

DESIGN OF THE SABAT SYSTEM FOR UNDERWATER DETECTION OF DANGEROUS SUBSTANCES

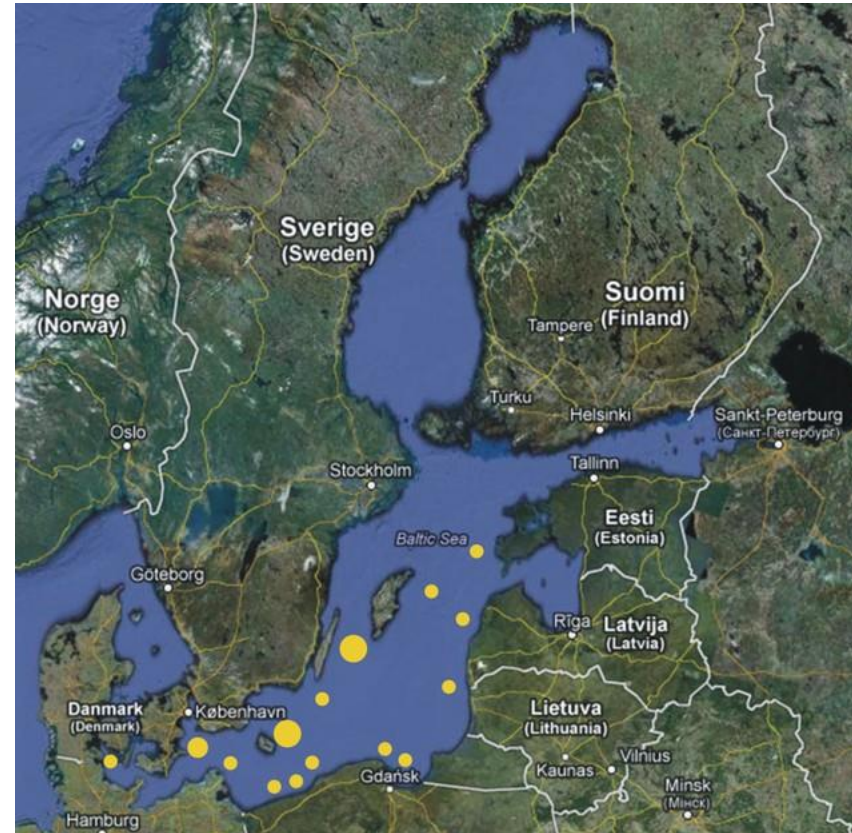
M. Silarski
Jagiellonian University
on behalf of the SABAT collaboration



- ☐ Introduction
- ☐ Neutron Activation Techniques
- ☐ Application in the underwater environment
- ☐ Status of the project
- ☐ Summary

Introduction

- ❖ „Ghosts” of World Wars: ~250 kt of munition (including 65 kt of chemical agents) sunk in the Baltic Sea
- ❖ Main known contaminated areas: Little Belt, Bornholm Deep (east of Bornholm) and the southwestern part of the Gotland Deep
- ❖ **Unknown amount of chemical leftovers are spread around the Baltic Sea**
- ❖ Serious threat for people and environment
 - ❖ „Fake amber” on the coast
 - ❖ Mustard gas „fished” out the sea
 - ❖ Menace to navy
 - ❖ Genetic mutations of marine fauna



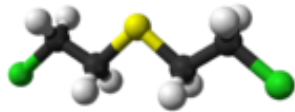
<http://www.sfora.pl/polska/Napalm-w-Baltyku-Przed-katastrofa-nie-ma-ratunku-a52539>

- ❖ **1/6 of the sunk munition released into Baltic = entire degradation of live in the sea and at its shores for 100 years!!**

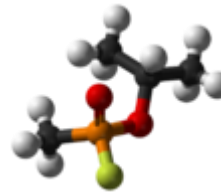
Introduction

❖ Main agents to deal with:

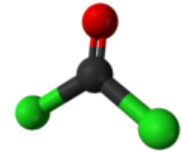
Mustard gas ($C_4H_8Cl_2S$)



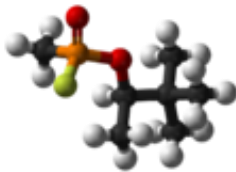
Sarin ($C_4H_{10}FO_2P$)



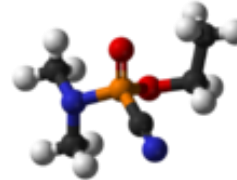
Fosgen ($COCl_2$)



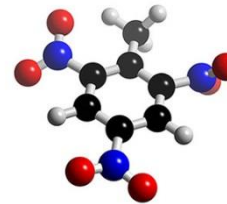
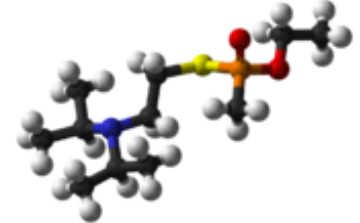
Soman ($C_7H_{16}FO_2P$)



Tabun ($C_5H_{11}N_2O_2P$)



VX ($C_{11}H_{26}NO_2PS$)



TNT ($C_7H_5N_3O_6$)

❖ Presently used detection methods:

- ❖ Sonars (shape and localization) + diver/robot inspection (evaluation of the ammunition shell and type)
- ❖ „By chance”: during fishing, etc.

❖ High economic and environmental costs have been preventing so far any activities aiming at extraction of these hazardous substances.

