Development of Neutron Interrogation System for Illicit material

Dr. (Smt.) Bishnoi Saroj

Technical Physics Division, Bhabha Atomic Research Centre, Mumbai, India.

Email:saroj@barc.gov.in

Problem and Motivation

Goal: Neutron interrogation system development using lab based D-T Neutron Generator for detection and imaging of illicit material in bulk volume of car, truck etc.

Problem: Presently control systems are mostly X-Ray/Gamma based scanner. These systems provide images based on shape, size, density etc and have have high throughput and are ideally suited for detection of metallic objects with distinctive shapes and size such as gun, metallic weapon and ammunitions. However, most of the current potential threats material (RDX,TNT, etc) do not possess specific discernible shapes and these systems fail to differentiate these low density materials (containing H, C ,N, O etc) including narcotics and explosives.

To meet such challenges alternative approach is required and that is Neutron based interrogation techniques

Neutron based interrogation techniques can characterizes the illicit/benign materials detecting

- Chemical composition with particular ratios of light elements (H, C, N, O)
- Presence of particular elements (Cl, S, P, F, etc.)

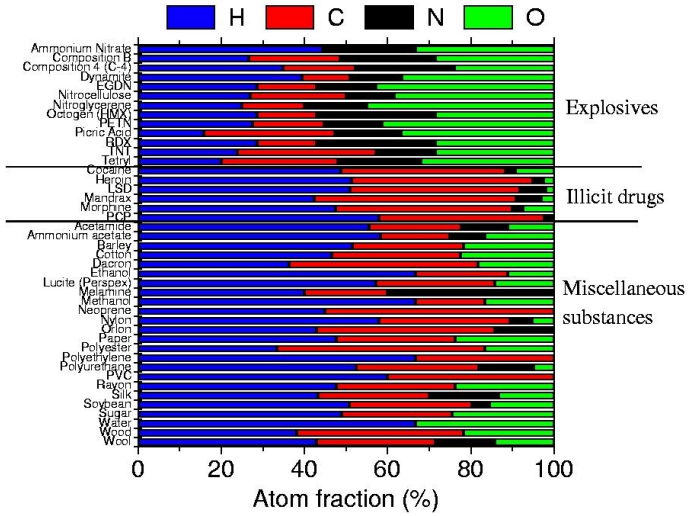


Fig: Chemical composition of C,H,N,O elements which constitutes a selection of explosives, illicit drugs & miscellaneous everyday materials.

CHEMICAL COMPOSITION of different material showing : WHAT MAKES THREAT (EXPLOSIVES) DIFFERENT FROM BENIGN MATERIALS

Examples of elemental compositions of some threats and common benign materials (concentration of the elements is given in weight %).

	C	H	N	O	N/C
Explosives					
C4	21.9	3.6	34.4	40.1	2
TNT	37	2.2	18.5	42.3	1
PETN	19	2.4	17.7	60.8	1
AN	0	5	35	60	∞
Benign					
Water	0	11.1	0	88.9	0
Paper	44	6	0	50	0
Plastic	86	14	0	0	0
Salt	0	0	0	0	0

