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Efficiency calibration of a portable CZT detector for non-destructive activation assessment of a cyclotron bunker

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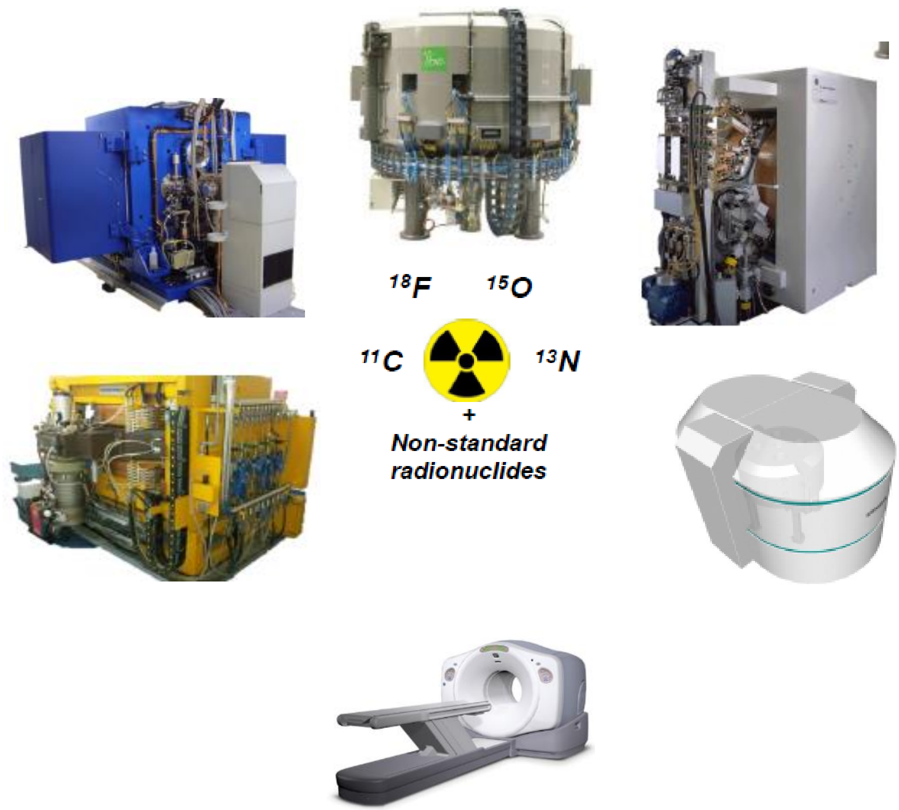
Introduction

- The use of accelerators in the medical field has grown significantly in the last two decades.

- The estimated life expectancy, as well as the reasons for shutting down accelerators are almost as diverse as the type of accelerators present :

  - financial or political issues;
  - market evolution;
  - technological improvements:
  - changes in institution goals;
  - aging of equipment;
  - ….



According to IAEA in the world there are actually 15000 accelerators installed, of which only a few hundred for research while 97% are used for medical and industrial application

Introduction

In Italy there are 36 PET cyclotrons, most of these are in use by 10-15 years.

During the operational life of a PET Cyclotron, the concrete walls of the cyclotron vault are activated by the secondary neutron flux interacting with rare earth's and metals present in the concrete or in reinforcement bars

when considering dismantling of such accelerators, the amount of radioactive waste has to be preventively evaluated to identify any critical issues or possible countermeasures to be taken in order to define an **optimum decommissioning strategy**

Introduction

Critical Aspects

As long as an accelerator is operational, experimental measurements inside the bunker are problematic for different reason:

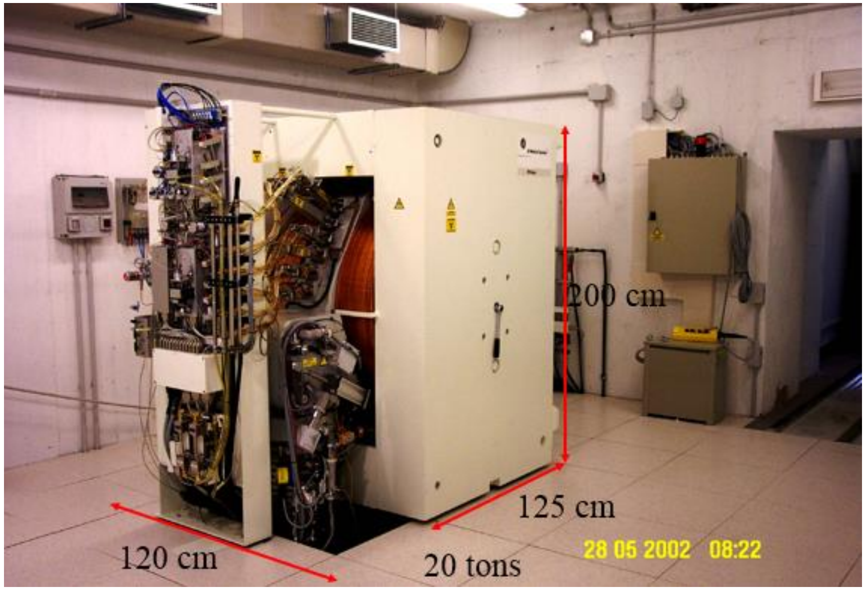
- Access time in bunker is limited;
- The radioactive background due to activated material of cyclotron itself is high;
- Presence of short-lived radionuclides with an activity concentration significantly higher respect to activity concentration of long-lived radionuclides;
- Impossibility to perform core drilling;

Aim of this work is to define a non-destructive in-situ measurement methodology for a preliminary activation assessment of a cyclotron bunker without the need of core drilling.