Neutron Activation Techniques

- ❖ Novel methods of **nondestructive** chemical threat detection based on neutron activation:



Thermal neutron capture
(sources, D+D generators)

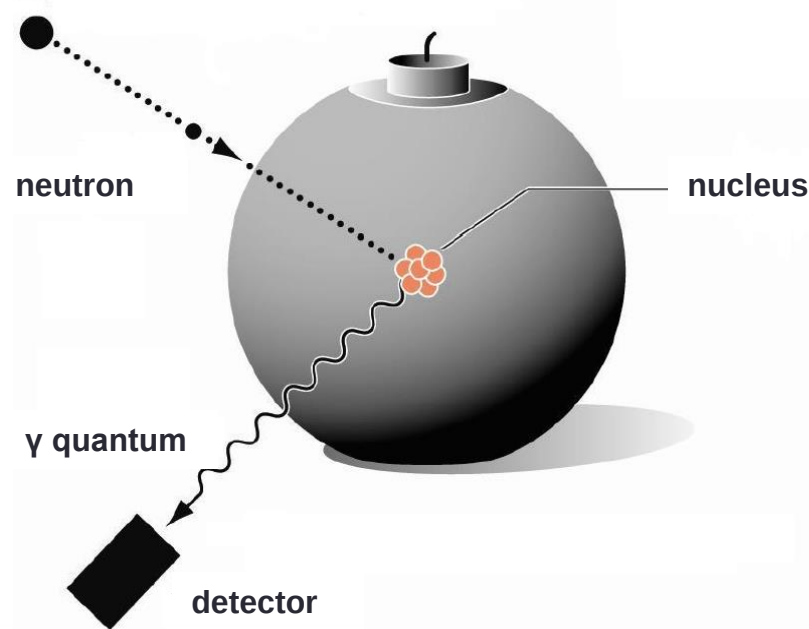


Neutron inelastic scattering
(D+D/D+T generator)

Excited nuclei emit gamma quanta of energy characteristic of the element



Relative content of elements $\Leftrightarrow$ Stoichiometry



Identification

Neutron Activation Techniques

❖ Signature:

gamma quanta of the following nuclei: ^{12}C (4.44 MeV), ^{16}O (6.13 MeV), ^{14}N (2.31 MeV, 5.11 MeV), ^{37}Cl (1.73 MeV, 3.1 MeV) ^{32}S (3.78 MeV) ^{31}P (1.27 MeV) ^{19}F (0.11 MeV, 0.197 MeV)

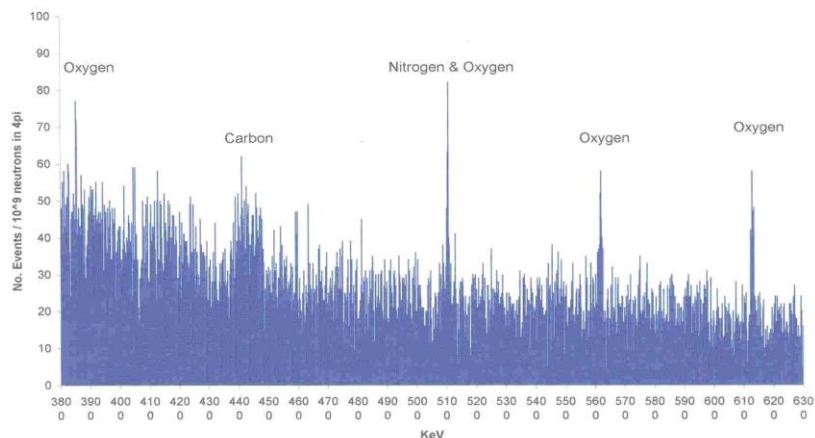
- ❖ High penetration allows detection of explosives/ which are hidden in vehicles, buried, etc.
- ❖ The use of pulse generators and detection of correlated α particles allows to measure the neutron time of flight $\Leftrightarrow$ tomographical picture of the chemical composition of the substance



Neutron Activation Techniques

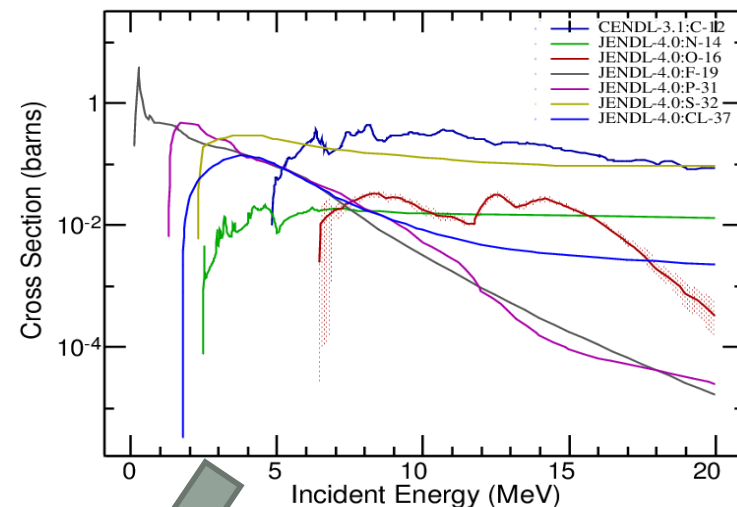
γ quanta detection

(Urea [77] inside artillery Shell) - (Shell [78] -- alpha normalized)

