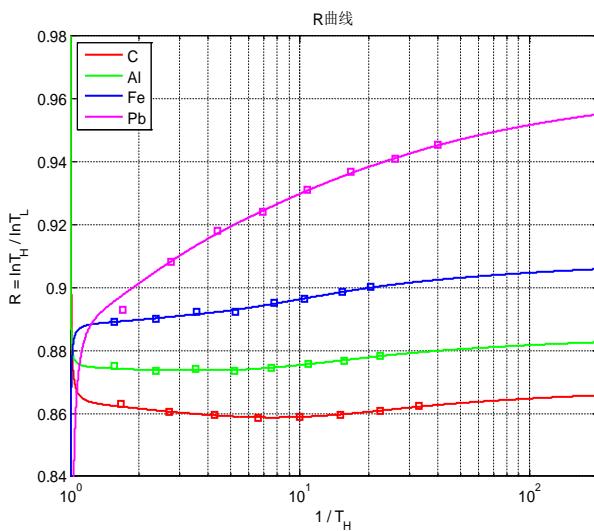
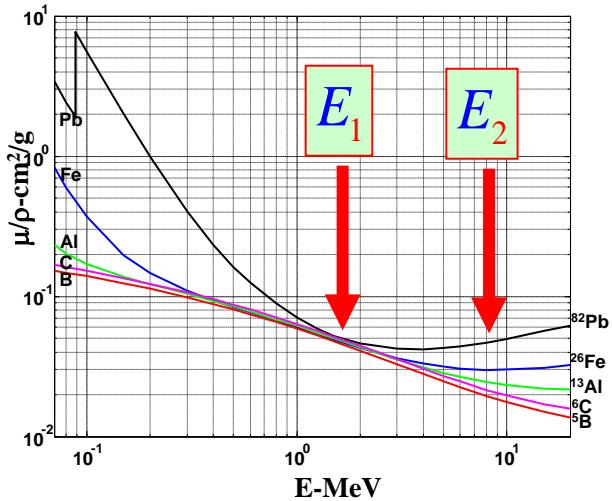
① High-Z materials detection with photons

② High-Z materials detection with photoneutrons

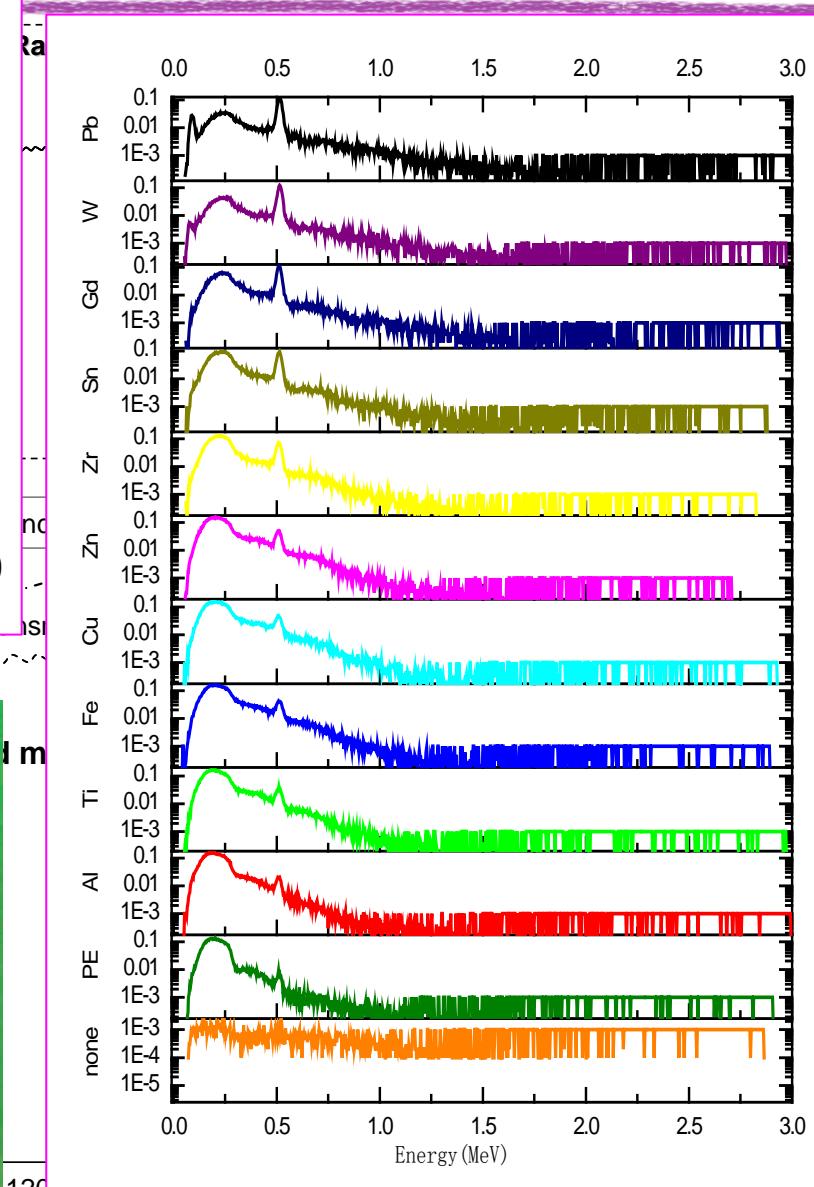
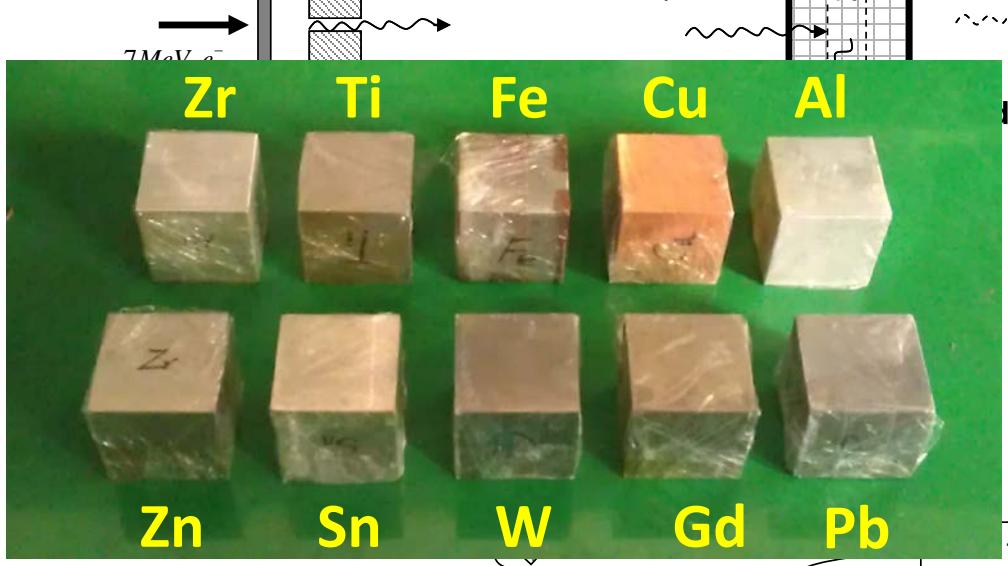
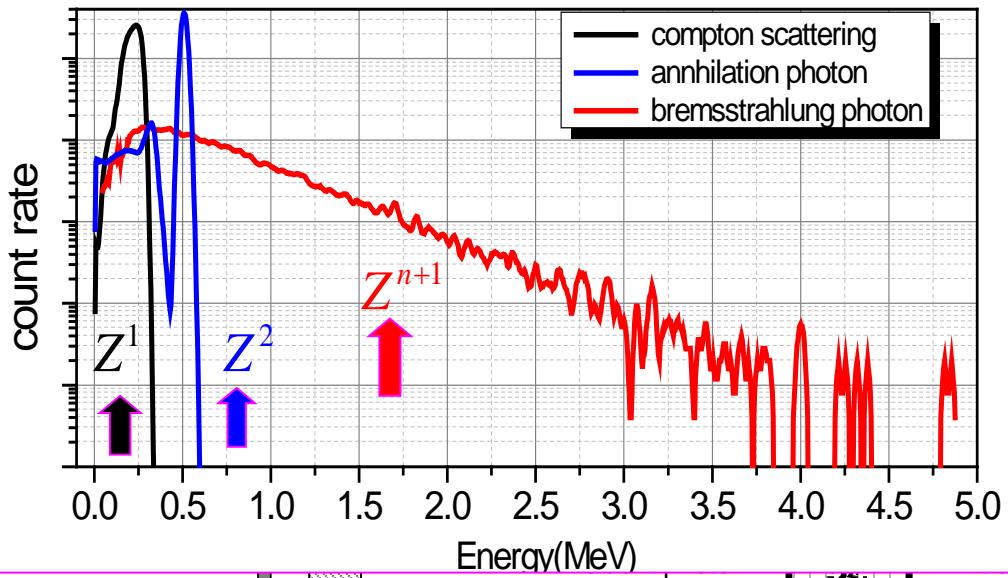
③ Explosives or Drugs detection

