Using Fast Neutrons to Detect Explosives and Illicit Materials

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International Symposium on Utilization of Accelerators, Dubrovnik, Croatia, 5-9 June 2005

(Paper IAEA-CN-115/59)

International Workshop on

Fast Neutron Detectors and Applications

University of Cape Town, Cape Town, South Africa

3 - 6 April 2006

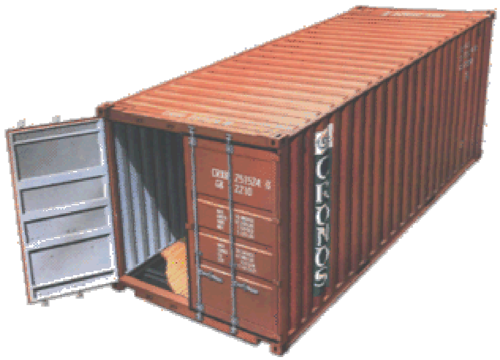
Jointly organized by:
University of Cape Town, Cape Town, South Africa
Physikalisch-Technische Bundesanstalt, Braunschweig, Germany
iThemba Laboratory for Accelerator Based Sciences, Faure, South Africa

www.fnda2006.de

Also incorporating courses **on unfolding methods in spectrometry** and **MCNPX**

Post 11 September 2001:

Increased awareness to protect the global supply chain from acts of terrorism and smuggling of contraband.



The problem: find the contraband!

Contraband =
- **nuclear materials**
- **illicit drugs**
- **money**
- **biological materials**
- **explosives**

Sommet KANANASKIS Summit

Canada 2002

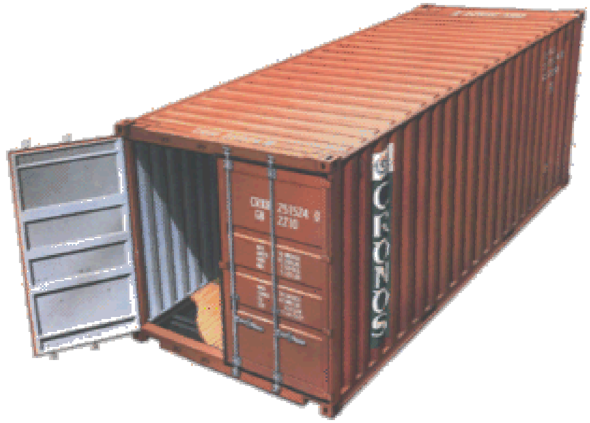
June 26 - 27 Juin

G8 Action Plan on Transport Security

Cooperative actions needed for improved security in the areas of:

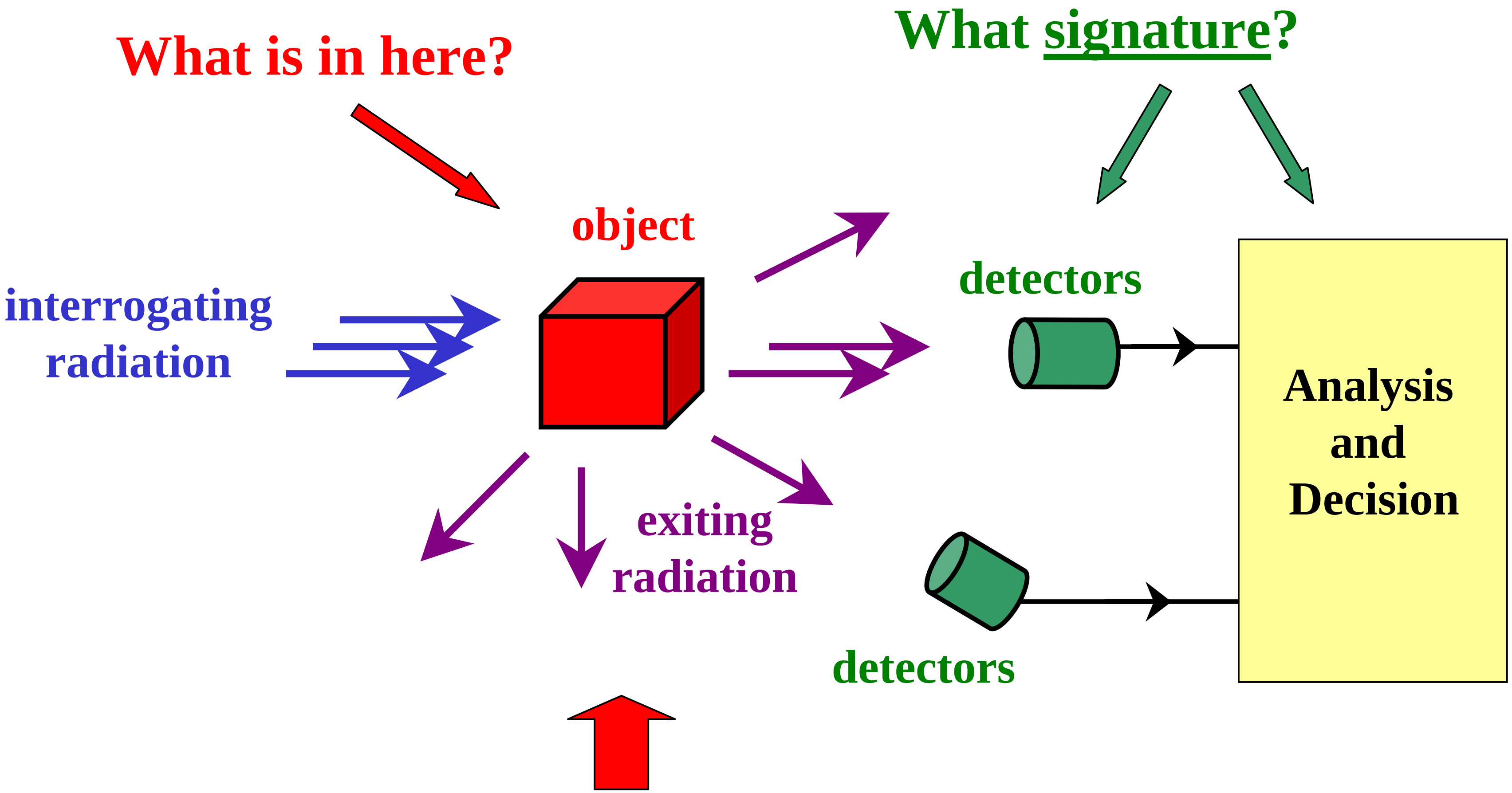
- people movements
- container security
- aviation security
- maritime security
- land transportation

The (United States)
Container Security Initiative



... Establish security criteria to identify high-risk containers

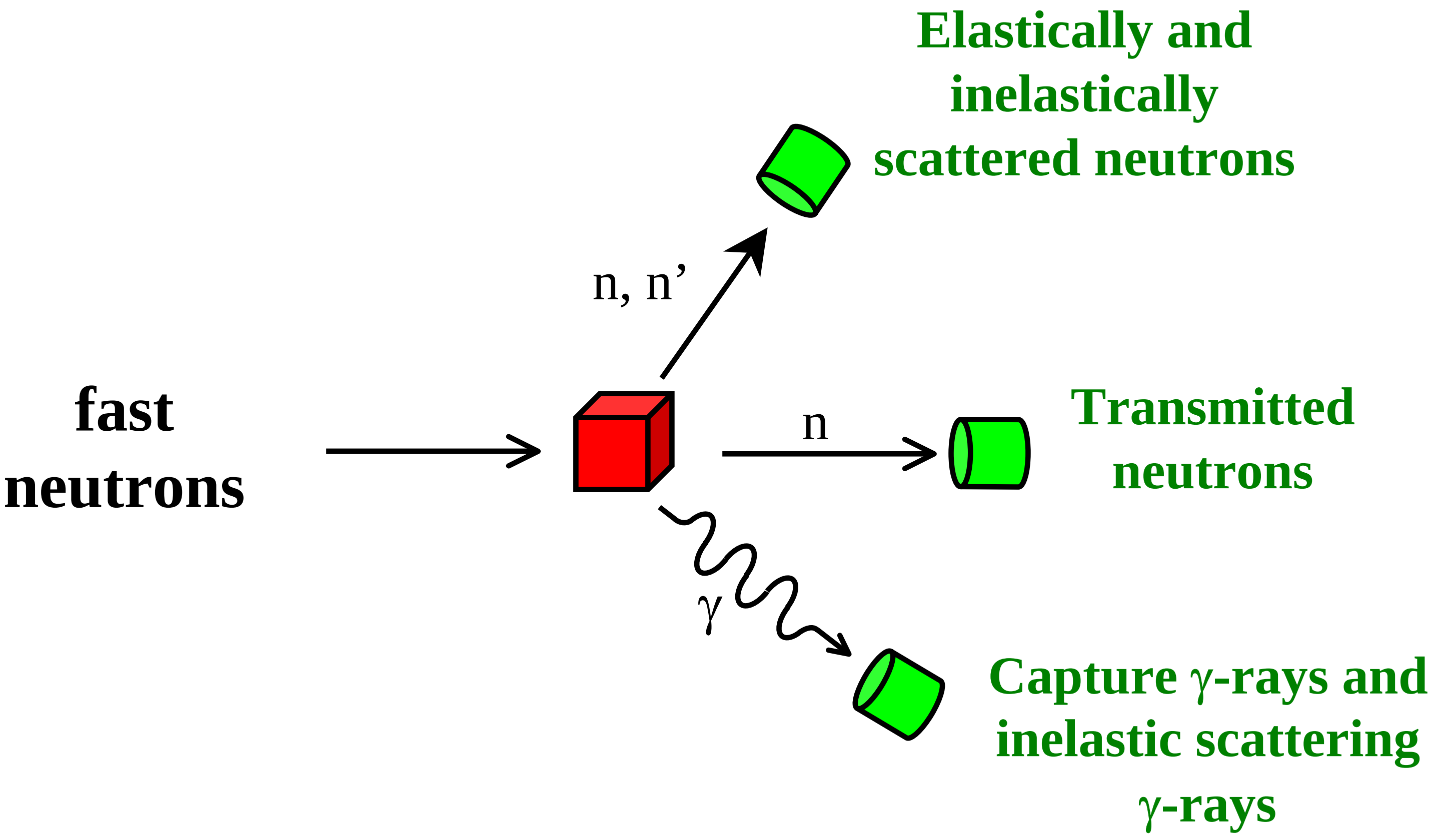
... Pre-screen containers using approved technology before they depart from the country of export



Do you want ... an **image** (regular or tomographic),
... or **elemental characterization**,
... or **both** (elemental image) ?