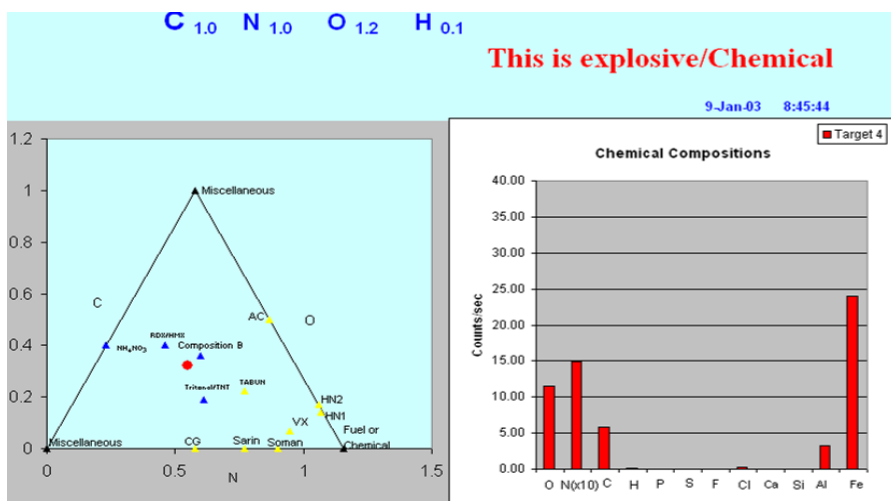


<http://www.calseco.com/>

Data analysis



Comparison with database of known substances & identification

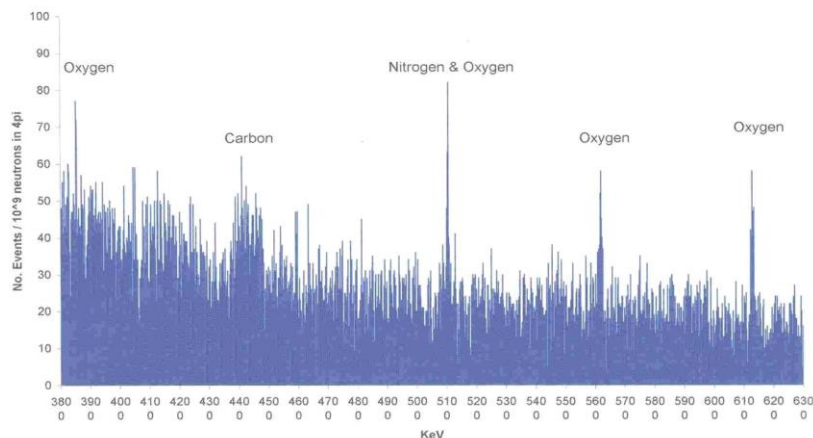


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Neutron Activation Techniques

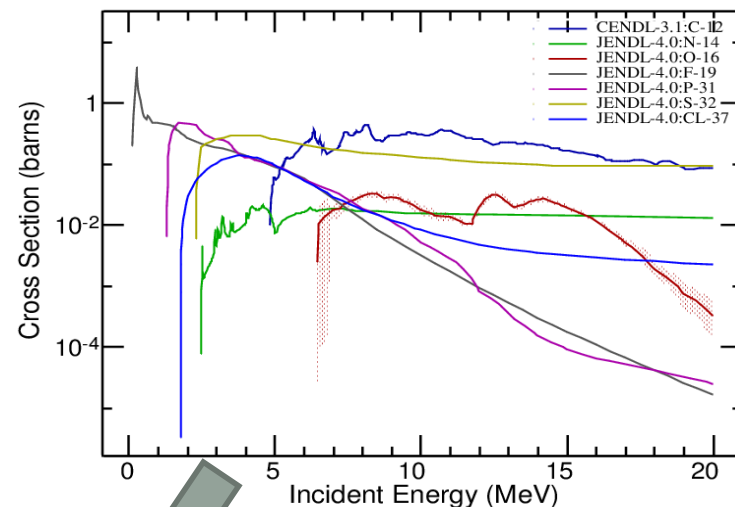
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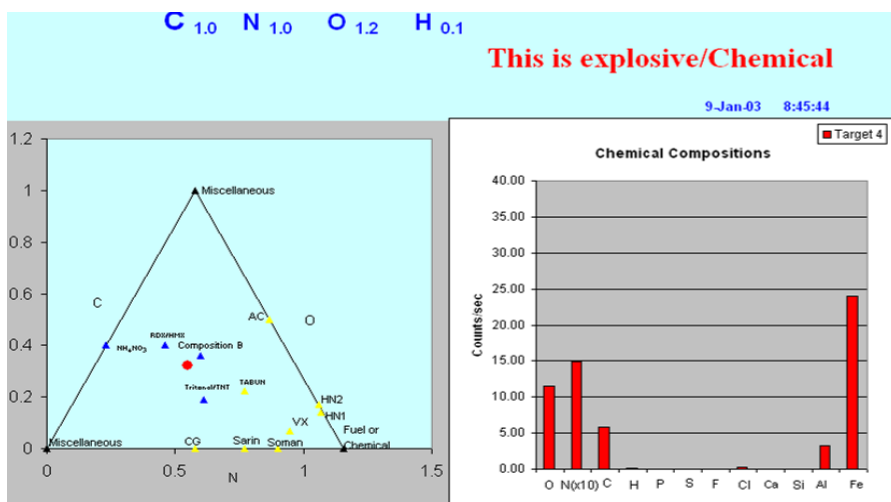
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Comparison with database of known substances & identification

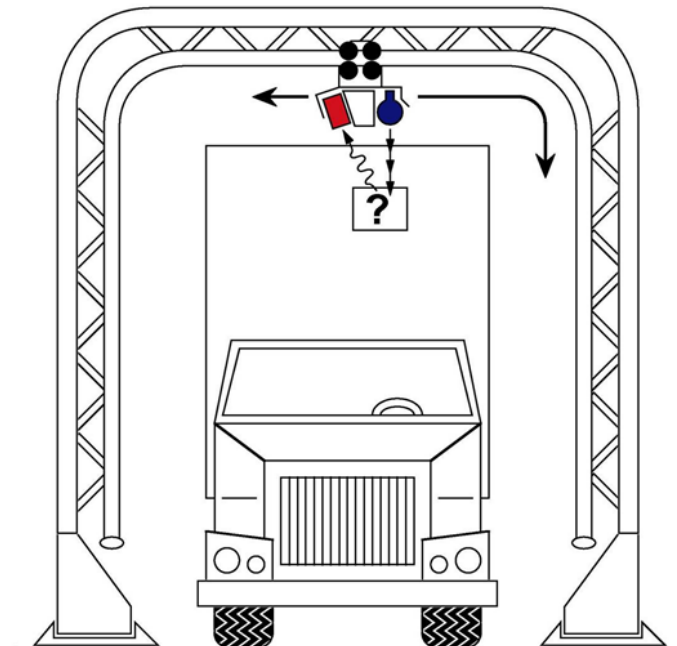
Drawbacks:

