Acquisition of neutron-induced gamma signatures of chemical agents

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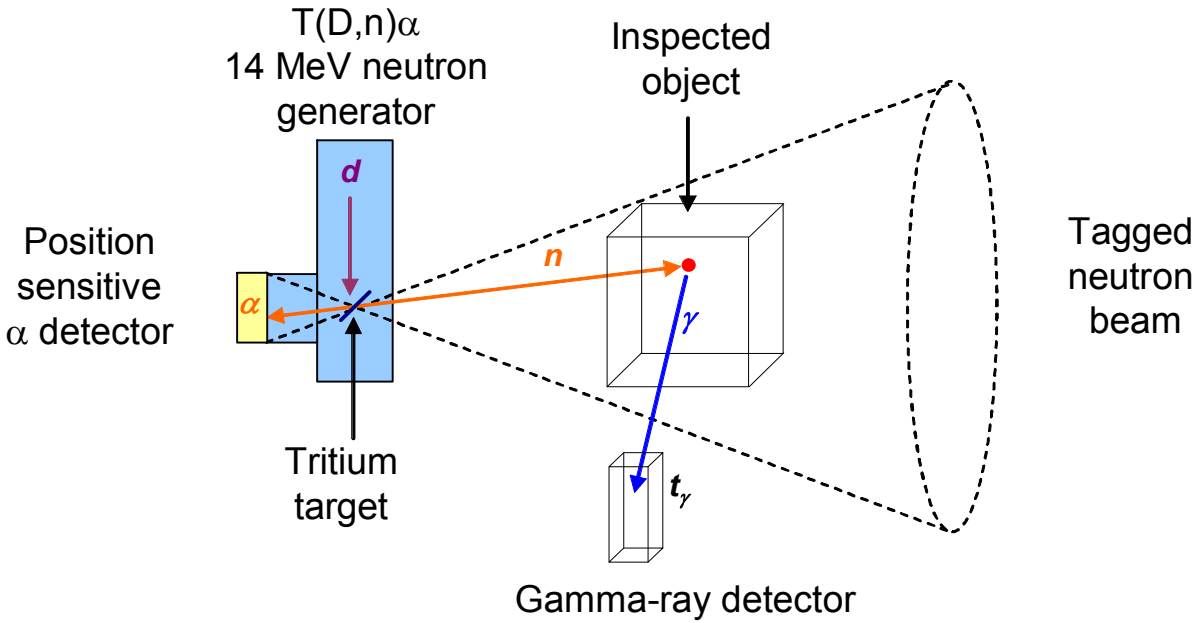
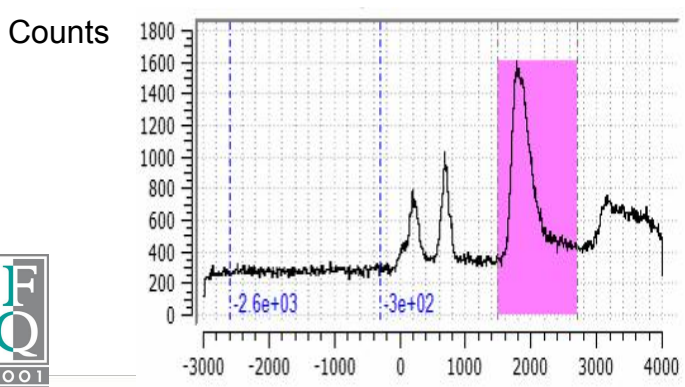
Frame and objectives

- French R&D program for the detection of CBRN & E threats
- Neutron interrogation ⇨ Chemical detection
  (Improvised Chemical Device hidden in an abandoned luggage)
  - X-ray imaging ⇨ presence, position and shape of suspicious items
  - Analysis of gamma rays induced by fast and thermal neutrons
  - ⇨ suspicious element identification : F, Na, P, S, Cl, As, Br, I, Hg, Tl…
- Coupling neutron interrogation techniques
  - Associated Particle Technique (APT): 3D localization of gamma rays produced by fast neutrons reactions (n,n'), (n,2n), (n,p), (n,α)…
  - Pulsed Fast Thermal Neutron Analysis (PFTNA) : neutron capture (n,γ)

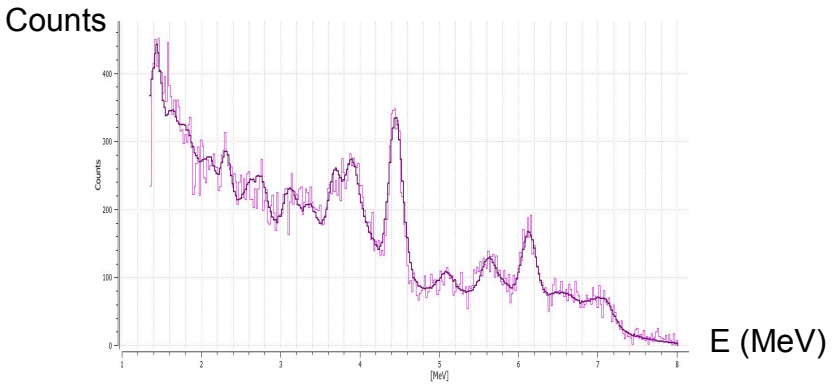
Associated Particle Technique (APT)



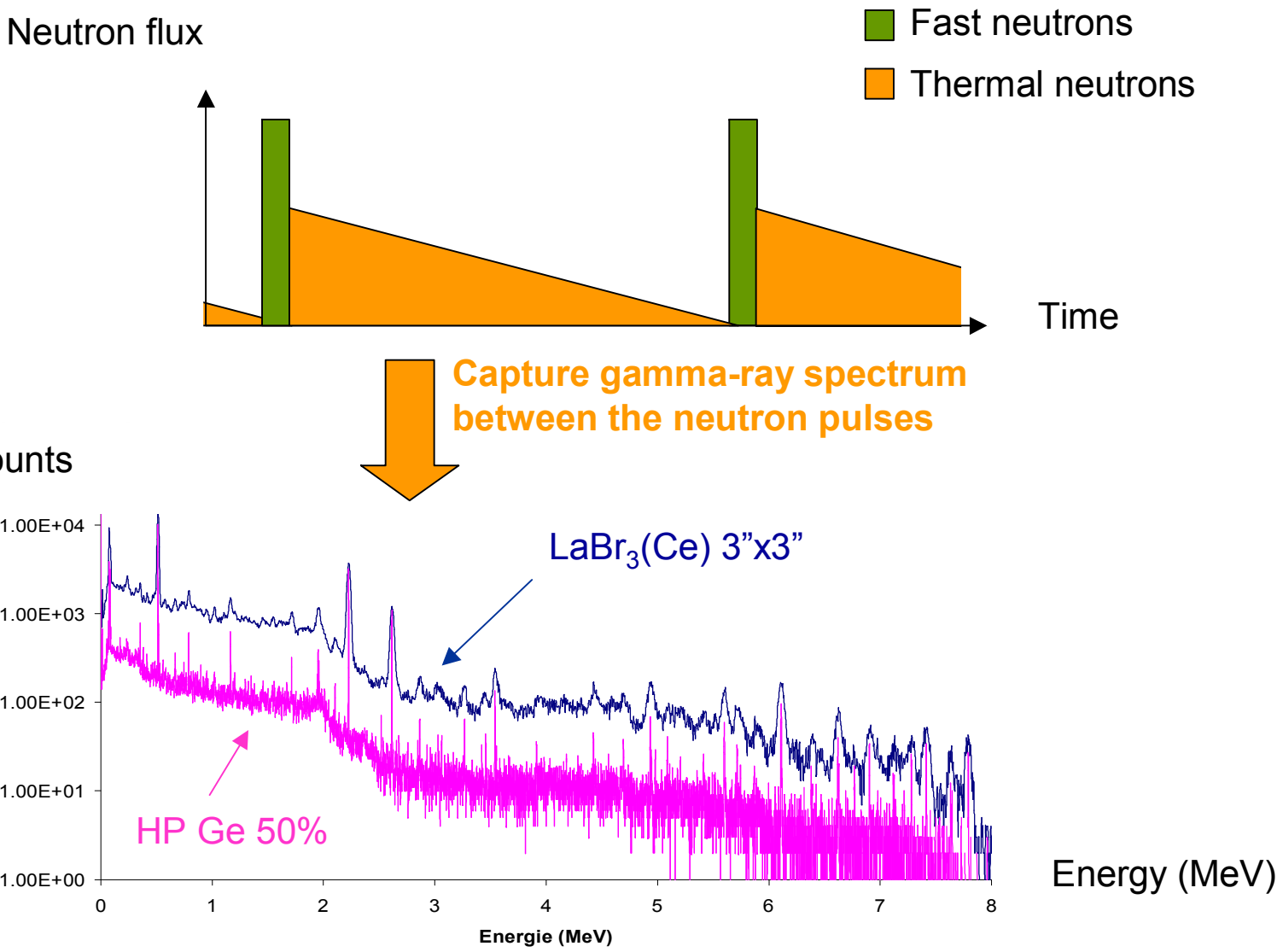
① Distribution of the neutron TOF ⇔ flight distance to interaction