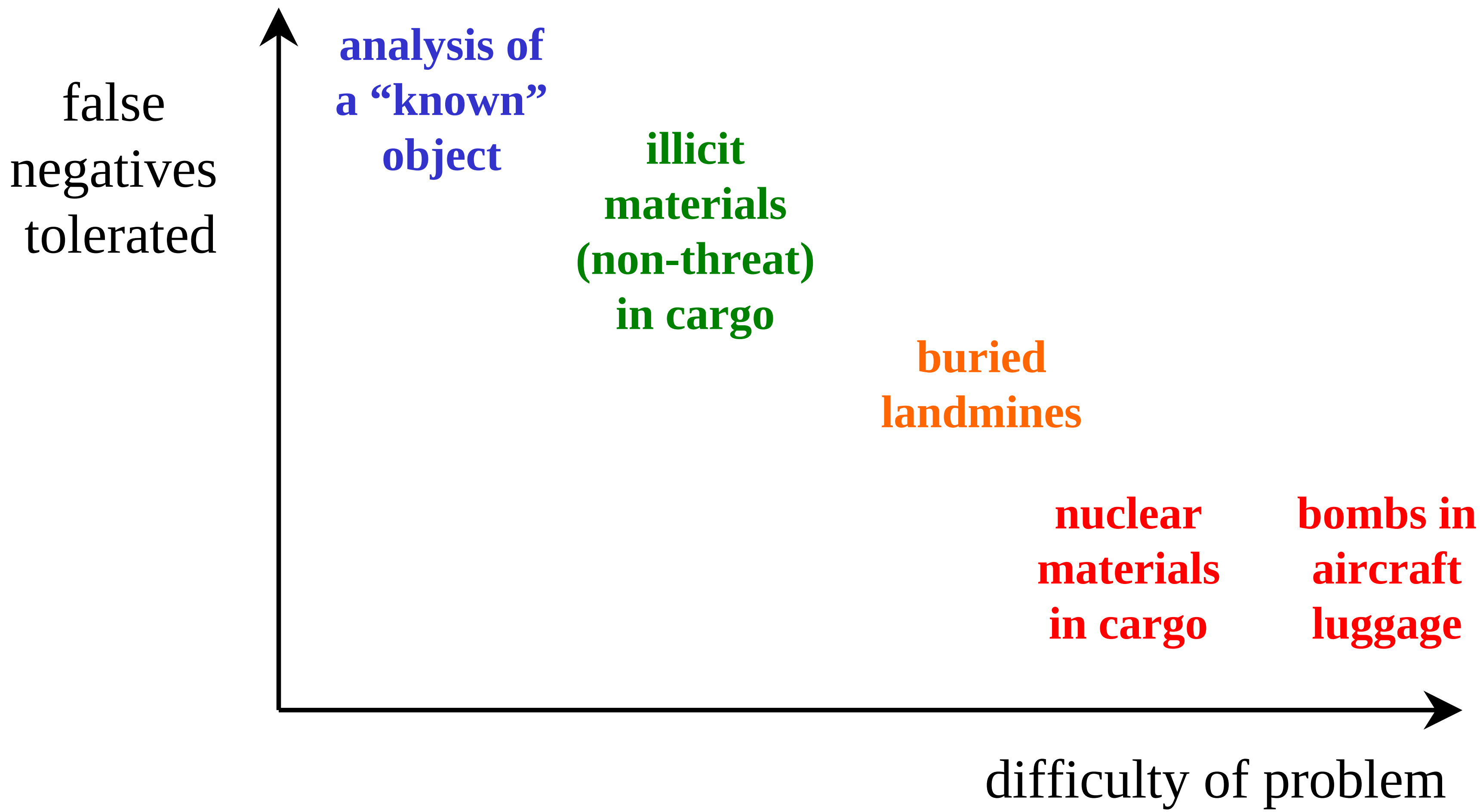
... the context of the problem is everything.

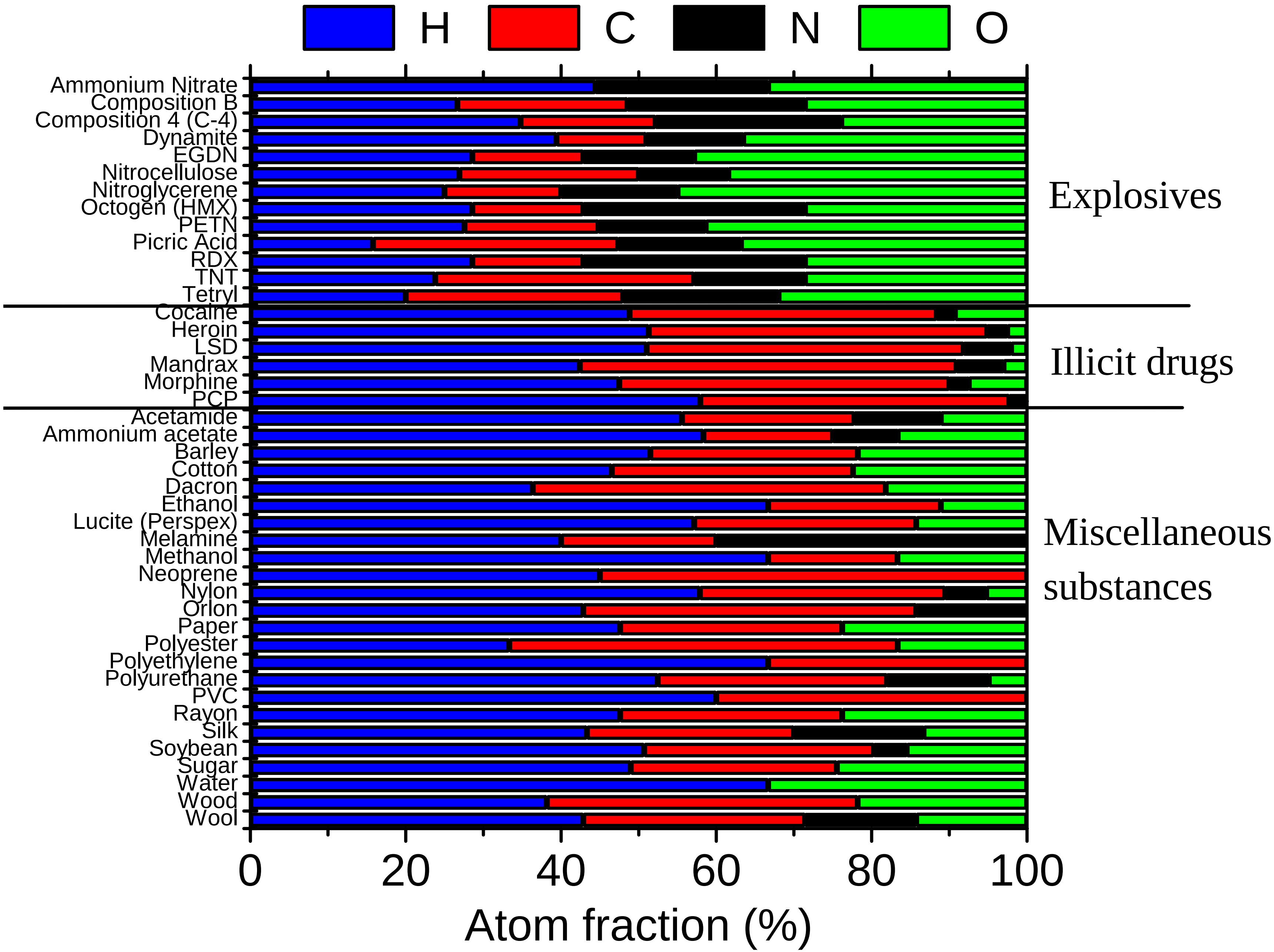
Analysis of bulk materials using fast neutrons



The context is **everything** ...