- Small cross sections for some of the elements
- Decreased mobility due to detector cooling
- High neutron flux needed
- Insensitivity to the structure of molecule
- **High neutron attenuation in water**
- **High background from oxygen and nitrogen**

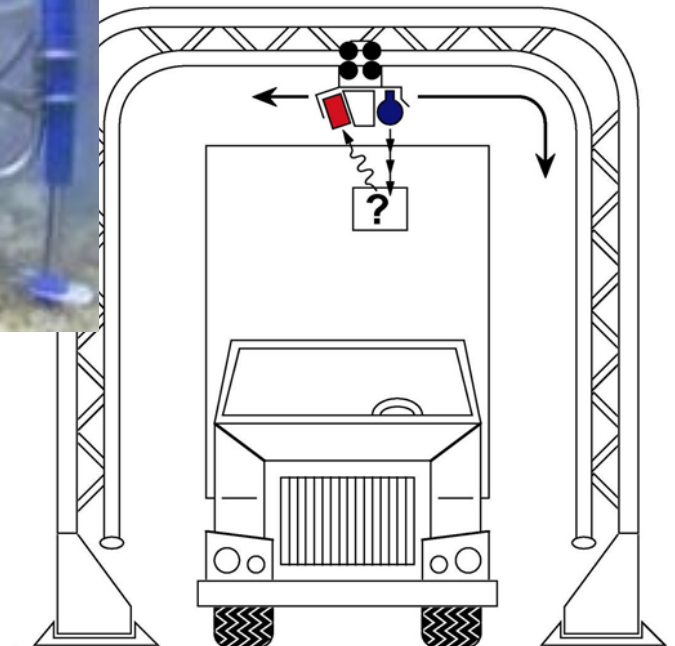


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Practical applications

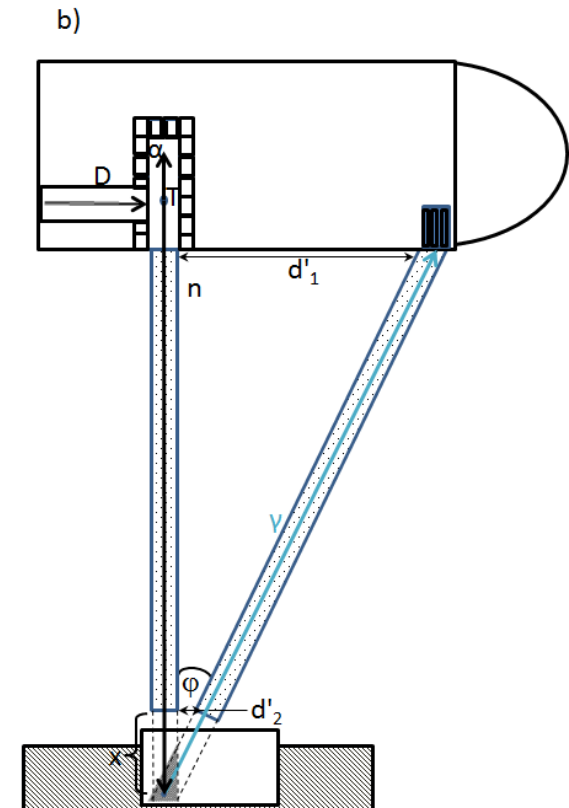
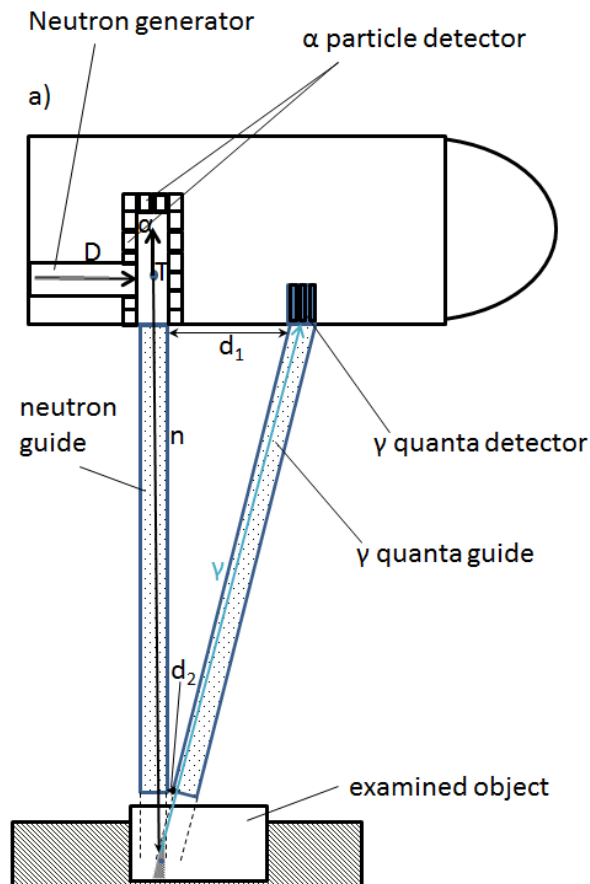