Material and methods

S. Orsola-Malpighi University Hospital

Medical Physics Department,
S. Orsola-Malpighi Hospital, Bologna



The GE PETtrace cyclotron (16.5 MeV) installed at “S. Orsola-Malpighi” University Hospital (Bologna, IT).

Typical daily production irradiation is made for 60 min with beams currents of 60 µA.

Detector: Kromek GR1

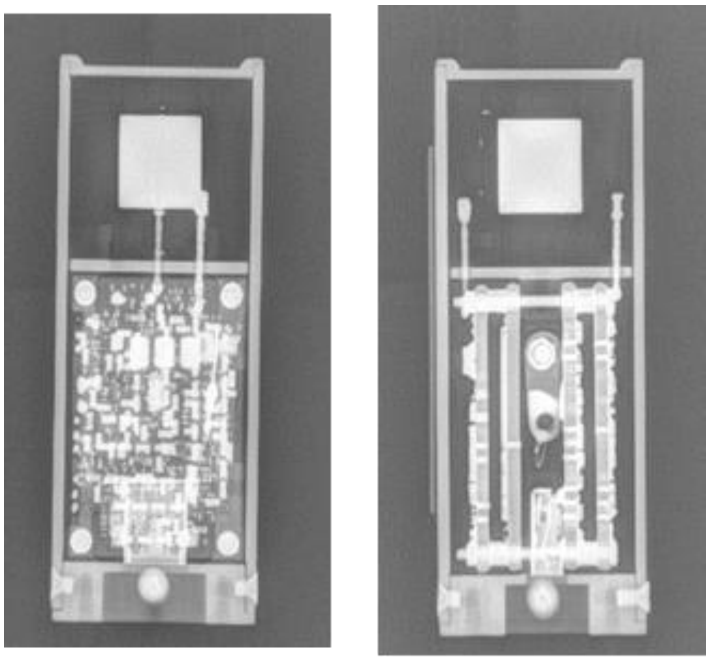
Specification

- **Detector:** 10mm x 10mm x 10mm CZT detector
- **Energy range:** 30 keV to 3.0 MeV
- **Energy resolution:** <2.5% FWHM @662 keV
- **Number of channels:** 4096 (12 bit)
- **Dimensions:** 25mm x 25mm x 63mm
- **Weight:** 60 gram

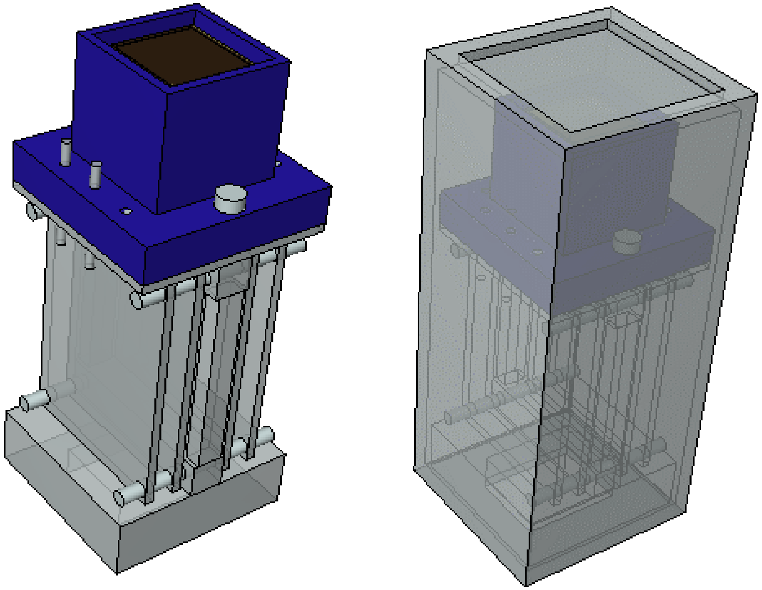
Critical Aspect:

Efficency calibration in non-standard geometry

Monte Carlo Model of the detector using FLUKA



Radiography of the detector



3D Model of the detector

FLUKA Input parameters

DEFAULTS: EM-CASCAde

- ➢ Electromagnetic interactions ON
- ➢ Delta ray production enabled
- ➢ Heavy particle bremsstrahlung activated with explicit photon production above 1 MeV
- ➢ Heavy particle e+/e- pair production activated with full explicit production