3. Summary

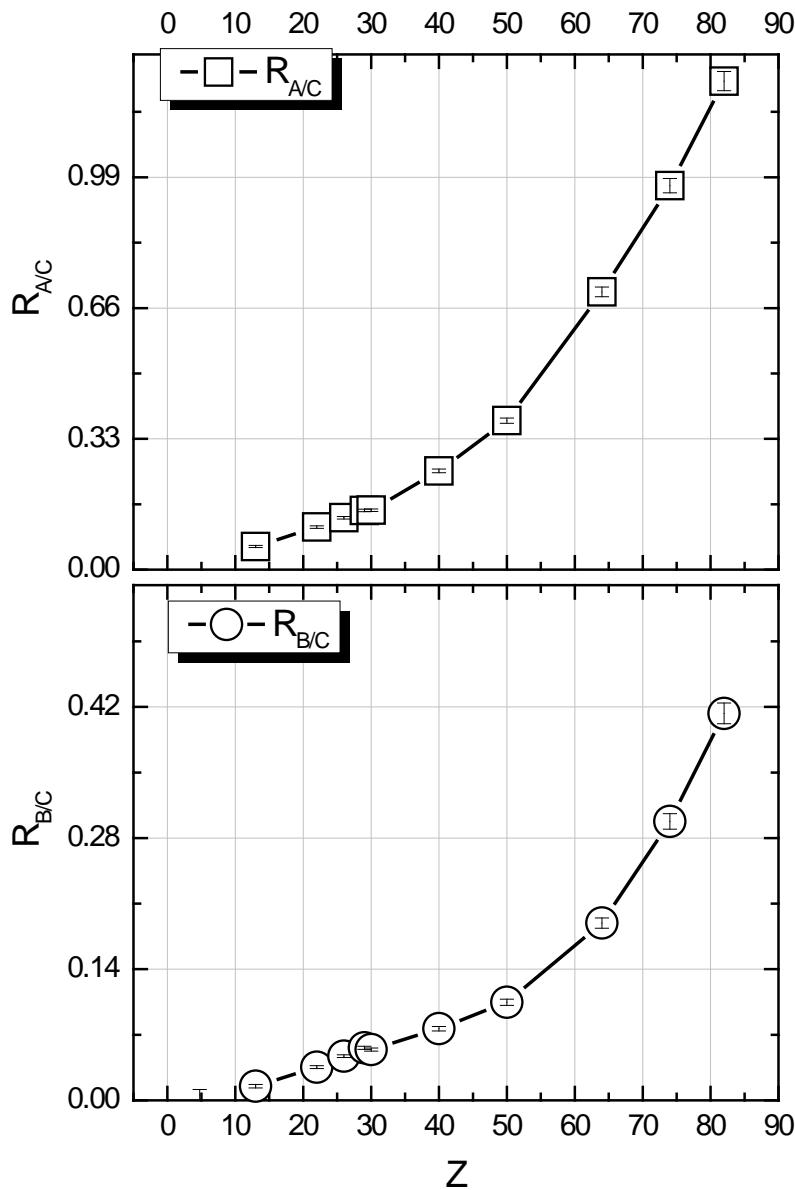
Dual-energy X-ray imaging



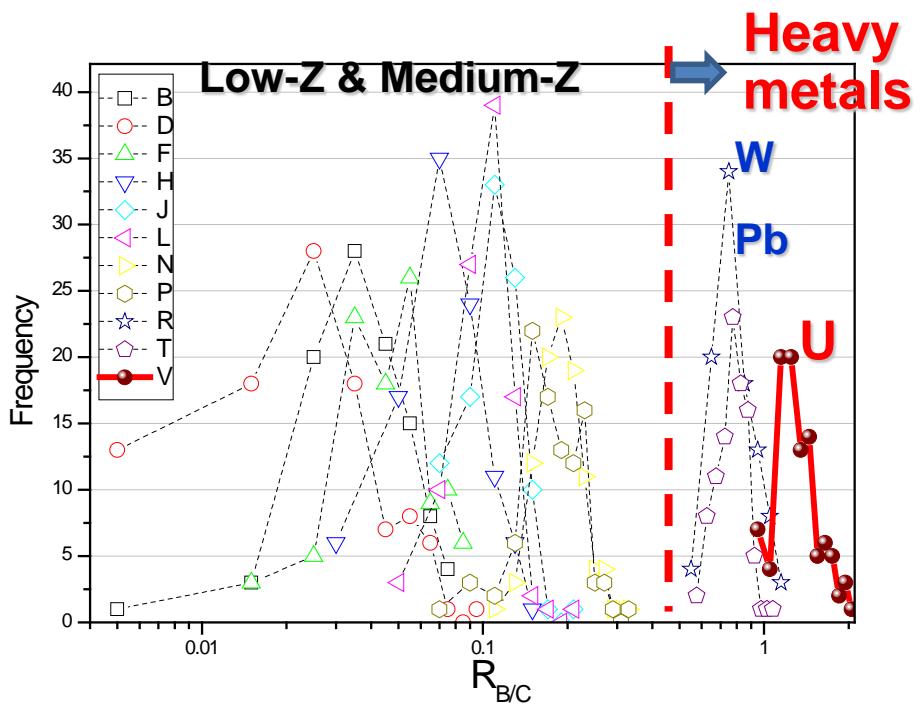
Scattering X-ray analysis



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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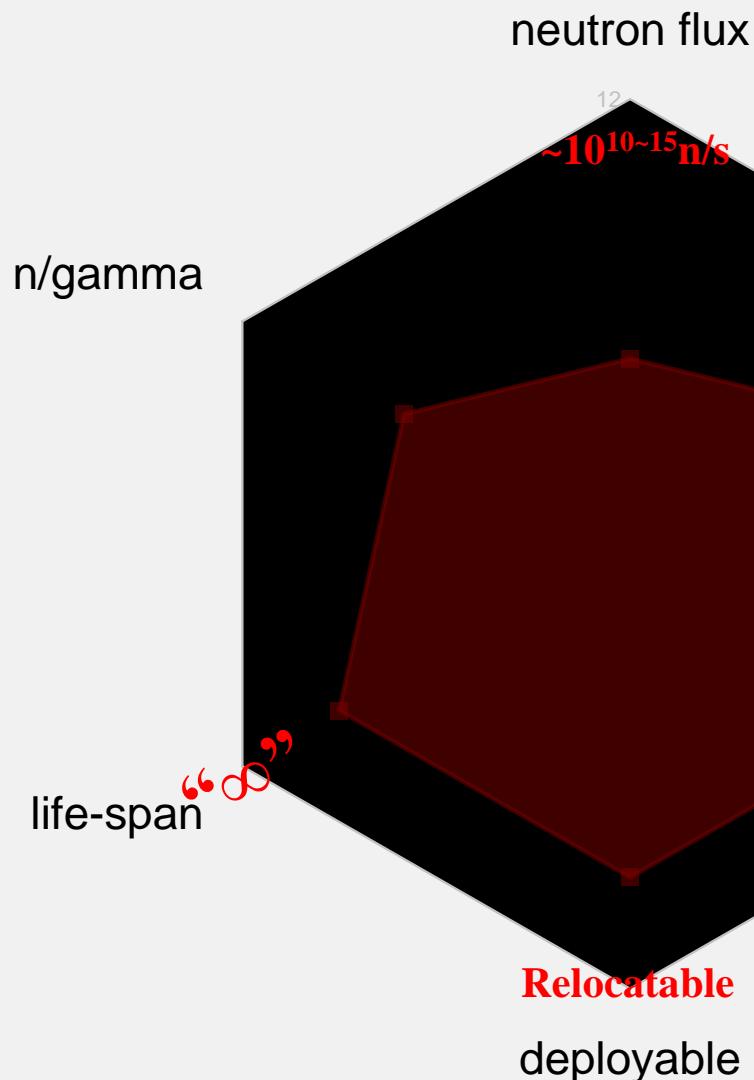
③ Explosives or Drugs detection

3. Summary

Fermion and neutral particle

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

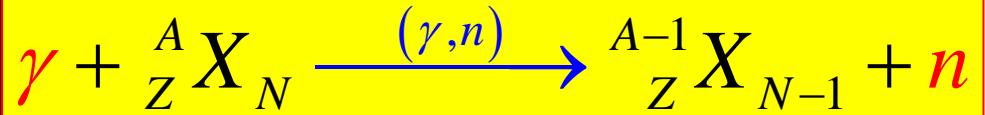
Why e-linac driven neutron source?