Practical applications



The SABAT detector

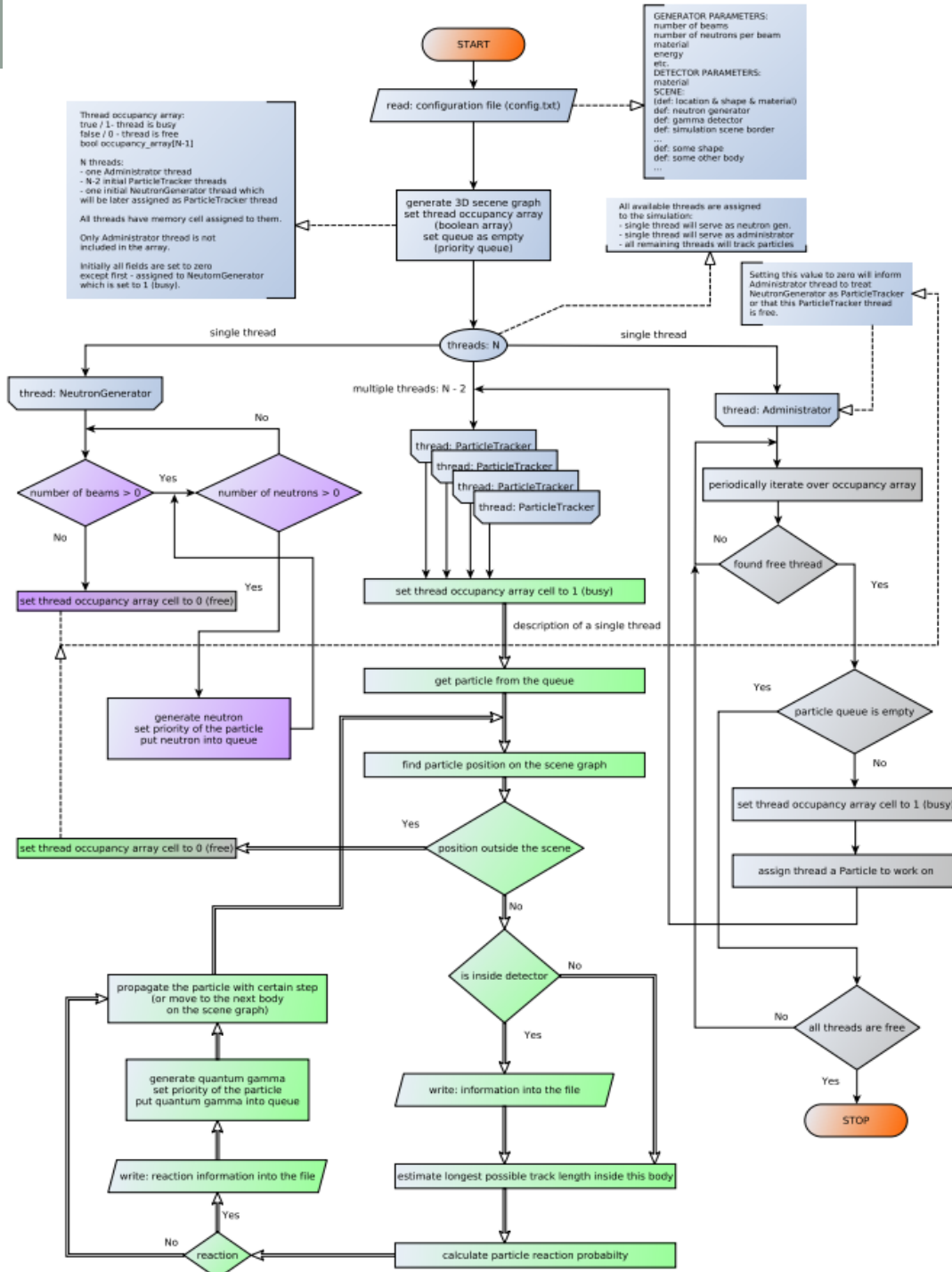
- ❖ The 14.1 MeV neutron generator with α particle detection
- ❖ Neutron and γ quanta attenuation in water minimized by guides filled with air or some other gas
- ❖ Changeable position and orientation of guides
- ❖ Position sensitive detector (**scintillator**)
- ❖ Depth of neutron interaction determined from the time difference between neutron and γ quantum registration times:

