Detection of Explosives and Other Illicit Materials by Nanosecond Neutron Analysis

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2 Presentation Layout

1. Introduction: NNA / APT
2. Recent Progress
   - Hardware
   - Software
3. Recent Experimental Results
   - Detection of Explosives in a Suitcase
   - Identification of UXO
   - Experimental “Response Functions”
4. Summary

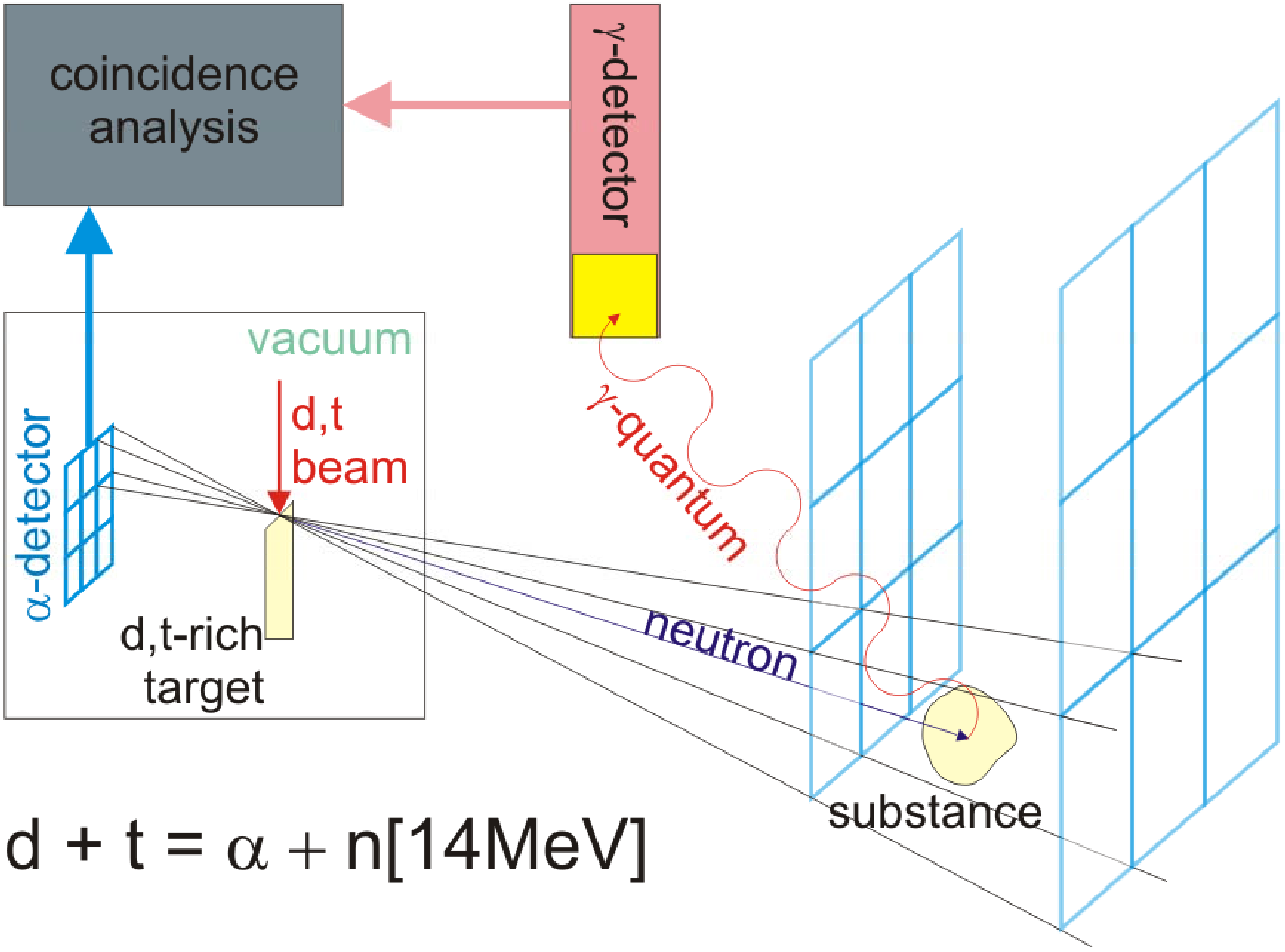
3 NNA / APT

Nanosecond Neutron Analysis / Associated Particle Technique

- Irradiate the object with “tagged” neutrons
- Detect γ-rays produced in the object
- Determine elemental concentrations from γ-spectrum
- Analyze concentrations and identify the object

3D elemental “image” of the inspected volume

4 NNA / APT



$$d + t = \alpha + n[14MeV]$$

5 NNA / APT: Major Challenges

Hardware ("Lego" parts):

- **AP neutron generator** – intensity, stability, lifetime…
- **Detectors of α-particles** – radiation damage, sealed vacuum, X-rays, beam particles, electrons, light…
- **Detectors of γ-rays** – efficiency, counting rates, energy & time resolution…
- **Data acquisition system** – counting rates…

Software:

- **Data analysis** – calibrations, spectral regression…
- **Decision-making** – multiple scenarios, automation…

6 Existing devices

SENNA III
(explosives)


SENNA IV
("Dirty bombs" and SNM)

SENNA V
(luggage)

Prototype
(liquids)