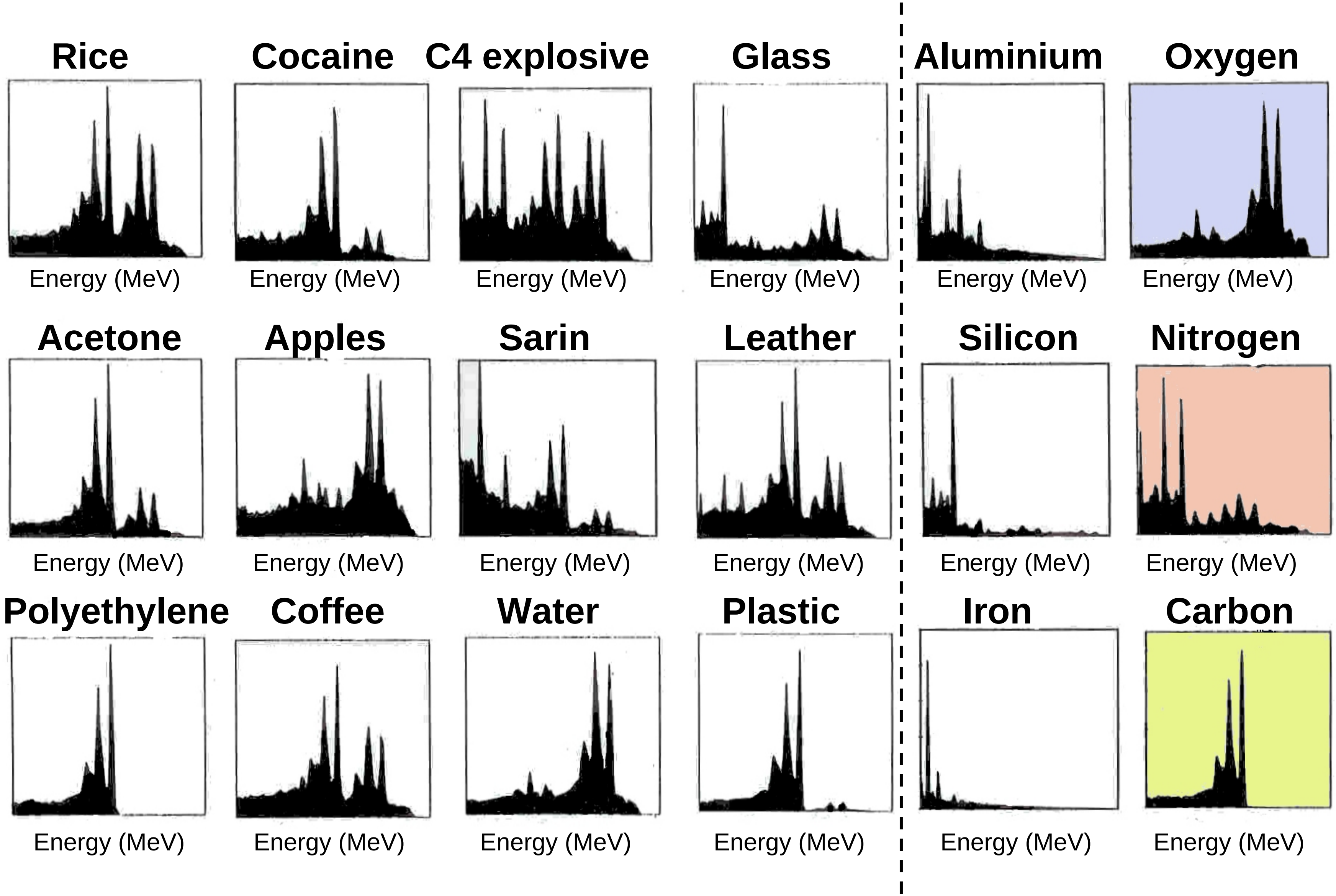
What is the real problem that needs to be solved?

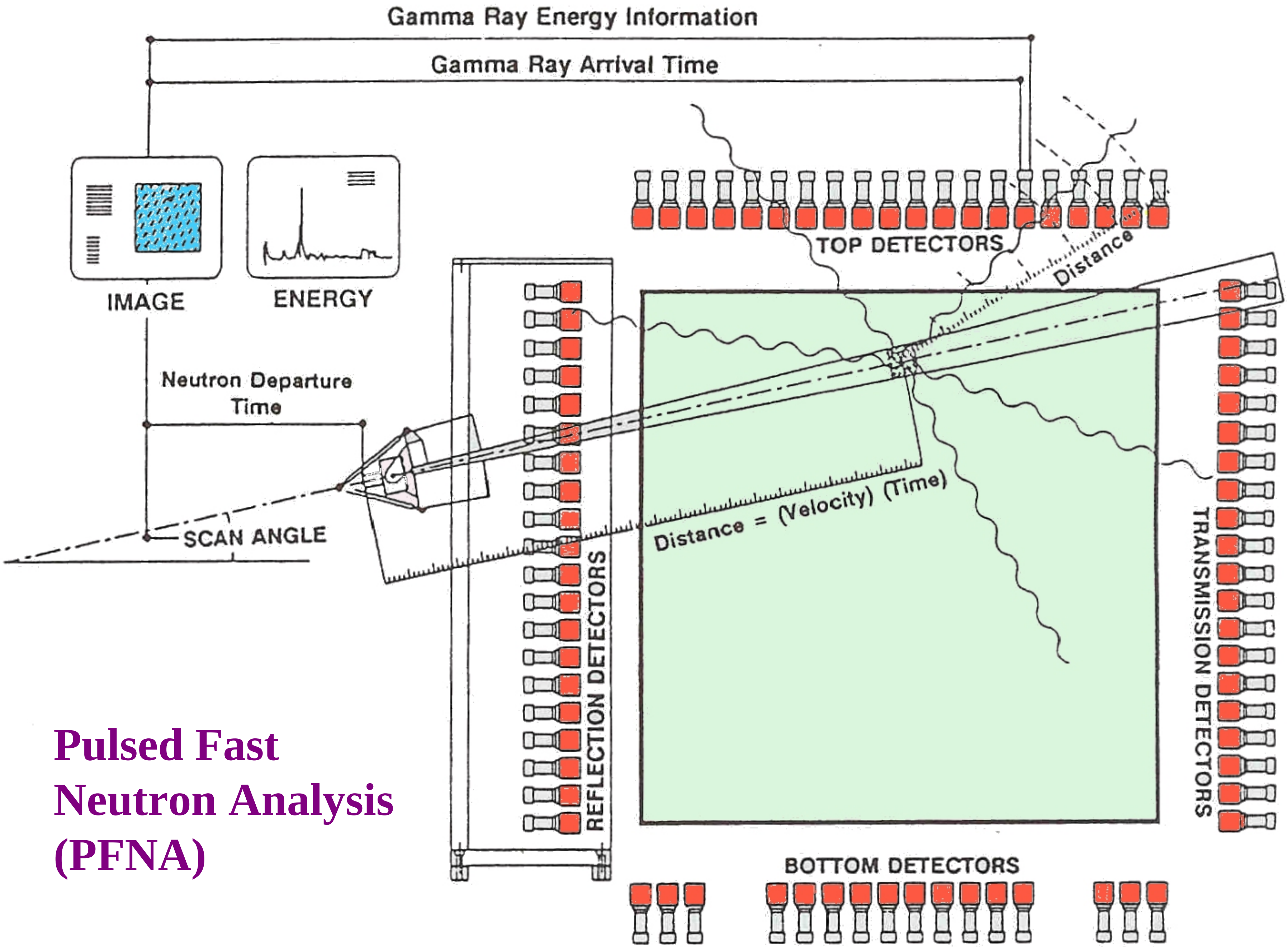




H
C
N
O
Ammonium Nitrate
Composition B
Composition 4 (C-4)
Dynamite
EGDN
Nitrocellulose
Nitroglycerene
Octogen (HMX)
PETN
Picric Acid
RDX
TNT
Tetryl
Cocaine
Heroin
LSD
Mandrax
Morphine
PCP
Acetamide
Ammonium acetate
Barley
Cotton
Dacron
Ethanol
Lucite (Perspex)
Melamine
Methanol
Neoprene
Nylon
Orlon
Paper
Polyester
Polyethylene
Polyurethane
PVC
Rayon
Silk
Soybean
Sugar
Water
Wood
Wool
Explosives
Illicit drugs
Miscellaneous substances
0
20
40
60
80
100
Atom fraction (%)

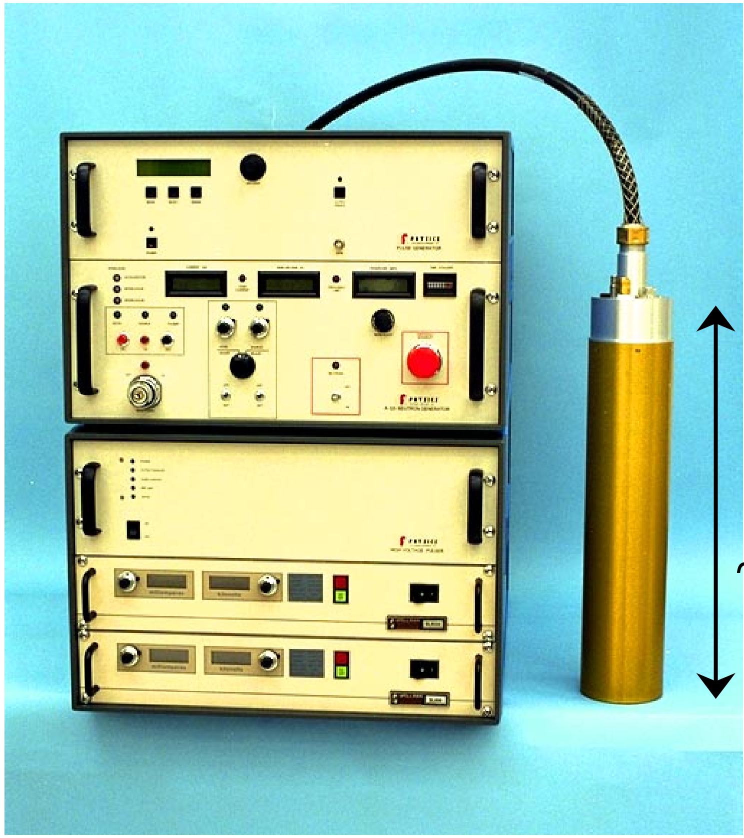
Fast Neutron Analysis gamma ray signatures