② Gamma-ray spectrum of the inspected voxel



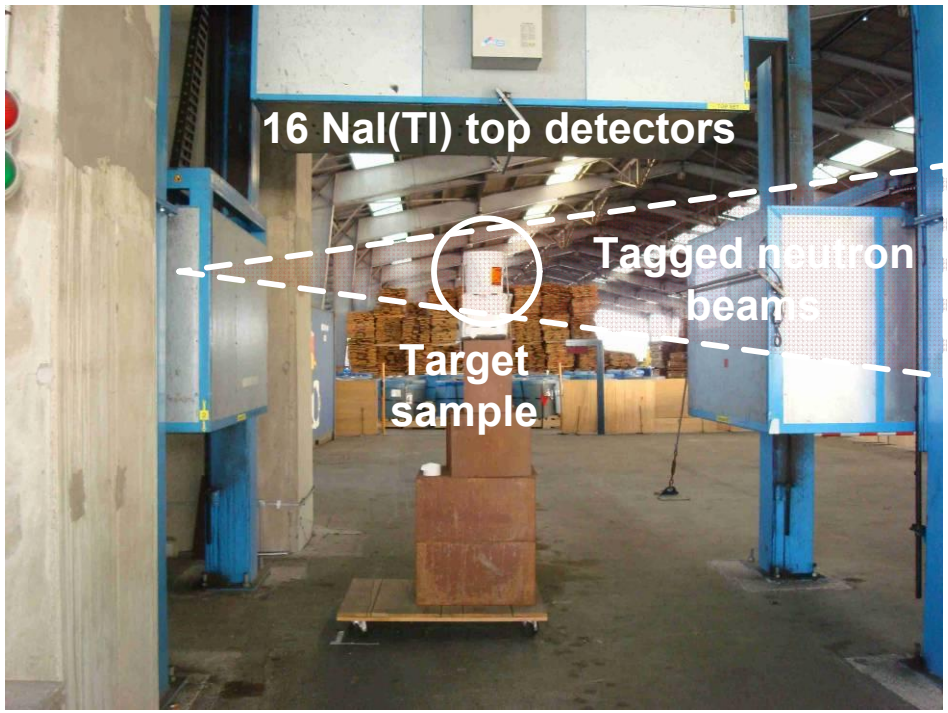
Pulsed Fast and Thermal Neutron Analysis (PFTNA)



Acquisition of APT gamma-ray signatures

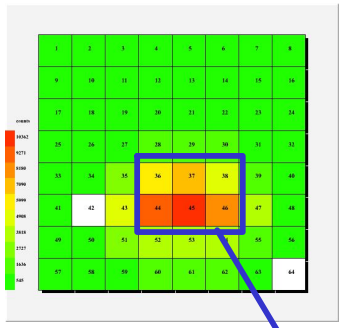
EURITRACK system
Seaport of Rijeka, Croatia
http://www.euritrack.org