Photoneutron source

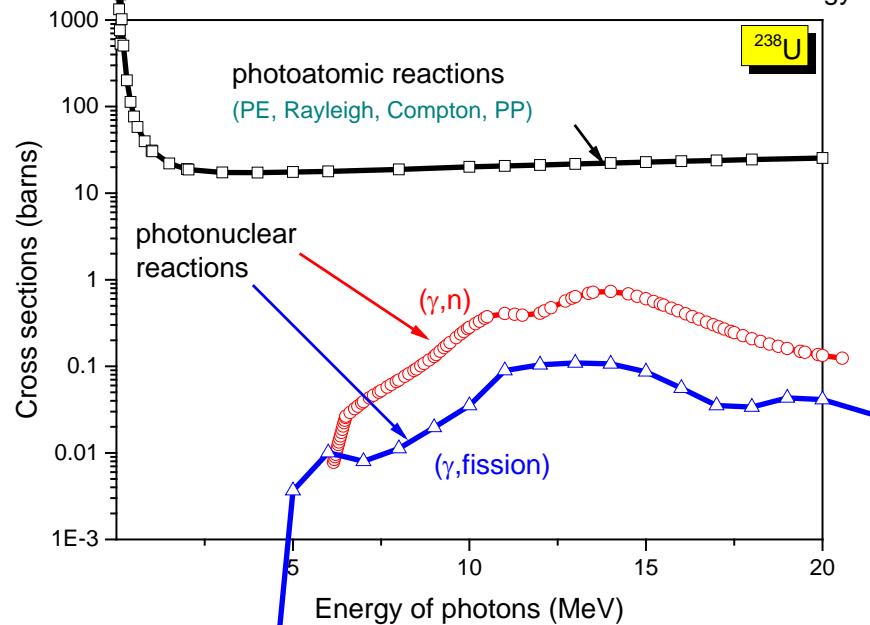
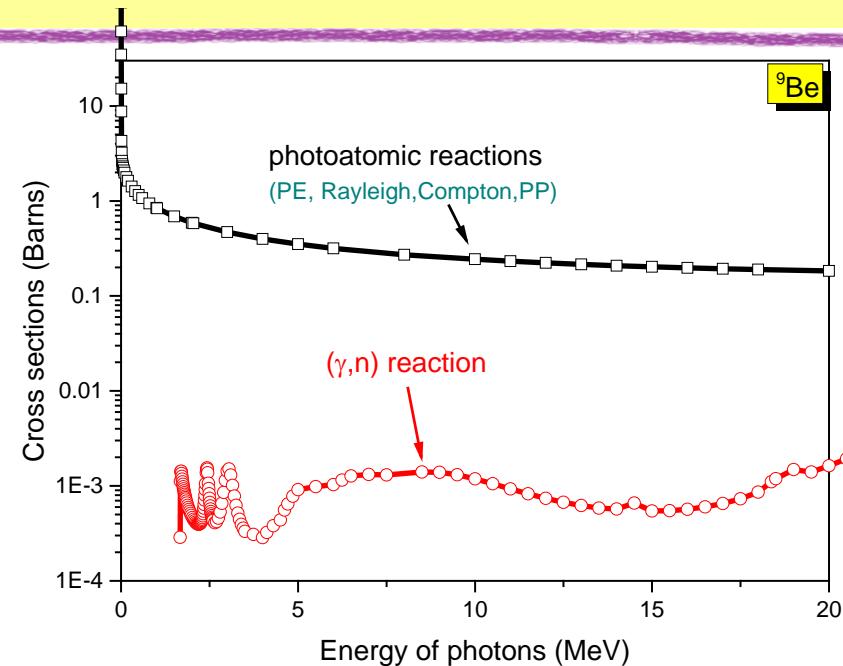
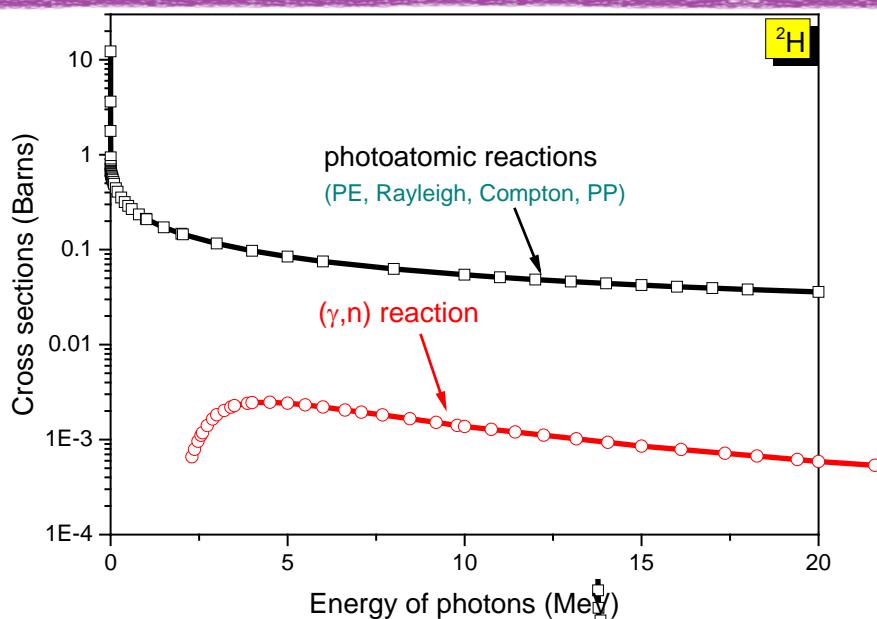
generator

fixed cost



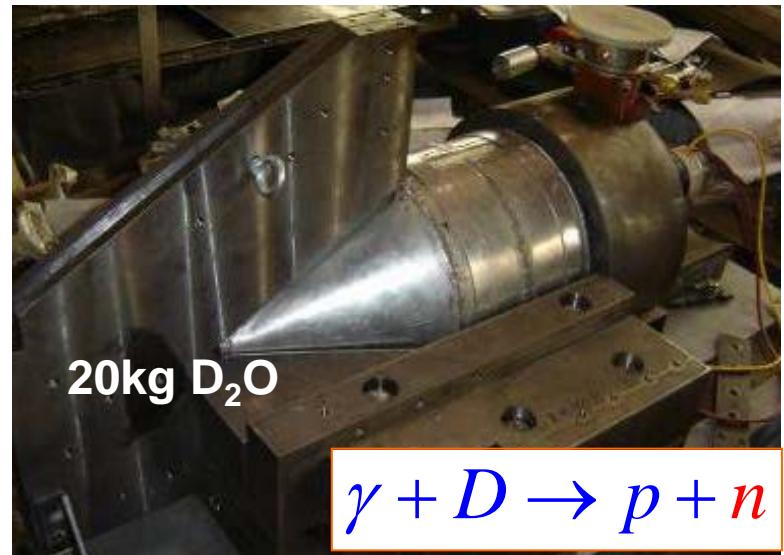
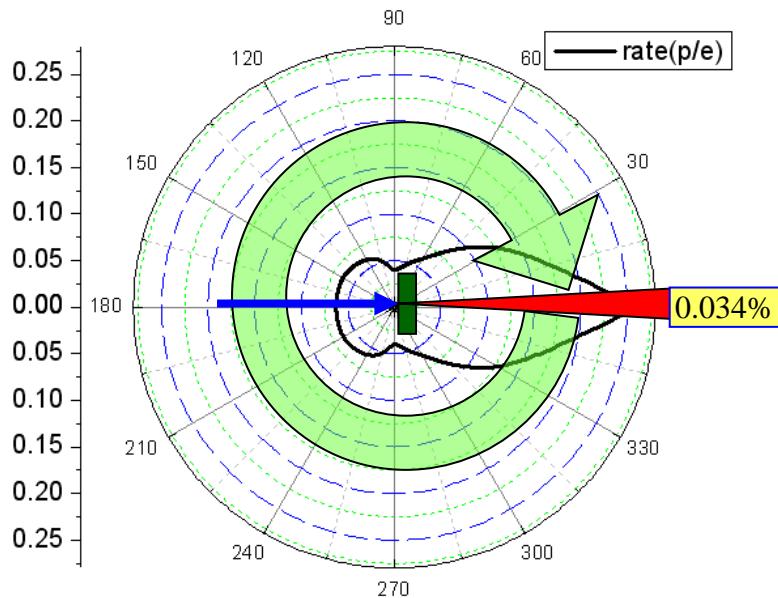
Low operation cost

