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Principles and Applications of Neutron Based Inspection Techniques

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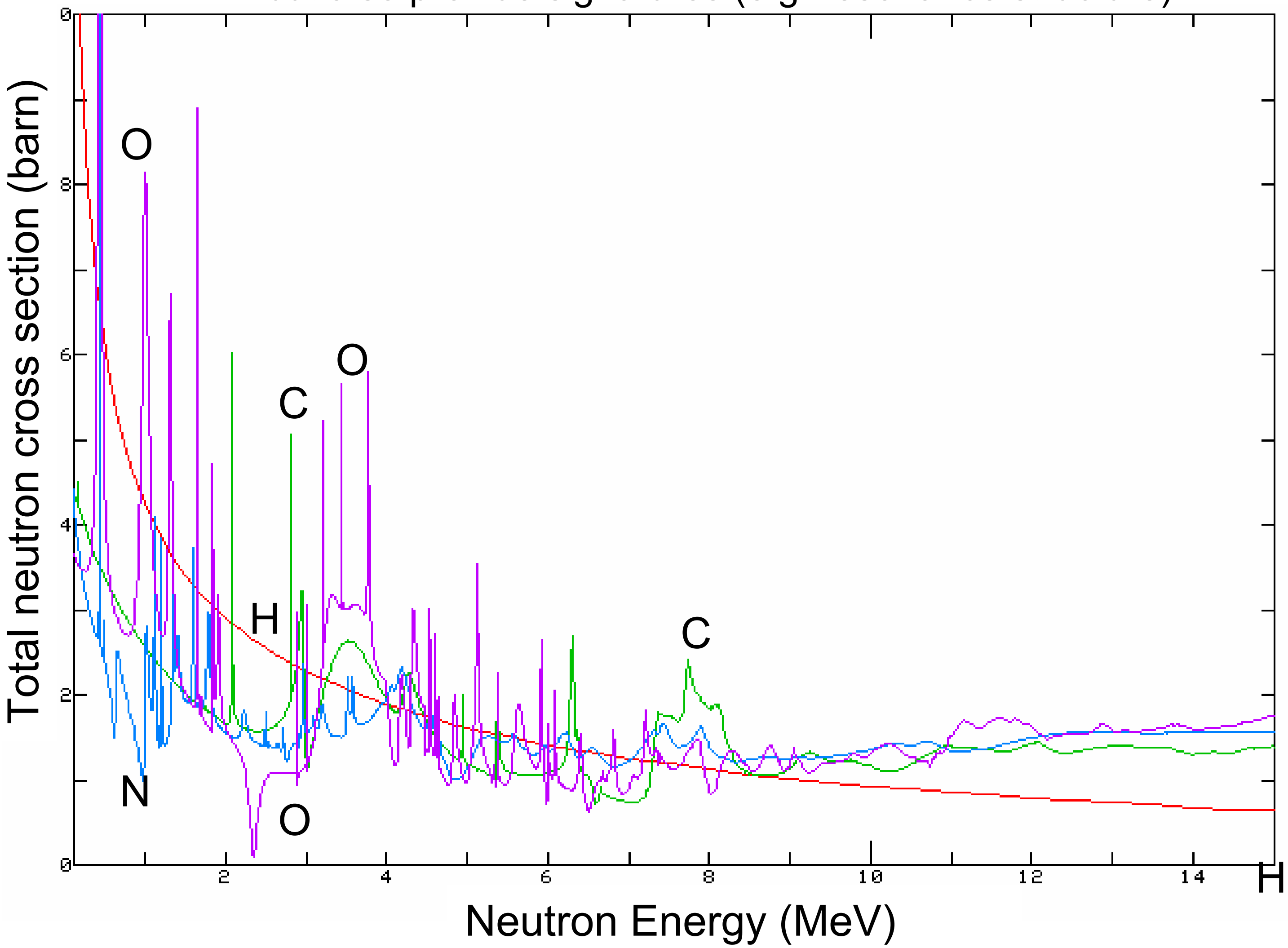
Elemental composition of typical threats & benign materials

Threat/Material determination ⟸ **Elemental composition** ⟸ γ spectral signatures

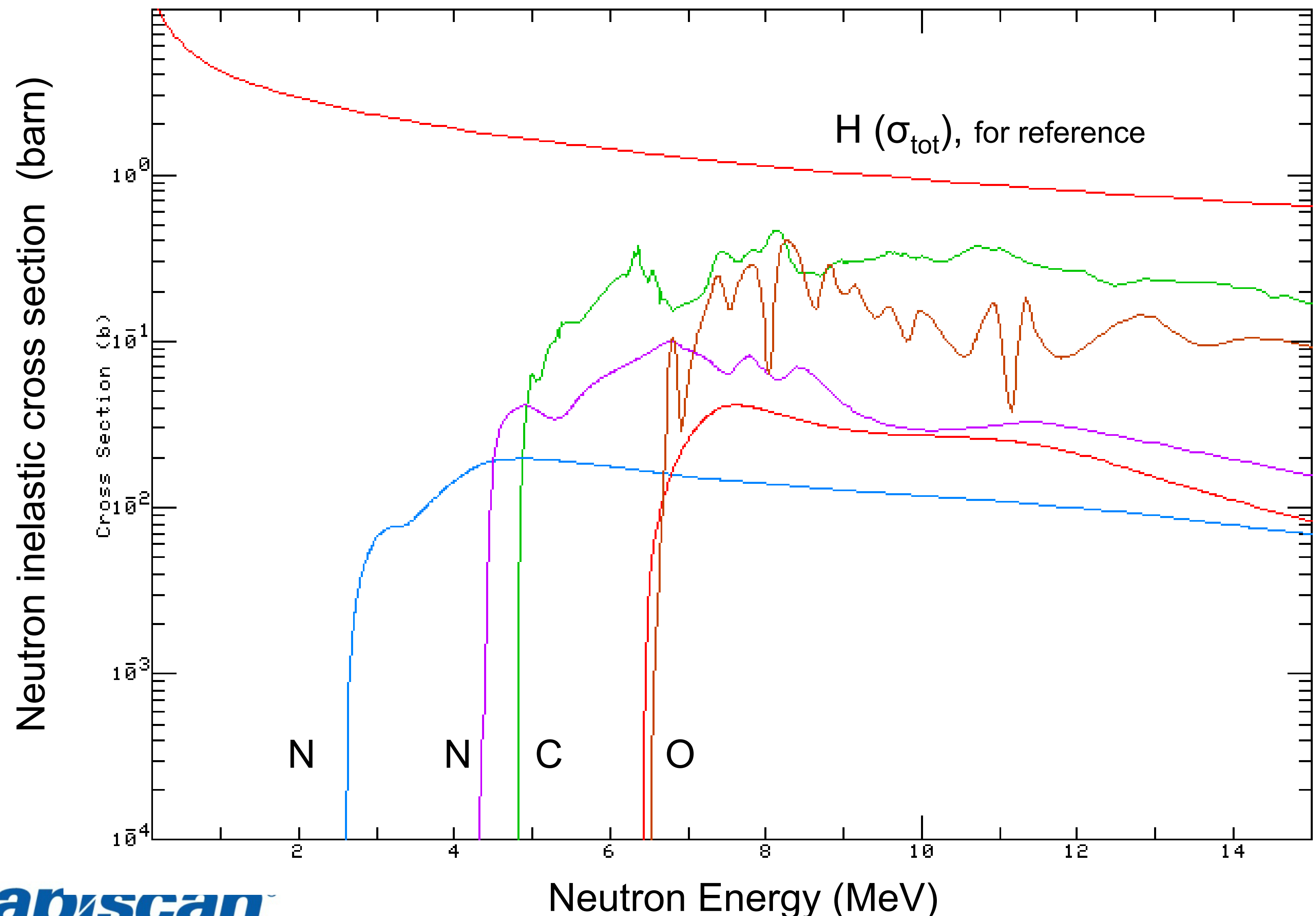
Threat	C	H	N	O	P	F	Cl	S	N/H	N/C
Explosives										
C4	21.9	3.6	34.4	40.1					10	2
TNT	37	2.2	18.5	42.3					8	1
PETN	19	2.4	17.7	60.8					7	1
AN	0	5	35	60					7	
Chem. agents										
Sarin	34.3	7.1		22.9	22.1	13.6			0	0
VX	49.5	9.7	5.2	12	11.6			12	1	0
CA (H-Cyanide)	44.5	3.7	51.8						14	1
HD (Mustrad gas)	30.2	5					44.6		0	0
Phosgene	12.1			16.2			71.7			0
Benign										
Water		11.1		88.9					0	0
Paper	44	6		50					0	0
Plastic	86	14							0	0
Salt							60			0