7 Directions of work

Existing devices

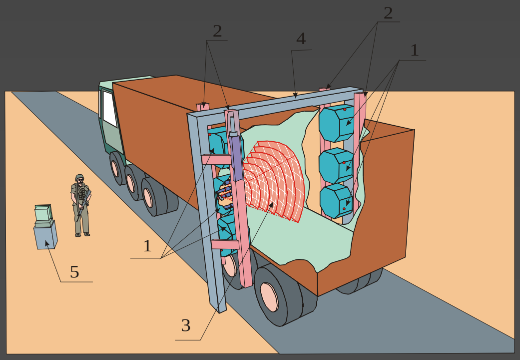
multiple NGs
and γ-detectors

portability

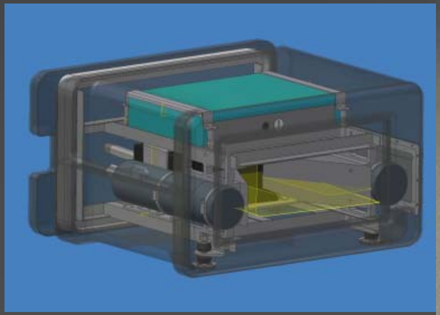
Confirmation sensor for cargo containers

Portable detector of hazardous materials

ISTC project #3534
IAEA Contract 13474

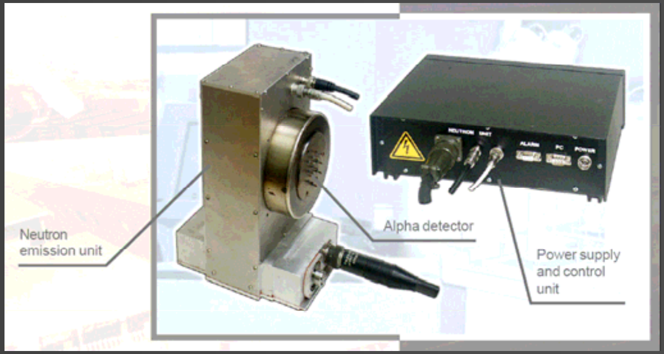


Built by APSTEC



8 Neutron generators

ING-27 (VNIIA, Russia)



Intensity: $(2 \div 10) \times 10^7$ n/s

Lifetime: ~1000 hours

Weight: ~8kg

Dimensions: 270mm × 200mm × 140mm

Now cooperating with another NG producer:

- ASPECT, Dubna, Russia

9 APSTEC's α-detectors

Existing detectors of α-particles

3 × 3 = 9 pixels (commercial)

6 × 6 = 36 pixels

New types of α-detectors

12 × 12 = 144 pixels
(for large volumes)

Diamond
(extra-long lifetime)

10 γ-detectors

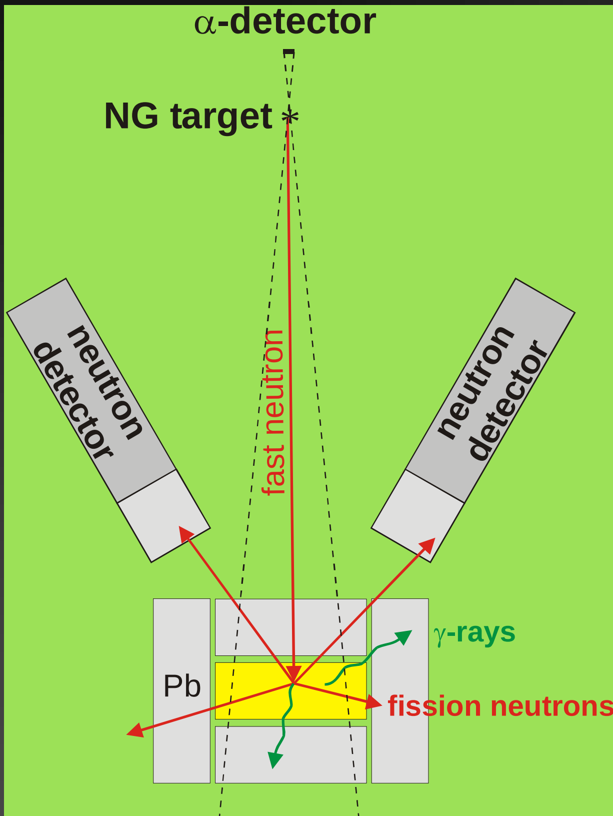
So far we used 3” × 3” BGO-based γ-detectors