photoatomic or photonuclear reactions

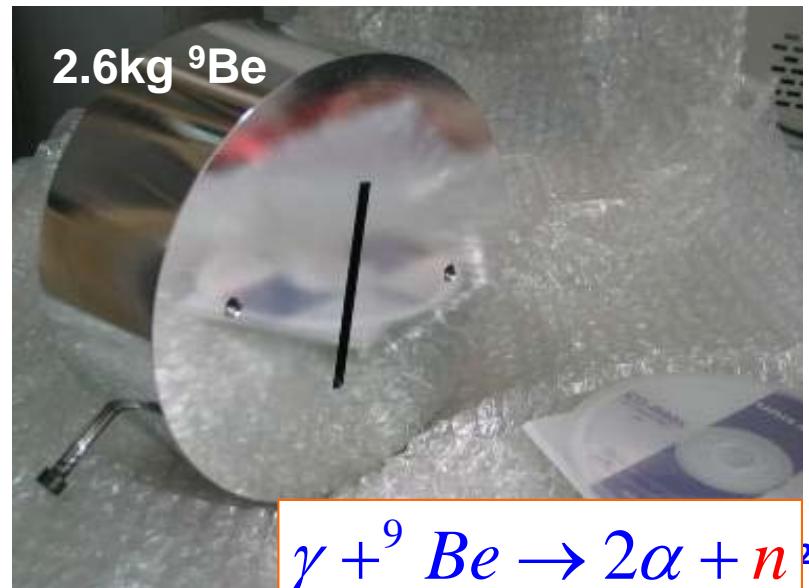


Photons → Neutrons

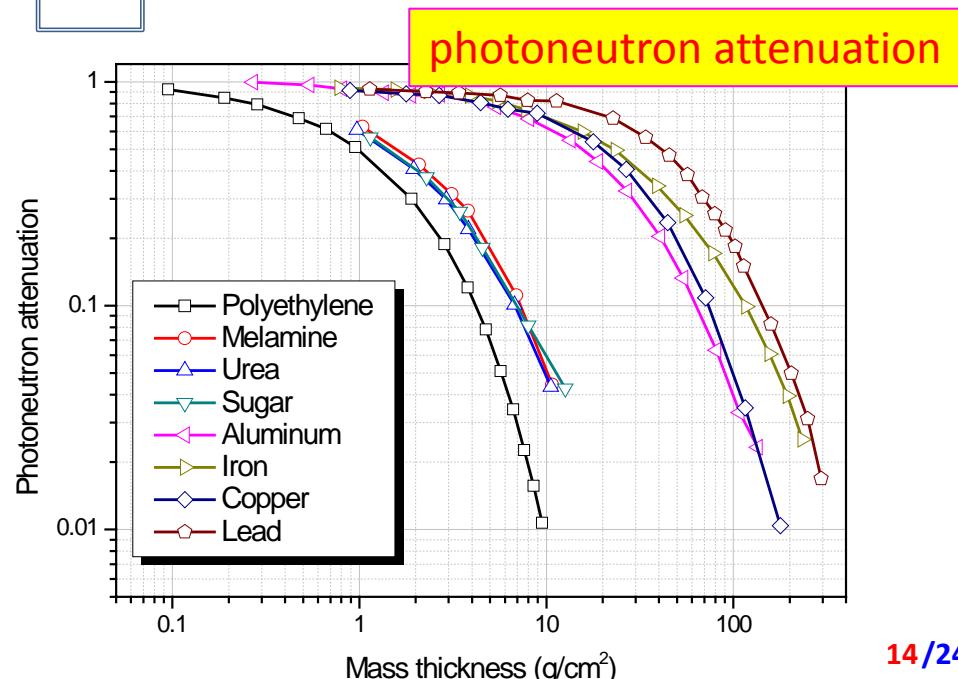
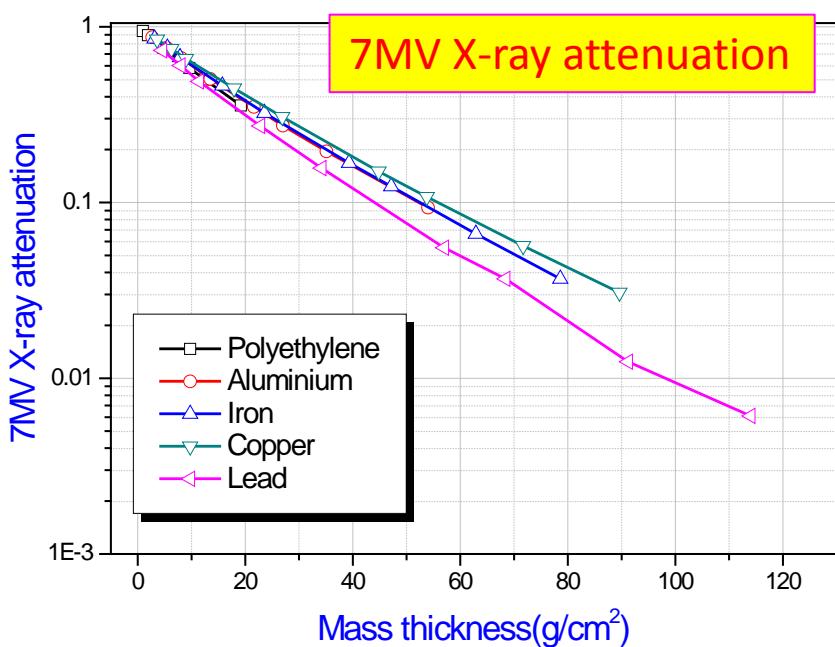
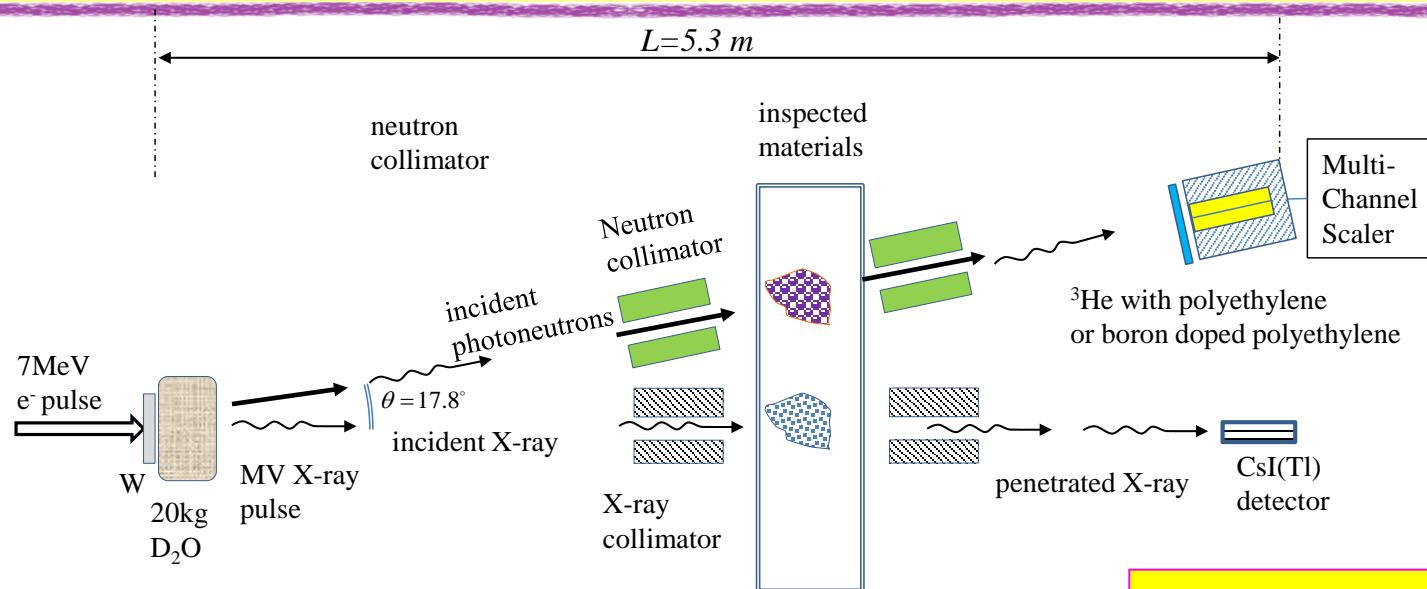
Angular distribution of X-ray



- Photoneutron yield
 - 7MeV/100W : **10¹⁰n/s**
 - 10MeV/20kW : **6.7×10¹²n/s**

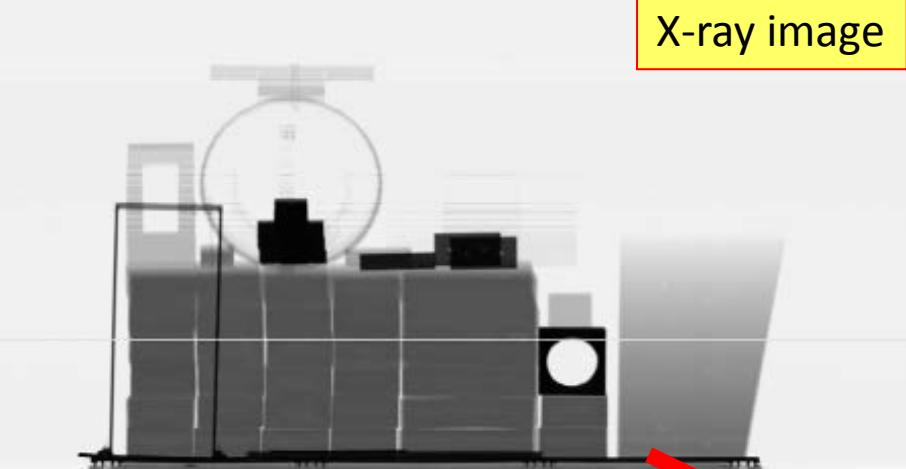


PhotoNeutron X-ray Radiography (PNXR)