Total cross sections of organic elements-determining penetrability

but also provide signatures (e.g. resonance structure)



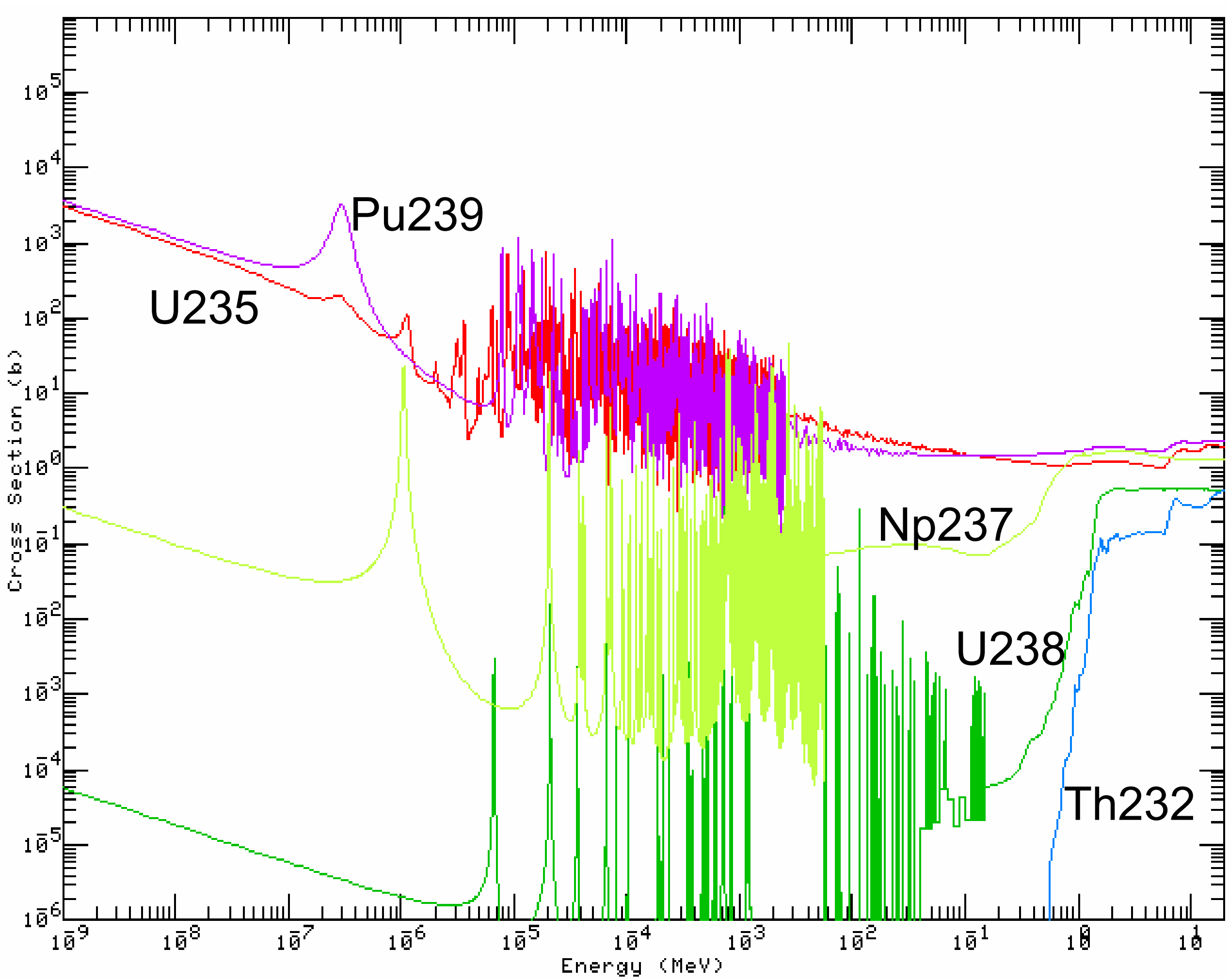
Neutron inelastic scattering cross sections. Reaction provides unique γ signatures