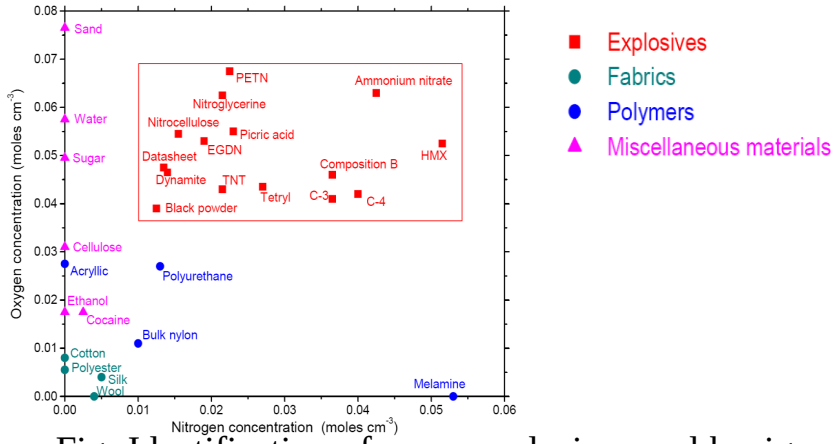
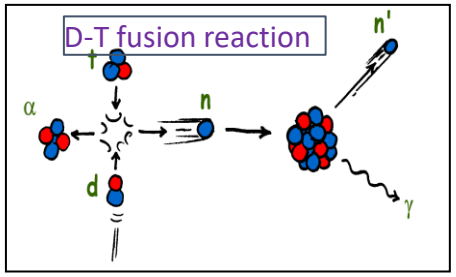


Fig: Identification of some explosives and benign materials based on nitrogen and oxygen fraction.

Neutron Interrogation -Associated Particle Technique (APT)

- ✓ APT is based on D-T neutron (14 MeV) produced from D (T, n) α fusion reaction in a D-T neutron generator.
- ✓ Alpha particle emitted back-to-back direction detected with a position sensitive detector to tag the neutron in its emission time as well as its direction.
- ✓ Tagged neutrons are used for probing the material and an image of the inspected voxel can be reconstructed in 3D volume along with material identification by detecting neutron induced gamma signature in coincidence with alpha particle.