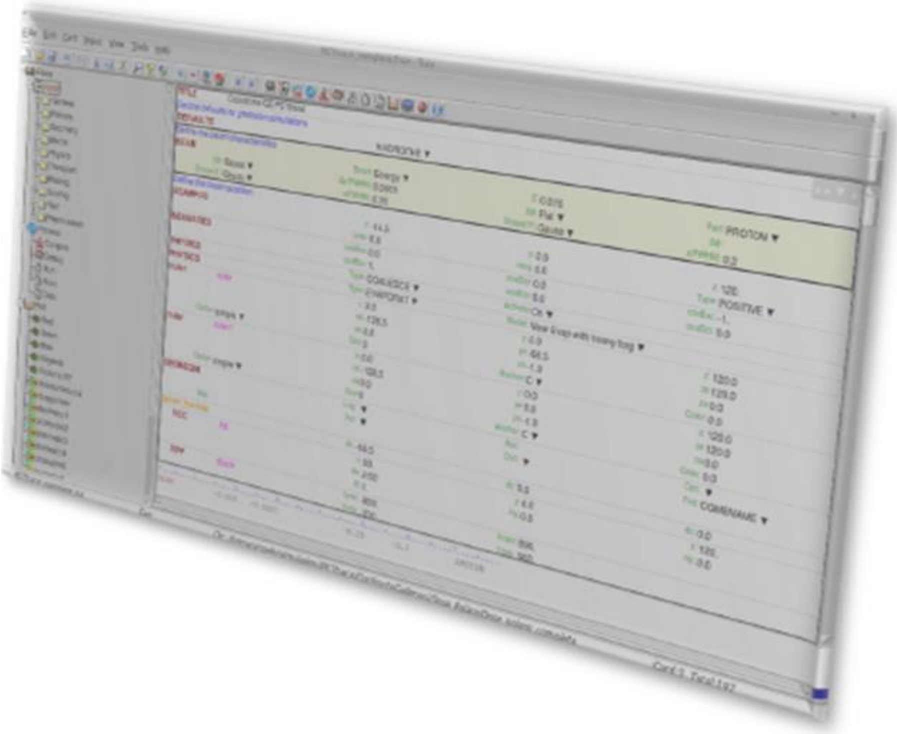
PHYSICS & TRANSPORT

➢Energy thresholds for electron and photon production 1 keV

➢Electron and photon transport cutoffs 1 keV

SCORING

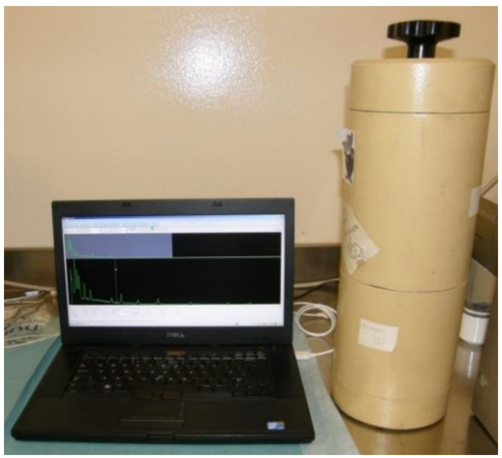
➢Photopeak Efficiency (DETECT)



Validation of the MC model in standard geometry

Experimental measurements

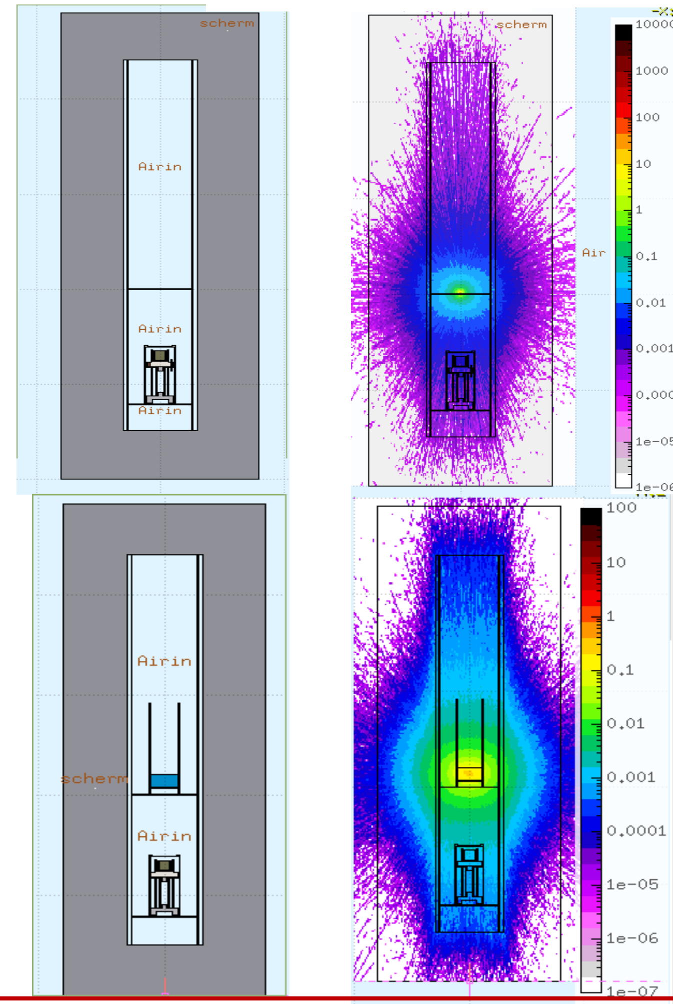
- **Point source:**
^{57}Co ^{139}Cr ^{51}Cr ^{113}Sn ^{85}Sr
^{137}Cs ^{88}Y ^{60}Co