5"x5"x10" NaI(Tl) detectors

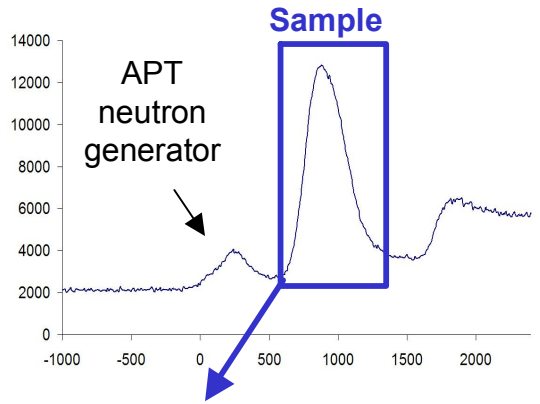


① Localisation of the sample target

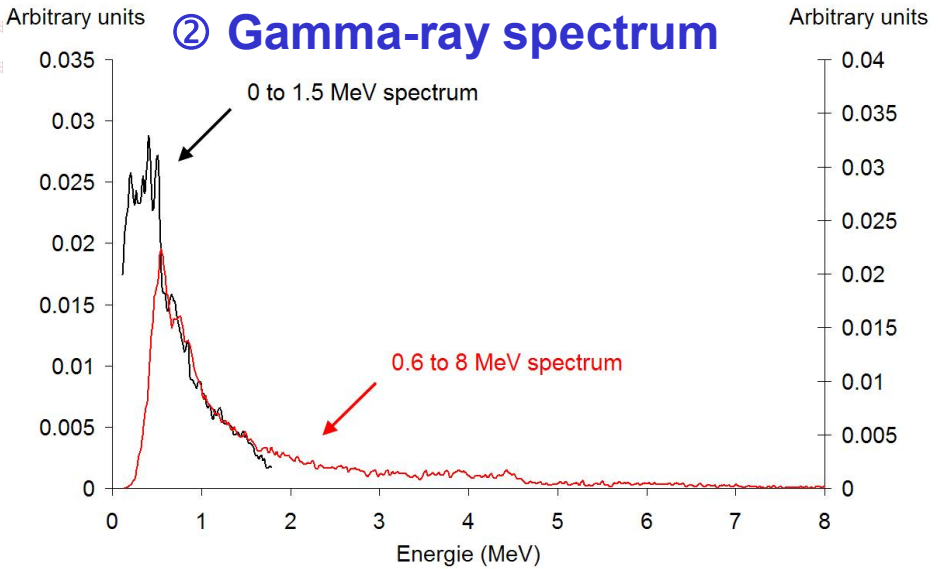
Alpha pixel map



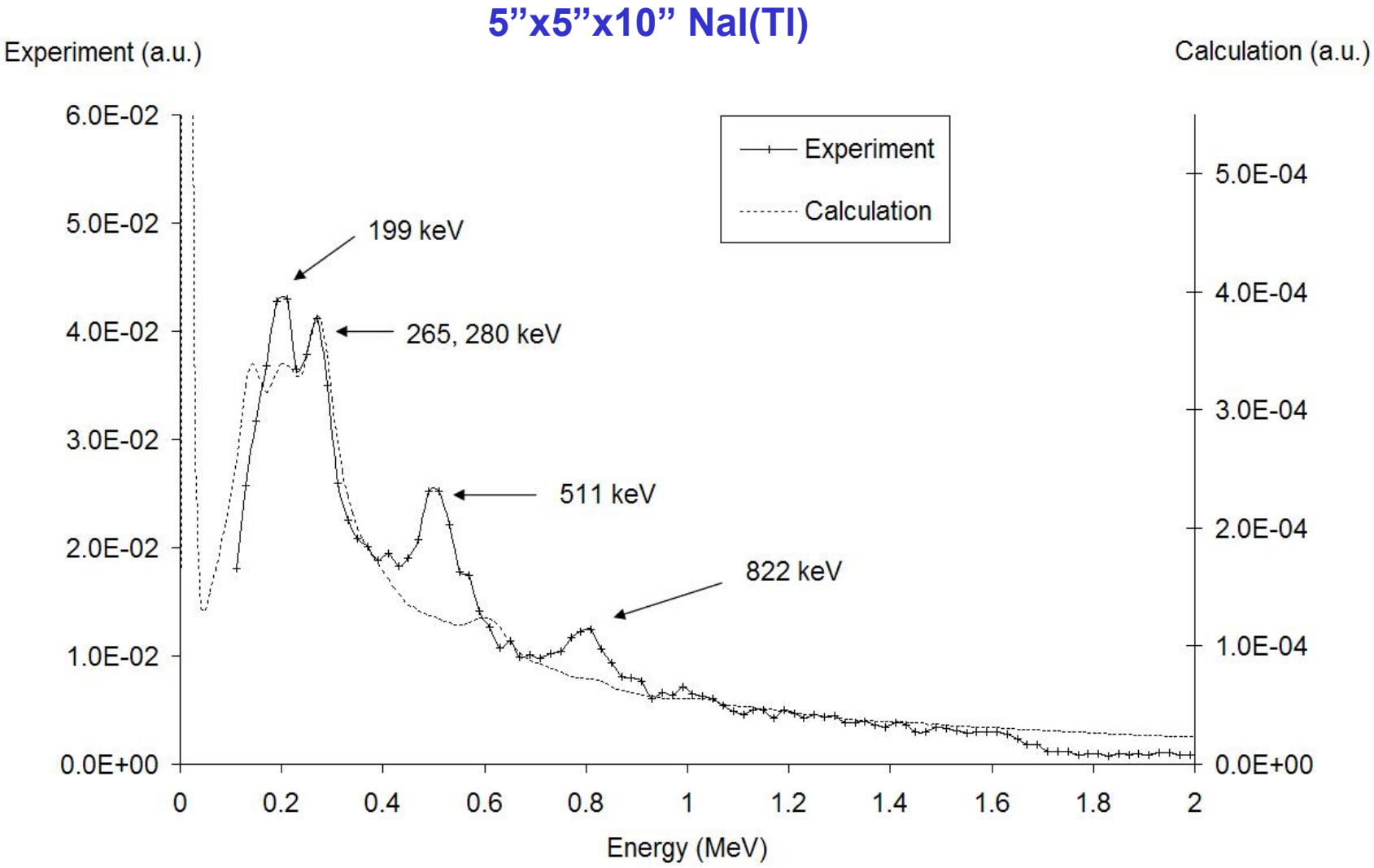
Neutron TOF



② Gamma-ray spectrum

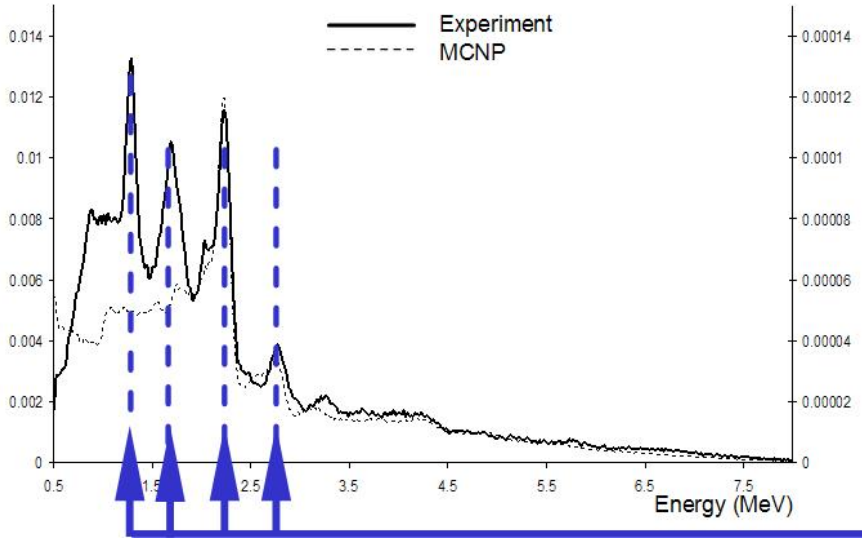


Comparison with MCNPX calculation (e.g. arsenic)

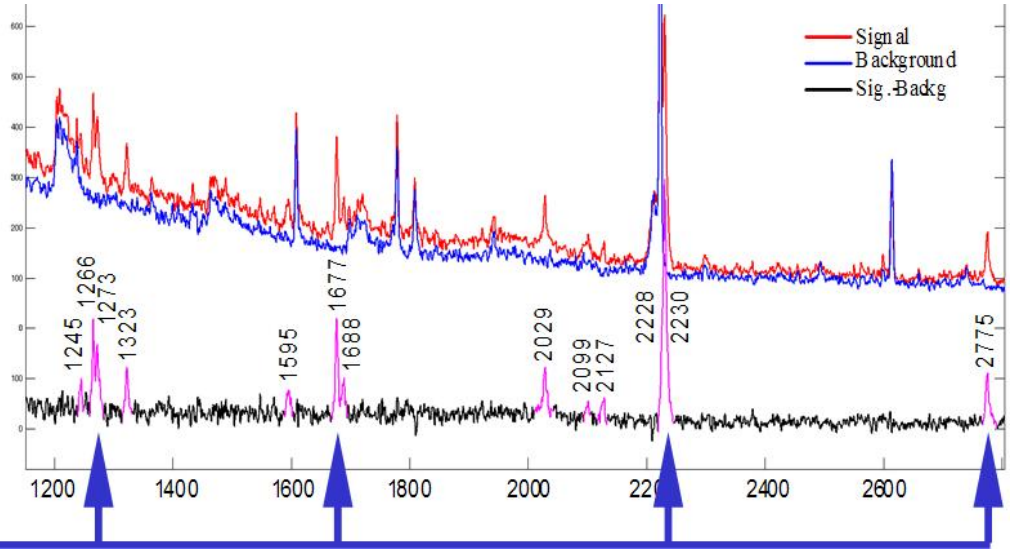


Comparison with PFTNA gamma-ray spectra (e.g. sulfur)

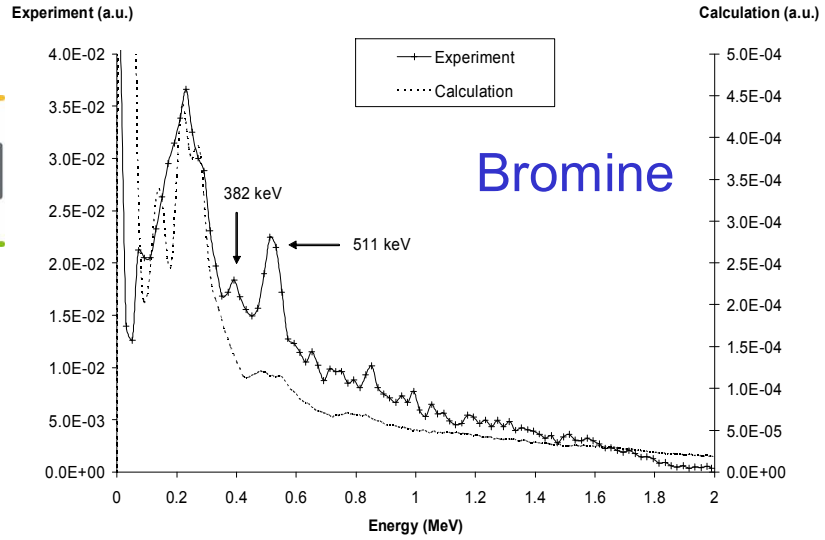
Sulfur APT spectrum
5”x5”x10” NaI(Tl)