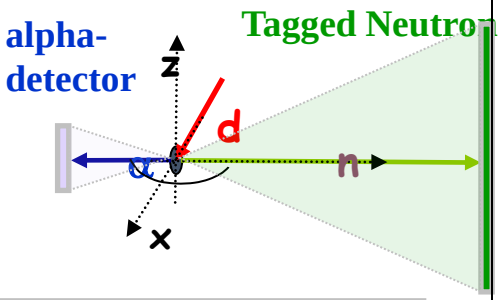
Methodology of APT

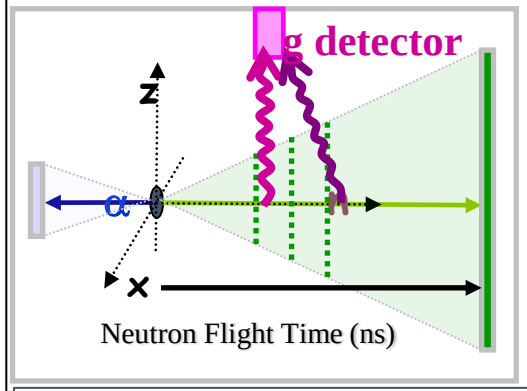


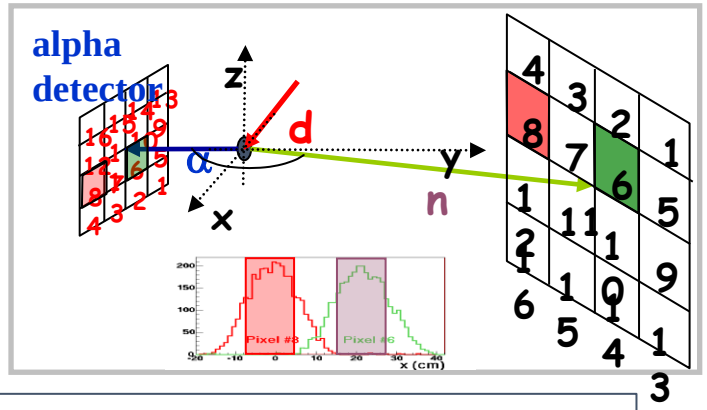
$v_g \sim 30$ cm/ns

$v_{n\_14.1MeV} \sim 5$ cm/ns

time of flight

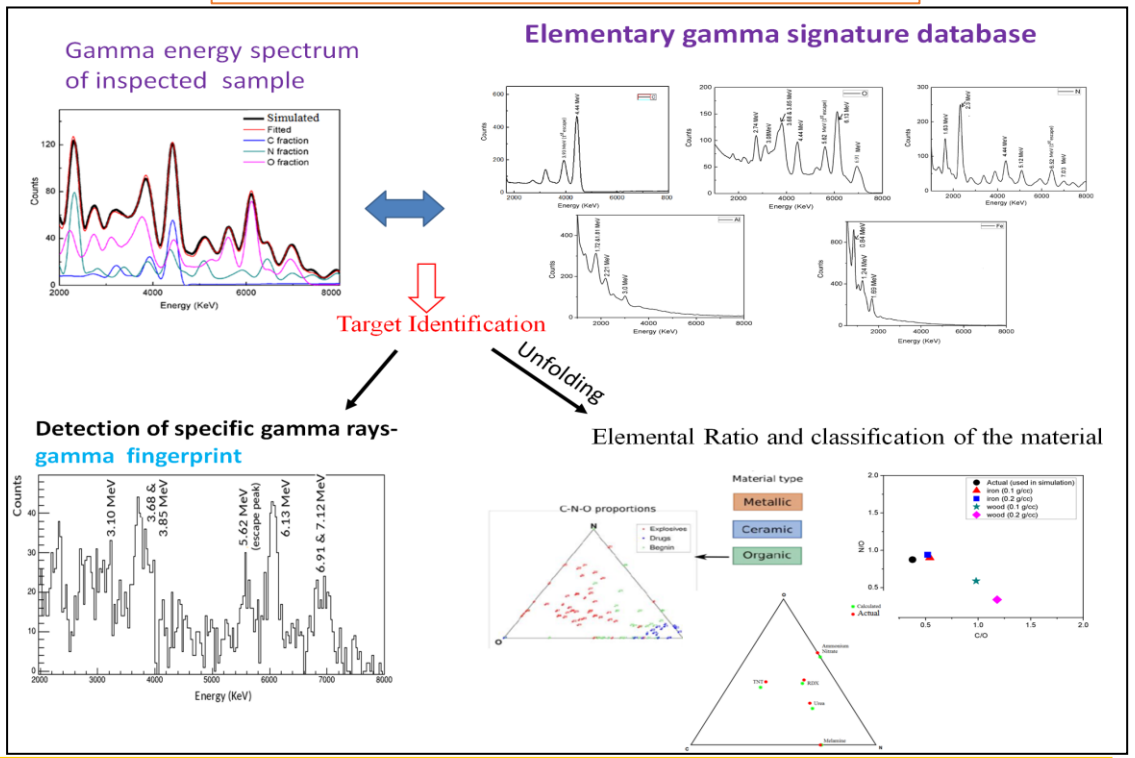






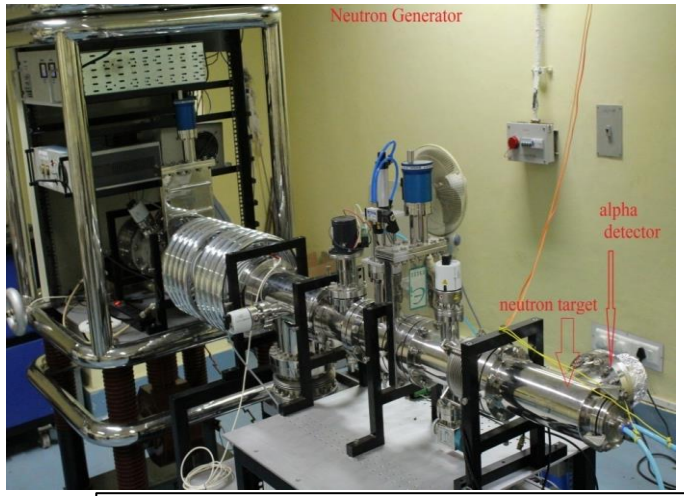
Neutron induced gamma detection in coincidence with alpha and position of investigated voxel