- **5cc Vial:**
^{57}Co ^{137}Cs
^{60}Co

VS

Simulations



Validation of the MC model in standard geometry

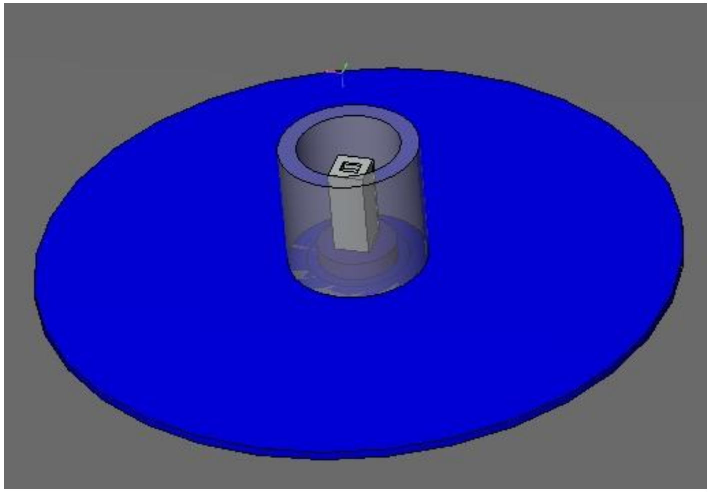
Experimental measurements

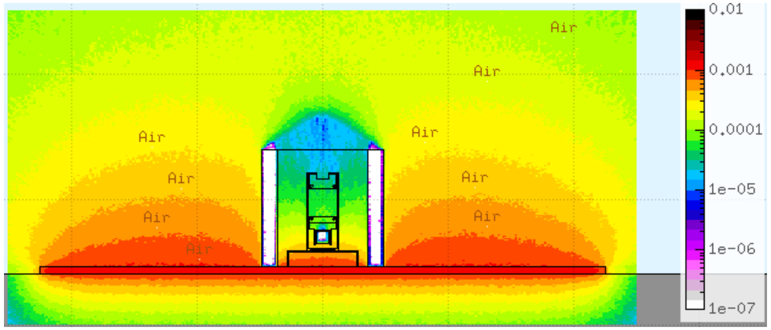
- **Extended source of ^{133}Ba (22 cm radius)**

(80 keV; 302 keV; 356 keV; 383 keV; 276 keV)

VS

Simulations

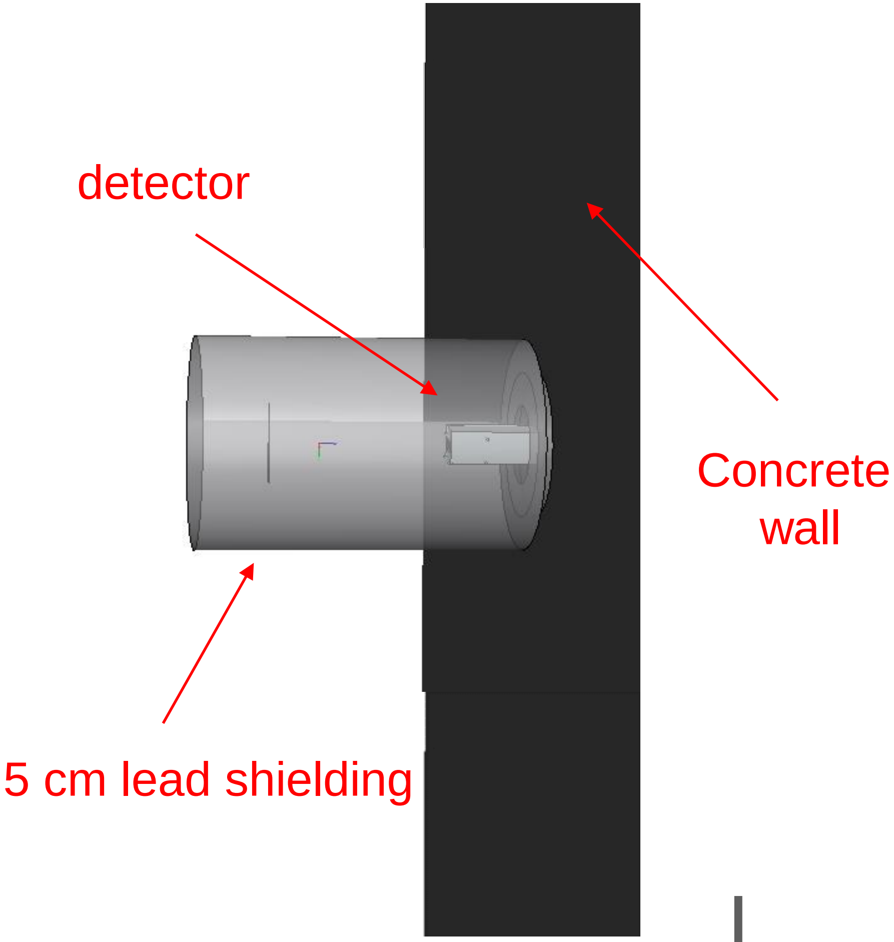




Photons/ cm^3 per primary

Efficiency calibration in non-standard geometry

- **Source:** concrete wall uniformly activated
- **Primary particles:** photons (122.06 keV; 165.86 keV; 320.08 keV; 344.27 keV; 391 keV; 514.00 keV; 661.66 keV; 847 keV; 898.04 keV; 1173.23 keV; 1332.49 keV)
- **N° of primaries simulated**: $1x10^9$
- **Processor:** i7-4790
- **N° core:** 4 (8 thread)
- **N° runs:** 8
- **N° cicle:** 5