Fission cross sections-cover more than 2 orders of magnitude

Affording thermal, epi-thermal and fast fission

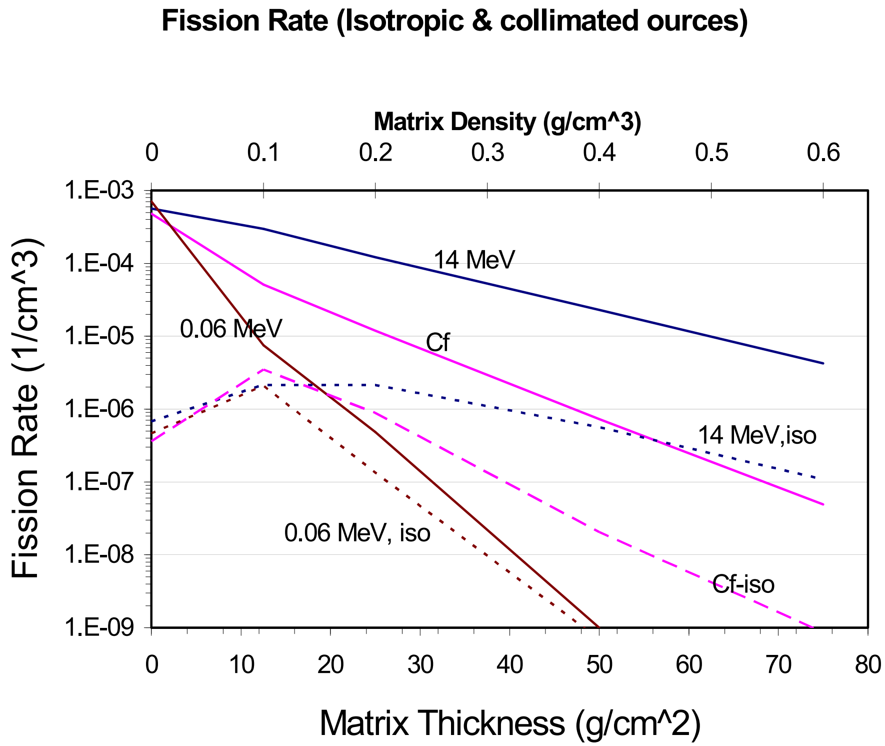
Fission cross section (barns)

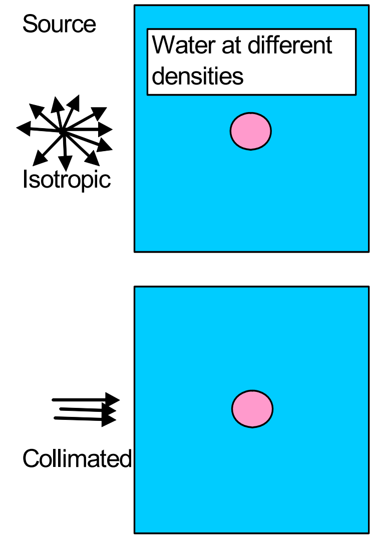


Neutron Energy (MeV)

Penetrability of source neutrons

Neutron flux (fission rate) vs. water density for different neutron source energies