Implementation Procedure of APT



APT REDUCES BACKGROUND for Fast Neutron Analysis

APT based Tagged Neutron System



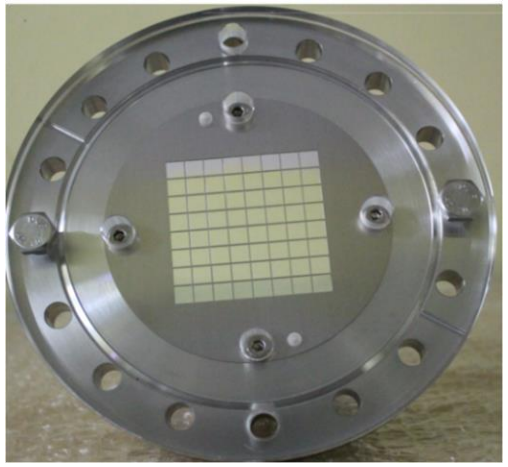
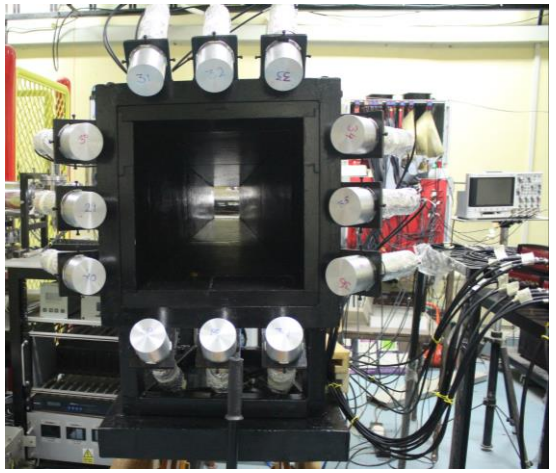
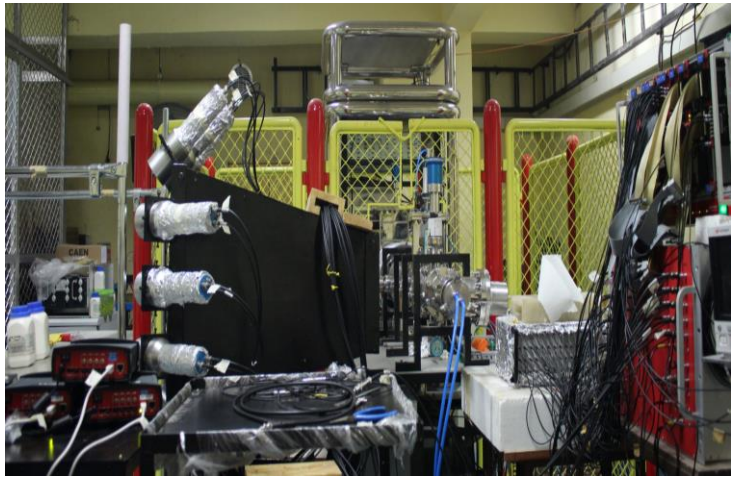
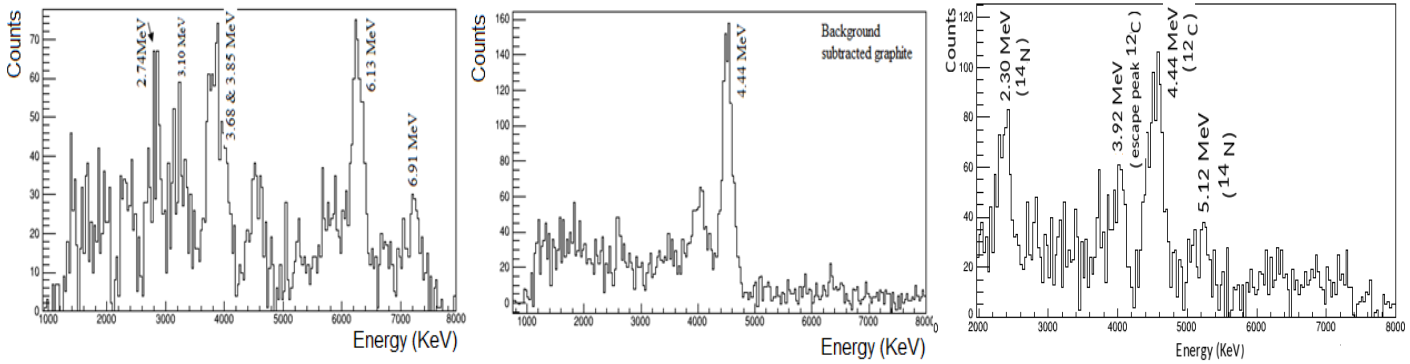