Results

Validation of the MC model

Point source

		Experimental measurements		FLUKA		
Nuclide	Energy (keV)	**efficiency**	Uncertainty (%)	**efficiency**	Uncertainty (%)	**FLUKA/experimental**
^{57}Co	122.06	**1,21E-03**	1.56	**1,21E-03**	0.91	**0.997**
^{139}Cr	165.86	**1,11E-03**	1.59	**1,10E-03**	1.09	**0.993**
^{51}Cr	320.08	**3,94E-04**	1.76	**3,91E-04**	1.60	**0.992**
^{113}Sn	391.70	**2,56E-04**	1.60	**2,59E-04**	2.20	**1.010**
^{85}Sr	514.00	**1,67E-04**	1.71	**1,57E-04**	2.81	**0.944**
^{137}Cs	661.66	**9,89E-05**	1.62	**9,91E-05**	3.18	**1.000**
^{88}Y	898.04	**5,50E-05**	1.77	**5,83E-05**	4.63	**1.060**
^{60}Co	1173.23	**3,31E-05**	1.76	**3,36E-05**	1.72	**1.020**
^{60}Co	1332.49	**2,92E-05**	1.79	**2,97E-05**	5.80	**1.020**
^{88}Y	1836.05	**1,57E-05**	2.24	**1,59E-05**	6.75	**1.010**

Validation of the MC model

5cc Vial Source

		Experimental measurements		FLUKA		
Nuclide	Energy (keV)	**efficiency**	Uncertainty (%)	**efficiency**	Uncertainty (%)	**FLUKA/experimental**
^{57}CO	122.06	**7.67E-04**	1.92	**7.35E-04**	1.17	**0.958**
^{137}CS	661.66	**6.09E-05**	1.64	**6.33E-05**	3.98	**1.040**
^{60}CO	1173.23	**2.42E-05**	1.82	**2.41E-05**	2.04	**0.996**
^{60}CO	1332.49	**1.99E-05**	1.88	**2.03E-05**	2.21	**1.020**

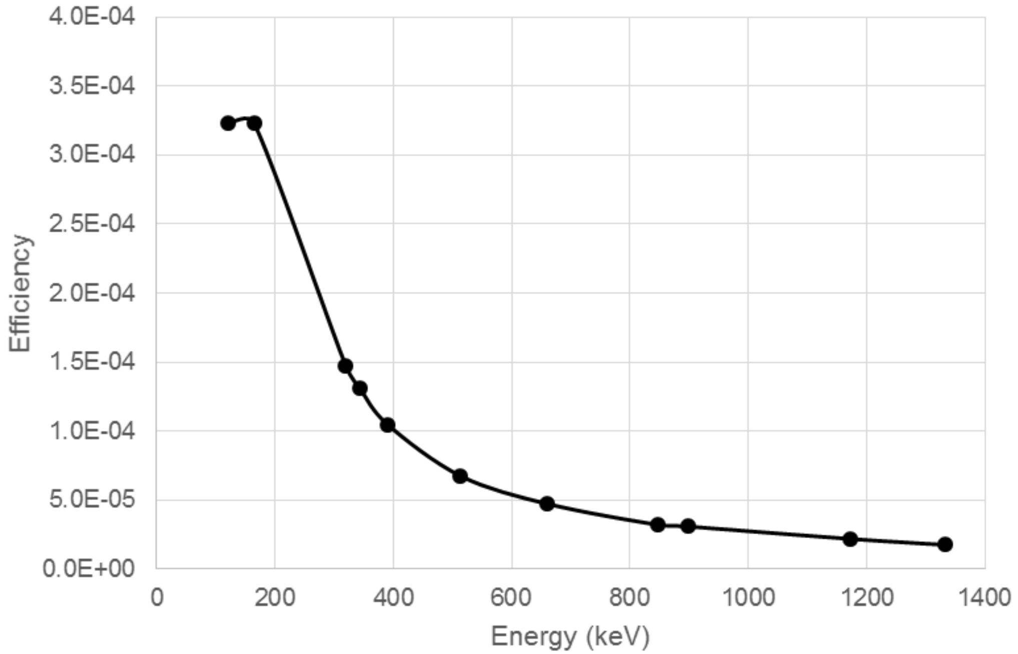
^{133}Ba Extended Source

	Experimental measurements		FLUKA		
Energy (keV)	**efficiency**	Uncertainty (%)	**efficiency**	Uncertainty (%)	**FLUKA/experimental**
276.40	**5,40E-05**	4.10	**5.63E-05**	1.33	**1.040**
302.85	**4,76E-05**	4.04	**4.95E-05**	1.42	**1.040**
356.02	**3,81E-05**	1.55	**3.80E-05**	1.62	**0.995**
383.85	**3,31E-05**	1.71	**3.32E-05**	1.83	**0.999**