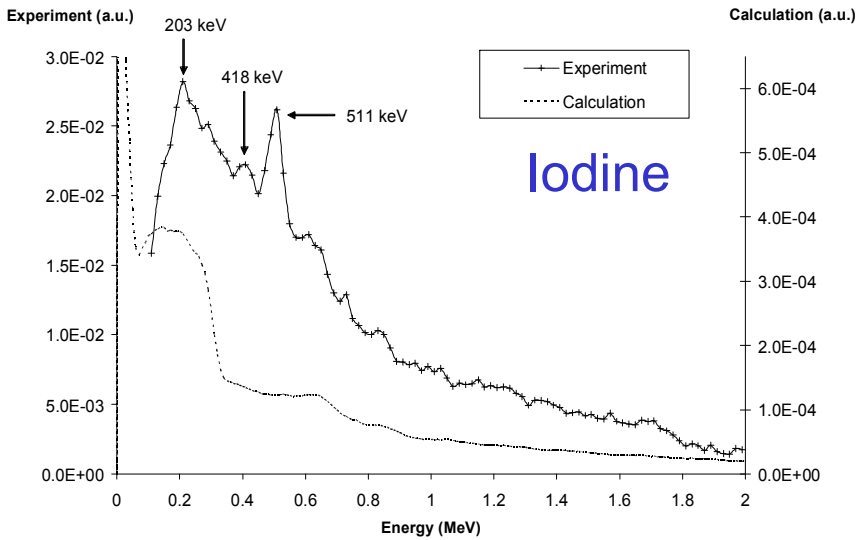


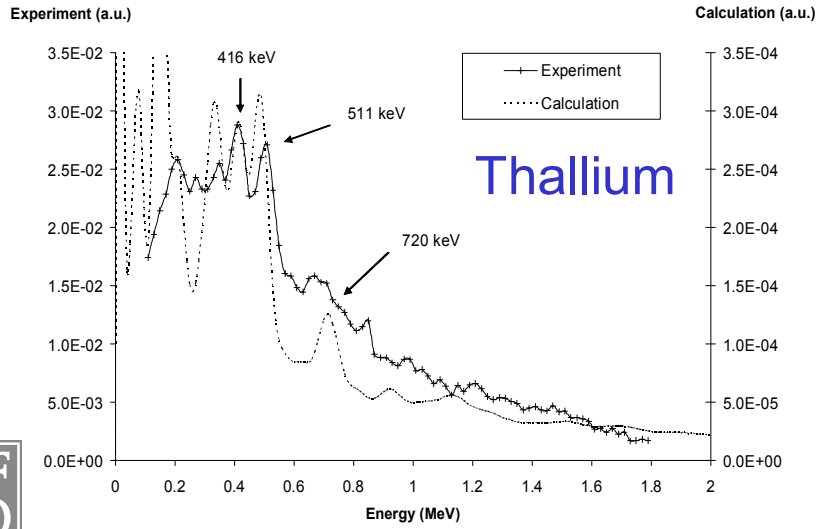
Sulfur PFTNA spectrum
70% HP Ge (during the pulses)

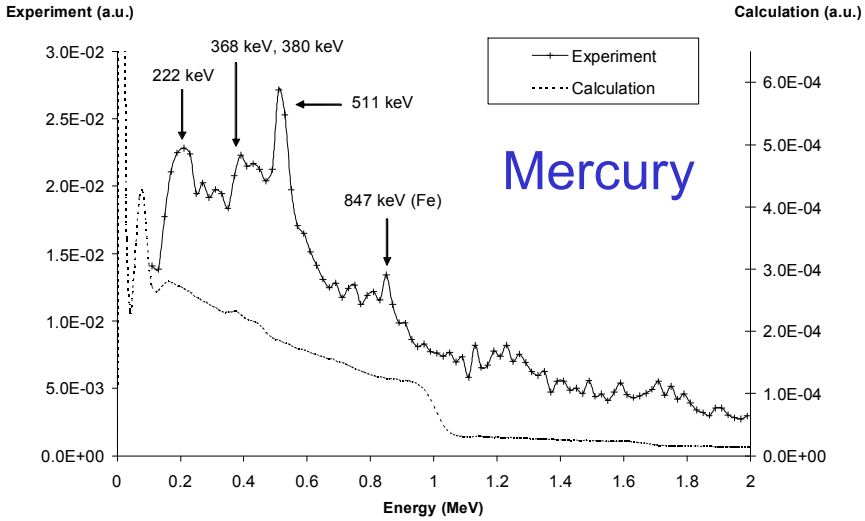


5”x5”x10” NaI(Tl) APT gamma-ray signatures

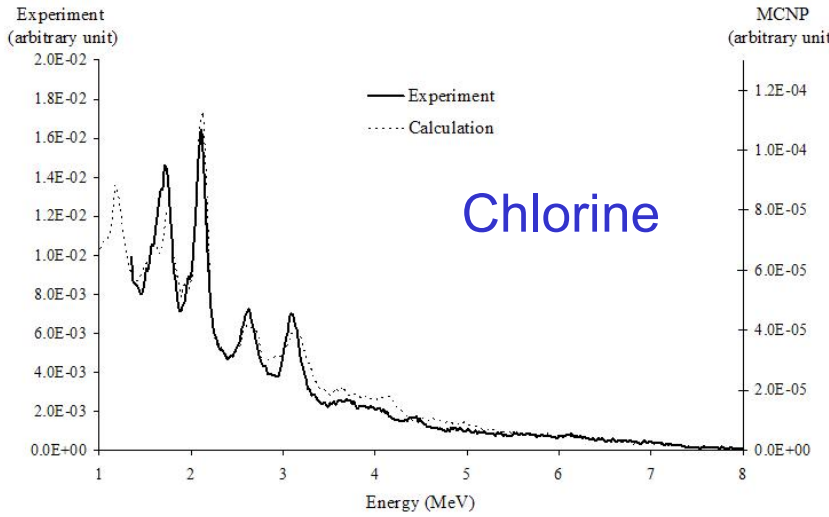


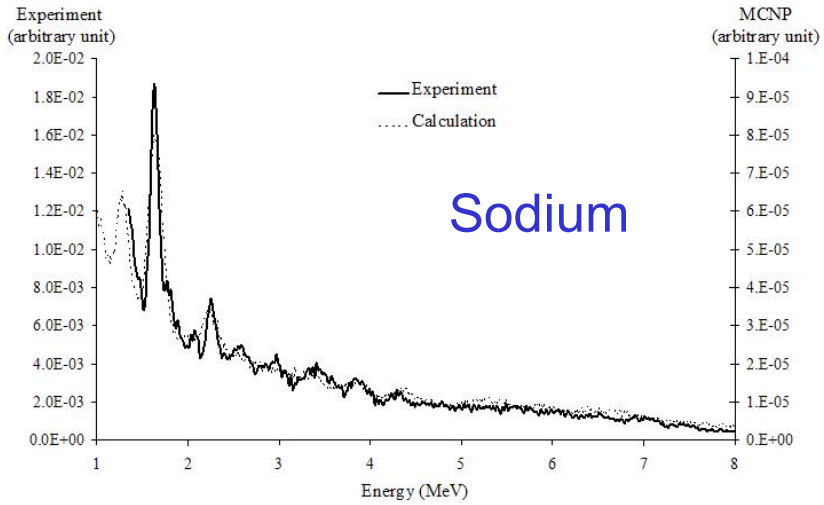


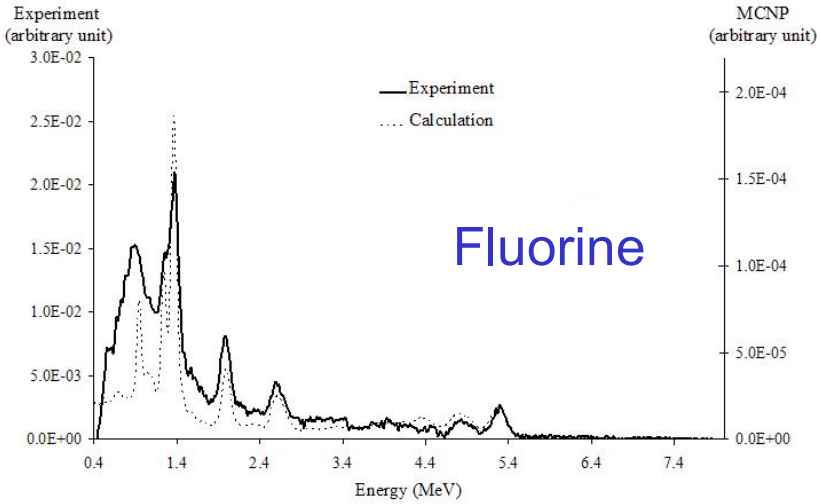


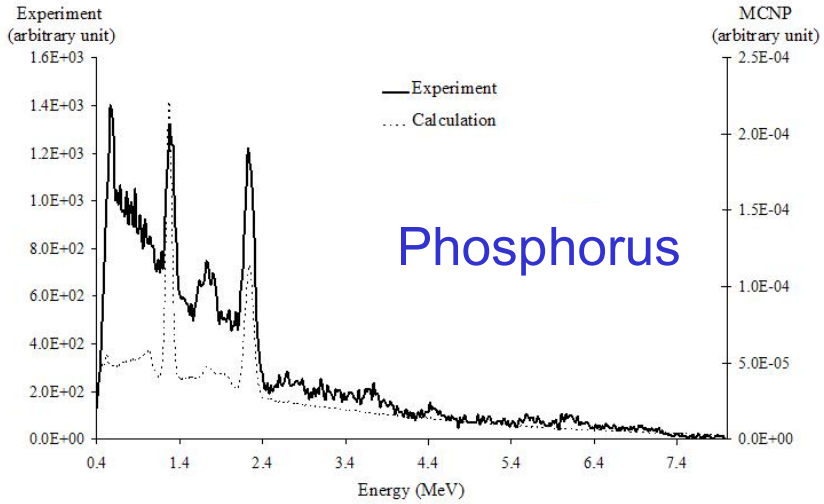


5”x5”x10” NaI(Tl) APT gamma-ray signatures (continued)