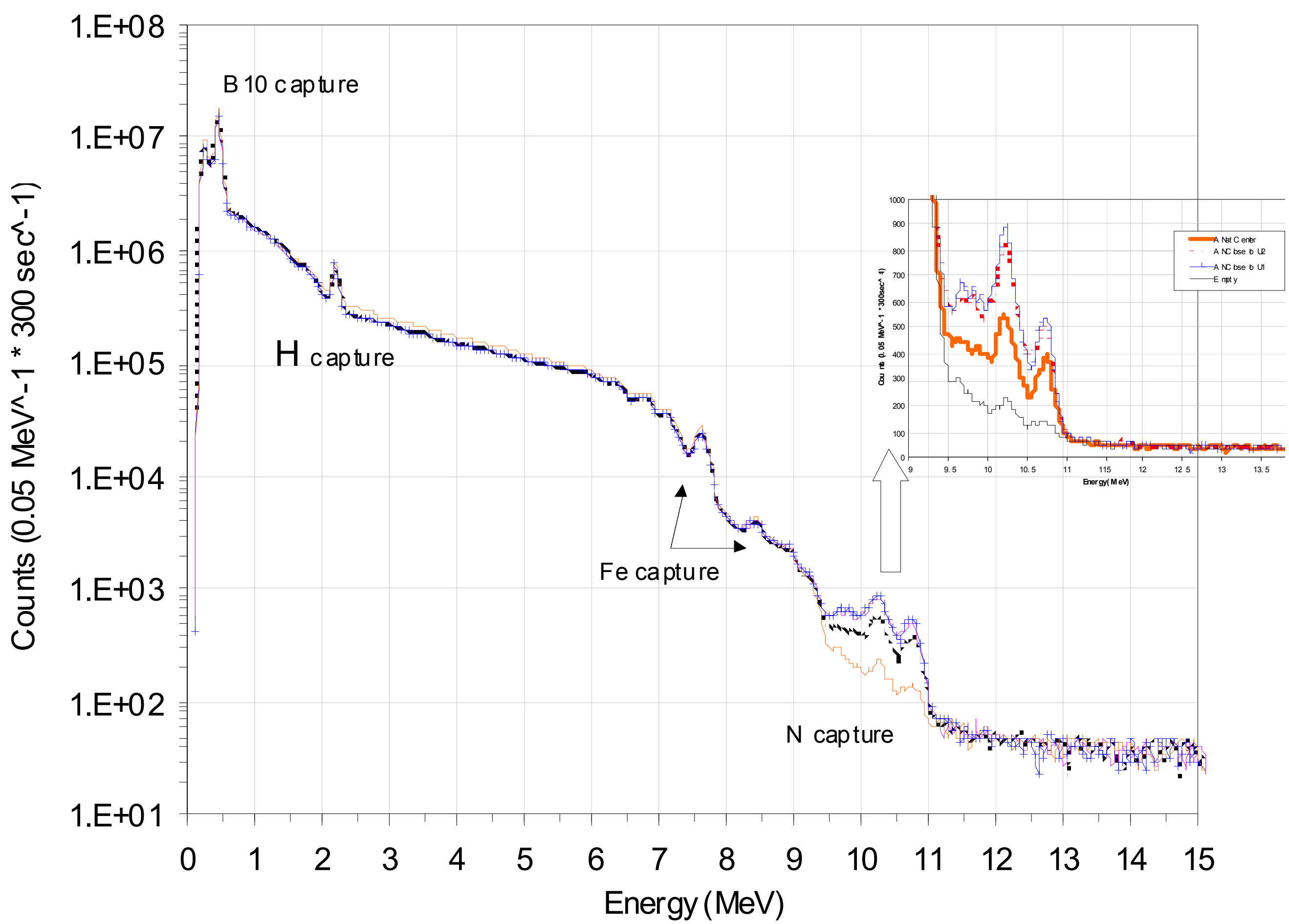




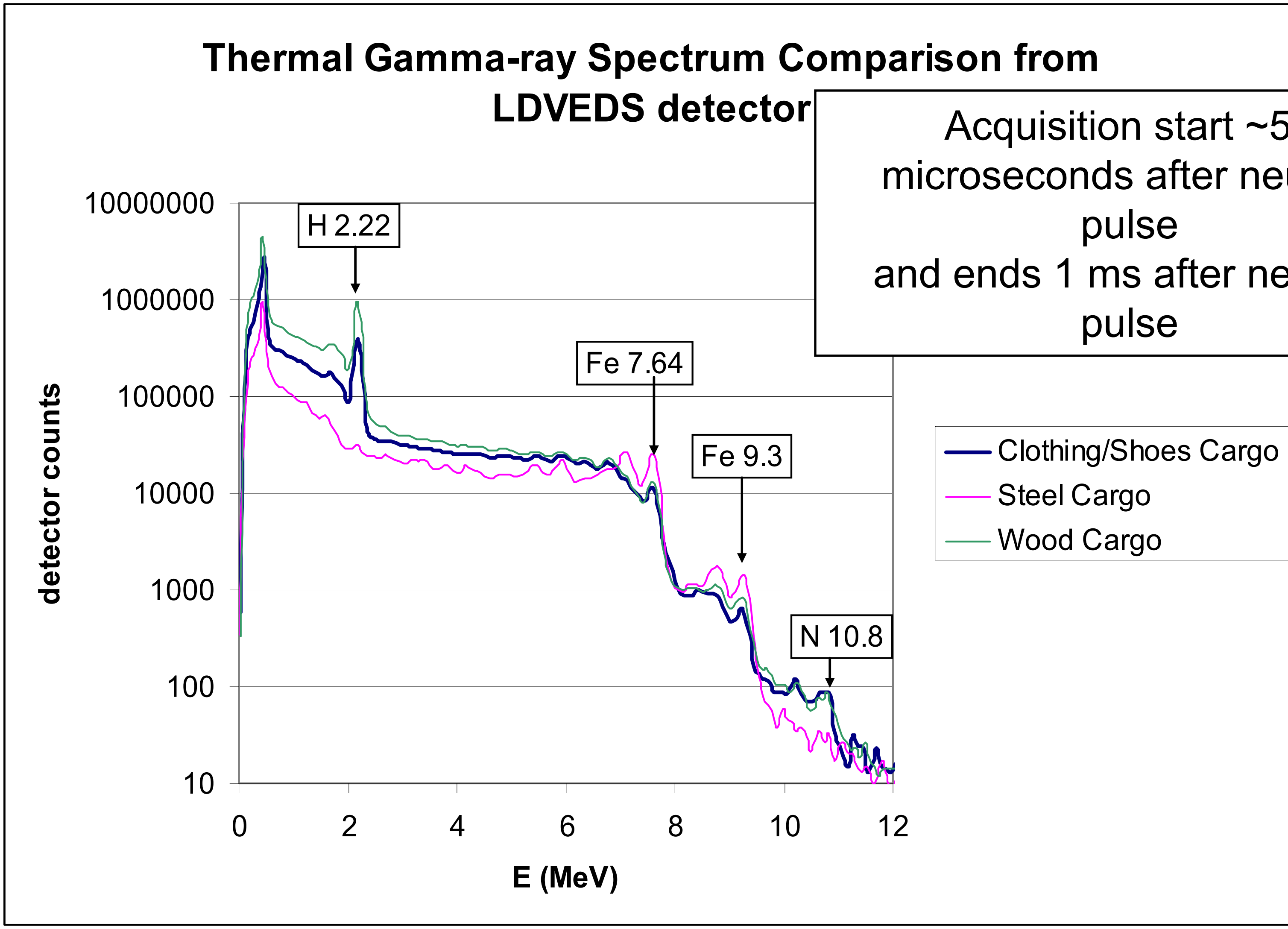
Neutron attenuation in water (and other hydrogenous substances).

The lower the source energy the higher the attenuation. The flux is lower by several order of magnitude between lower (<100KeV) and higher (>2MeV) neutron energies.

Explosive signature provided by VEDS (TNA component)