Fig: Neutron Generator, Multipixel alpha detector, array of the gamma detector, system with sample and DAQ

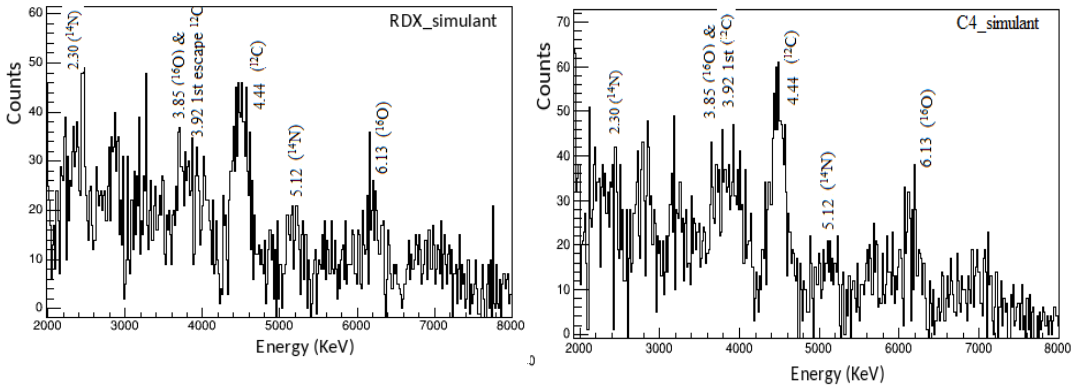
- An experimental APT based Tagged neutron system (TNS) has been developed using in-house developed D-T neutron generator coupled with multipixel (64-pixels) YAP:Ce alpha tagging detector and an array of BGO detector.
- Integrated with VME based data acquisition, custom deigned compact shielding structure
- Various software tools required for data processing, spectrum unfolding, image reconstruction (2D/3D) and visualization were developed indigenously. In order to verify these tools, a complete model of the TNS was developed in Monte-Carlo based GEANT4 simulation tool.
- Proof-of-concept experiments with various benign (melamine, Urea etc) and illicit material simulants (RDX, C4 etc) has validated the efficacy of the system toward illicit material detection.

Results and discussion

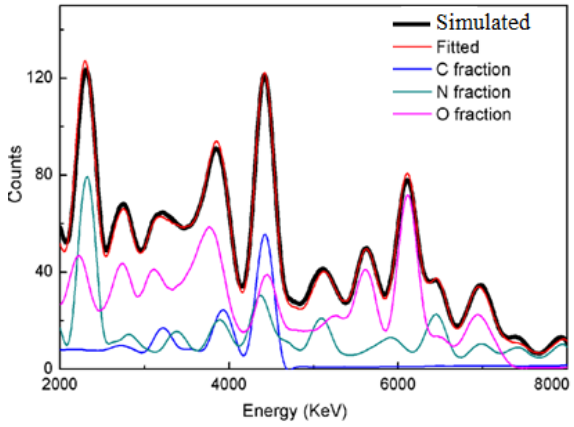
Energy spectra of Benign Materials –Water, graphite, Melamine



Energy spectra of Explosive simulants – RDX, C4



Analysis: Unfolding of unknown sample spectra to identify and imaging of the location of the investigated region



$S = \sum a_i R = a_1 C + a_2 N + a_3 O + \ldots\ldots$

Fig: Decomposition of complex spectra to elemental spectra of C, O and N.