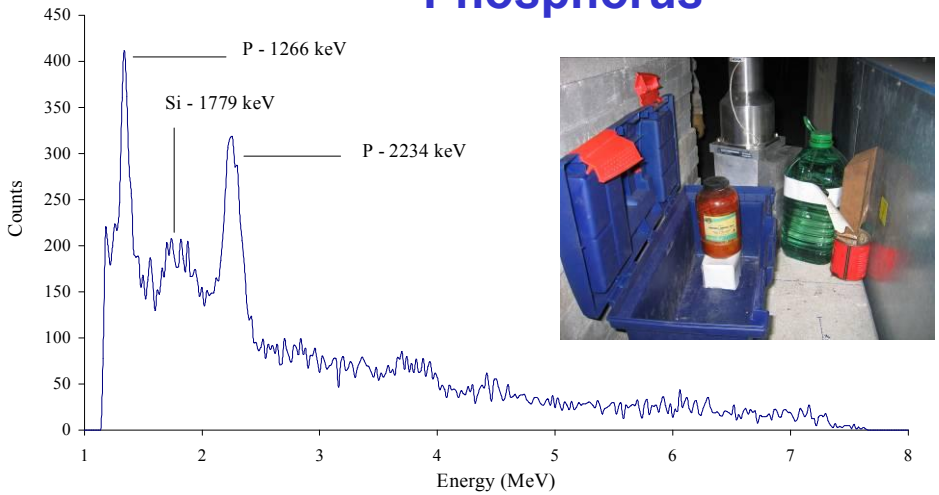




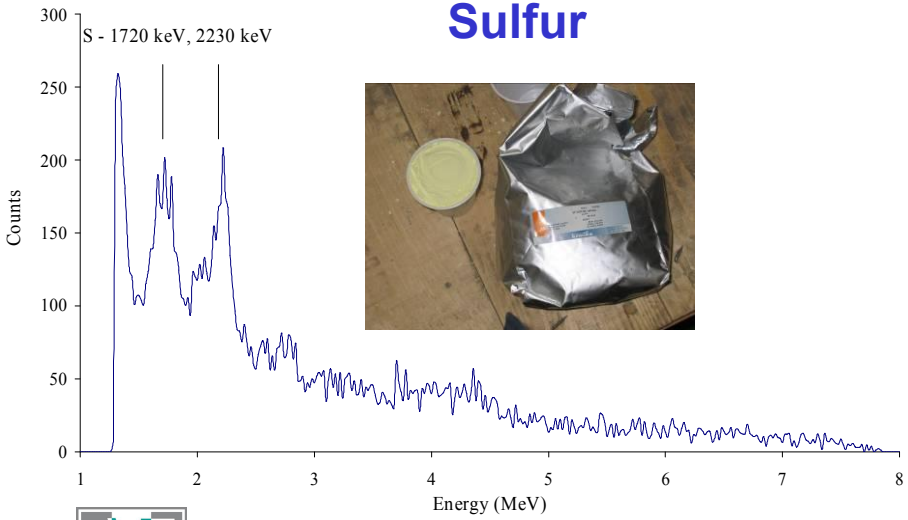
APT detection tests with Teflon®, S, and P samples

- 20 min. acquisitions
- One 5”x5”x10”NaI(Tl)
- ~ 200 g of each element
- 10^7 n/s (⇔ 10^5 tagged n/s)
- ~ 15 cm far from the wall

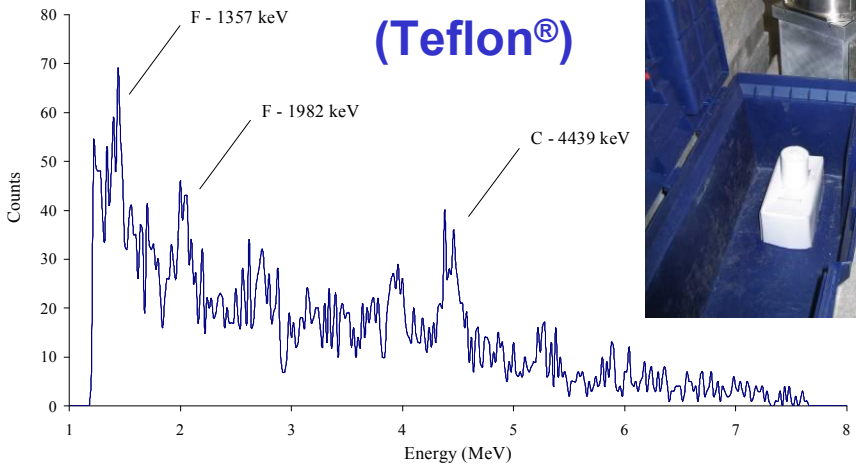
Phosphorus



Sulfur

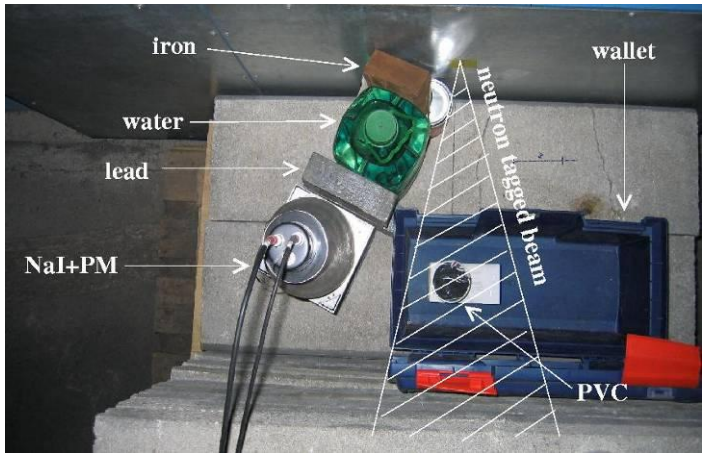


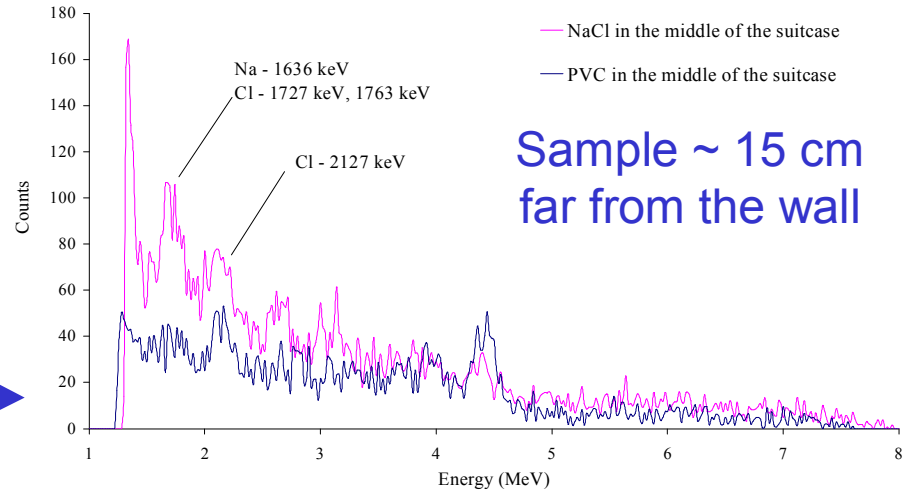
Fluorine (Teflon®)



APT detection tests with NaCl and PVC samples (~200 ml)