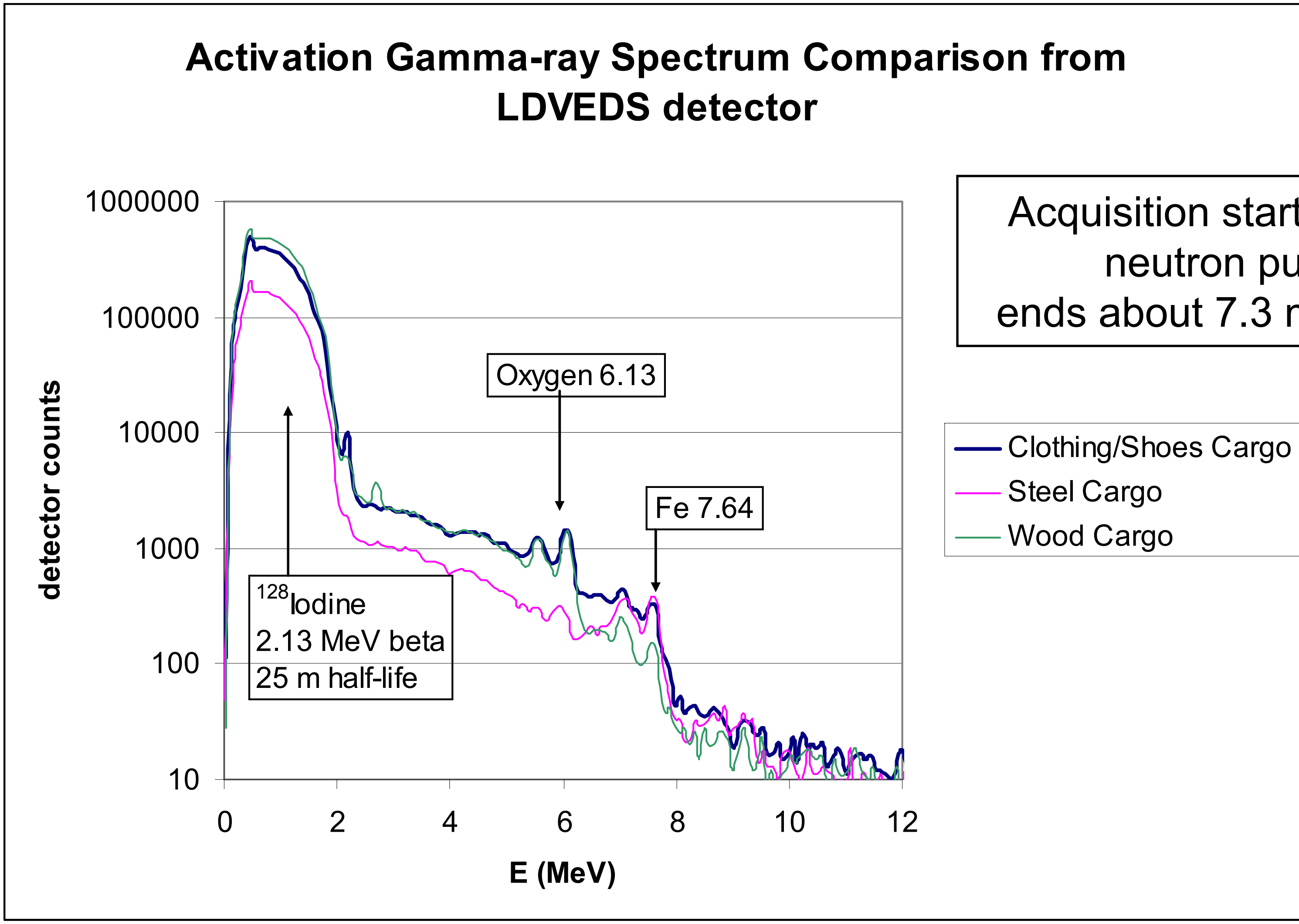


Signatures: **VEDS (TNA) Time Dependent Spectra- Early Thermal n-Capture Time Domain**



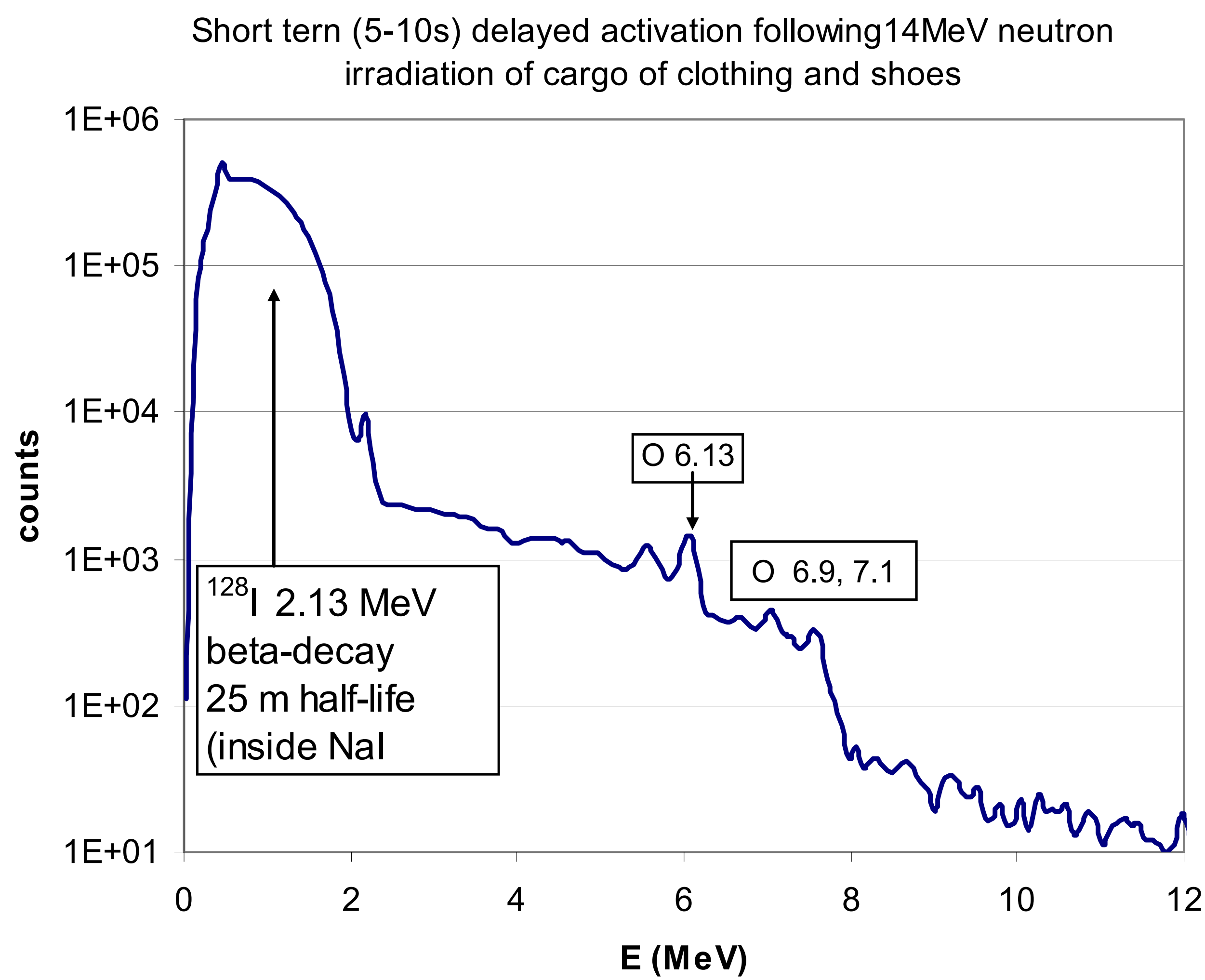
Acquisition start ~50 microseconds after neutron pulse and ends 1 ms after neutron pulse

Signatures: **VEDS (TNA) Time Dependent Spectra- Late Thermal n- Capture Time Domain**