Pulsed Fast Neutron Analysis (PFNA)

Compact **sealed tube neutron generators** provide **cheap fast neutrons**



~ 1 m

$^{2}\mathrm{He(d,n)}^{3}\mathrm{He}$ 2.5 MeV neutrons

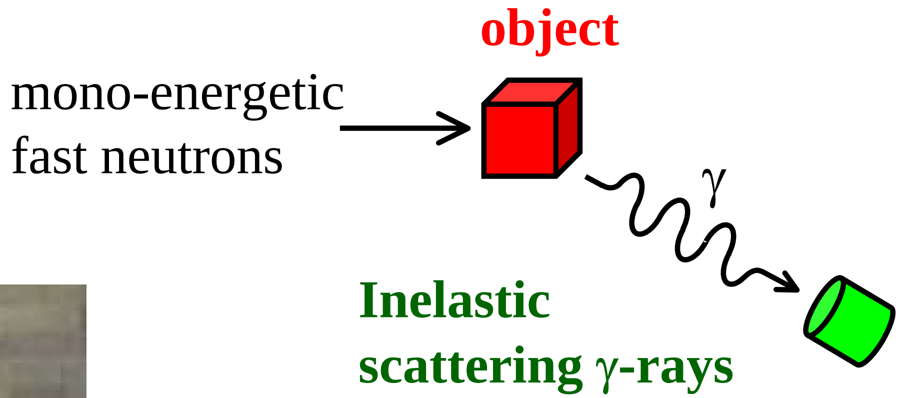
or

$^{3}\mathrm{He(d,n)}^{4}\mathrm{He}$ 14.1 MeV neutrons

MF Physics A-325:

10^{9} 14 MeV neutrons s^{-1}, μs-pulsed

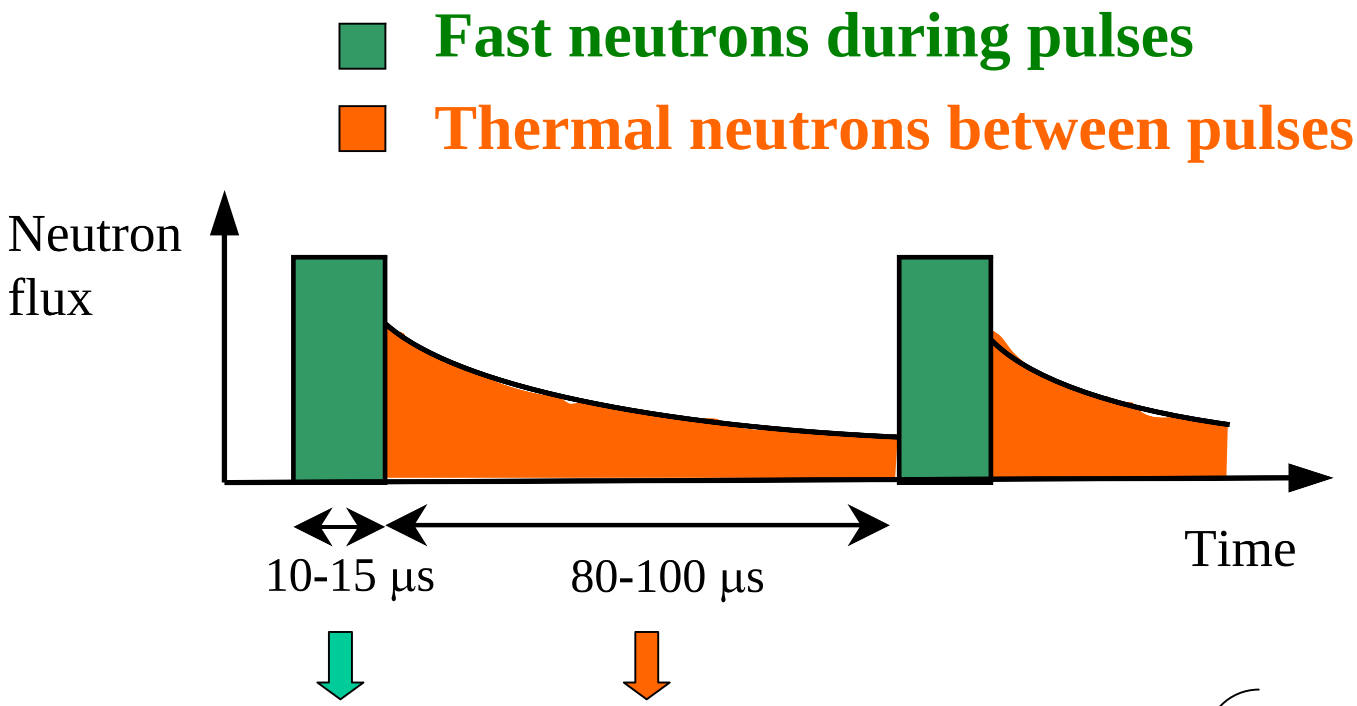
Fast neutron inelastic scattering



Portable system based around a 14 MeV sealed tube neutron generator and BGO detector to detect de-excitation γ-rays from **neutron inelastic scattering** interactions.

Pulsed Elemental Analysis with Neutrons (PELAN) [Vourvopoulos]

μs-pulsed 14 MeV sealed tube neutron generator



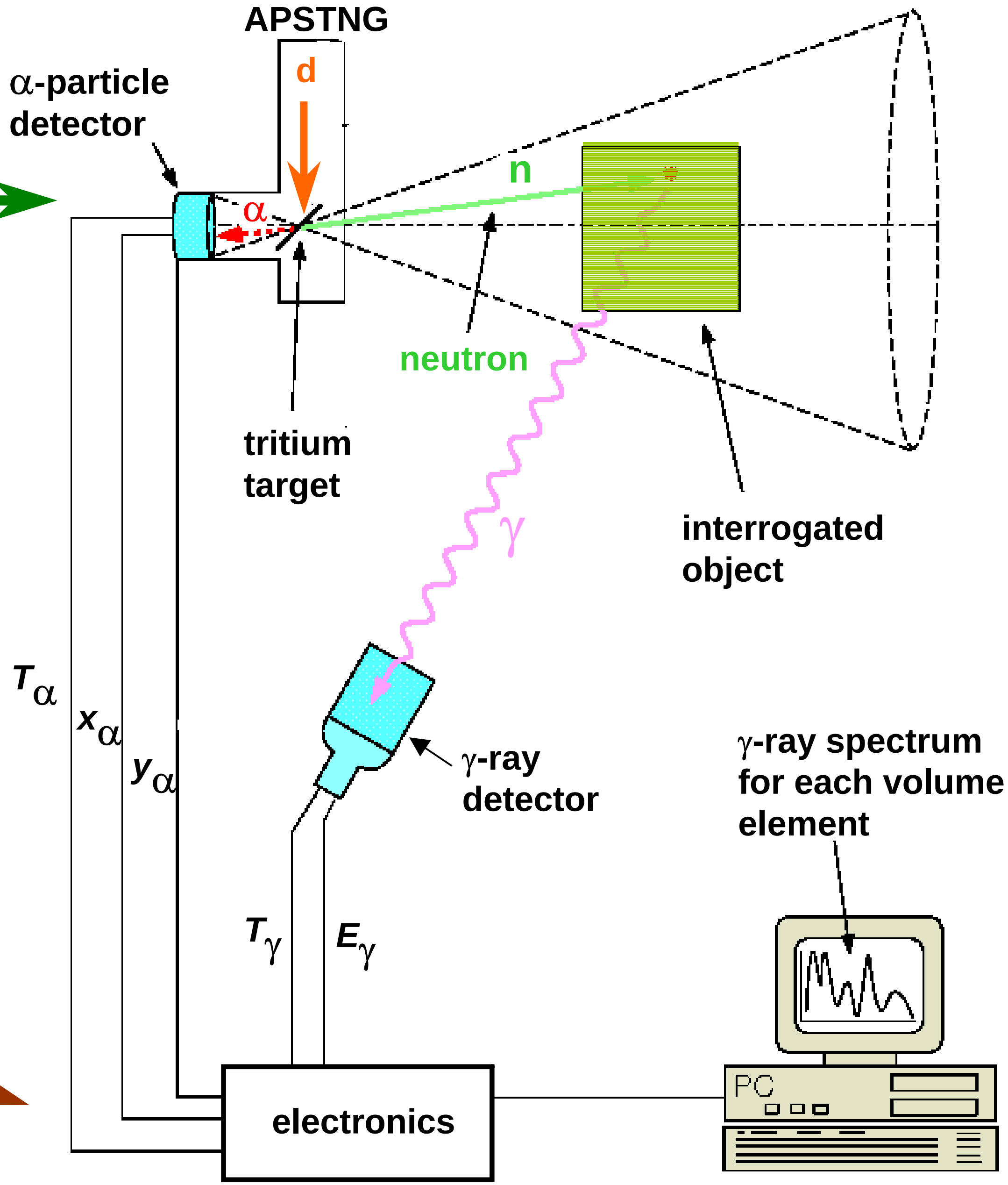
	Scattering	*Capture*	*Activation*
Interaction:	(n, n' γ)	(n, γ)	(n, α), (n, p)
Gammas:	Prompt	Prompt	Delayed
Elements:	C, O	H, N, S, Cl, Fe, ...	O, Al, Si, ...