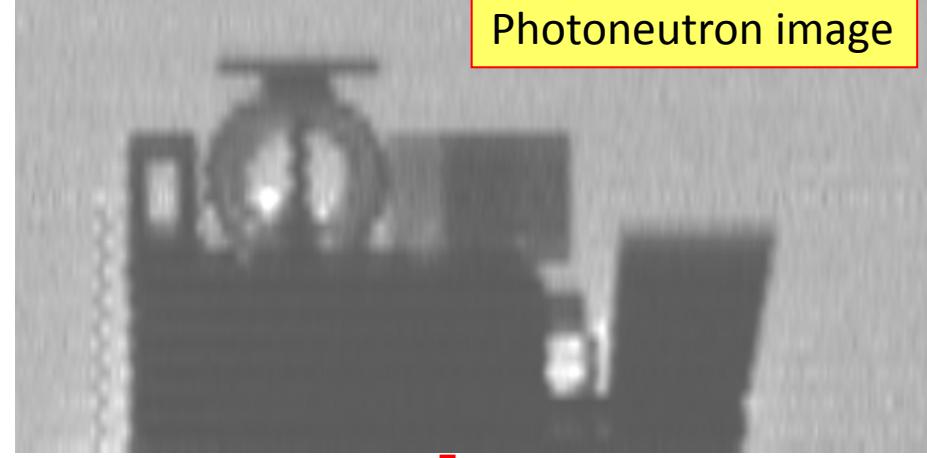


Fused X-ray image and Photoneutron image

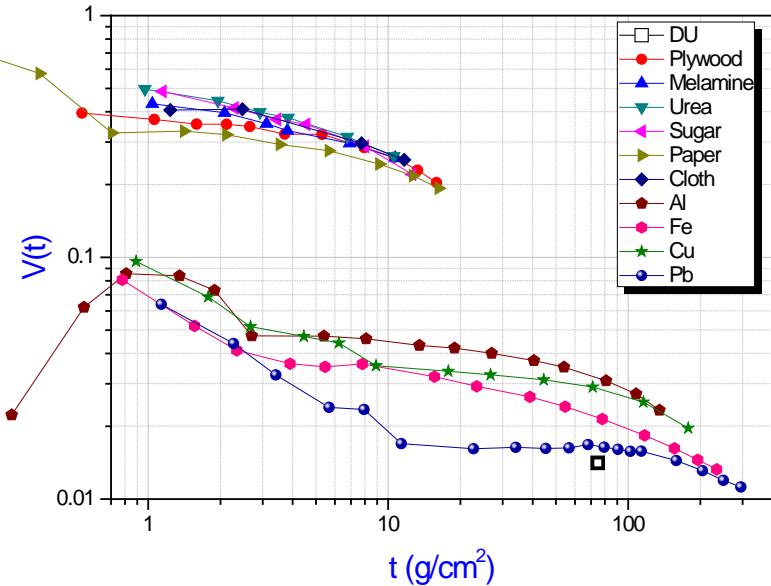
X-ray image



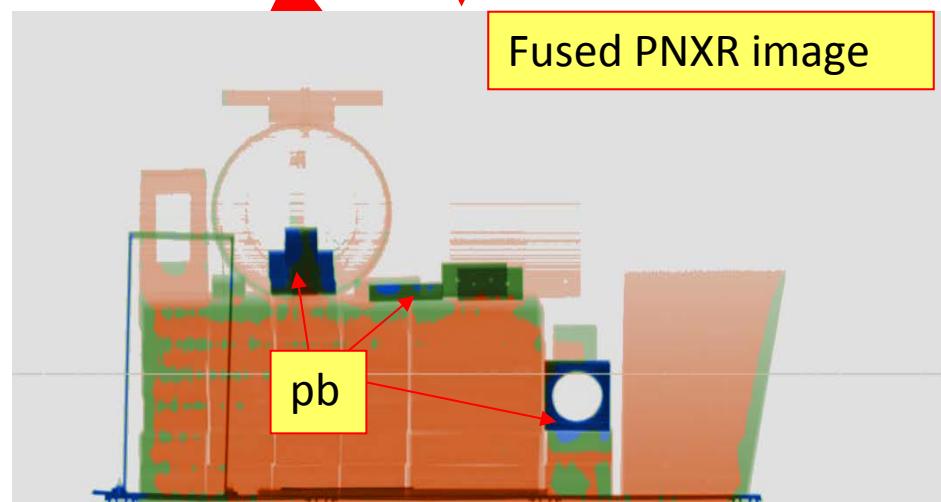
Photoneutron image



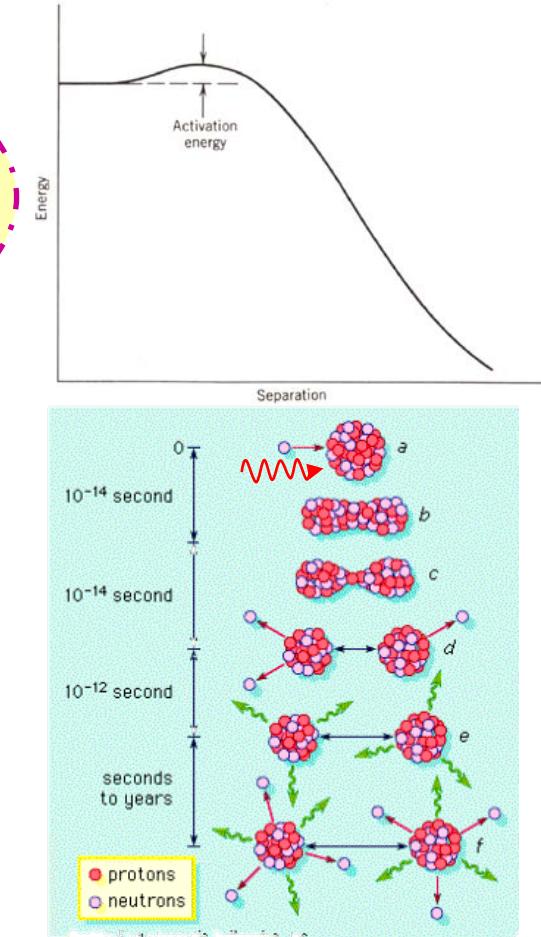
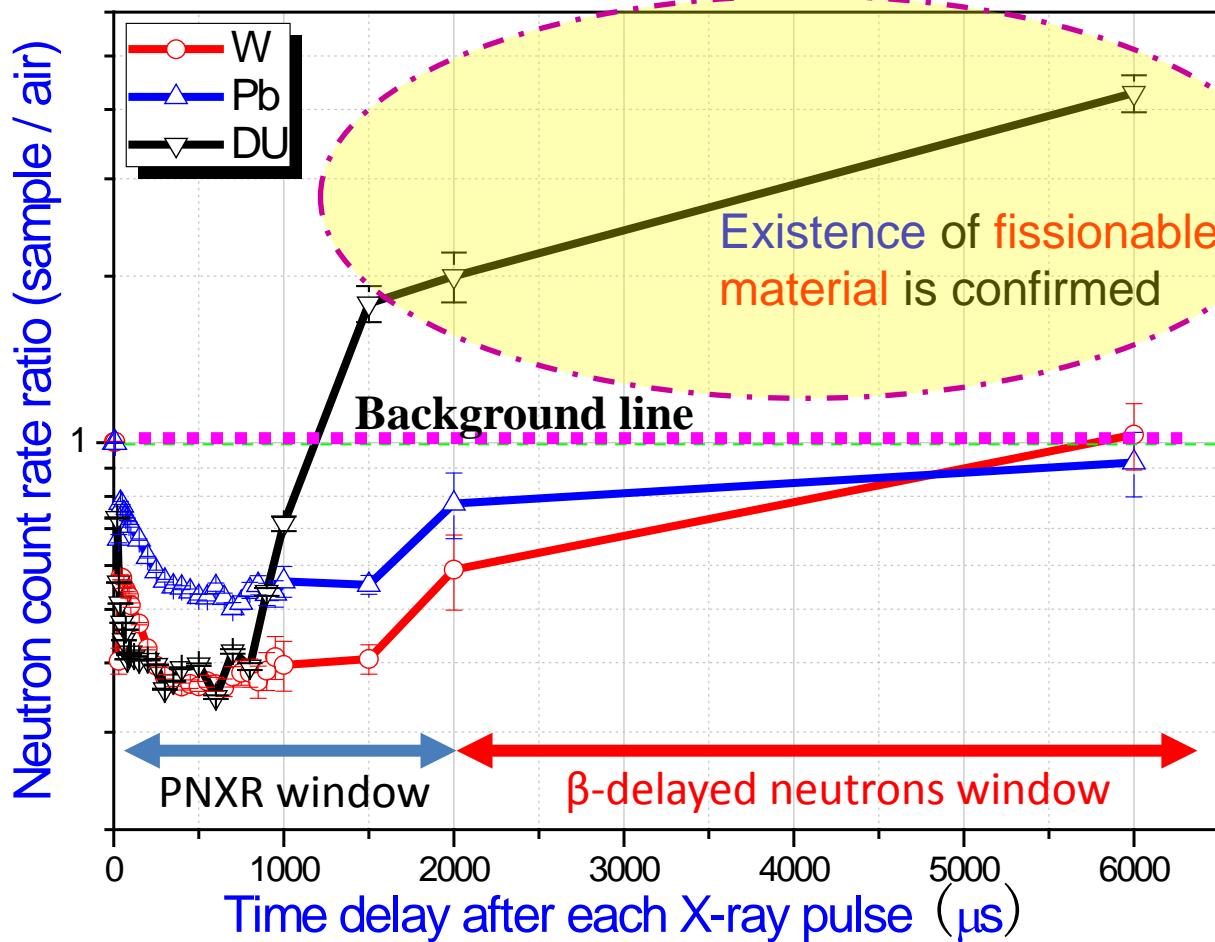
$$V(t) = \frac{\ln(\frac{I_n(t)}{I_n(0)})}{\ln(\frac{I_X(t)}{I_X(0)})} = \frac{\mu_n(t) \times t}{\mu_X(t) \times t} = \frac{\mu_n(t)}{\mu_X(t)} = \frac{\sigma_n(t)}{\sigma_X(t)}$$