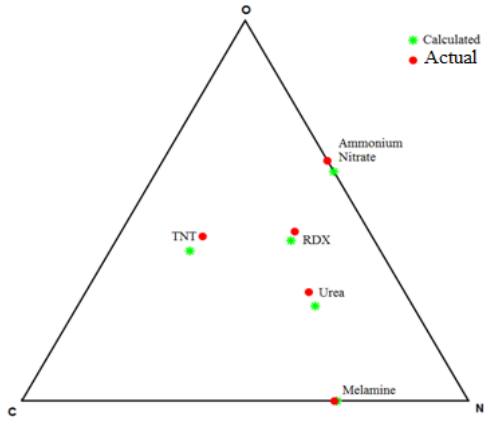
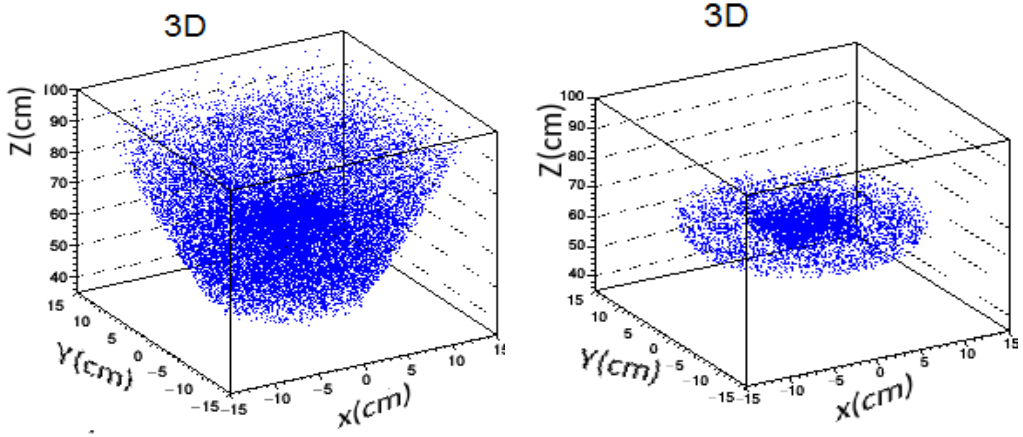


Fig: Triangle diagram showing position of the different investigated samples based on their carbon, nitrogen and oxygen composition, evaluated from simulated vs actual values.

2D and 3D imaging of interrogated object with TNM



Reconstructed 3D images of hidden illicit material inside an iron matrix (0.1 gm/cc) container (left) with and (right) without time window selection.

References

1. V. Valkovic et.al., Neutron-charged particle coincidence measurement from 14.4 eV neutron induced reactions. Nucl. Instrum. Methods 76, 29–34 (1969)
2. Buffler, Contraband detection with fast neutrons. Radiat. Phys. Chem. 3, 853–861 (2004)
3. S. Bishnoi et al., Study of tagged neutron method with laboratory D-T neutron generator for explosive detection, Eur. Phys. J. Plus 135,428(2020).
4. S. Bishnoi et al., Modeling of Tagged Neutron Method for Explosive Detection using GEANT4. Nuclear Inst. and Methods in Physics Research, A 923 (2019) 26.

Acknowledgements

We are thankful to Dr. L. M. Pant Head ,TPD for his consistent technical support and guidance to develop system. We also acknowledge our team mates Dr. P. S. Sarkar, Tarun Patel, Jilju Ratheesh, Manoj Pal, Mr P S Adhikari, Mr Chandrakant and TPD staff for their support in developing Neutron generator and operating during performing various experiments.

Thank You