- High efficiency
- Medium resolution
- Low cost

Recently switched over to 3” × 3” $LaBr_3$

- High efficiency
- Excellent resolution
- Expensive

11 Neutron detectors

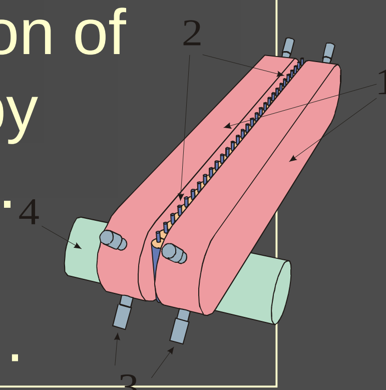


Plastic-based, small-size

proof-of-principle only

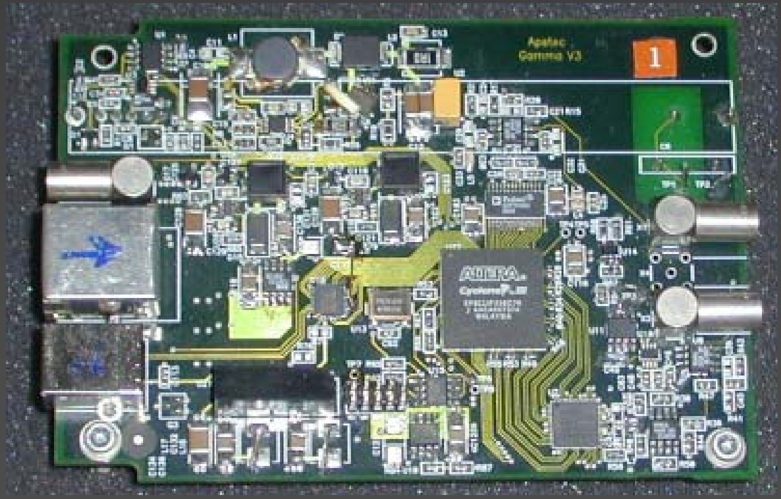
Low-background large-area neutron detector for standoff detection of shielded nuclear materials by passive and active methods.

New ISTC Project planned…



12 γ-detector spectrometers

- Pulse digitized by 200MHz ADC
- Pulse shape analyzed by PLD
- HV microchip + controller on board
- Installed on detector body
- Control method:
  - via Ethernet – as part of an NNA/APT device
  - via USB – as a standalone spectrometer



13 Data Acquisition System (DAQ)

“Traditional” modular DAQ:

1. Real-time α-γ coincidence analysis
2. Control HV and other detector parameters
3. High counting rates ($<10^6$ α/s, $<10^5$ γ/s each)
4. Multiple γ-detectors (12 maximum)

Built-in data collection PC

Single 19”-wide 4U-high crate

14 DAQ

New requirements to portable DAQ:

1. Ultra-compact

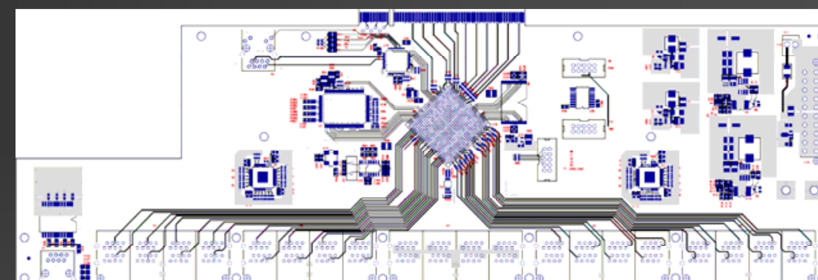
New requirements to “container” DAQ:

1. Multiple neutron generators
2. More γ-ray detectors
3. Higher total counting rate
4. “Manageable”:
   - one cable per detector
   - easily transportable
   - simple to configure and to use

DAQ

New data acquisition systems

Ultra-compact (α-detector + 4 γ-detectors)	Universal (up to 40 $\alpha/\gamma/n$ detectors)



DAQ is a part of a PLD microchip of the α-detector electronics

DAQ is a separate 2U-high, 19”-wide module

16 DAQ

	"Old"	New "portable"	New "container"
Max number of AP NGs	1	1	40 + can be daisy-chained
Max number of n/γ detectors	12	4	
DAQ computer required	yes	no	no
Max data transfer rate (event/s)	2×10^6	10^6	10^7
Data transfer channel	USB 2	Ethernet, 100Mb	Ethernet, 1Gb
Form-factor	19", 4U	n/a	19", 2U

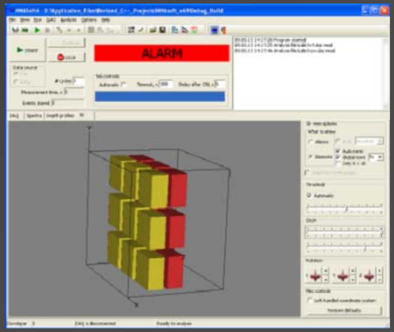
17 Software

Energy spectra of γ-rays

Fitting the spectrum with “response functions” to individual chemical elements

Concentrations of chemical elements

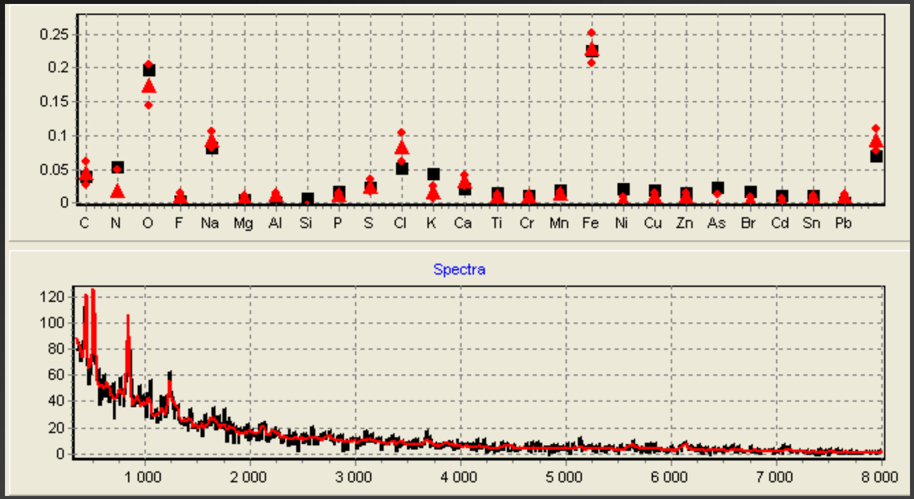
Analyzing concentration by “fuzzy” logic-based procedure