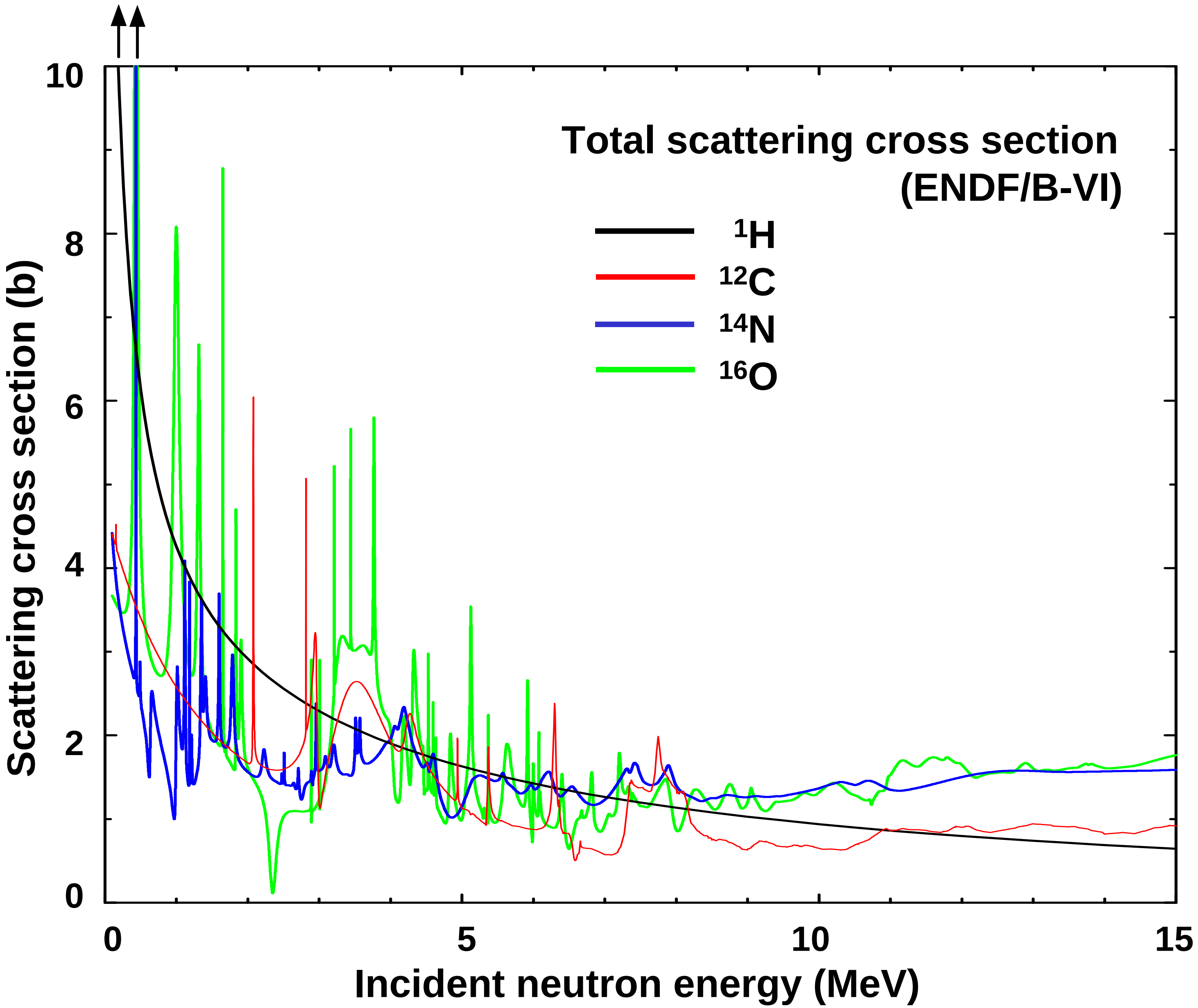
Associated particle sealed tube neutron generator

utilising the T(d,n)α reaction.

The 14.1 MeV neutron is tagged in time and direction by detecting the associated α-particle released in the opposite direction.

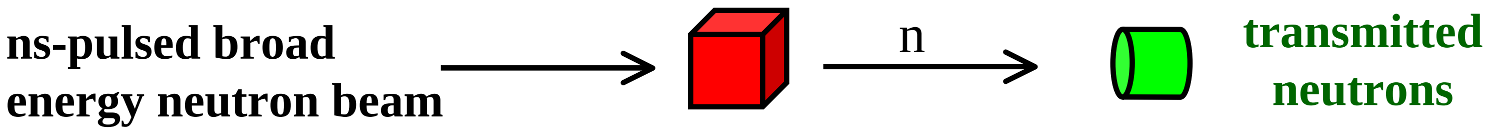
... allows **ns-timed measurements** to be made.





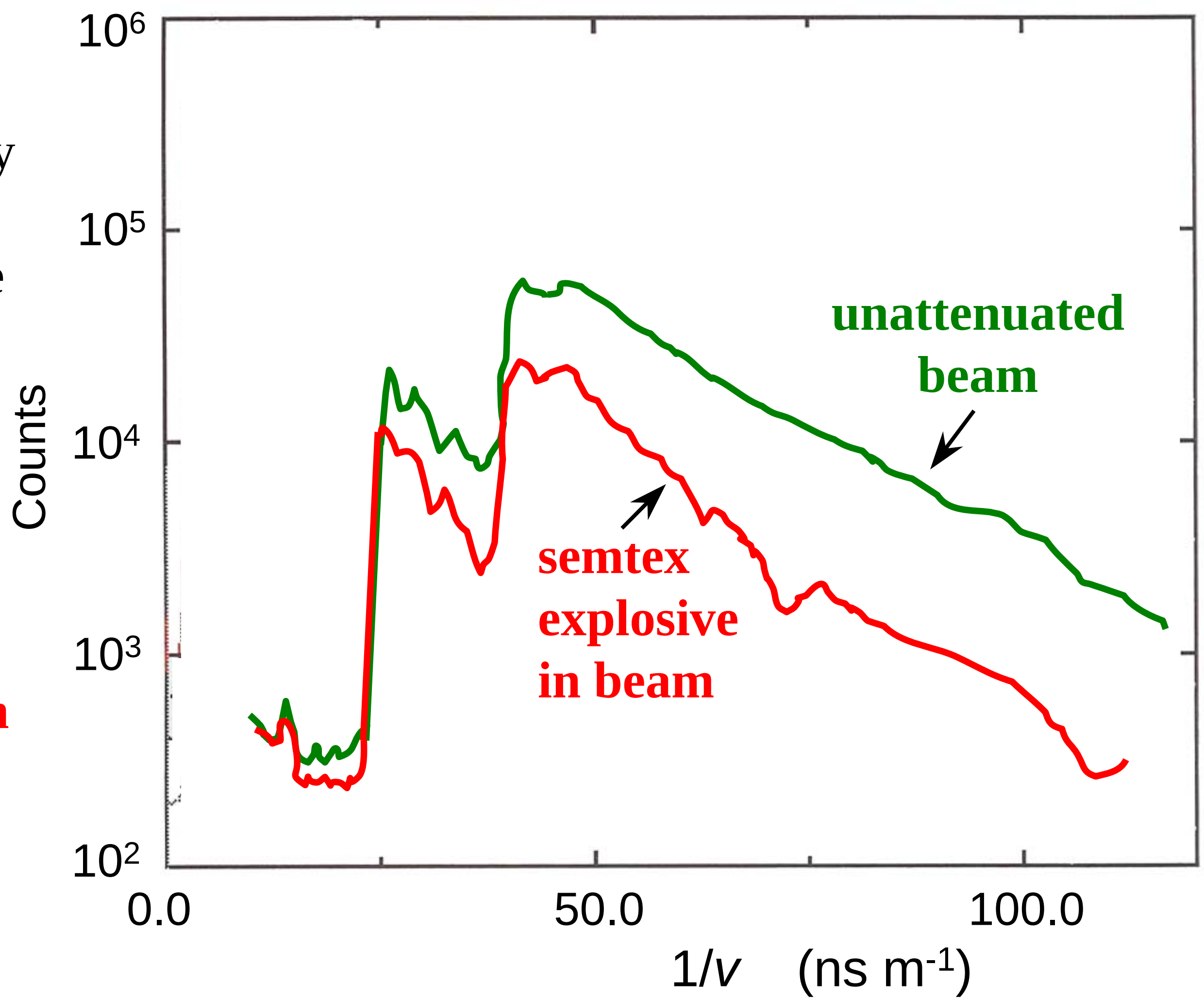
Total scattering cross section
(ENDF/B-VI)
1H
12C
14N
16O
Scattering cross section (b)
Incident neutron energy (MeV)
0
2
4
6
8
10
0
5
10
15

Pulsed Fast Neutron Transmission Spectroscopy spectrum



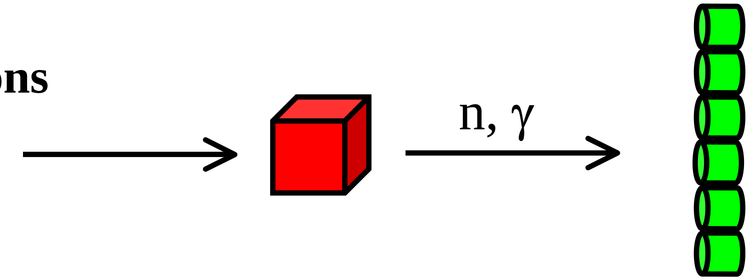
... ns-pulsed broad energy neutron beam is **attenuated** in the sample according to total scattering cross section for each element in the sample.