Fused PNXR image



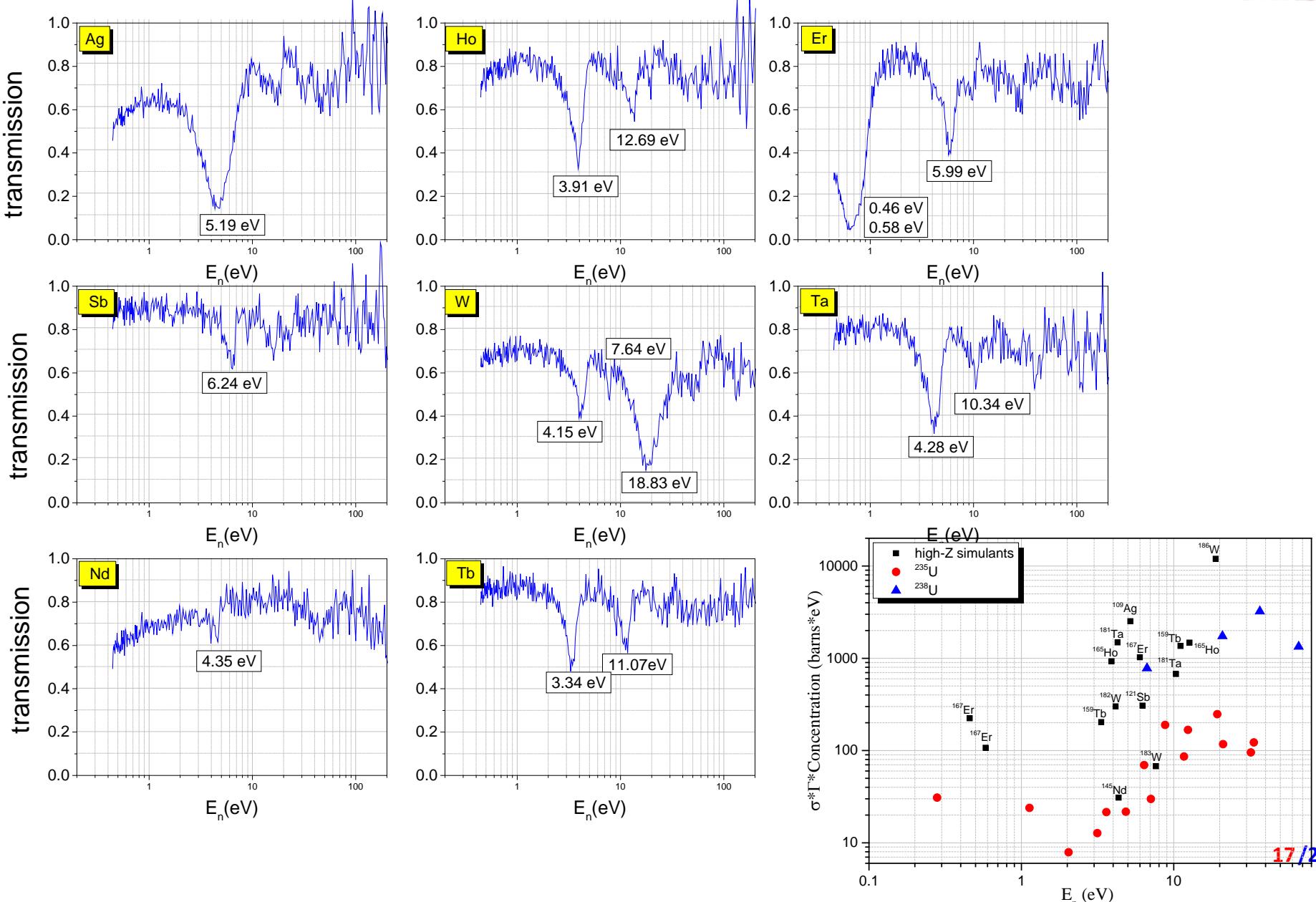
Beta-delayed neutrons after the (γ ,fission)