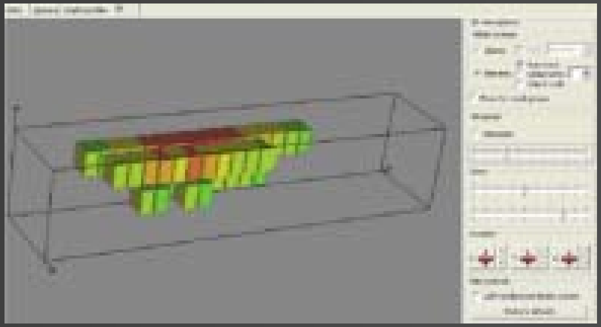


Decision

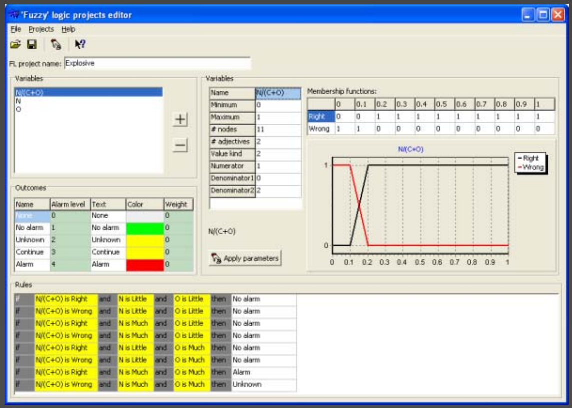
18 Software

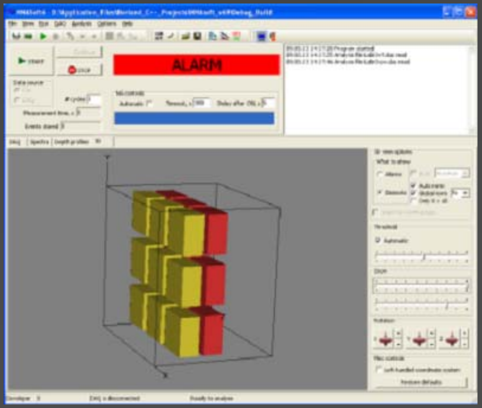
Spectral fitting: Partial Least Squares (PLS)





Decision-making: “Fuzzy” Logic





Also studied: neural networks and SVM

19 Recent Results: Explosives

Detecting 200g-500g explosives' imitators in suitcases by SENNA IV device (four BGO-based γ-detectors)

(Test supervised by Bruker Daltonics and DSTL)

20 Recent Results: Explosives

Scenario:

nitrogen-rich explosive (AN, RDX) in a suitcase filled with benign materials (books, cotton, wool, water, vodka, electronics, toothpaste, cocoa butter, etc.)

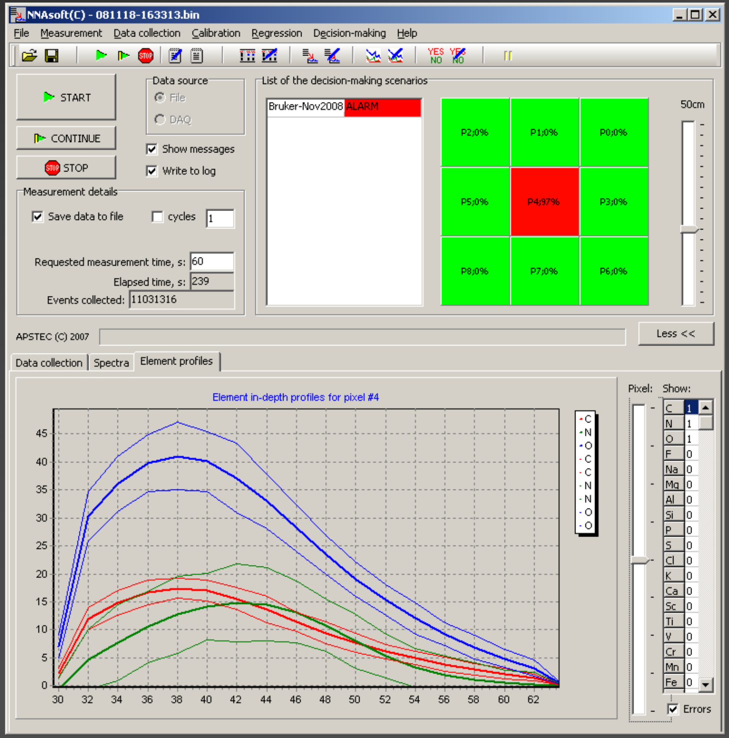
Measurement time: 4 min.