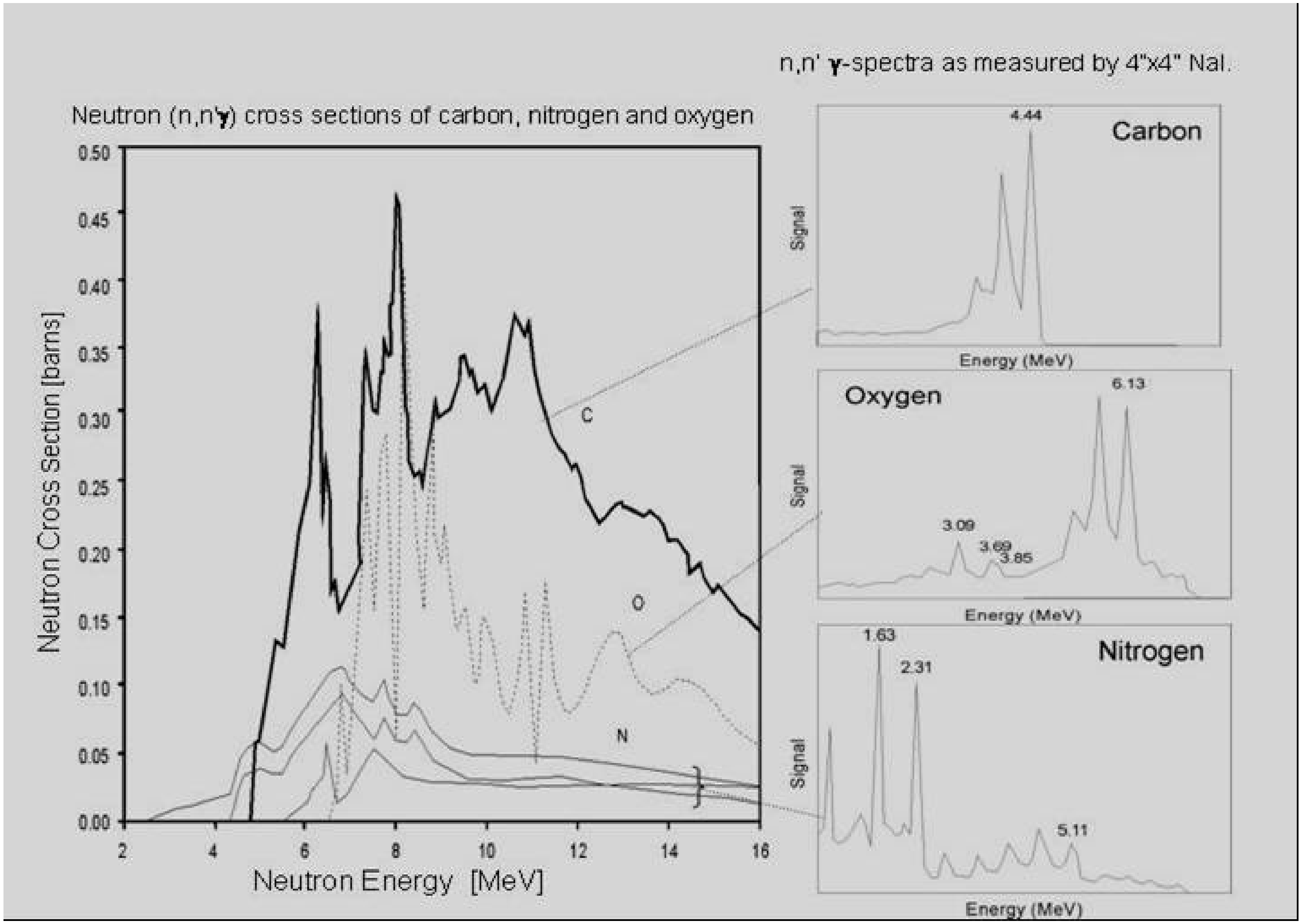


Acquisition start 4.3 ms after neutron pulse and ends about 7.3 ms after pulse

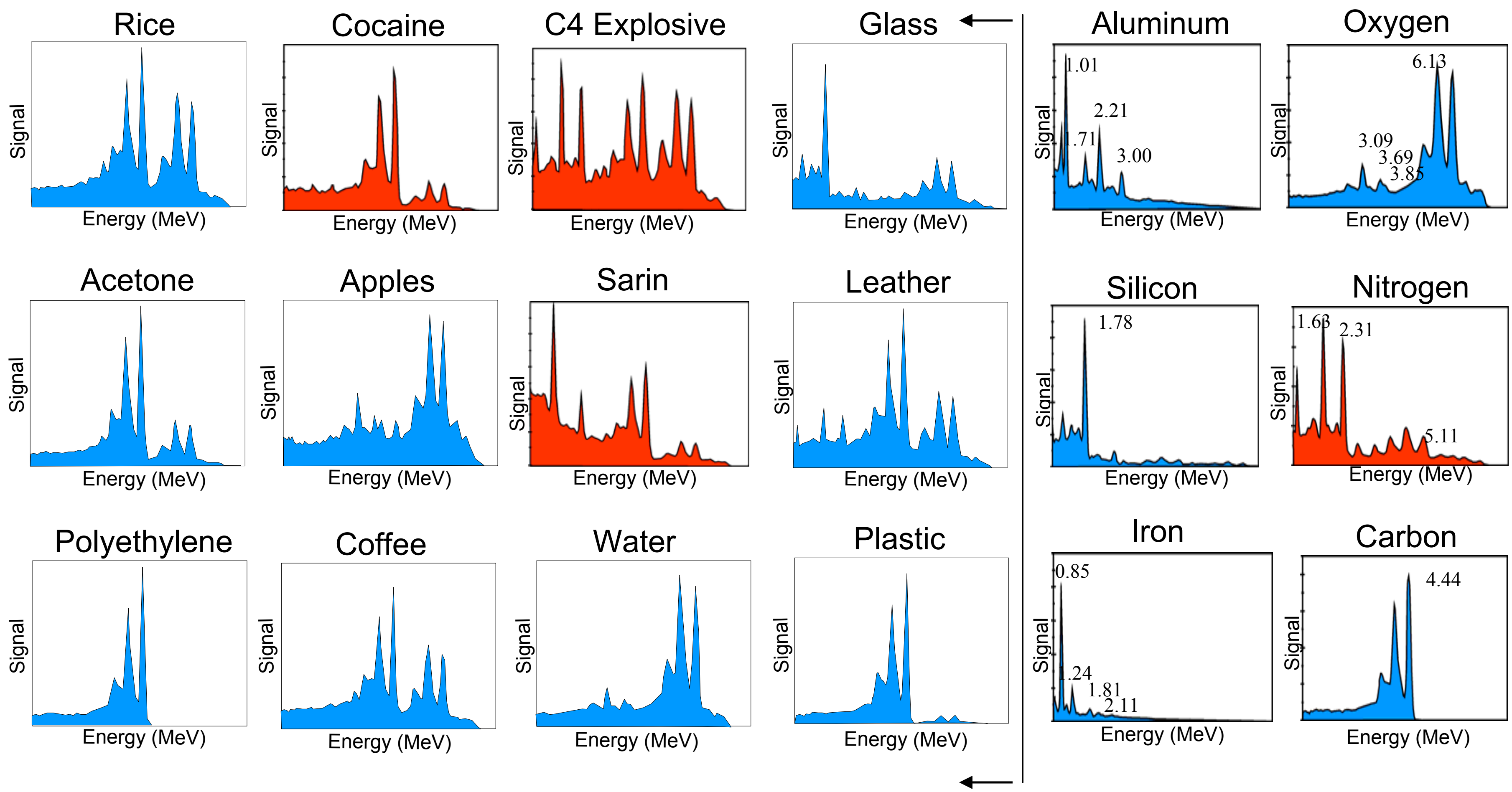
Signatures: **VEDS (TNA) Time Dependent Spectra-Activation (long term) Time Domain**