Unfolding analyses of the transmitted neutron spectra allows the elemental content of the sample to be determined [Overley].

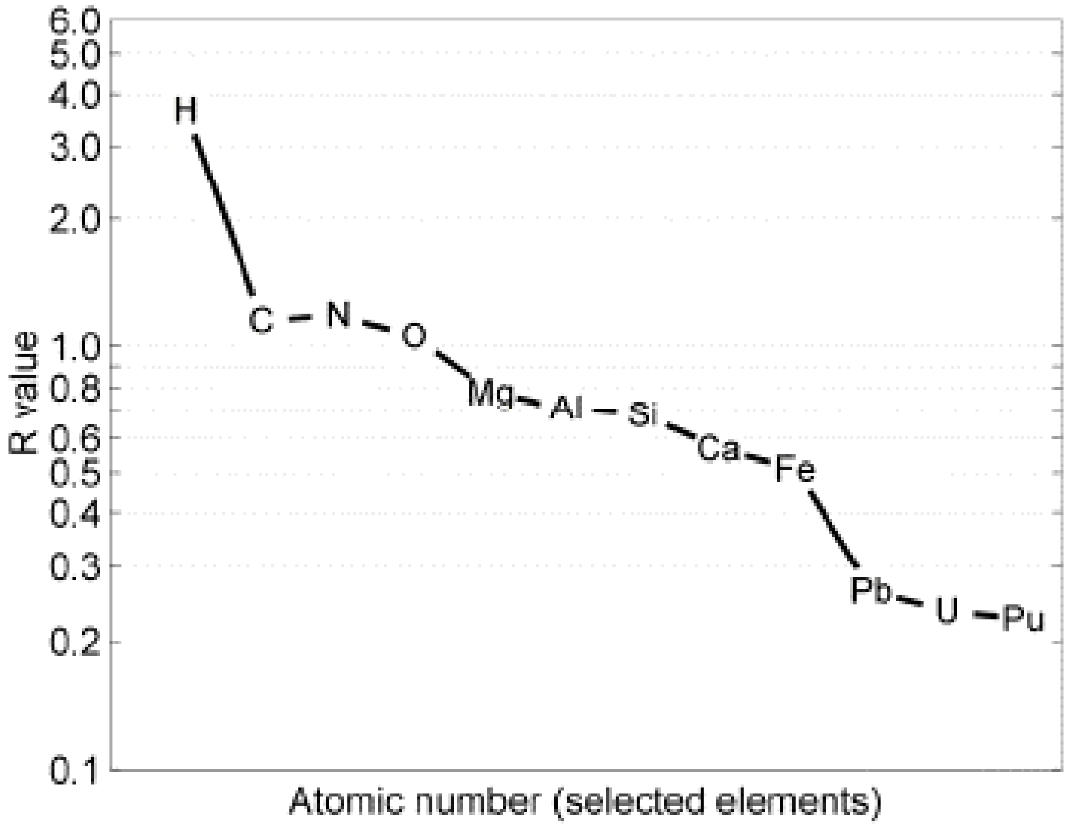


Fast Neutron and Gamma Radiography

14 MeV STNG neutrons and ^{60}Co γ-rays



transmitted neutrons and γ-rays



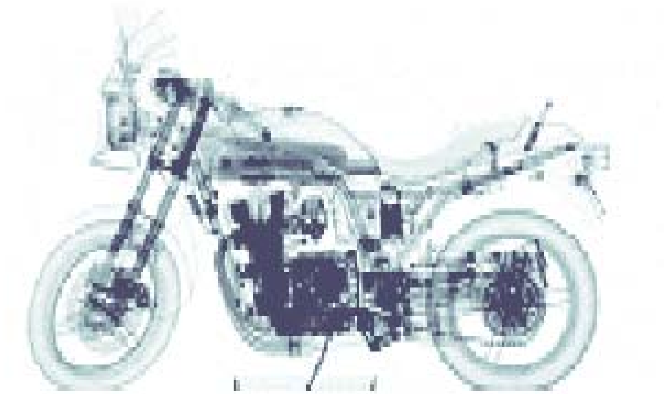
$$R = \frac{\mu_n}{\mu_g} = \frac{\ln\left(I_n / I_n^0\right)}{\ln\left(I_g / I_g^0\right)}$$