NG intensity: 5×10^7 n/s

21 Recent Results: Explosives

Results:

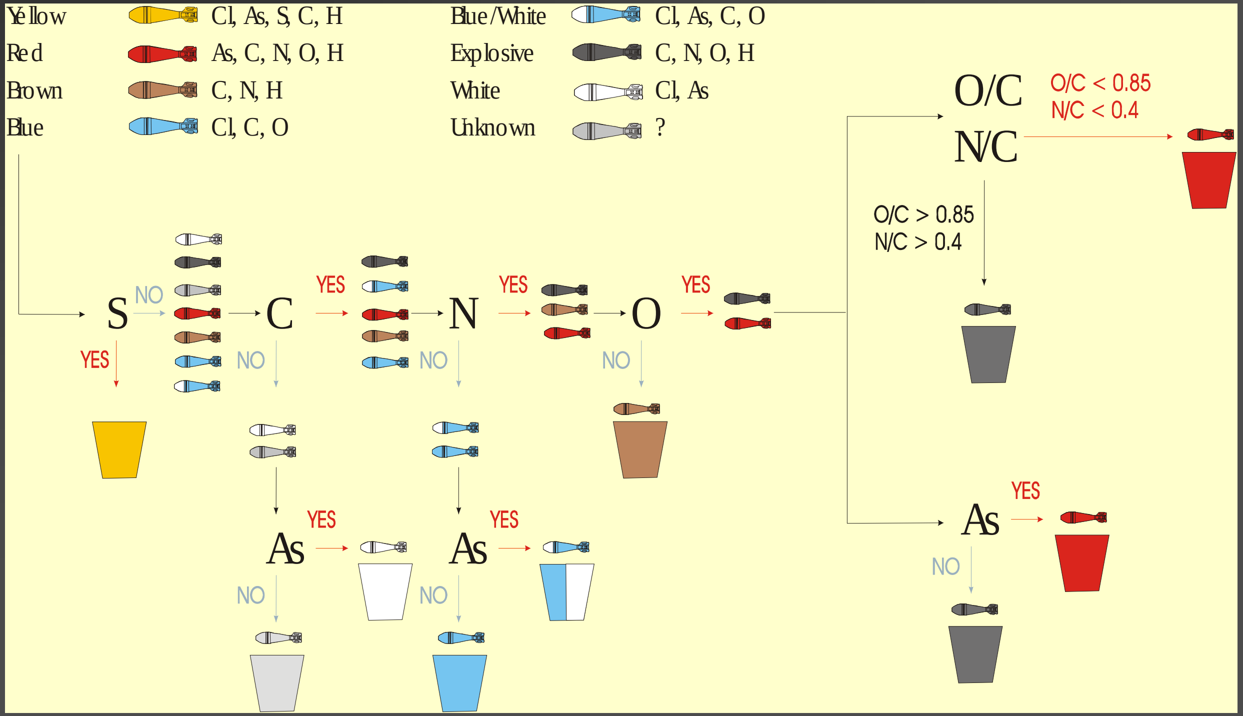
- 100% samples within sensitive volume detected
- No false alarms from “benign” suitcases
- No false alarms from areas with benign objects



Recent Results: UXO

Scenario: rusty shells are on a conveyor belt at a disposal facility (ACWD Project).

8 types of shells + empty, partially filled + filled with water/sand



23 Recent Results: UXO

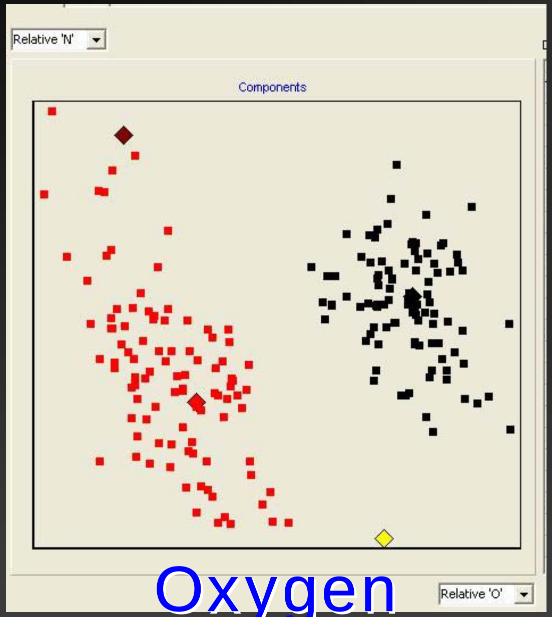
Experimental conditions:

- Duration of each measurement was **60 seconds**
- **100 measurements** with each imitator
- **Automatic** identification

Type	Composition of the real shell	Simulated by…
“yellow”	50% mustard gas + 50% Lewisite	arsenic oxide, sulfur, salt, graphite, water
“black”	explosive	melamine, water, graphite
“red”	diphenyl-cyanoarsine + explosive	arsenic oxide, melamine, water, graphite
“brown”	Prussic acid	melamine, graphite