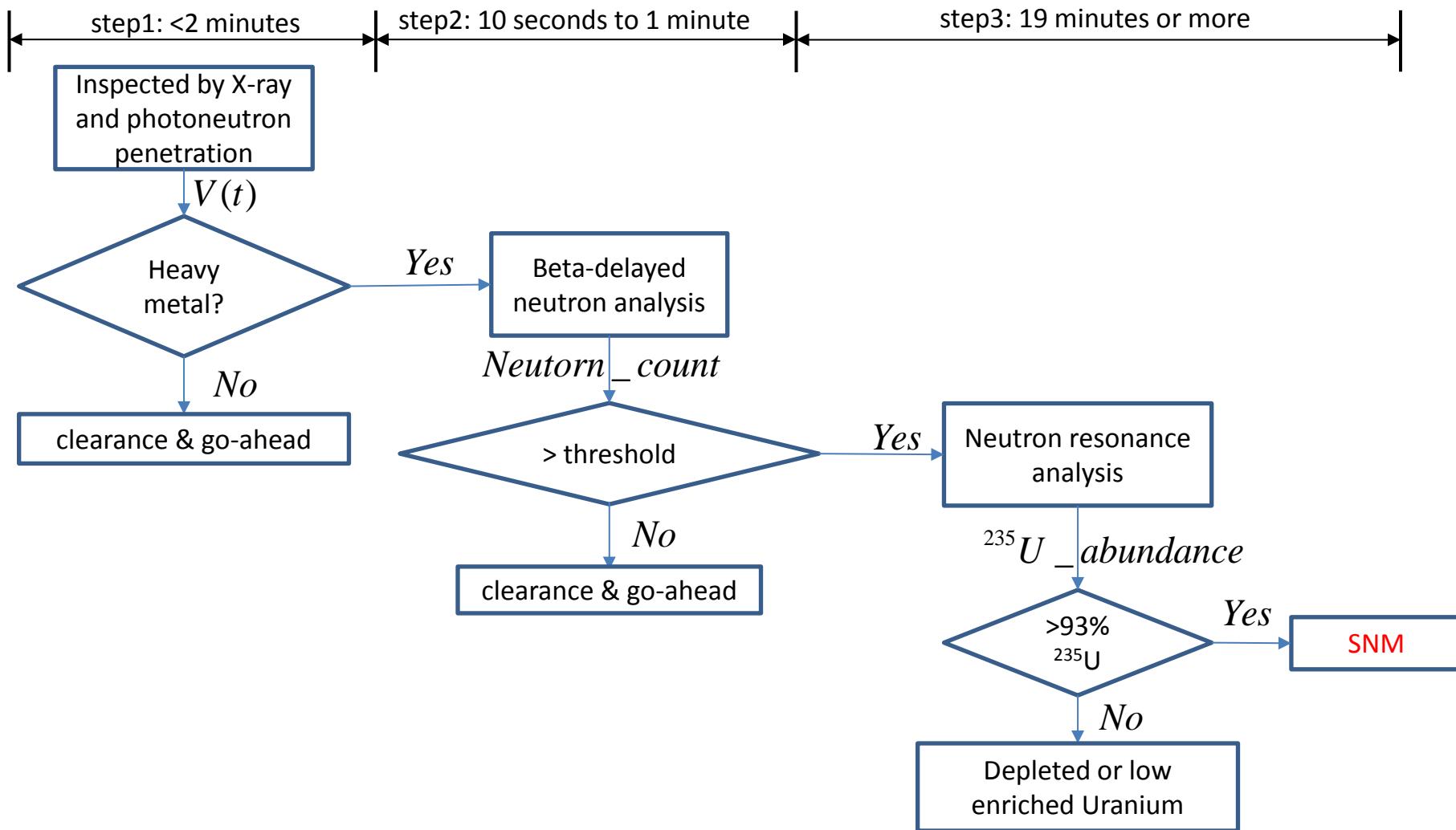
delayed
neutrons of
 U^{235}

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

Isotopes identification through photoneutron resonant attenuation



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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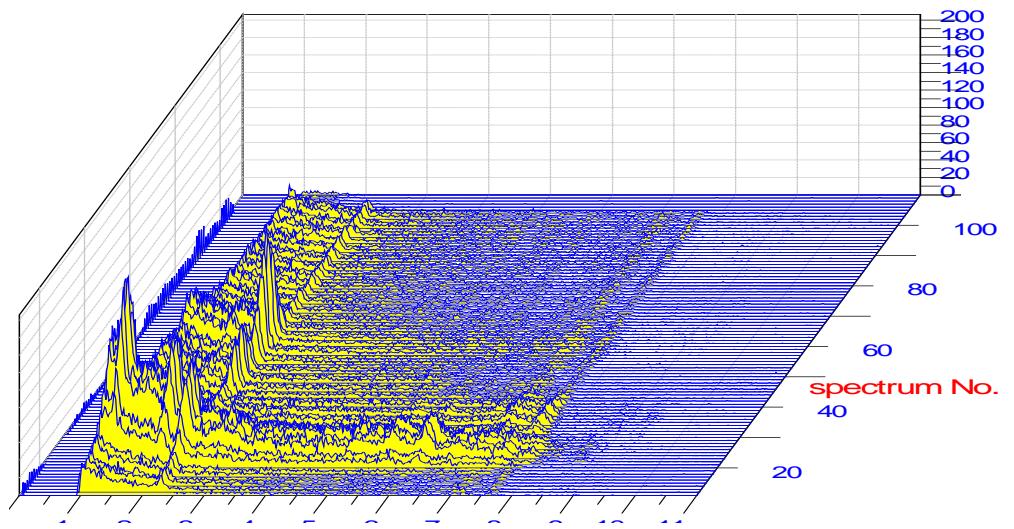
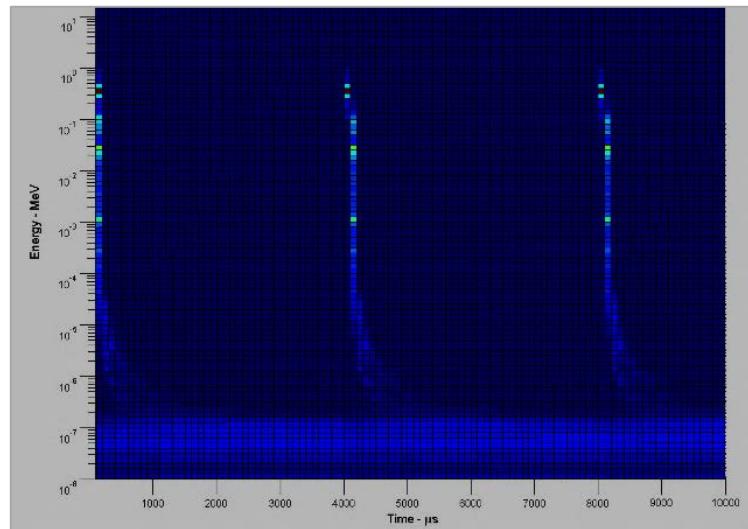
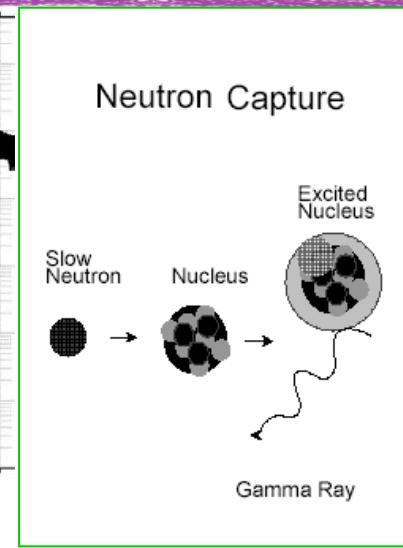
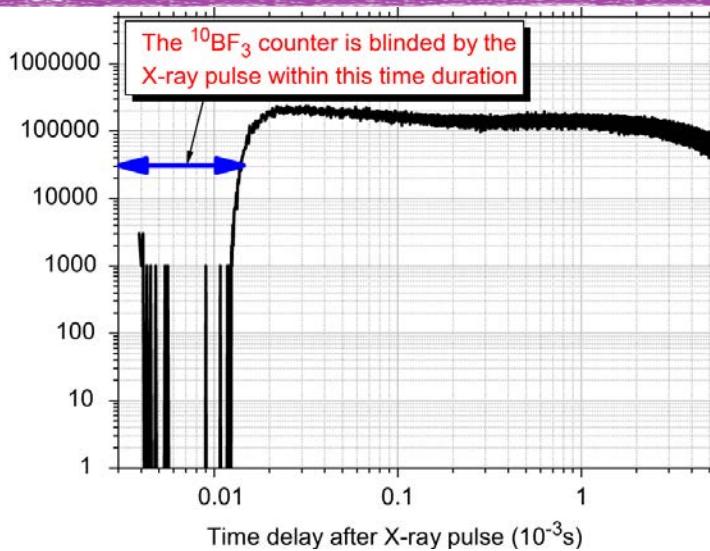
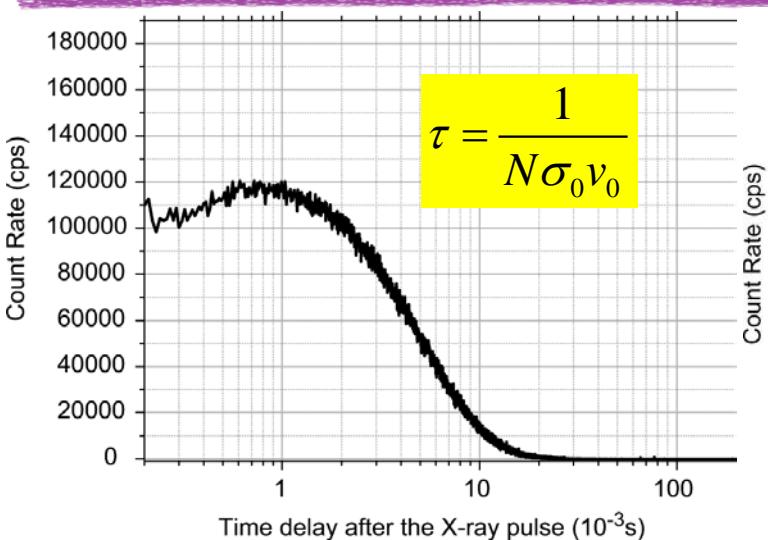
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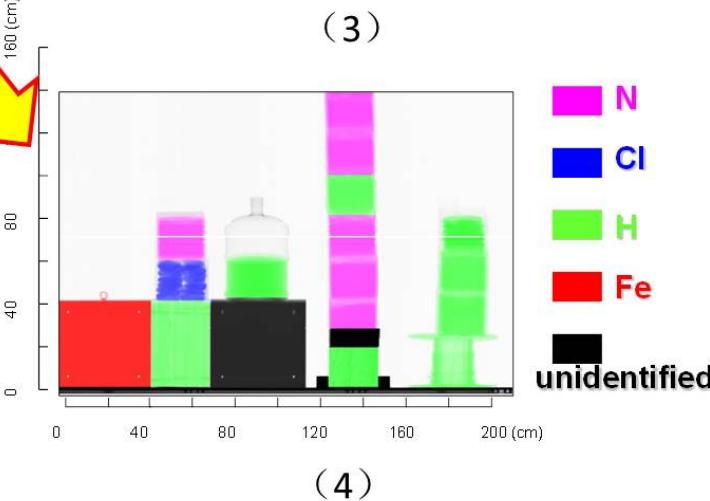
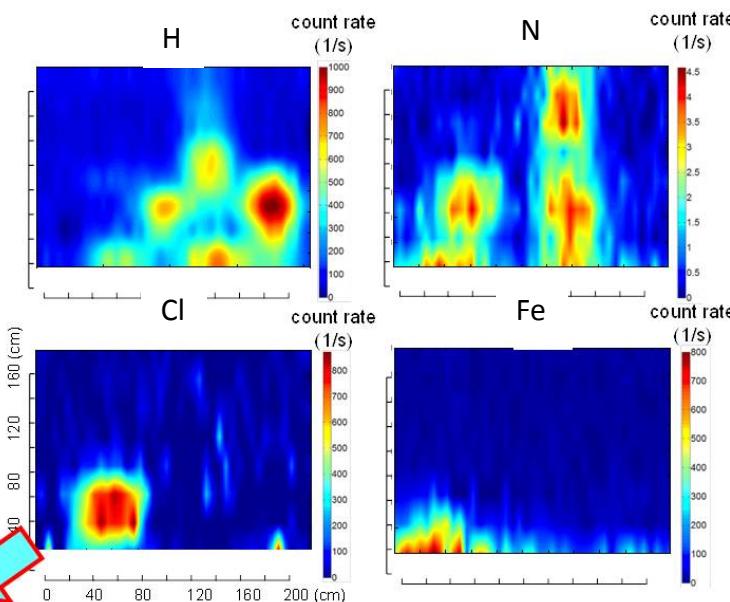
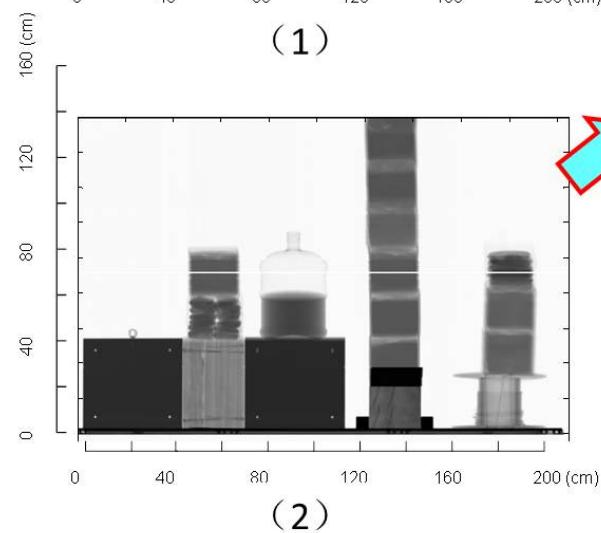
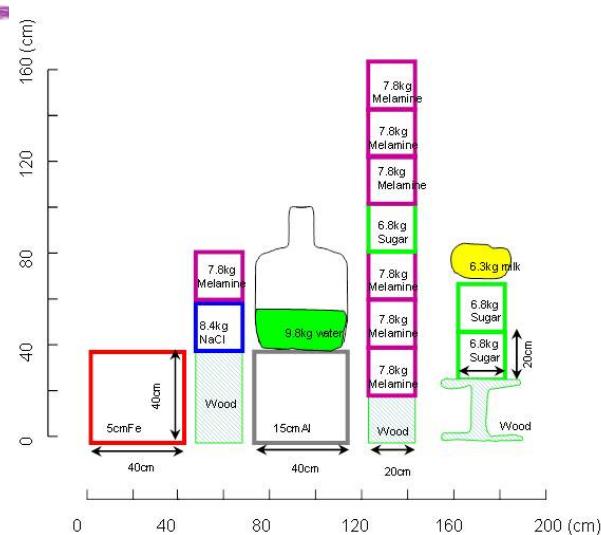
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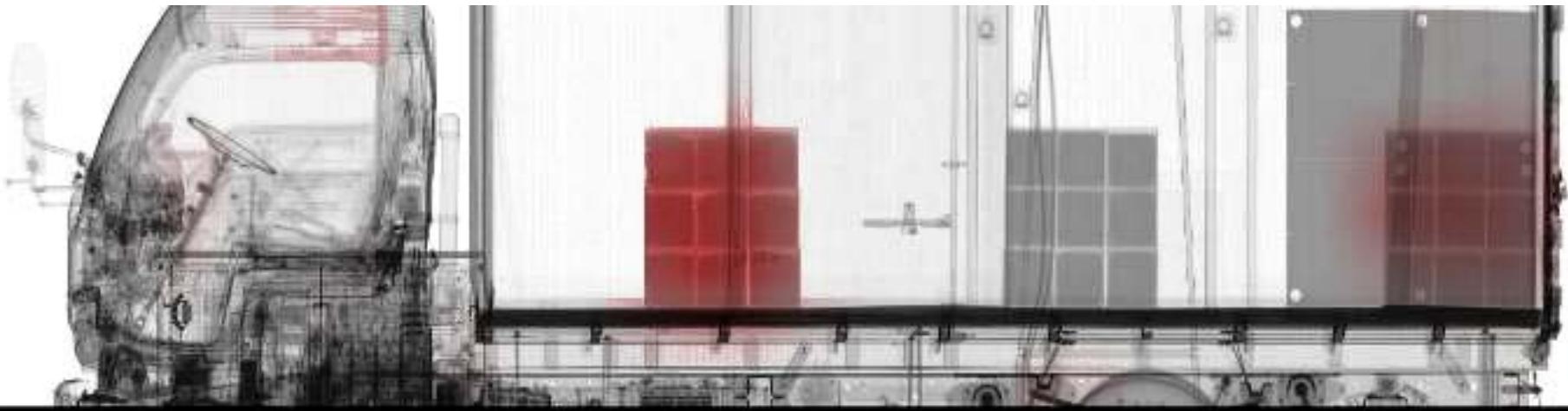
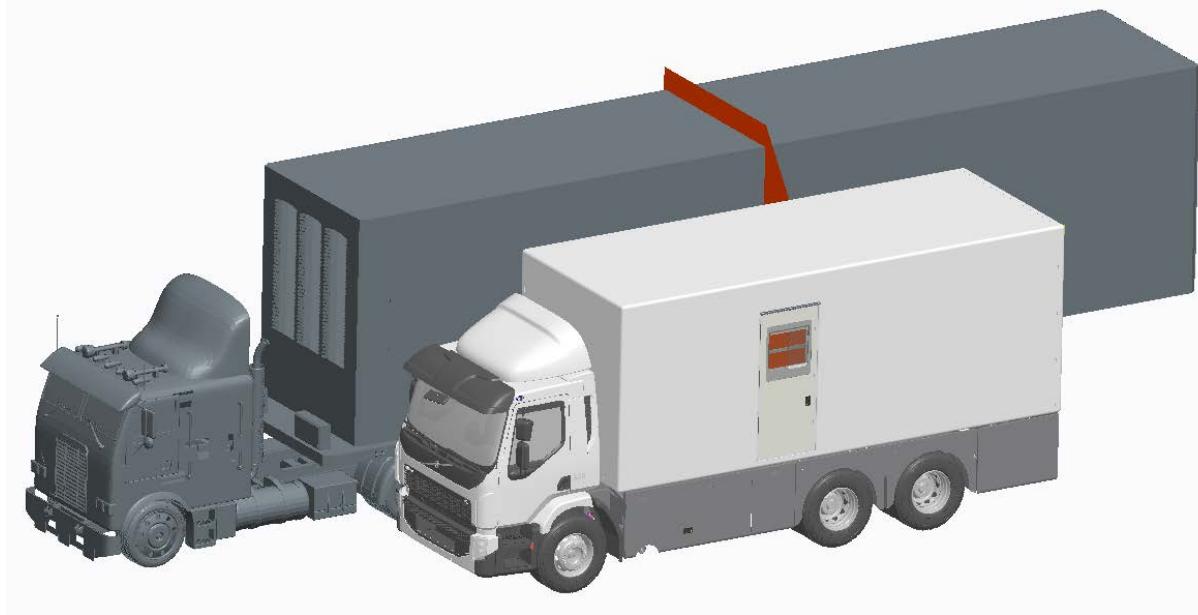
(n, γ) analysis for explosives or drugs



