Determination of masses of the super heavy elements in the experiments on synthesis of Cn and Fl using the reactions 48Ca + 242Pu and 48Ca + 244Pu

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Abstract

MASHA facility was built to identify Super Heavy Elements by measuring on-line their mass to charge ratio. In the test experiments, isotopes of Hg and Rn were used because of the shared chemical properties with elements Cn=112 and Fl=114. Mass separation and efficiency of Hg and Rn was measured in order to calibrate the mass separator and to predict the yields for the super-heavy isotopes. The report makes a summary of the installation and the methods used, then data consisting of α decay energies and branching ratios of radioactive isotopes are presented and discussed.

Introduction

The discovery of new chemical elements of the Periodic Table with atomic numbers 112-118 represents a very important scientific achievement. The half-lives of the new nuclides can reach up to 0.5 min. These results sugest a considerable increase in the stability of SHE with increasing neutron number [3]. The heaviest elements beeing many-body nuclear systems (more than approximately 250) should not have macroscopic nuclear stability anymore. Despite that, due to shell effects, nuclei around atomic number 114 and neutron number 184 should be rather stable against nuclear decay. Calculated halflives reach values of up to 10^9s[1]. The increase in stability of the newly discovered isotopes provide the first experimental confirmation of the theoretical predictions of the existence of an “Island of Stability” in the domain of hypothetical super-heavy elements [3]. Relatively long lifetimes of a number of new nuclides (>1 s) have made it possible to perform independent chemical identification of

elements 112–115 [2]. The chemical properties of elements 112 and 114 were difficult to measure due to the low production rate of about one atom per week of bombardment which is caused by the very low reaction cross section [1]. A calibration of the setup which could analize single atom elements is needed. The fact that element 112 has a behaviour typical of group 12 elements [4] justifies the choice of α radioactive Hg and Rn as chemical homologues for elements Z = 112 and Z = 114. In the following experiments, radioactive Hg isotopes were synthesized in the complete fusion reaction ^{40}Ar +^{148}Sm and the Rn isotopes were made in the multinucleon transfer reaction ^{48}Ca +^{242}Pu and fusion reaction ^{40}Ar +^{166}Er. Using the information gained from these elements we could predict the behaviour of elements Z=112 and Z=114 inside the mass separator.

The Setup

The setup consists of the target assembly with a hot catcher, an ion source based on the electron cyclotron resonance (ECR), a magneto-optical analyzer (a mass spectrometer) composed of four dipole magnets (D1, D2, D3a, and D3b), three quadrupole lenses (Q1–Q3), and two sextupole lenses (S1, S2) and a detection system located in the focal plane of the spectrometer.

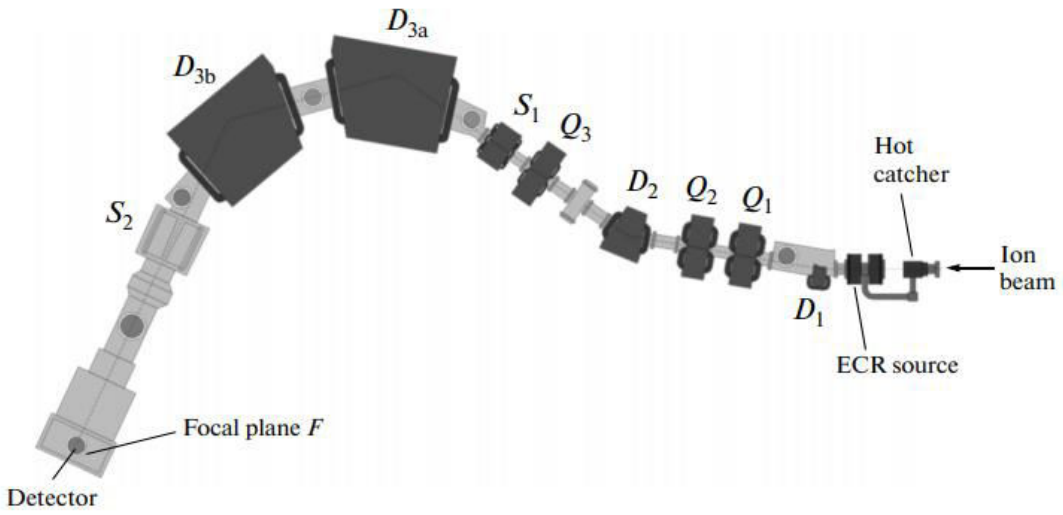


Figure 1. Schematic diagram of the MASHA mass separator: (D1, D2, D3a, D3b) dipole magnets, (Q1,Q2,Q3) quadrupole lenses, and (S1, S2) sextupole lenses. The detection system is in focal plane F of the separator [5].

Ion Source

The ion source is based on the ECR (the ECR source) with a 2.45GHz frequency of its microwave oscillator. In the ECR, atoms are ionized to charge state Q = +1, accelerated with the aid of the three-electrode system and gathered into a beam which is thereafter separated by the magneto-optical system of the mass spectrometer. The ECR source helps to obtain ion currents consisting of almost 100% of singly ionized atoms and the ionization efficiency of noble gases is as high as 90%. Helium was used as a buffer gas and its pressure was regulated using a controlled piezoelectric valve. The optimal parameters of the source were obtained at a helium pressure in the range of $(1–2) \times 10^{-5}$ mbar and a microwave oscillator power of ~30 W [5].