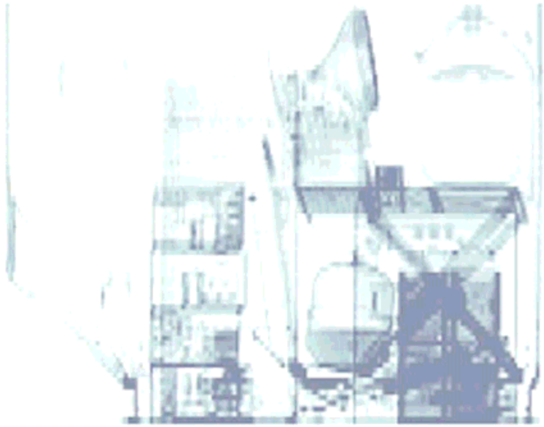
CSIRO

CSIRO

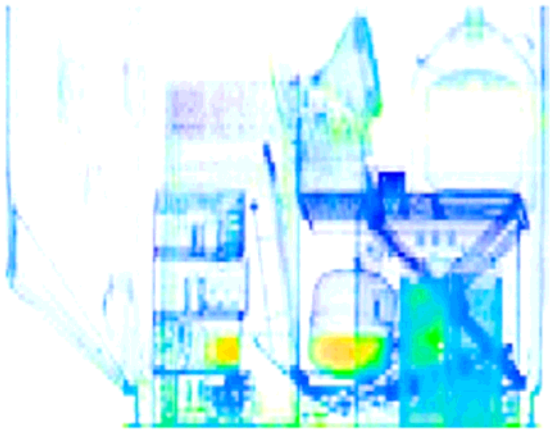
CSIRO

γ-rays only

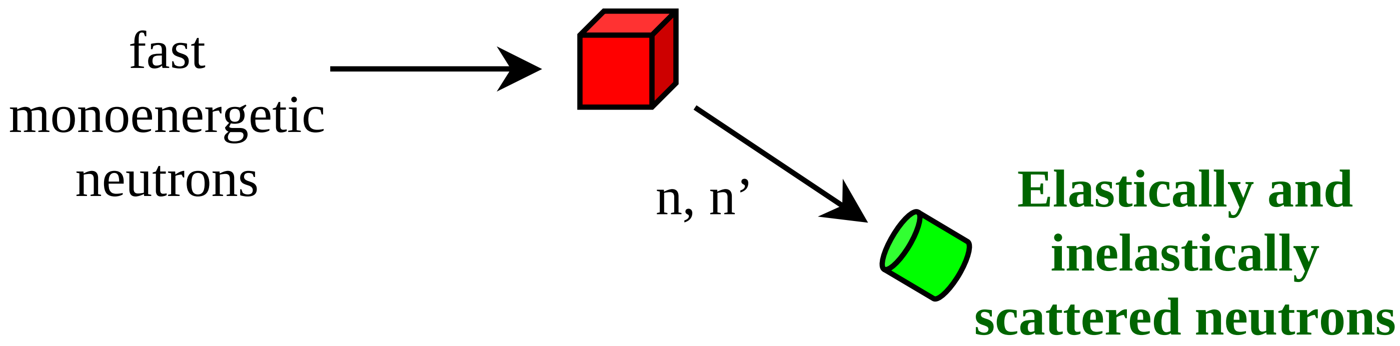




neutrons
and γ-rays



Neutrons in, neutrons out



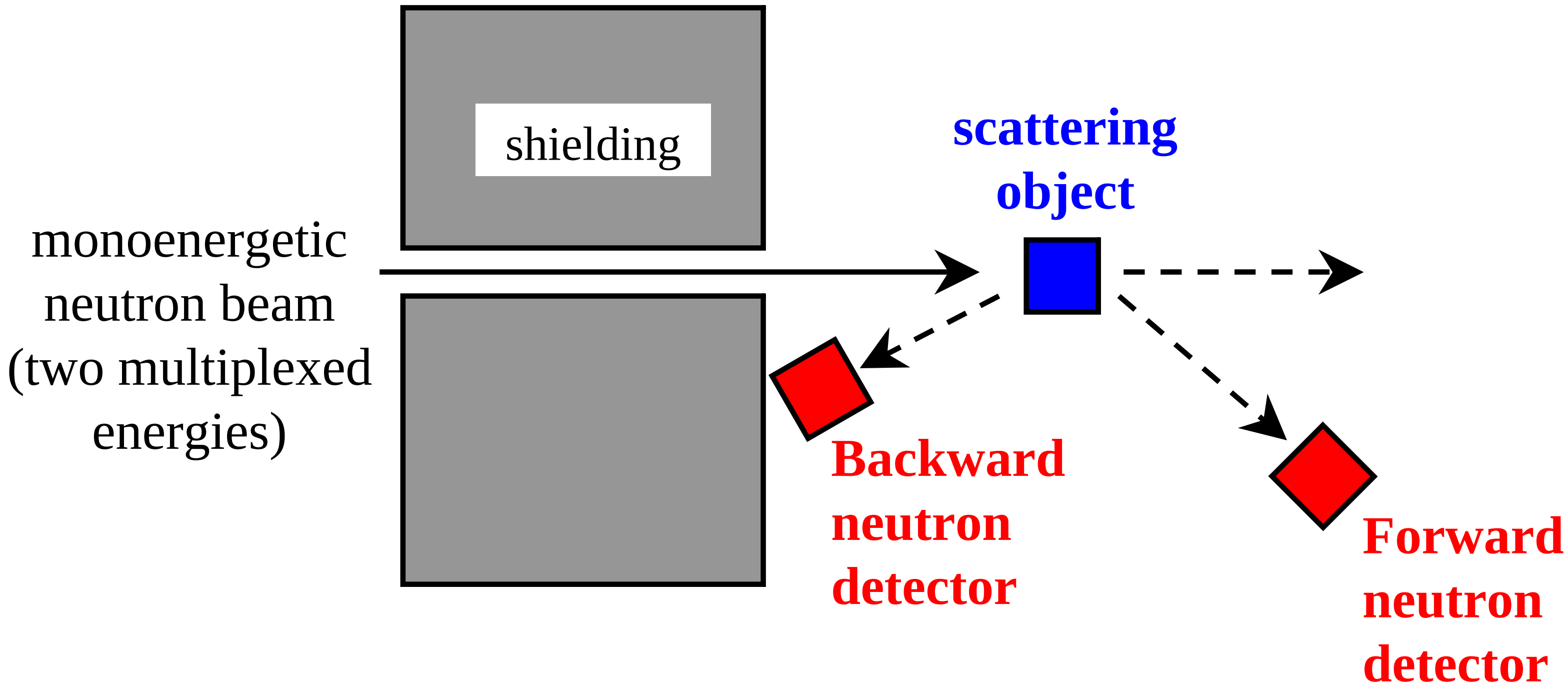
The **energy** and **intensity** distributions of the scattered neutron field are functions of the:

- incident neutron energy
- angle of scattering
- mass of the scattering nuclide

Fast Neutron Scattering Analysis (FNSA)

Andy Buffler and Frank Brooks, *et al.*
Department of Physics, University of Cape Town, South Africa

Fast Neutron Scattering Analysis (FNSA)



... development work undertaken at UCT and iThemba LABS ...

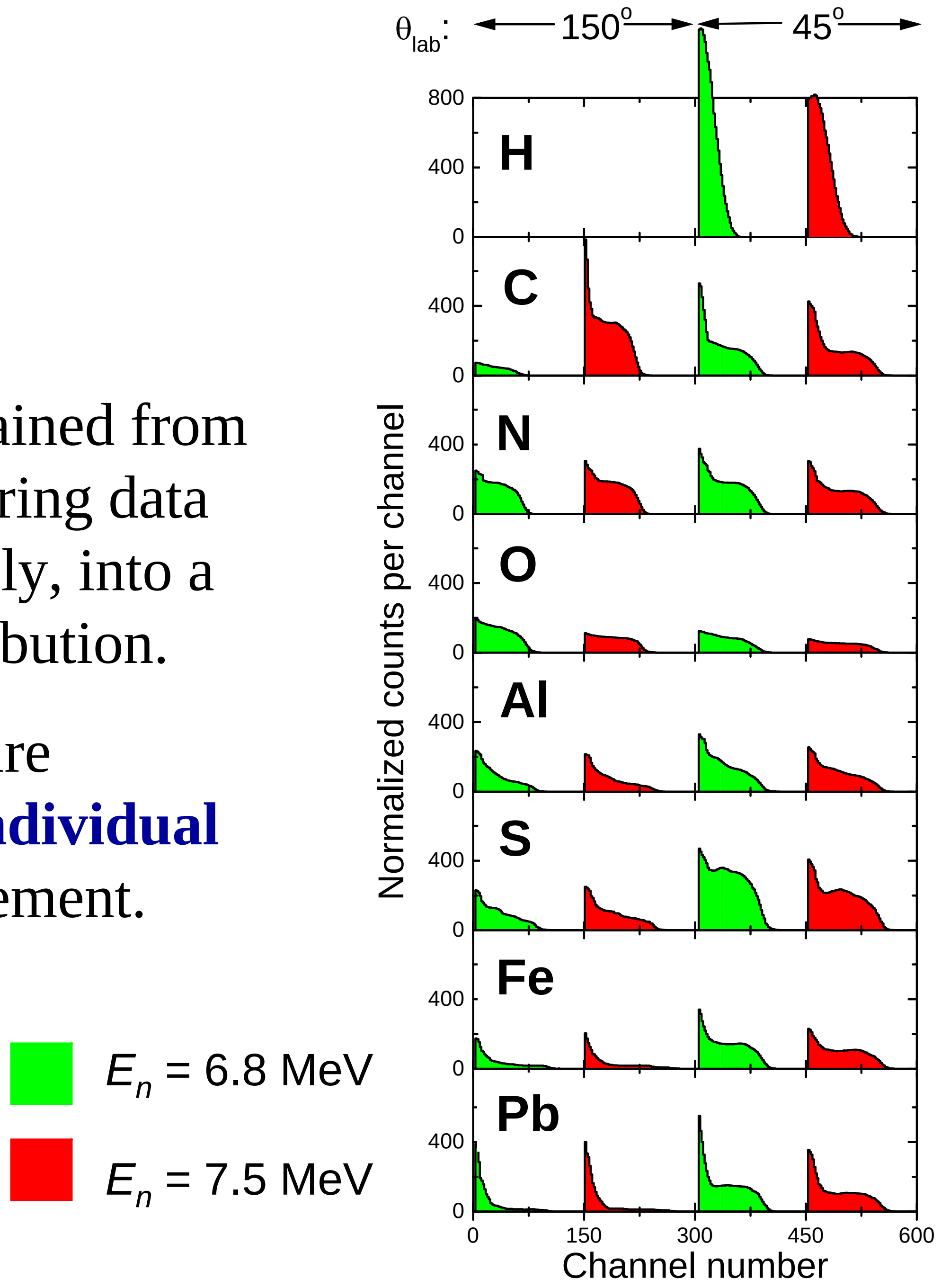
FNSA

The scattering signature

A scattering signatures obtained from **selections** of the raw scattering data which are **assembled** serially, into a single, spectrum-like, distribution.

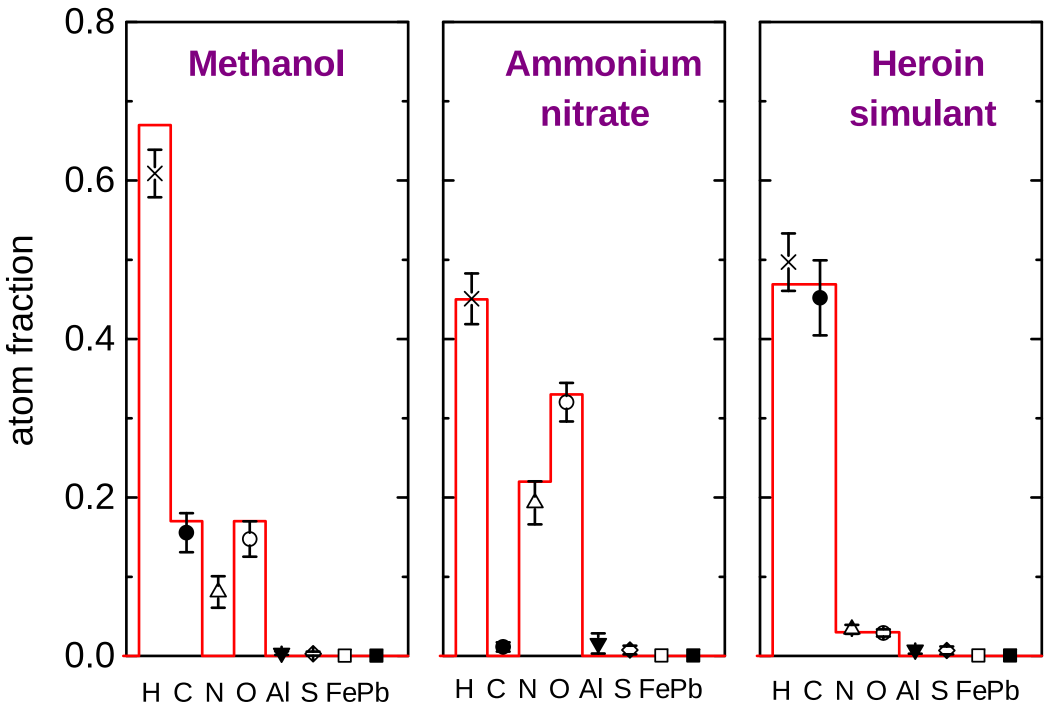
Scattering signatures for pure elements exhibit **distinct individual characteristics** for each element.

For example: one set based on **pulse height** only (does not require a pulsed neutron beam)



Scattering signatures measured for unknown samples are **unfolded** to determine the elemental composition of the sample.

The measured atom fractions **uniquely characterize** the elemental composition of the scattering sample.