Inelastic scattering & signatures



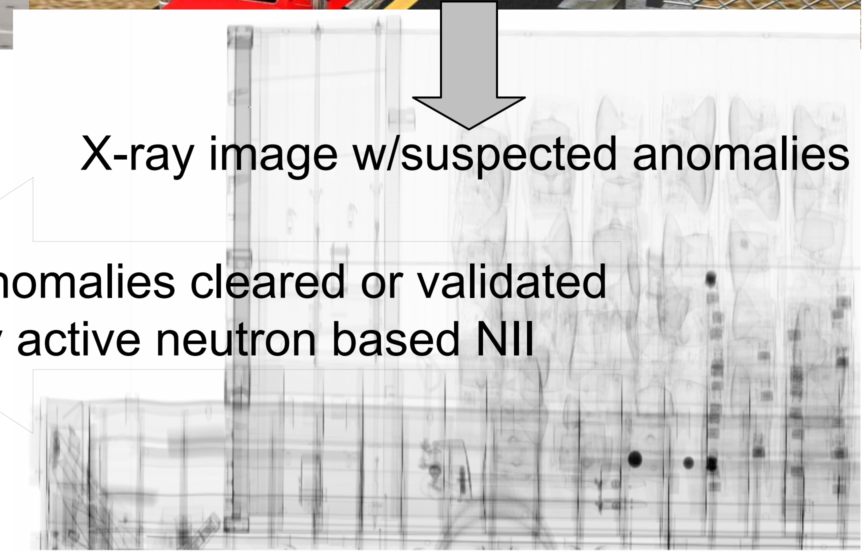
PFNA Material Signatures-TOF NaI spectra from (n, n'γ) reaction



A concept of operation of NII:

Neutron based technique clears alarms of high throughput primary inspection

X-ray inspection

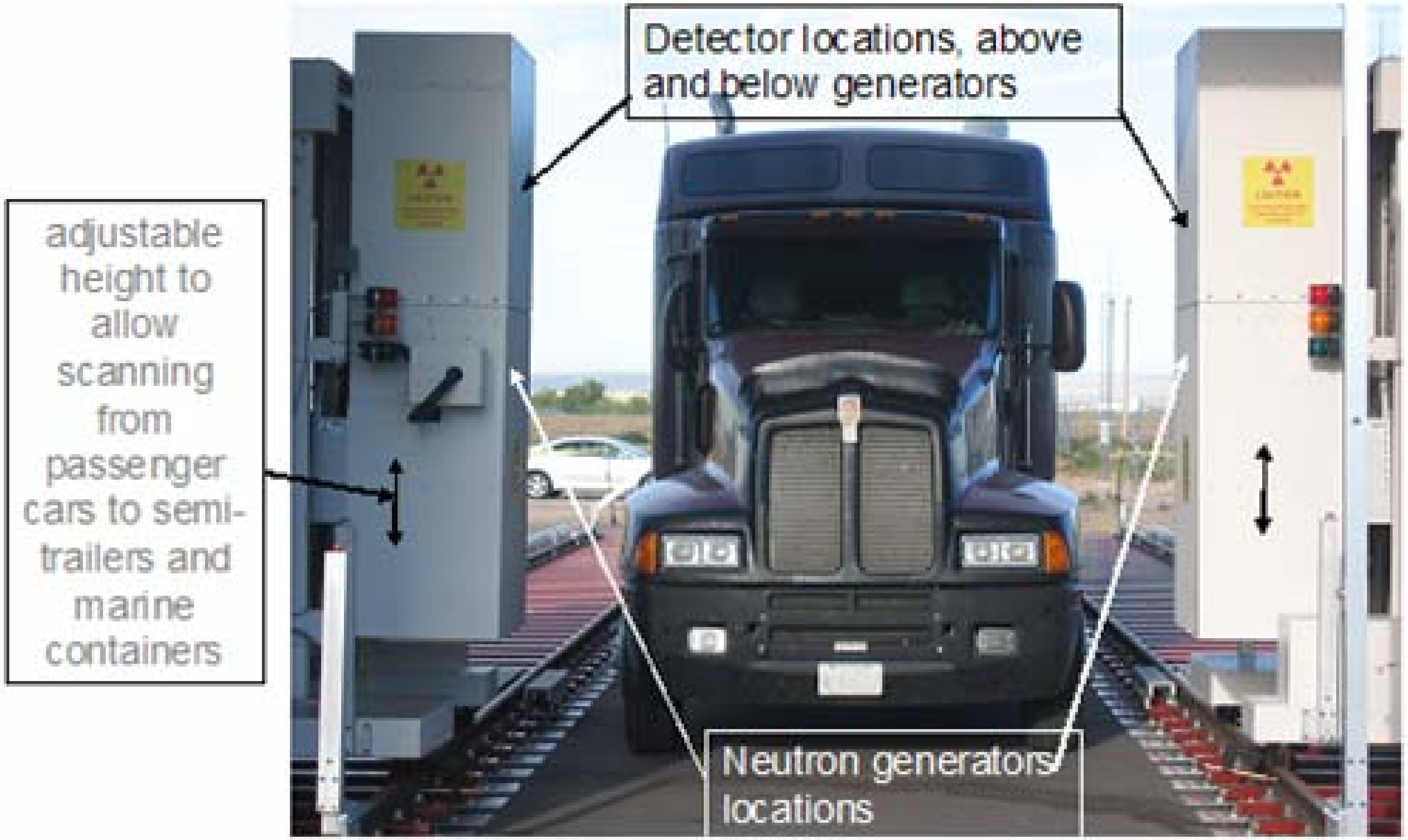


X-ray image w/suspected anomalies

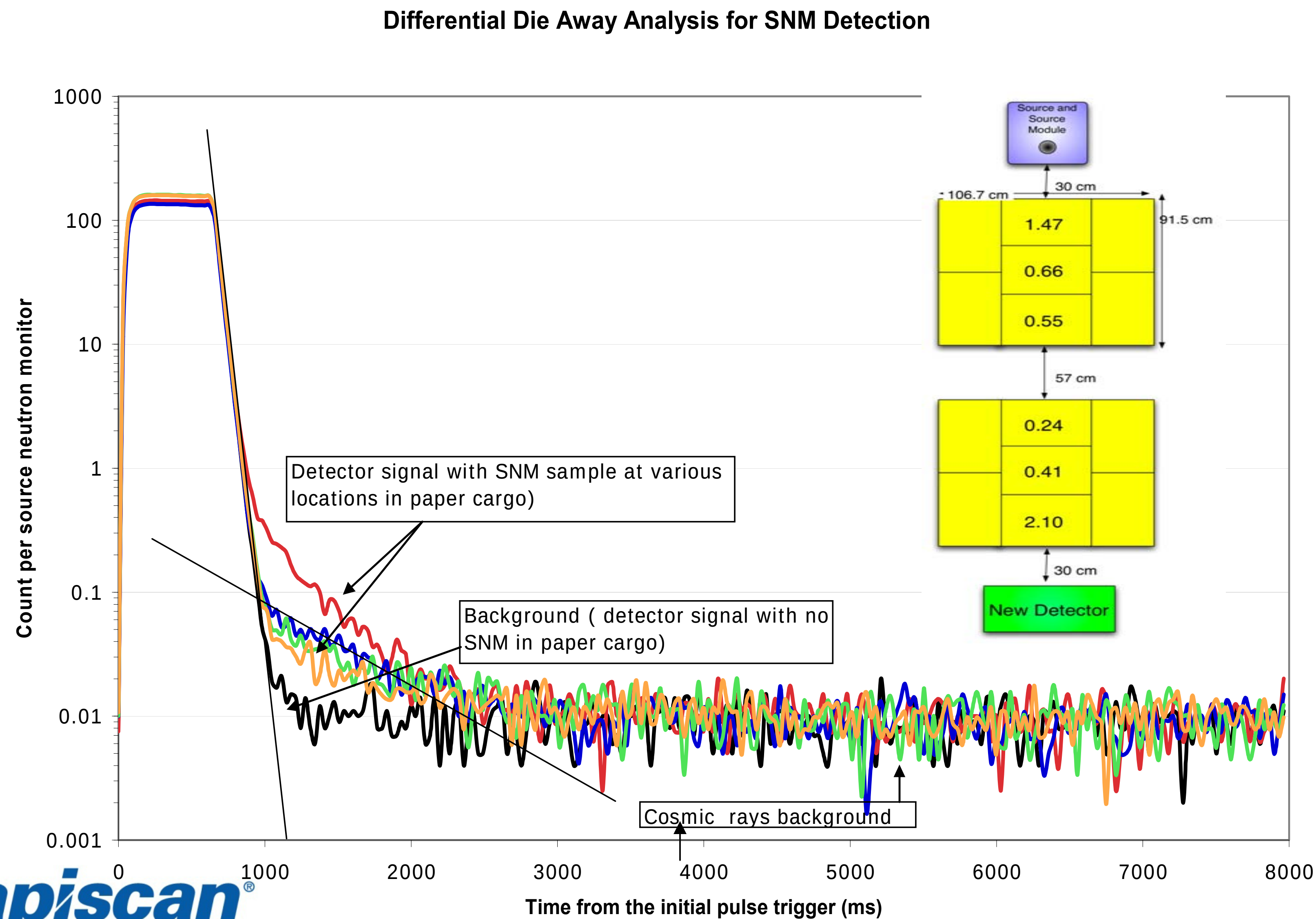
Anomalies cleared or validated by active neutron based NII

14MeV neutron based Vehicle Explosive Detection System (VEDS)

Track mounted dual sided VEDS system inspecting a truck



Differential Die Away Analysis for SNM Detection in Cargo



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Neutron Inspection Products

Rapiscan VEDS Mobile
Vehicle Explosive Detection System

Rapiscan VEDS Gantry
Vehicle Explosive Detection System

Rapiscan PFNA
Air Cargo Inspection System

Summary of techniques, principles & major elements detected

#	Technique Name	Probing Radiation	Main Nuclear Reaction	Detected Radiation	Sources	Primary & Secondary Detected Elements
1	TNA (Thremal neutron analysis)	Thermalized neutrons	(n,γ)	Neutron capture γ-rays/prompt & delayed neutrons and γ rays for SNM[2]	^{252}Cf, also accelerator based sources (ENG[1])	Cl, N, SNM** H, Metals, P, S
2	FNA (Fast neutron analysis)	Fast (high energy, usually 14 MeV) neutrons	(n,n'γ)	γ-rays produced from inelastically scattered neutrons	ENG based on (d,T)	O, C (N) (H) Cl, P
3	FNA/TNA	Pulsed neutron source; fast neutrons during the pulse, thermal neutrons between pulses	(n,n'γ) + (n,γ)	During pulse (FNA), after pulse (TNA)	μs pulsed ENG based on (d,T)	N, Cl, SNM H, C, O, P, S
4	PFNA (ns Pulsed fast neutron analysis)	Nanosecond (ns) pulses of fast neutrons	(n,n'γ)	Like FNA w/TOF[3] /prompt & delayed neutrons and γ rays for SNM	ns pulsed (d,D) accelerator with E_d ~6 MeV	O, C, N, Cl, Others, SNM H, Metals, Si, P, S, Others
5	API (Associated particles inspection)	14 MeV neutrons in coincidence with the associated α-particles	(n,n'γ)	Like FNA in delayed coincidence with α	(d,T)	O, C, N Metals
6	NRA (Neutron resonance absorption)	Nanoseconds pulsed fast neutrons (0.5-4 MeV), broad energy spectrum	(n,n)	Elastically and resonantly scattered neutrons	Accelerator based ns pulsed (d,Be) or (d,D) w/angular correlation, with $E_d \geq 4$ MeV	H, O, C, N (Others)

END