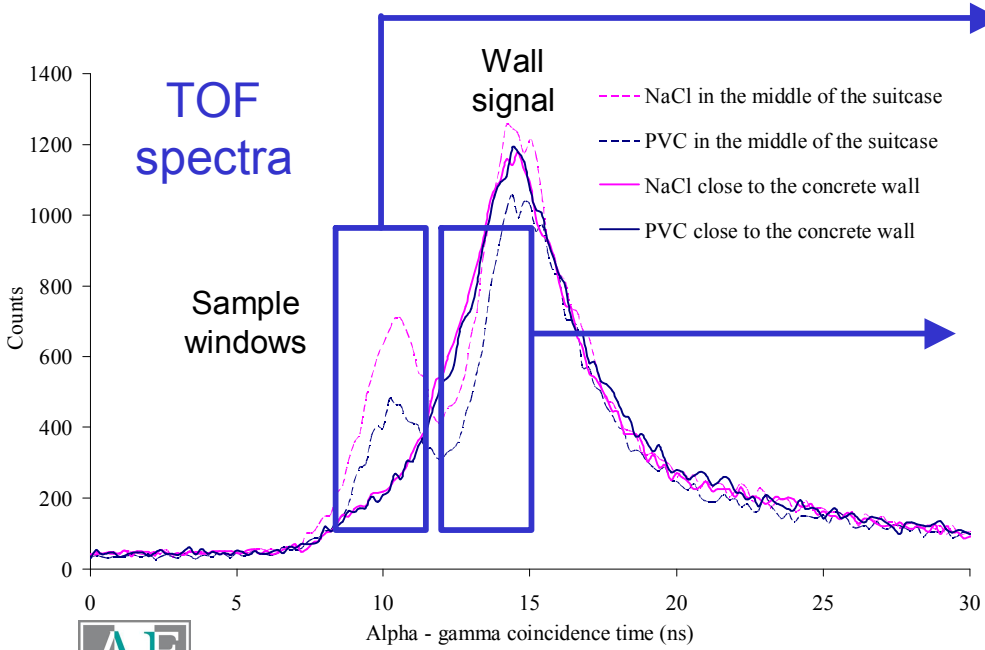
20 min. at 10^7 n/s (⇔ 10^5 tagged n/s) with one 5"x5"x10"NaI(Tl)

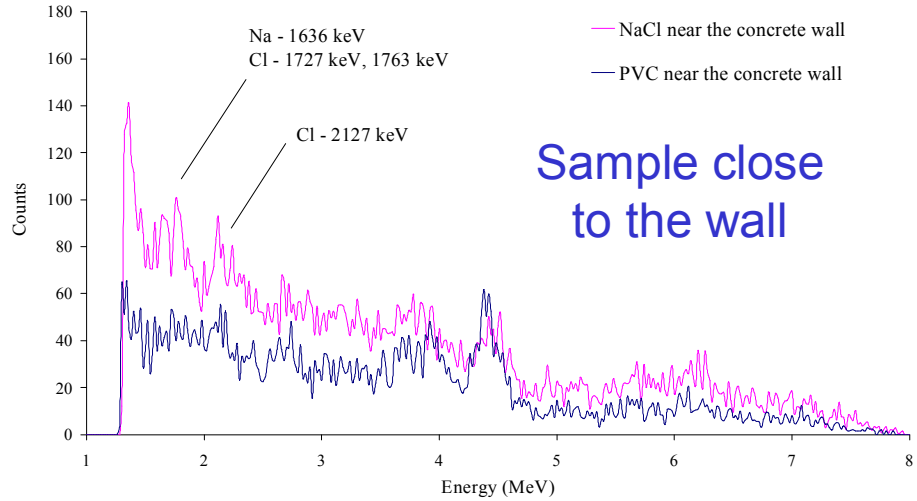




Sample ~ 15 cm far from the wall

TOF spectra





Sample close to the wall

Acquisition of PFTNA gamma-ray signatures

- **Pulsed DT Neutron generator**
  SODERN GENIE 16T
  14 MeV, 5.10^7 n/s

- **Compton Suppression Spectrometer**
  70% (HP)Ge + BGO veto shield

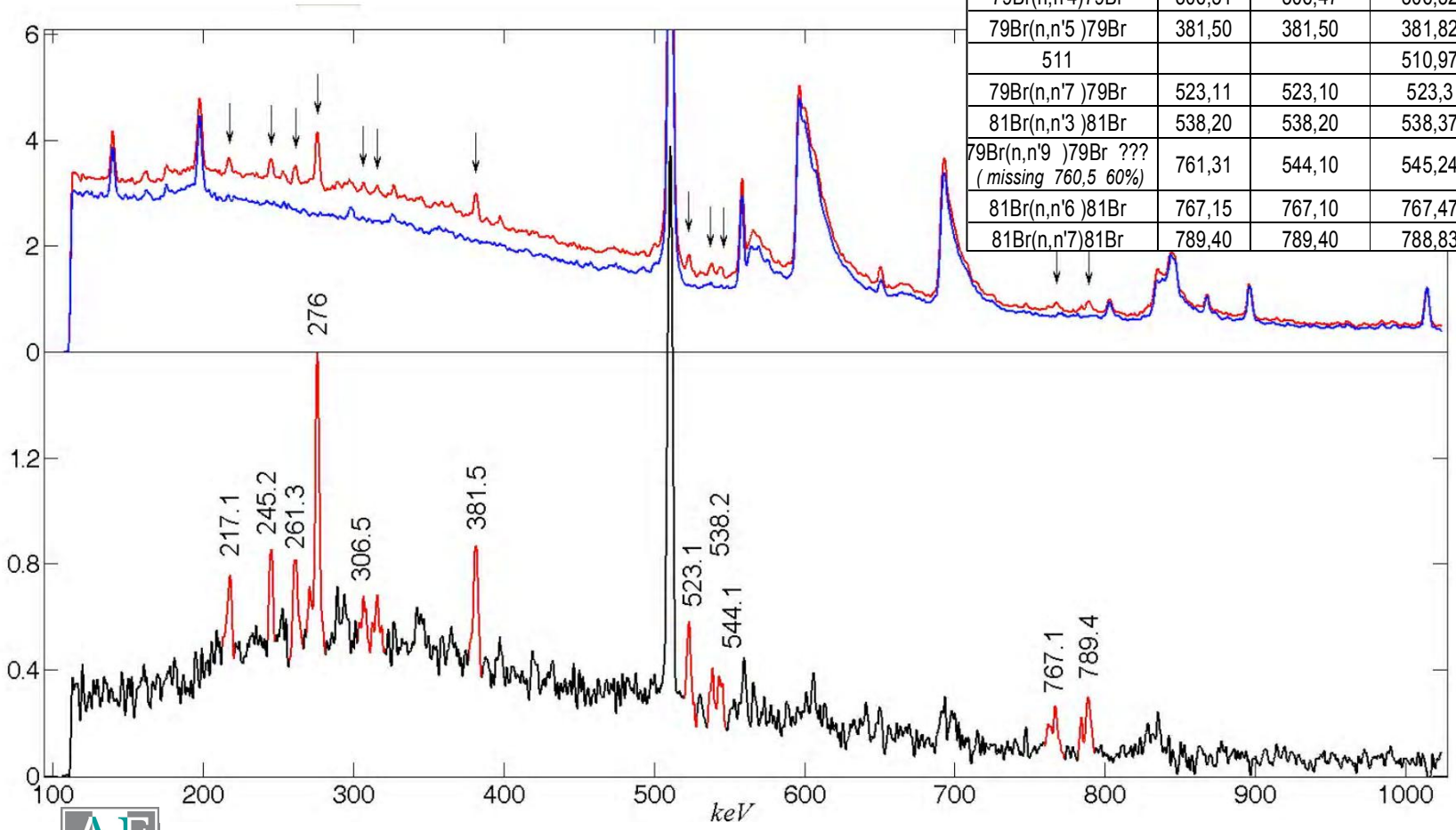
- **Efficient shielding**
  steel + polyethylene + lead

- **FNA spectrum** during neutron pulses
  TNA spectrum between neutron pulses
  (+ delayed spectrum after irradiation)