Efficiency calibration curve for wall activation assessment

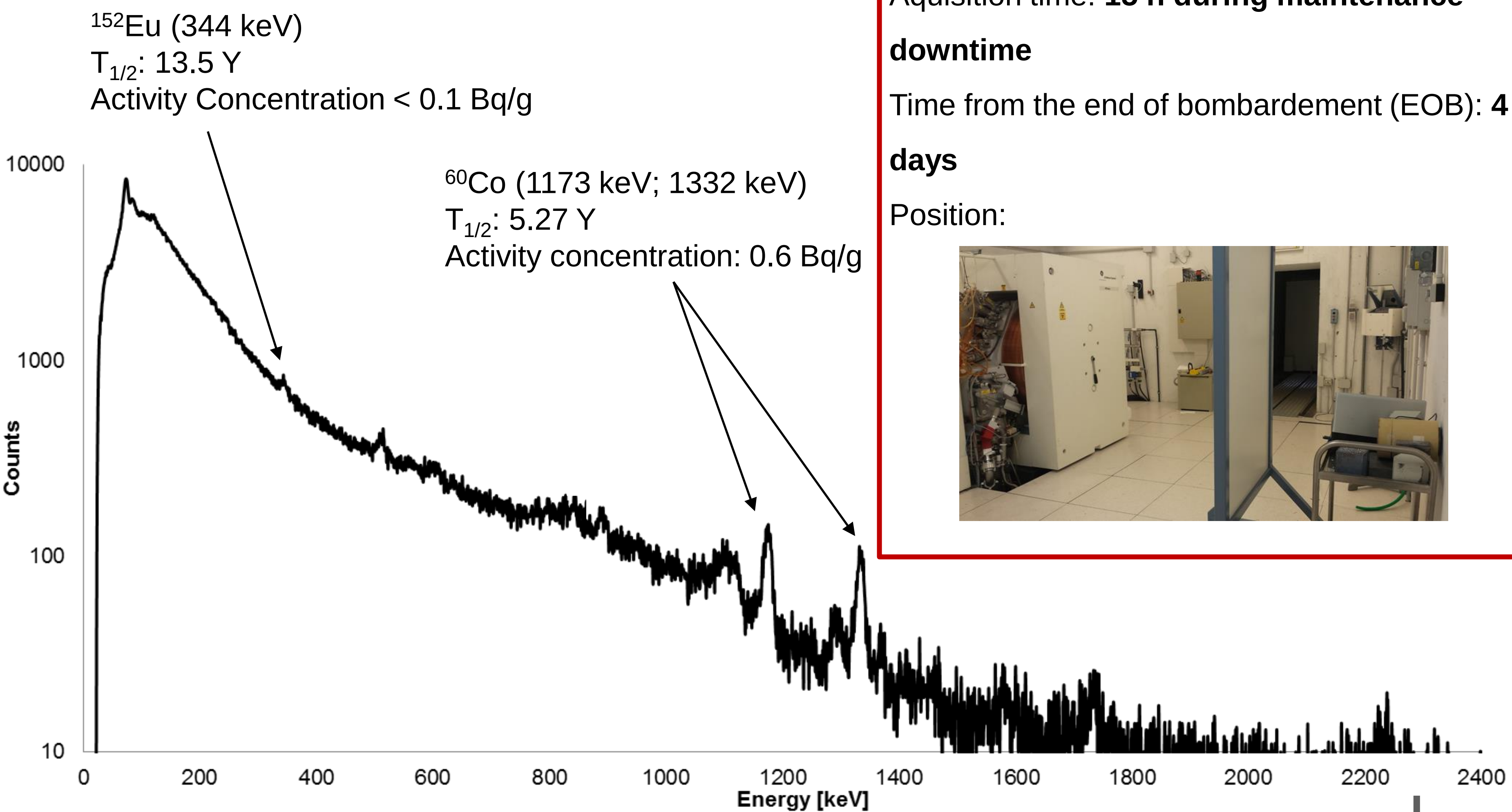
Concrete wall

Energy (keV)	efficiency	Uncertainty (%)
122.06	**3.23E-004**	0.6
165.86	**3.23E-004**	0.6
320.08	**1.47E-004**	0.8
344.27	**1.31E-004**	0.9
391	**1.04E-004**	1.0
514.00	**6.72E-005**	1.2
661.66	**4.71E-005**	1.5
847	**3.19E-005**	1.8
898.04	**3.07E-005**	1.8
1173.23	**2.17E-005**	2.1
1332.49	**1.74E-005**	2.4



The efficiency curve for wall activation measurements was calculated, allowing a quantitative evaluation of activity concentration.

Experimental measurements: long-lived radionuclides



Aquisition time: **15 h during maintenance downtime**

Time from the end of bombardement (EOB): **4 days**

Position:

Experimental measurements: short-lived radionuclides

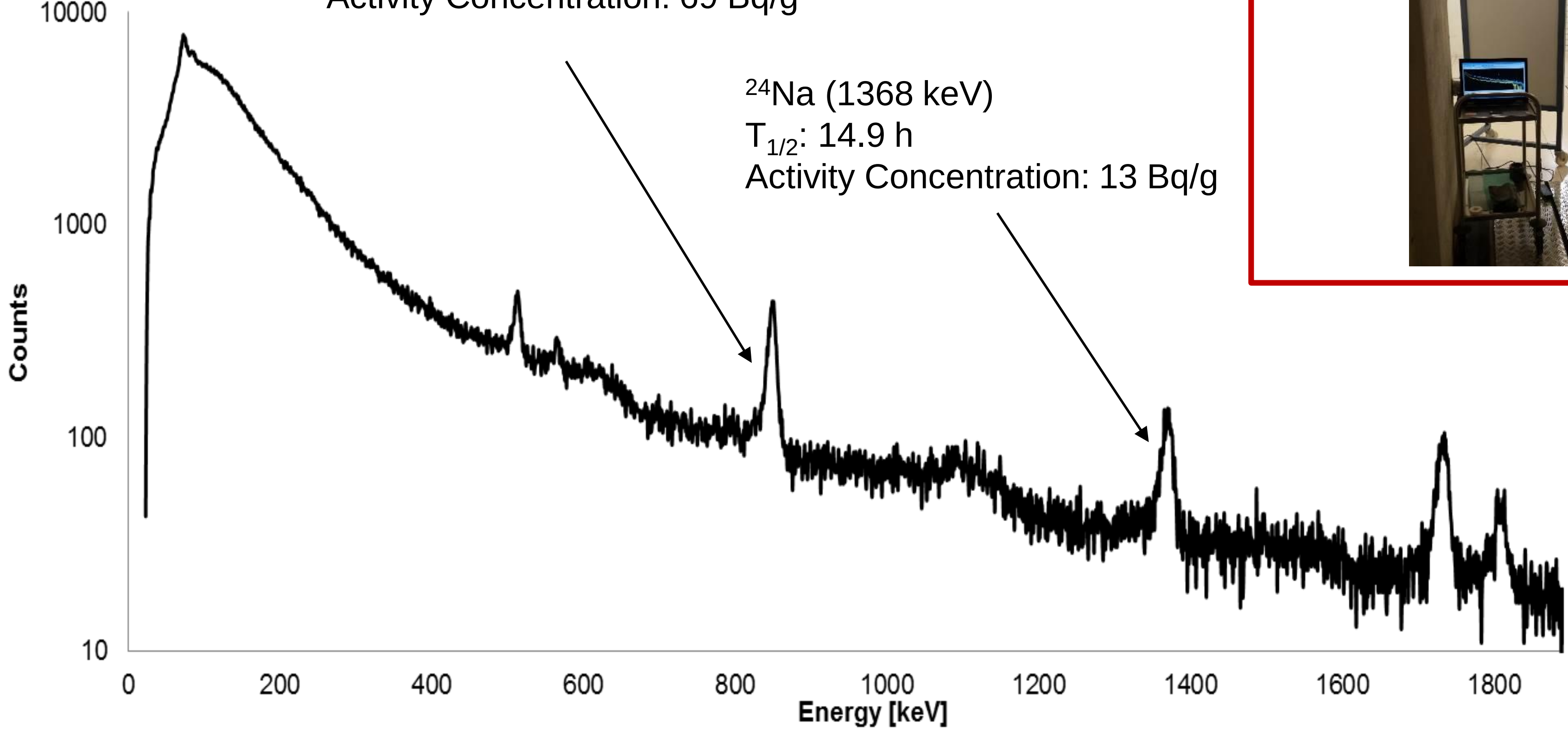
Aquisition time: **1 h**

Time from the EOB: **5 h**

Position:

^{56}Mn (847 keV)
$T_{1/2}$: 2.5 h
Activity Concentration: 69 Bq/g

^{24}Na (1368 keV)
$T_{1/2}$: 14.9 h
Activity Concentration: 13 Bq/g



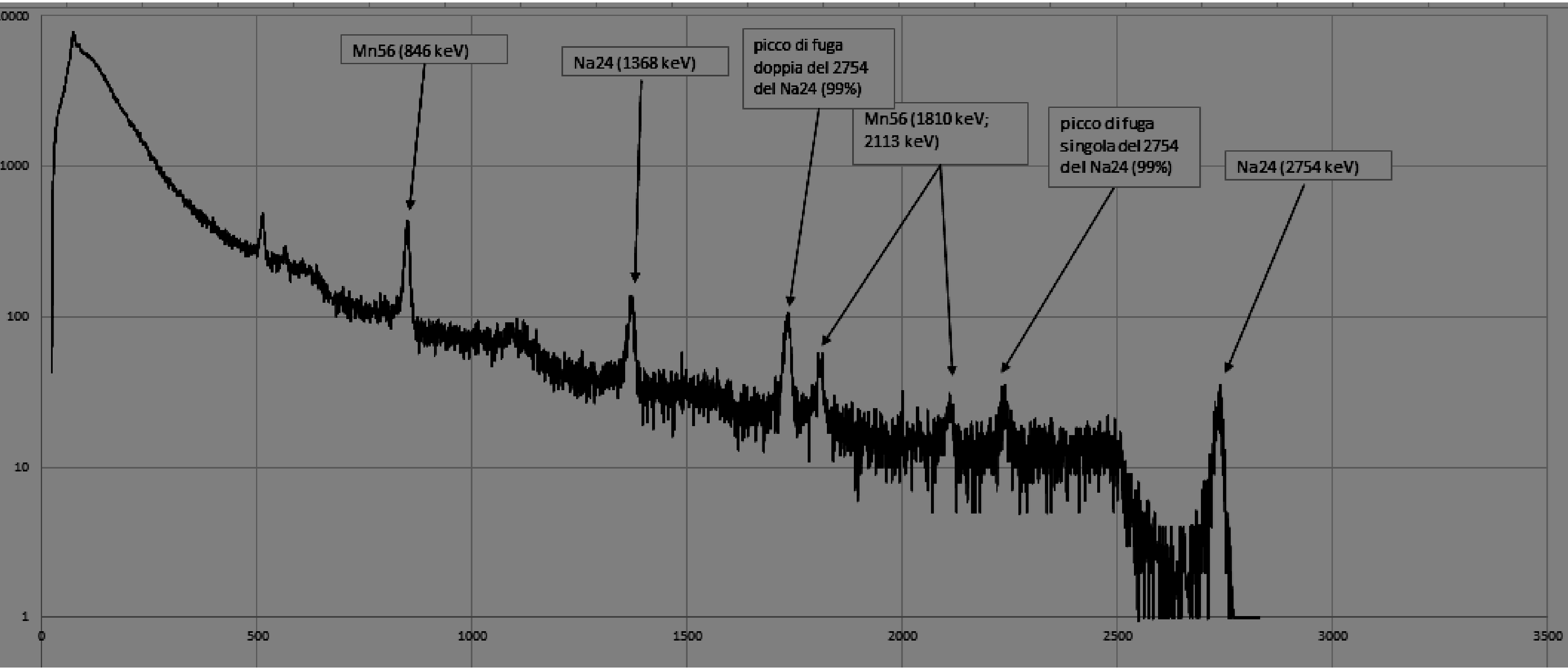
conclusions

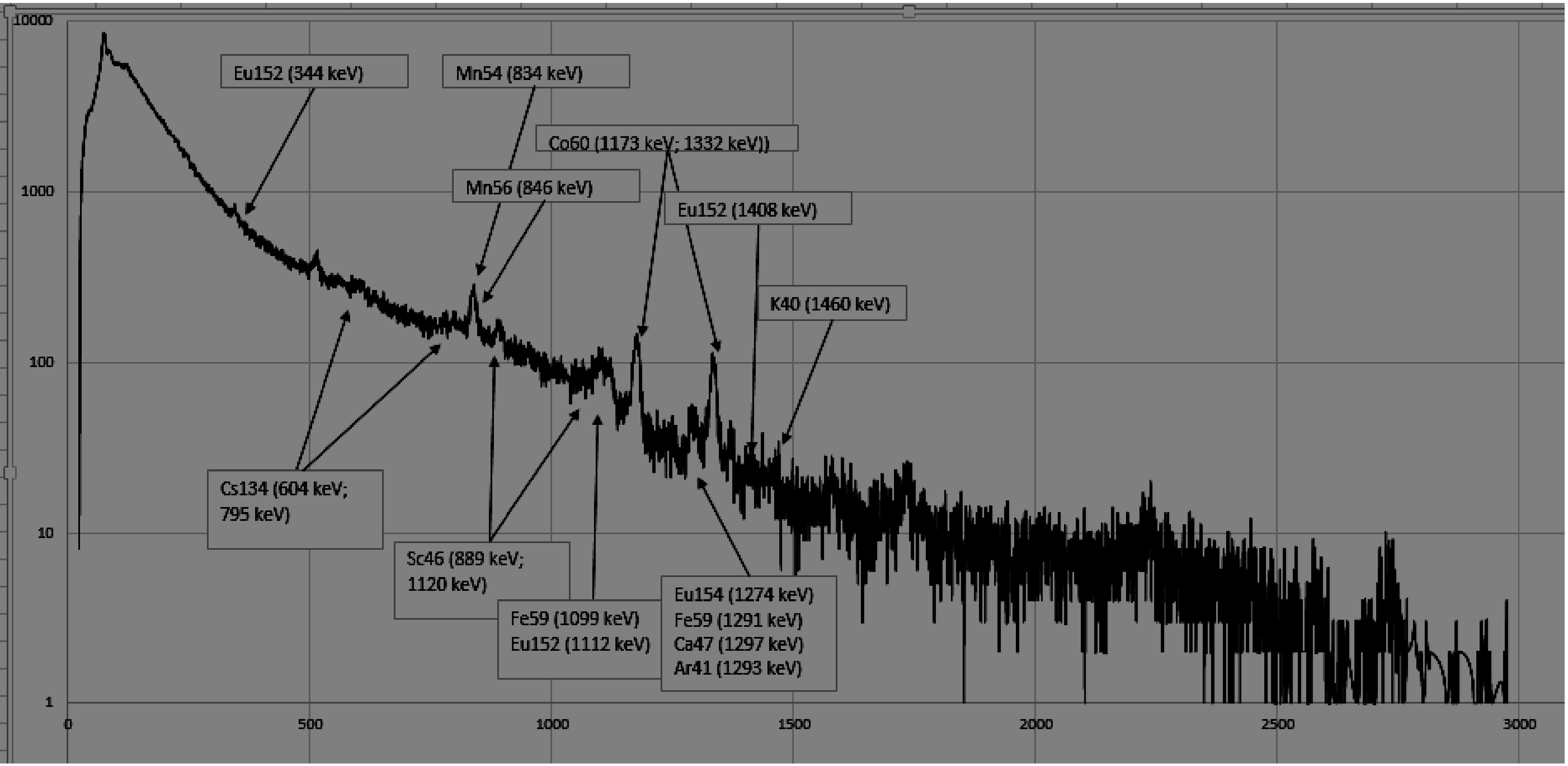
- a non-destructive in-situ measurement methodology with a compact and portable CZT detector was developed;

- this methodology can be applied in the study of cyclotron sites, but also to radiotherapy linacs and other accelerators.

- Monte Carlo simulation proved to be a powerful tool for assessment of efficiency calibration curves for portable instruments used on the field in non-standard geometry conditions.

Thanks for your attention!


Mn56 (846 keV)
Na24 (1368 keV)
picco di fuga doppia del 2754 del Na24 (99%)
Mn56 (1810 keV; 2113 keV)
picco di fuga singola del 2754 del Na24 (99%)
Na24 (2754 keV)
10000
1000
100
10
1
0
500
1000
1500
2000
2500
3000
3500



10000
1000
100
10
1
0
500
1000
1500
2000
2500
3000
Eu152 (344 keV)
Mn54 (834 keV)
Co60 (1173 keV; 1332 keV))
Mn56 (846 keV)
Eu152 (1408 keV)
K40 (1460 keV)
Cs134 (604 keV; 795 keV)
Sc46 (889 keV; 1120 keV)
Fe59 (1099 keV) Eu152 (1112 keV)
Eu154 (1274 keV) Fe59 (1291 keV) Ca47 (1297 keV) Ar41 (1293 keV)