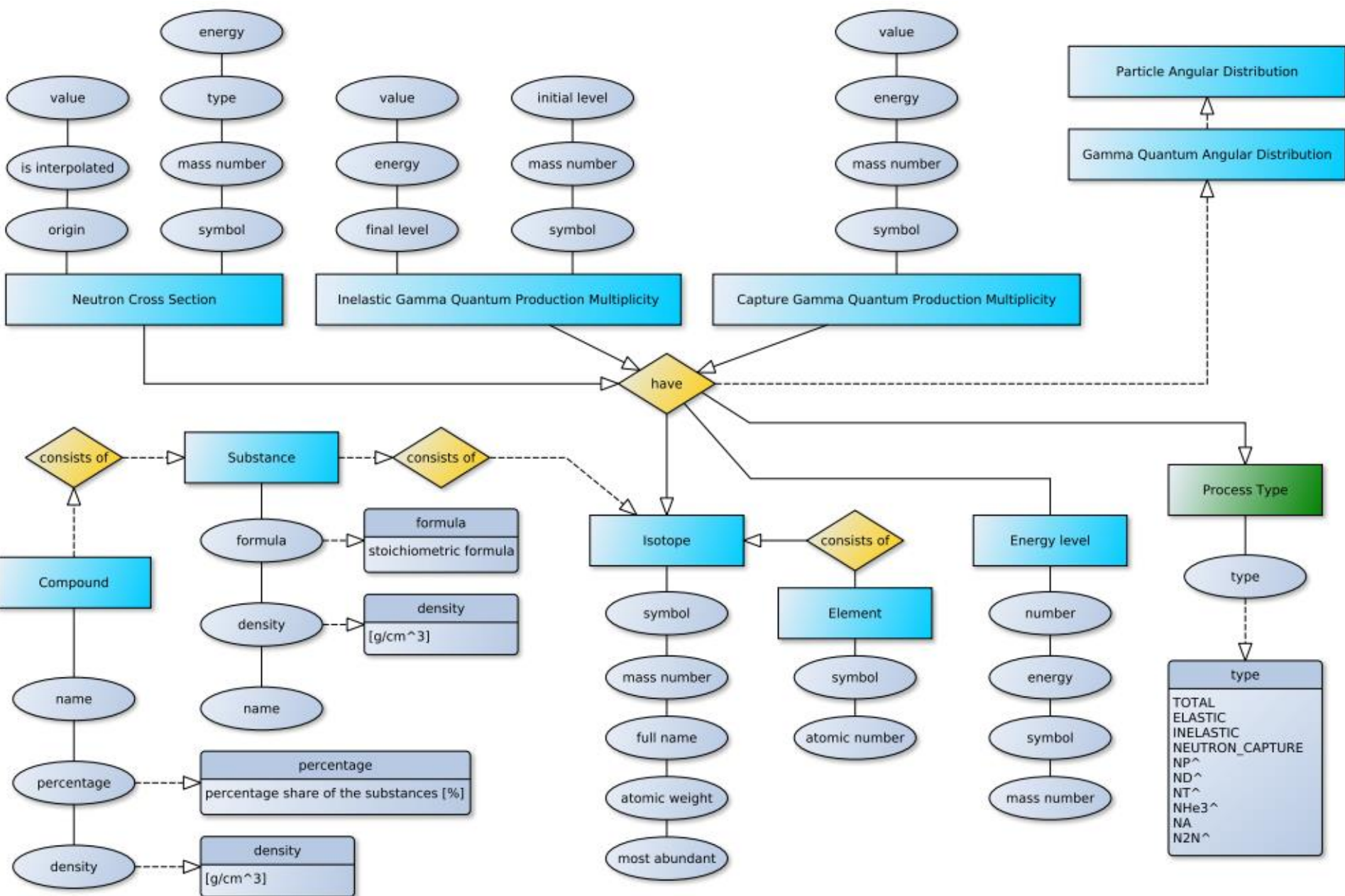


$$x = \left(\Delta t + \frac{l_{\alpha}}{v_{\alpha}} - \frac{l_n}{v_n} - \frac{l_{\gamma}}{c} \right) \frac{c v_n \cos \varphi}{c \cos \varphi + v_n}$$

Design of the first prototype: Monte Carlo simulations

- ❖ Fast independent simulations devoted only to the NAA applications
- ❖ Open source code (C++ as default programming language, standard version C++11)
- ❖ Target OS: Linux (Debian or Red Hat based)
- ❖ Multiple cores/threads (Open MPI standard & library)
- ❖ Parallel computing
- ❖ Physics: ENDF/ENSDF libraries used
- ❖ Database : SQLite3
- ❖ Relational DataBase Management System, most tables in the second normal or third normal form (2NF & 3NF)
- ❖ Novel method of geometry definition and particle tracking based on hypergraphs





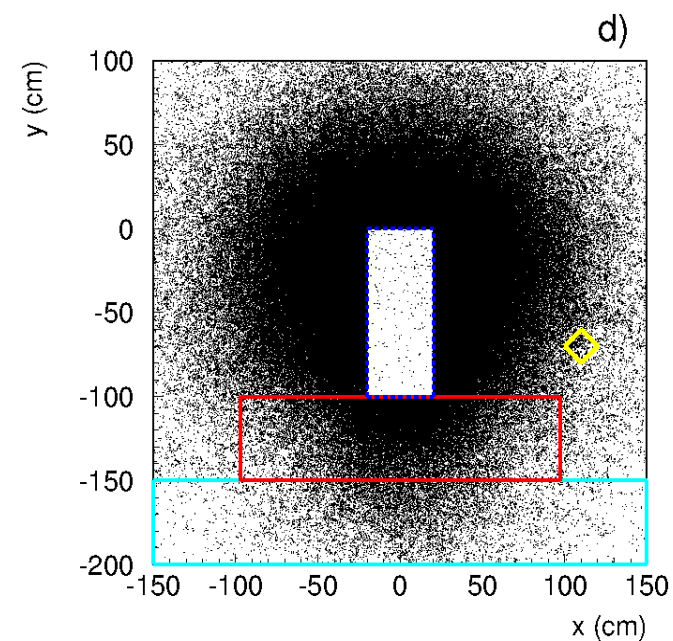
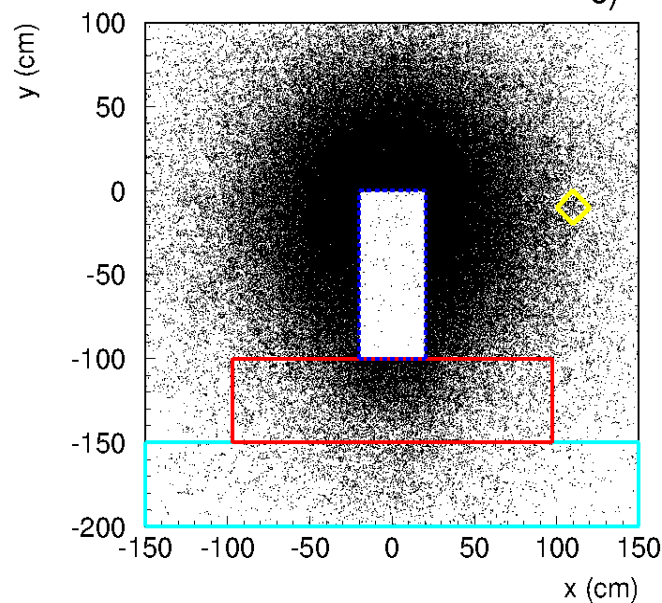
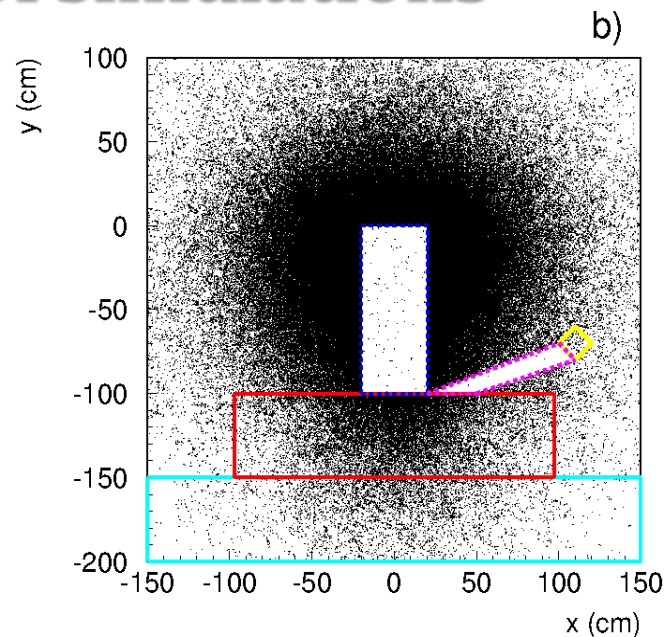
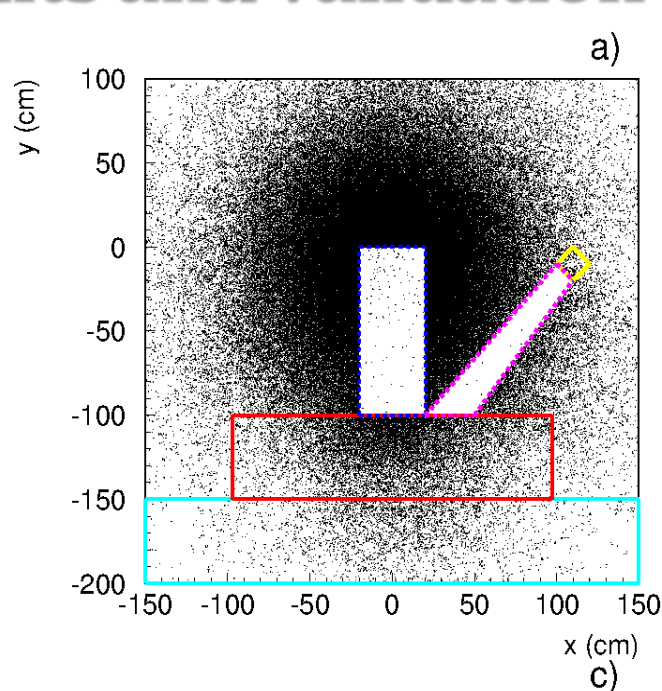
First results and validation of simulations