Recent Results: UXO

N



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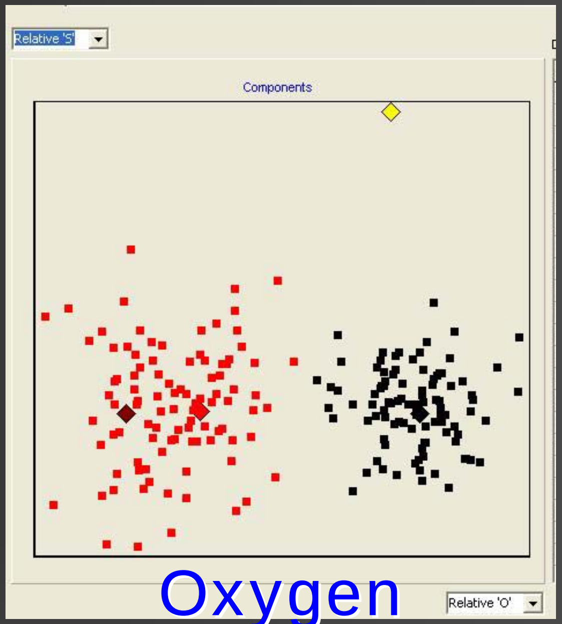
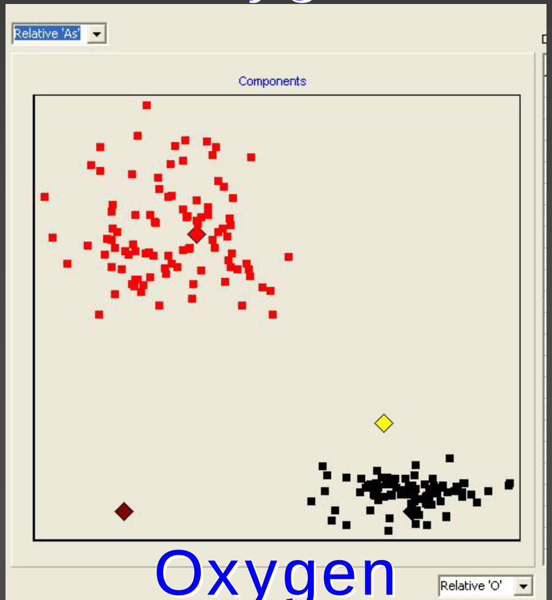


As



Each dot represents a single measurement

100% simulants identified correctly

25 Recent Results: UXO

UXO on the surface of sand

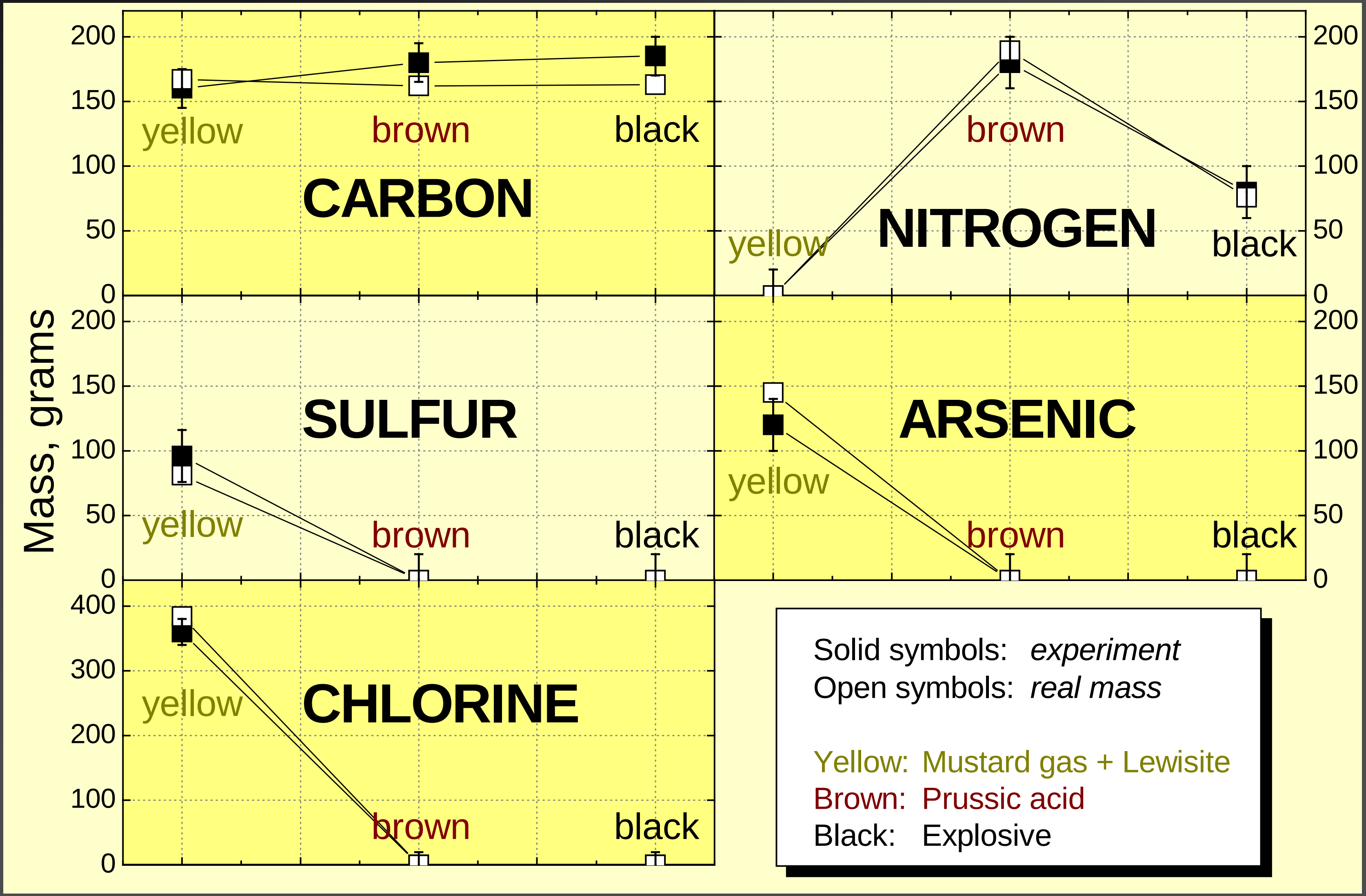
Difficult: many chemical elements

- CW constituents: H, C, N, O, S, Cl, As...
- Shell: Fe...
- Soil: H, O, Si, Al, Ca, Mg, K, Na, P ...