Fusion of X-ray image and elemental concentration distribution



Drugs or explosives detection system



3.Summary

- An e-LINAC can produce both X-rays and photoneutrons.
- 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.

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

Atomic number analysis by
analyzing the scattered MV
X-ray spectrum

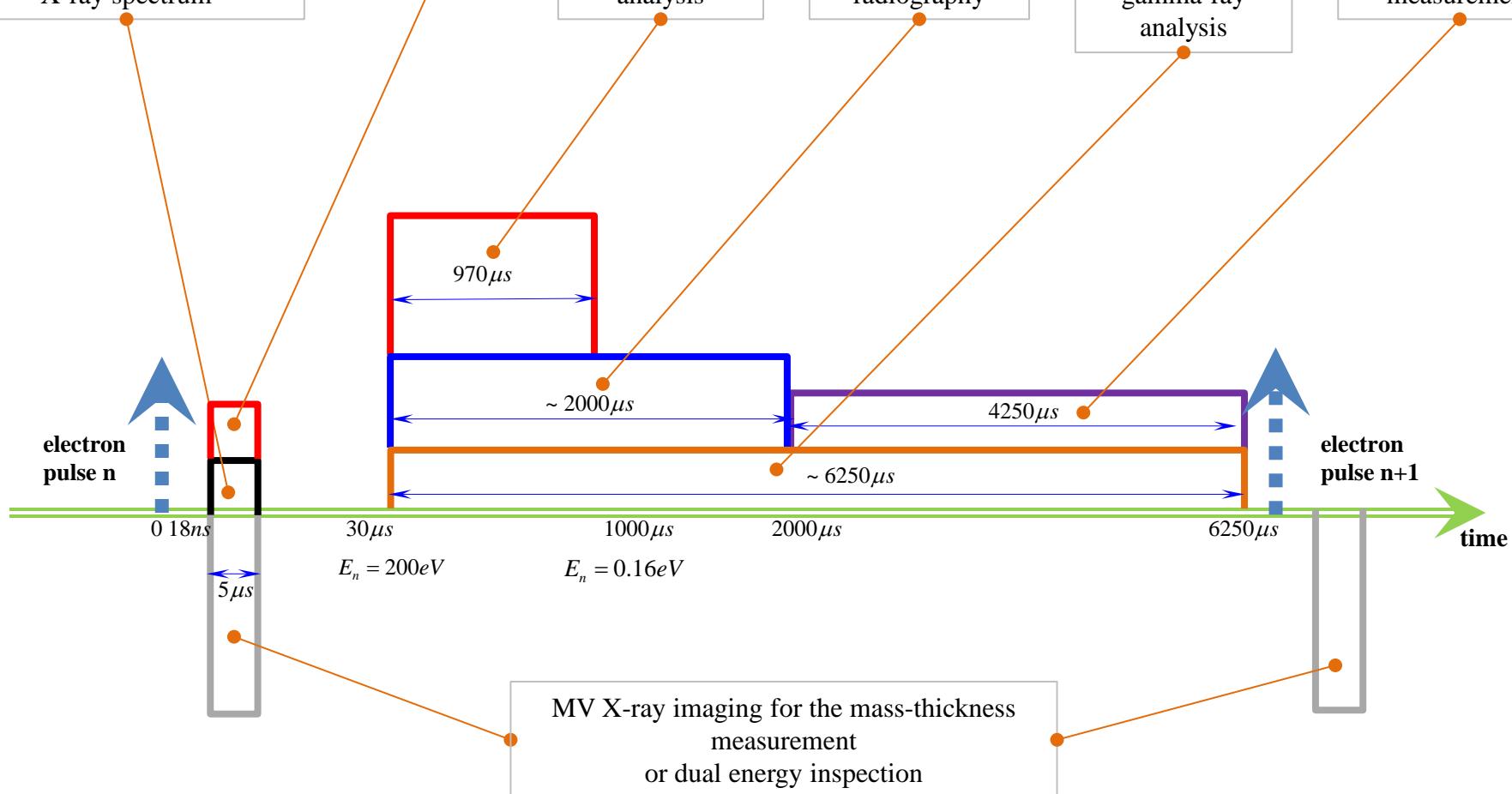
Photoneutron
production

Photoneutron
resonant
analysis

Photoneutron
and X-ray
radiography

Photoneutron-
induced
gamma-ray
analysis

Beta-delayed
neutron
measurement



Thanks for your attention

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Questions please