❖ The first test „scene“
($\sim 10^7$ neutrons):

- ❖ **Container with mustard gas**
($194 \times 50 \times 50 \text{ cm}^3$)
- ❖ **Neutrons guide**
($40 \times 100 \times 40 \text{ cm}^3$)
- ❖ **Ge detector**
($15 \times 15 \times 20 \text{ cm}^3$)
- ❖ **γ quanta guide**
(polyhedron with $15 \times 20 \text{ cm}^2$ and $30 \times 30 \text{ cm}^2$ bases)
- ❖ **Sea bottom (sand)**

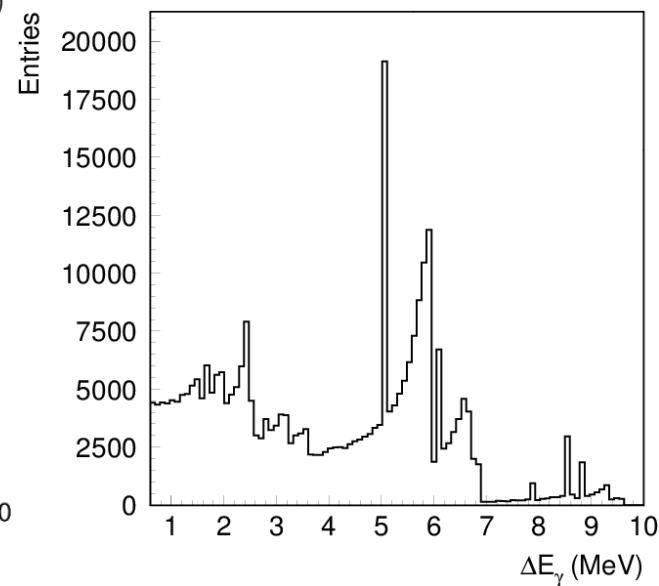
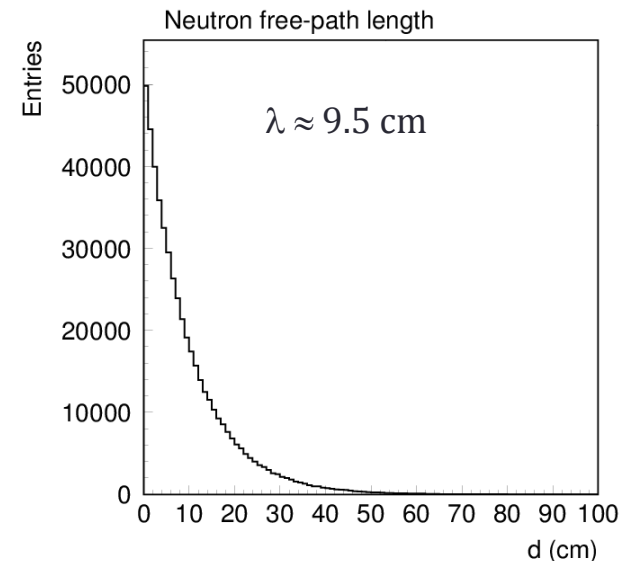
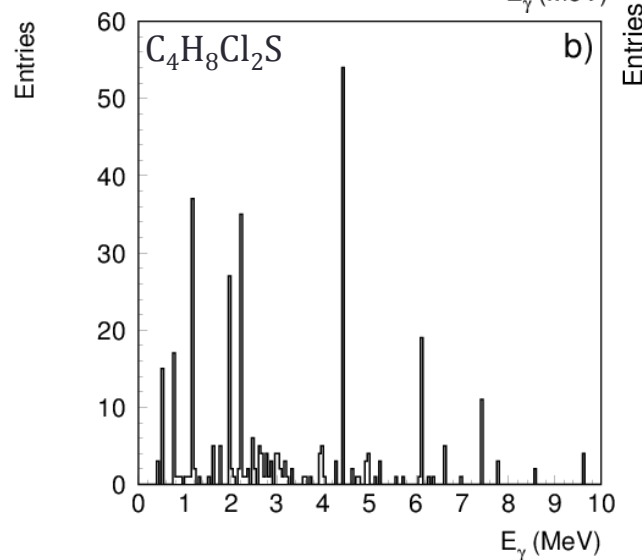
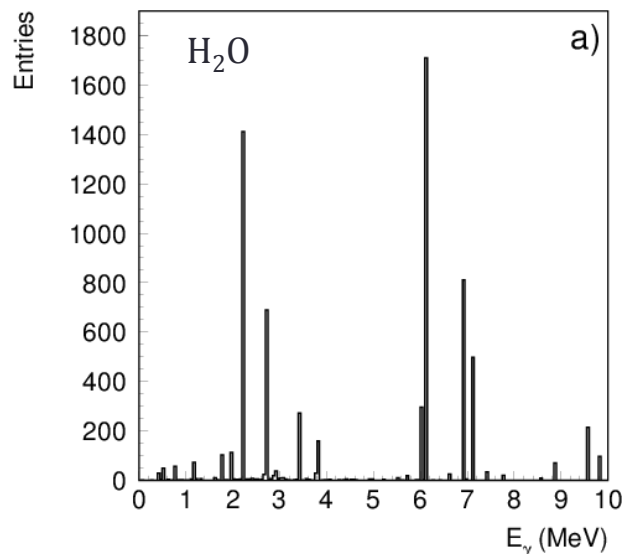
❖ Simulated (so far)
interaction processes:

- ❖ For neutron: capture, inelastic and elastic scattering
- ❖ For γ quanta: Compton scattering, pair production and photoelectric effect



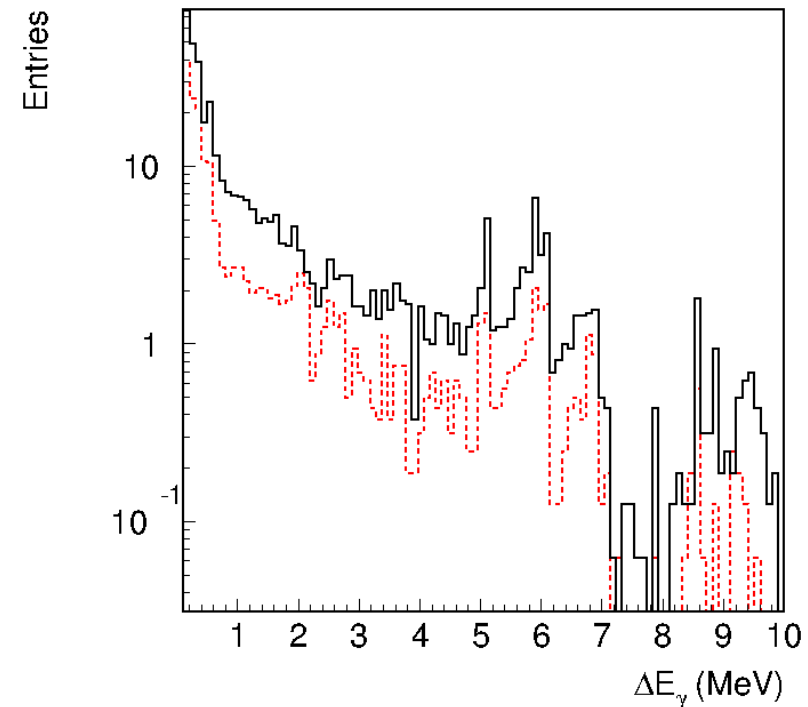
First results and validation of simulations

- ❖ Strong lines from the excitation of oxygen (~ 3 MeV, 6 MeV and 7 MeV), and characteristic line of neutron capture by hydrogen (about 2.2 MeV) visible
- ❖ For the container with mustard gas: big peak for gamma quanta emitted by carbon ^{12}C ($E_\gamma = 4.43$ MeV) and chlorine ^{37}Cl (~ 6 MeV)
- ❖ Hydrogen and sulfur compose one line at $E_\gamma = 2.2$ MeV $\Rightarrow$ hard identification of ^{32}S .



First results and validation of simulations

- ❖ Among all of the detected gamma quanta $\sim 80\%$ originate from oxygen in the water independently of the detector position or presence of the guide
- ❖ The amount of registered gamma quanta created in the mustard gas is quite small but the advantage of using guide is visible
- ❖ The 4.4 MeV carbon line is overwhelmed by background while we see clearly gamma quanta from carbon with energy of about 9.6 MeV.



Setup	H	C	N	O	Na	Si	S	Cl	n	Mustard Gas
a	0	0.77	0	85.17	0.24	0	0	0.26	13.56	1.02
b	0.53	1.68	0.10	76.50	0.38	0.08	0.63	1.78	18.32	3.30
c	0.59	0	0	81.71	0.88	0	0	0.89	15.93	0
d	7.88	0.59	0.05	77.04	0.69	0.24	0.10	6.95	6.46	2.25

Summary

- ❖ The chemical munitions sunk in seas constitute a very serious threat for environment and people
- ❖ Methods of detection used so far are not efficient enough to detect all contaminated sea areas
- ❖ Promising improvement: neutron activation techniques used on the submarine
- ❖ Design of the prototype of such device has started in the Institute of Physics of the Jagiellonian University
- ❖ We are developing a new fast simulation tool devoted to the Neutron Activation Analysis applications
- ❖ In case of chlorine and sulfur (lines of 6.5 MeV and 2.2 MeV, respectively) the oxygen background has to be significantly reduced.
- ❖ This can be done requiring of the coincident detection of the α particle generated together with neutron or by covering all the detector faces not connected to the gamma quanta guide with thick layer of absorber.
- ❖ First simulations of complete identification system expected in the beginning of 2017

Thank You
for attention