http://uxoinfo.com/uxoinfo/newsletters/80Dec_2007.htm

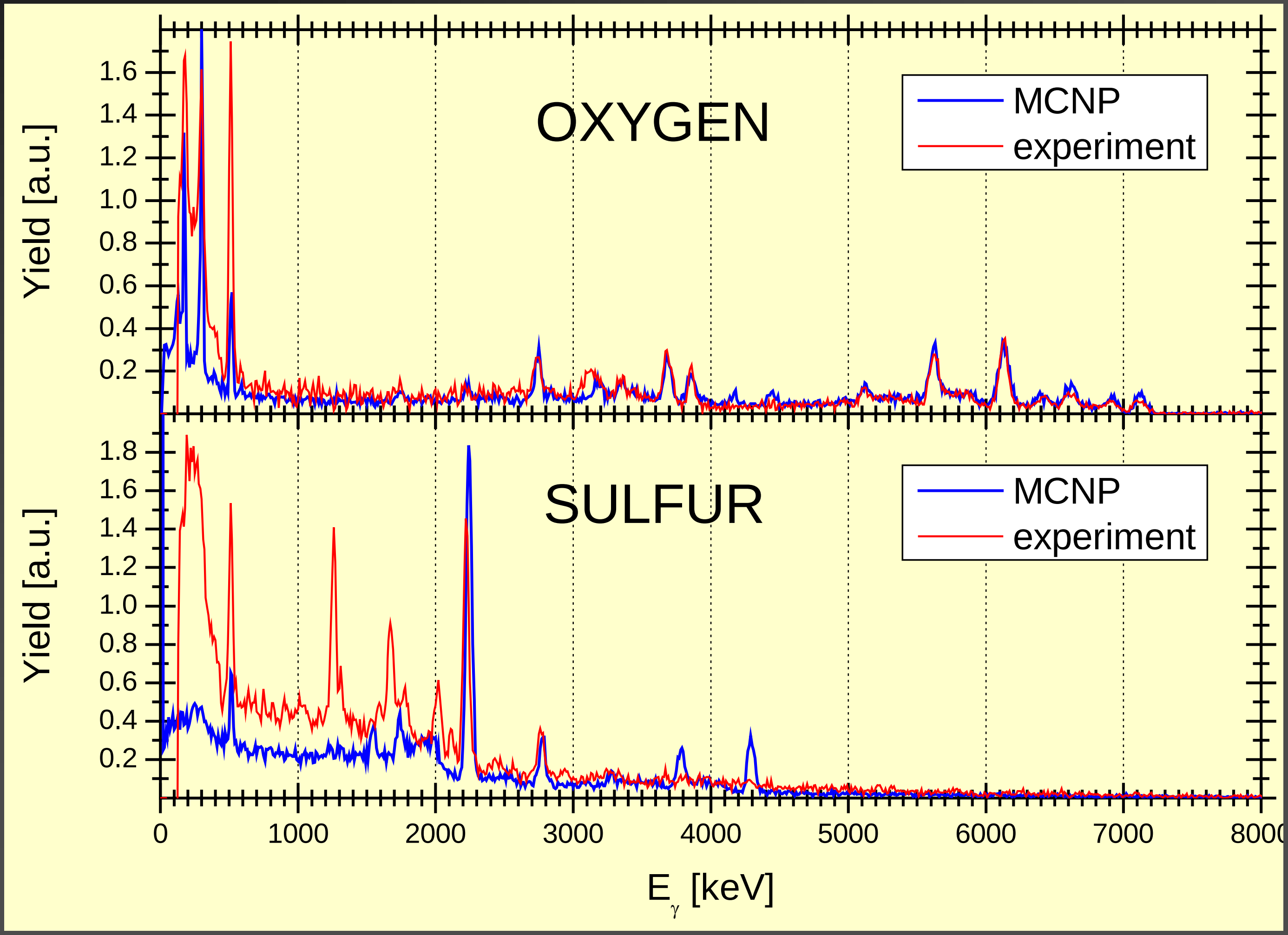
Recent Results: UXO

Masses of elements in UXO are reproduced!



27 “Response functions”

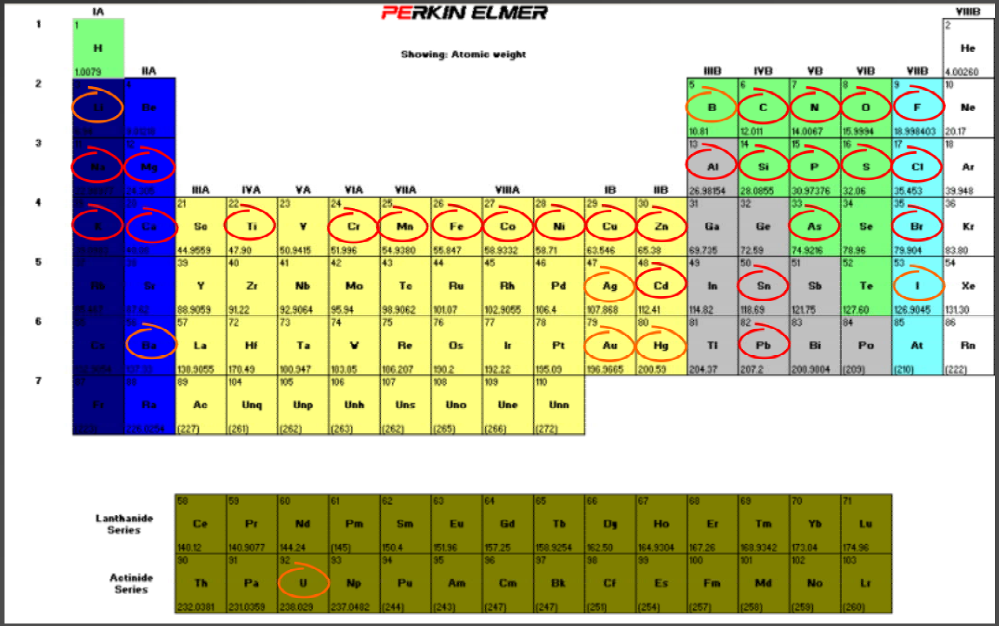
For some elements MCNP produces wrong “response functions”