The **identification of specific materials** from measured atom fractions can be facilitated by introducing a χ^2-based **screening procedure** to compare the atom fractions measured for an "unknown" sample with the known atom fractions of a large set of candidate materials.

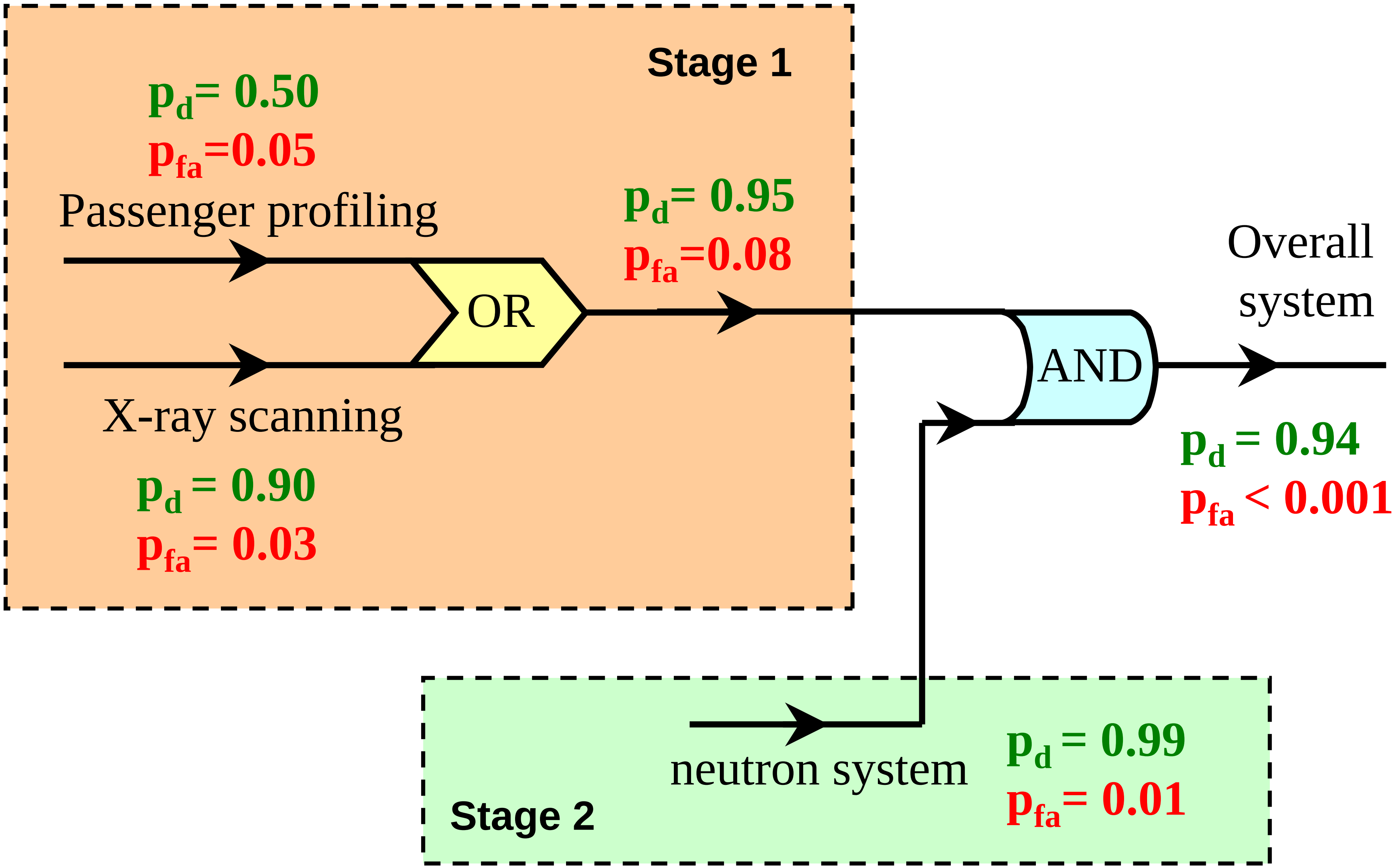
The hardest problem to solve (by far) is the detection of explosives in airline luggage.

... so is there a real future for neutrons inside an airport terminal ?

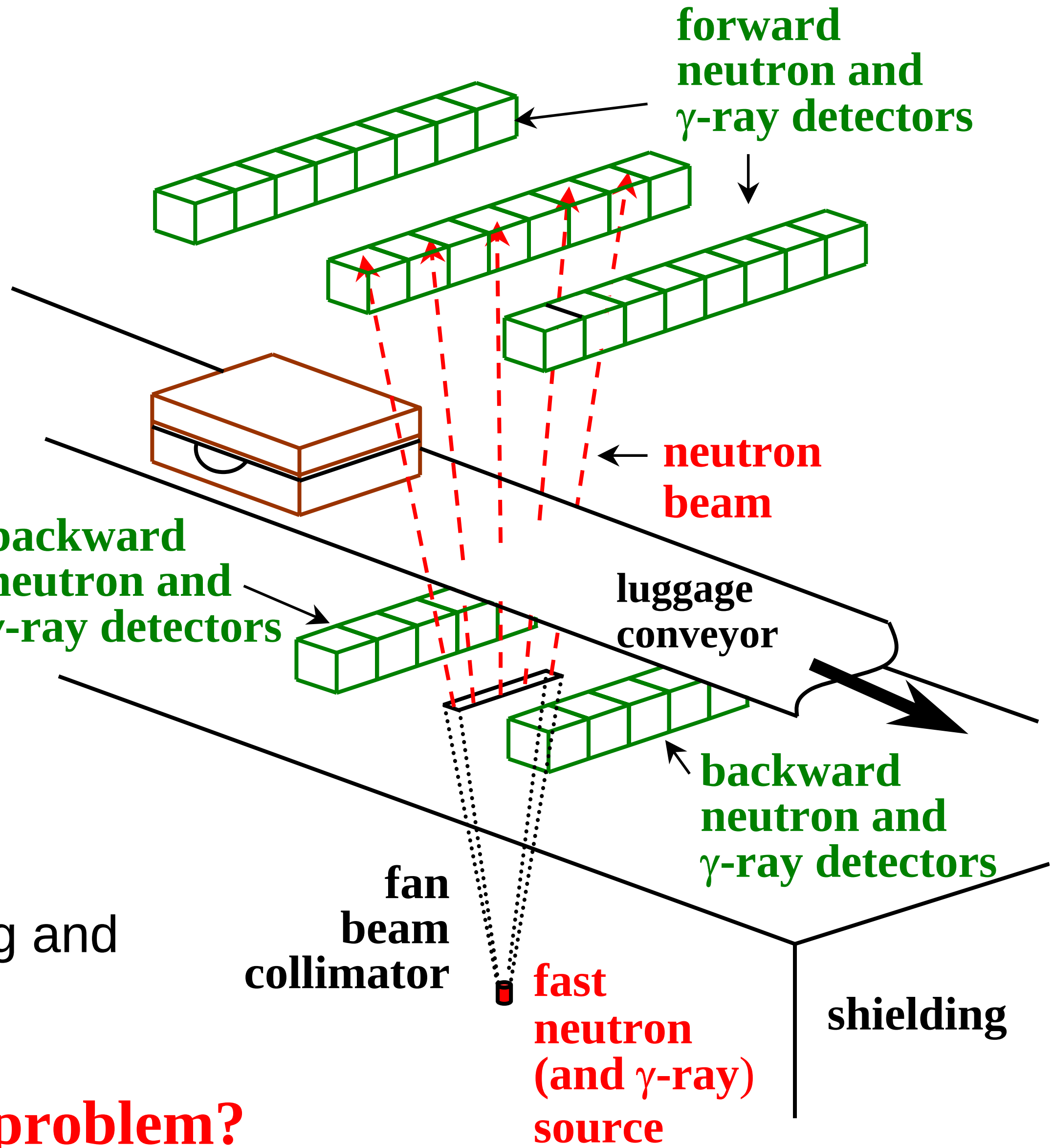
It all depends on ...

... the perceived threat
... political pressure
... financial concerns
... radiation safety compliance
... **the physics**

Combined detection probabilities for a multi-stage system



The ultimate neutron-based system for the detection of explosives and illicit drugs in **airline luggage.**



... system based on the fusion of signatures of:

- transmitted and scattered fast neutrons
- backscattered thermal neutrons (from H)
- γ-rays from inelastic scattering and thermal neutron capture

… but will this solve the problem?

Fast neutron menu

Mono-energetic beam (single or multiplexed)

Neutron generator ... 2.5 MeV or 14.1 MeV ?

... μs - pulsed ?

... associated particle ?

Linac

Van de Graaff or small cyclotron ... ns-pulsed?

White (broad energy) beam

Radioisotopic (^{252}Cf, Am-Be, Pu-Be ...)

Van de Graaff or small cyclotron ... ns-pulsed?

… but unless you are not worried about size, cost, time, …
For contrast, you need **two** (or more) flavours of interrogating radiation … and **a signature with at least two components**.

Closing thoughts

Massive research and development since Lockerbie has **not** resulted in a significant case for fast neutrons to be the solution to all problems.

Explosive detection with neutrons has been the "flavour of the decade" with very little practical accomplishment.

The most successful developments have occurred when there has been **total** collaboration between the laboratory scientists and the end users.

Fast neutrons are likely to be useful for specific, **targeted applications**: the detection of threat (nuclear, …) materials in air and sea cargo, and for the analysis of materials of "known" composition (possibly landmine detection).