Bromine (KBr) FNA spectrum

Recorded during the pulses

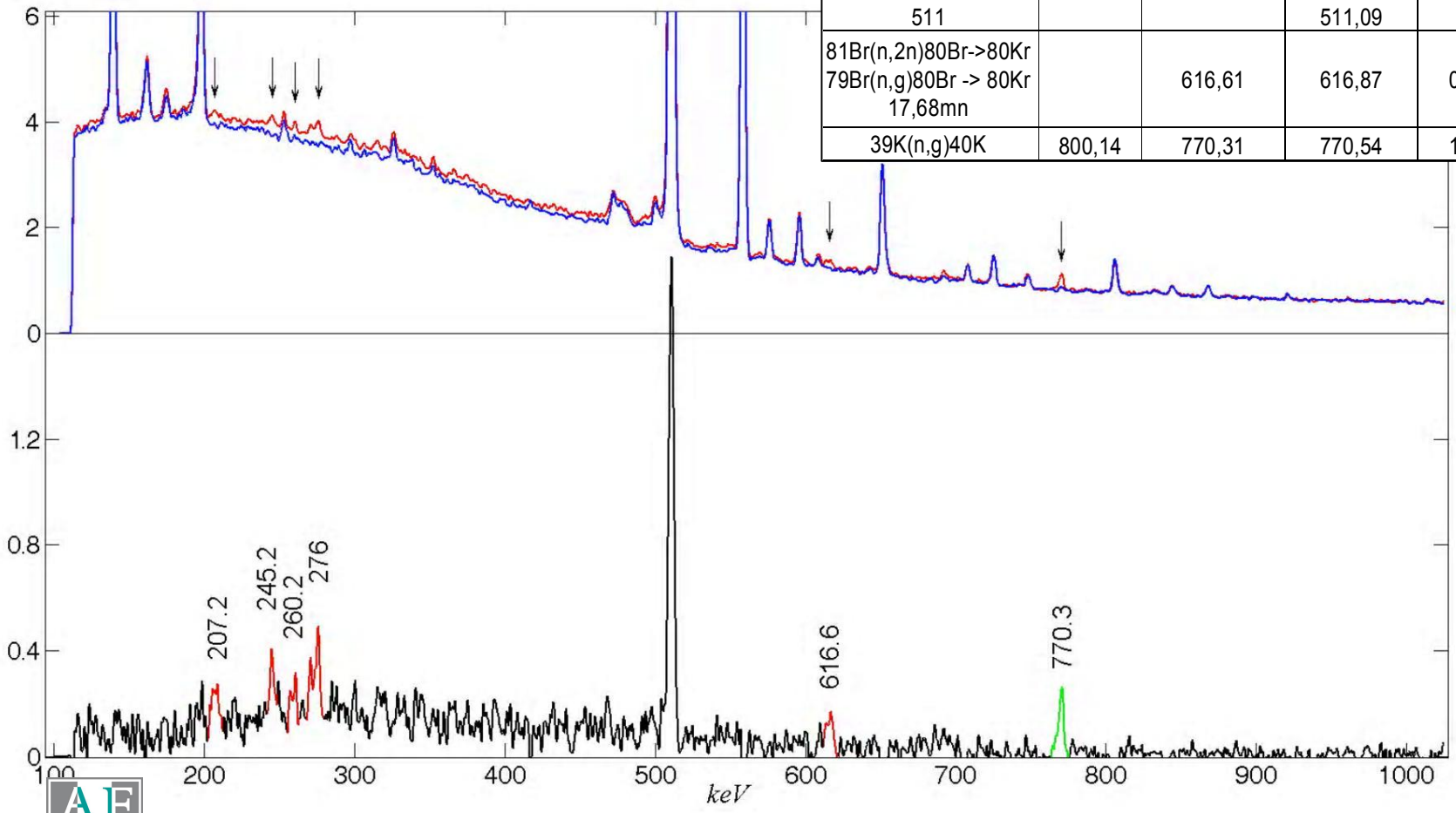
Reaction	Table (ensdf2) level (keV)	Table (ensdf2) gamma (keV)	Measure energy (keV)	Measure relative intensity	Measure FWMH (keV)
79Br(n,n'2)79Br	217,10	217,07	217,45	0,30	2.88
81Br(n,2n5)80Br	281,30	244,24	245,53	0,34	2,70
81Br(n,2n9)80Br	331,05	245,20			
79Br(n,n'3)79Br	261,33	261,33	261,58	0,35	2,94
81Br(n,n'2)81Br	536,20 (34.6µs)	260,21			
		275,99 ↓	276,26	**1,000**	2,85
81Br(n,n'1)81Br	275,99	275,99			
79Br(n,n'4)79Br	306,51	306,47	306,52	0,09	1,38
79Br(n,n'5)79Br	381,50	381,50	381,82	0,45	2,65
511			510,97		3,78
79Br(n,n'7)79Br	523,11	523,10	523,3	0,16	1.86
81Br(n,n'3)81Br	538,20	538,20	538,37	0,17	2.37
79Br(n,n'9)79Br ??? *(missing 760,5 60%)*	761,31	544,10	545,24	0,11	2,58
81Br(n,n'6)81Br	767,15	767,10	767,47	0,06	2,13
81Br(n,n'7)81Br	789,40	789,40	788,83	0,15	2.73



Bromine TNA spectrum

Recorded between the pulses

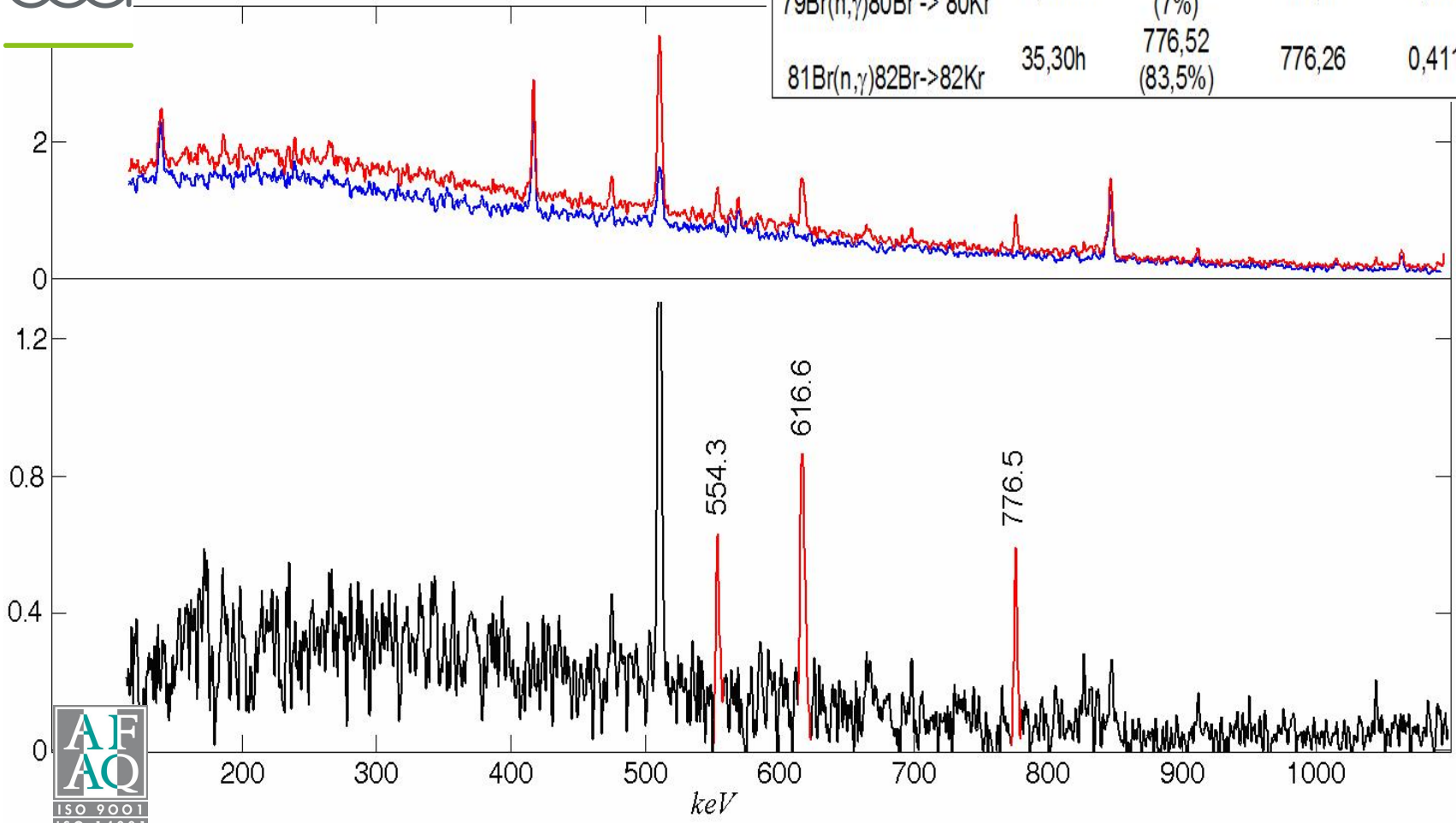
Reaction	Table (ensdf2)		Measure		
	level (keV)	gamma (keV)	energy (keV)	relative intensity	FWMH (keV)
79Br(n,n'1)79Br	207,10 (4.86 s)	207,07	207,08	0,31	2,21
79Br(n,g)80Br 79Br(n,g)80Br 81Br(n,g)82Br	281,30 331,05 290.80	244,24(0.45b) 245,20(0.8b) 244.83(0.15b)	245,12	0,49	2,13
81Br(n,n'2)81Br	536,20 (34.6 µs)	260,21	260,54	0,62	2,18
81Br *1level*	275,99	275,99	276,30	**1,00**	2,7
511			511,09		3,72
81Br(n,2n)80Br->80Kr 79Br(n,g)80Br -> 80Kr 17,68mn		616,61	616,87	0,48	3,18
39K(n,g)40K	800,14	770,31	770,54	1,44	2,67