28 “Response functions”

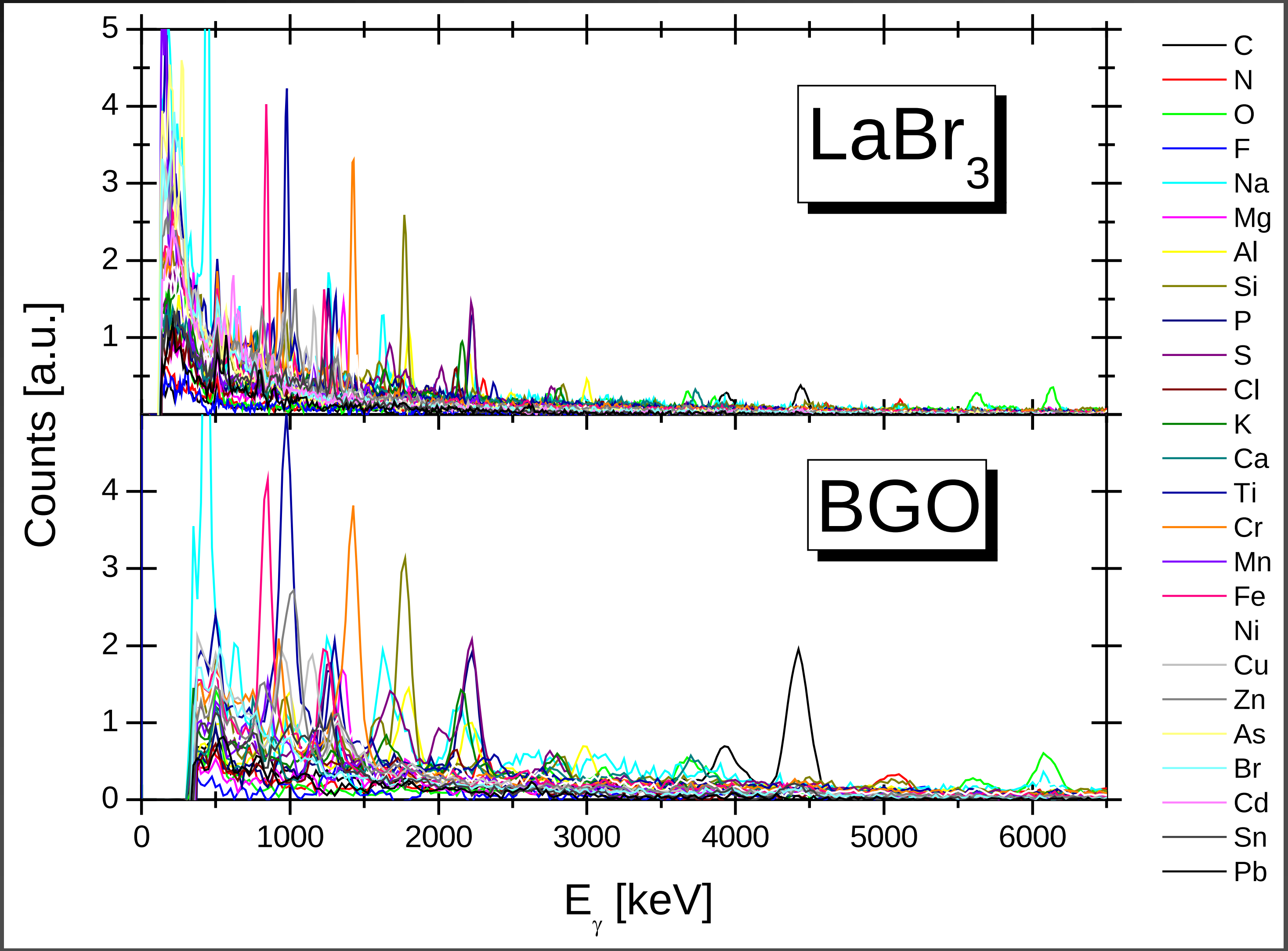
Experimental “response functions” for BGO & $LaBr_3$

- Neutron generator + BGO + NaI + $LaBr_3$
- Samples: pure chemical elements (where practical), oxides, hydroxides, acids: 300g of the pure element in each sample



“Response functions”

Experimental “response functions” for BGO & $LaBr_3$



30 Summary

NNA / APT devices automatically detect concealed explosives and SNM

Stationary and mobile NNA / APT devices are reliable UXO inspection tools

NNA / APT devices can now be assembled from ready “Lego” parts according to one’s needs