Bromine delayed spectrum

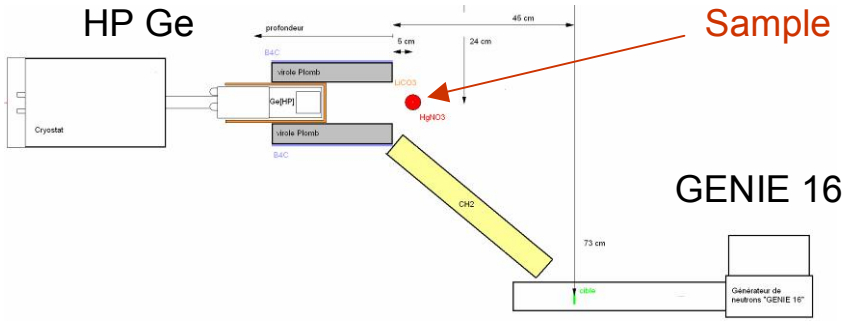
Recorded after irradiation

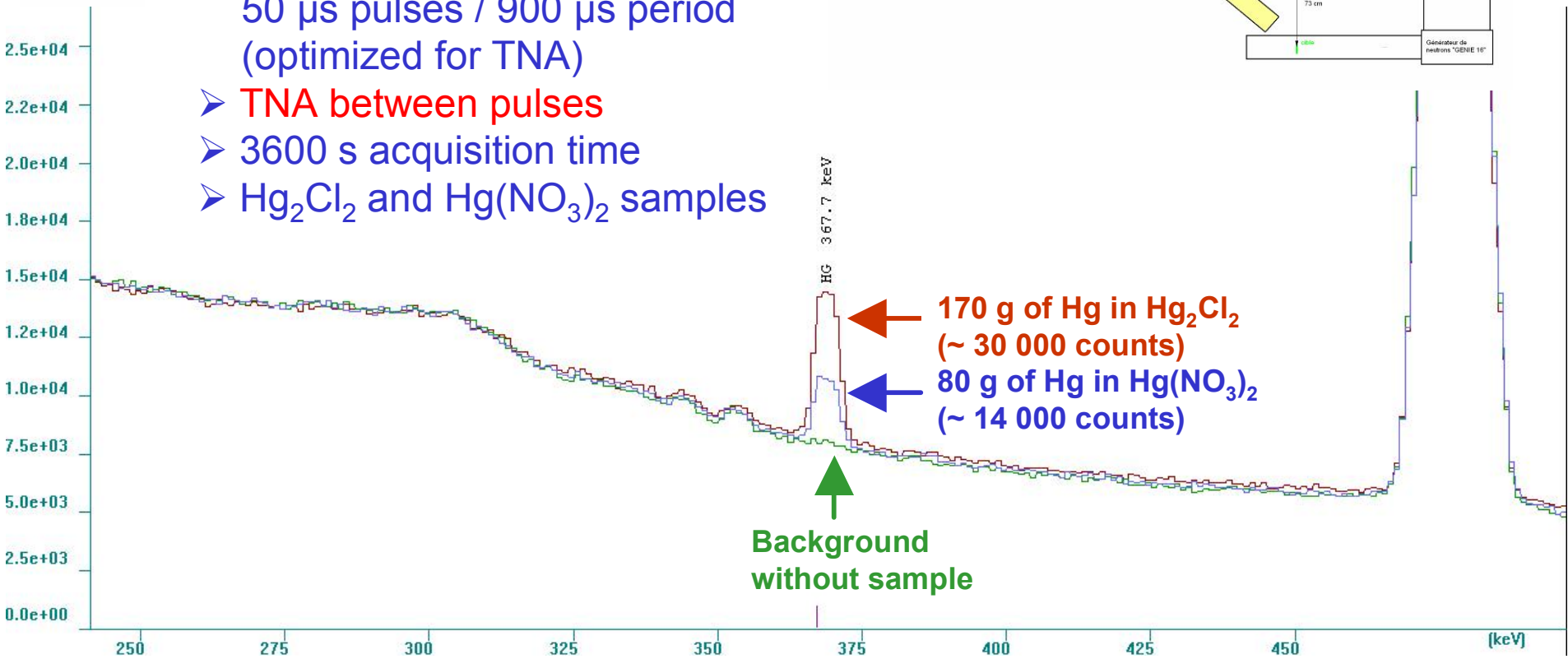
Reaction	Table (ensdf2) half life	Table (ensdf2) gamma (keV)	Measure energy (keV)	Measure relative intensity	Measure FWMH (keV)
β^+ annihilation			510,98	1,926	3,15
81Br(n,γ)82Br->82Kr	35,30h	554,35 (70,8%)	554,20	0,332	2,04
81Br(n,2n)80Br->80Kr 79Br(n,γ)80Br -> 80Kr	17,68mn	616,61 (7%)	617,33	**1,000**	3,84
81Br(n,γ)82Br->82Kr	35,30h	776,52 (83,5%)	776,26	0,411	2,13



PFTNA detection tests (e.g. mercury)

- Simplified “portable” setup
- 30% (HP)Ge detector
- SODERN GENIE 16 at 5.10^7 n/s
  50 µs pulses / 900 µs period
  (optimized for TNA)
- TNA between pulses
- 3600 s acquisition time
- Hg_2Cl_2 and $Hg(NO_3)_2$ samples





Conclusion and perspectives

- Detectors
  - APT: large volume NaI(Tl) or $LaBr_3(Ce)$
  - PFTNA: high efficiency HP Ge or $LaBr_3(Ce)$
  - Shield against neutron irradiation (polyethylene, lead…)
- APT gamma-ray signatures
  - Several useable gamma rays for Cl, Na, S, P, F
  - Low-energy peaks for As, Br, Tl ⇨ to be tested with $LaBr_3(Ce)$
  - Difficult for I and Hg
  - Inconsistencies between experiment and nuclear data / calculations
- PFTNA gamma-ray signatures
  - FNA spectra ⇨ help analyzing APT signatures
  - TNA ⇨ elements difficult to detect with APT (e.g. Hg)
  - Work under progress…

Acknowledgements

Thank you for your attention

- French R&D program for CBNR & E detection
- APT acquisitions performed with the EURITRACK system (FP6, EU) installed in the seaport of Rijeka, Croatia.

Many thanks to:

- Rijeka Custom Office and Port Authority, Croatia
- A.C.T. d.o.o. and Institute Ruder Boskovic (IRB), Croatia, for the implementation of the system in Rijeka, and for their constant support to logistics and measurements
- EURITRACK partners who took part with to the development and commissioning of the Tagged Neutron Inspection System: INFN, JRC, CAEN, SODERN, and IPJ