Target assembly

Hot catcher is a part of the target assembly. Prior to hitting the target, the primary beam of heavy ions passes through the diagnostic system. This allows control of the beam position relative to the ion guide. Behind the diagnostic system, there is a stationary target fixed in place between two grids, which are cooled with water and have a honeycomb structure with an 85% transparency. The diameter of the active part of the target is 15 mm. Nuclear reaction products escape from the target, pass through the separating foil and are stopped in the graphite absorber, which is heated to a temperature of 1500-2000 K. In the form of atoms, the products diffuse from the graphite absorber to the vacuum volume of the hot catcher and, moving over the pipeline, reach the ECR source [5].

Detection

The detection is made with a well-type silicon detector installed in the focal plane of the mass spectrometer to detect decays of nuclear reaction products. The plane of the frontal detector part is oriented along the normal to the beam direction and consists of 192 strips. The side detectors are divided into 64 and 16 strips respectively. The standard operating bias of the detectors is –40 V, and their energy resolution for α particles from a ^{226}Ra source is ~30 keV. The described geometry of the detector assembly makes it possible to detect no less than 90% α particles emitted in a single nuclear decay at the center of the detector's frontal part. The signals from each strip of the silicon detector are read out independently. The program allows viewing of one-dimensional energy spectra from each strip, as well as two-dimensional spectra of the energy dependence on the strip number for each crystal [5].

Method

MASHA was constructed at one of the beam outs of U-400M cyclotron in order to conduct on-line measurements of the physical properties of superheavy elements.The target was bombarded by beam of ^{48}Ca with energy E_{beam} = 7.3 MeV/n. The beam is stoped in the graphite catcher heated up to 1800K. Atoms diffuse from the graphite volume and, move along the vacuum pipe and reach the ECR ion source discharge chamber where they are ionized. Faraday cup allows beam intensity control or target protection by periodically intrerupting the beam.The separation efficiency and time were measured for Hg isotopes due to their similarity with element Z=112. α radioactive isotopes were obtained in the fusion reaction $^{40}Ar + ^{144}Sm \rightarrow ^{184-xn}Hg + xn$. α decay energy of the fusion products was measured as a function of the strip number [5]. The full separation efficiency for the short-lived mercury isotopes was 7 % and the separation time was 1.8 s. Rn was obtained in the $^{40}Ar + ^{166}Er$ reaction and in the multinucleon transfer reaction $^{48}Ca + ^{242}Pu$, which also has a high cross section and used as a homologue of Cn [6].

Data

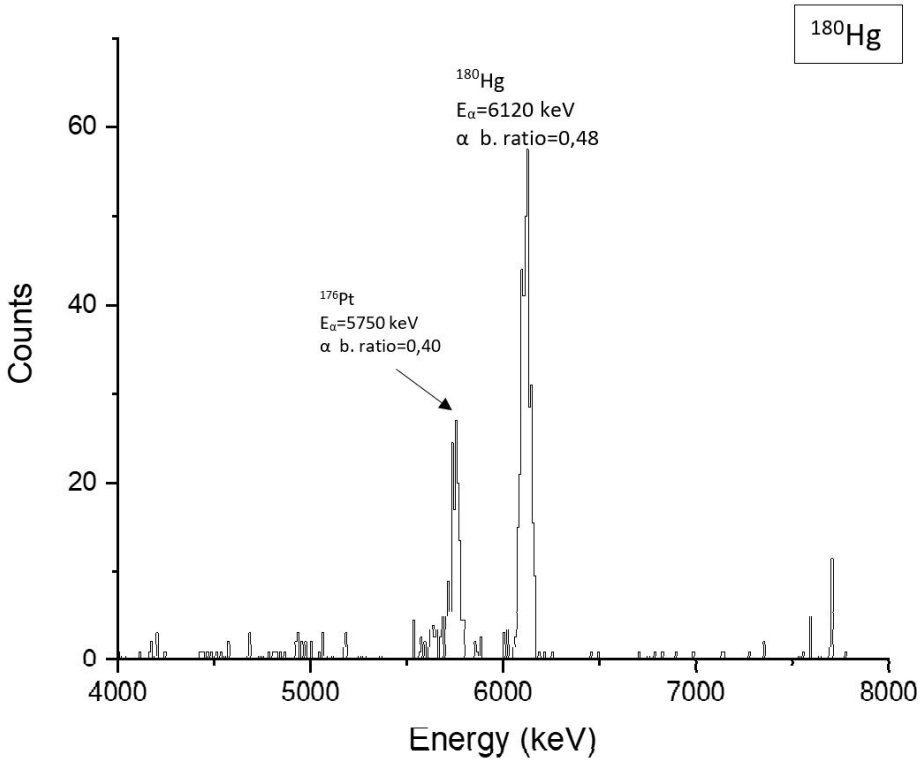
Data aquisition programs are used which allow viewing one-dimension energy spectra from each strip, as well as two-dimensional spectra of the energy dependence on the strip number. Decay energies were measured for the Hg and Rn isotopes. Matching the results with the tabulated α decay energy allowed identification of each isotope. It is easy to discriminate between the isotope formed and their daughter nuclei. In the last heat map, we notice that $^{213-217}Rn$ isotopes are not present in the matrix graph, the explanation is being that their half lives are shorter than 0.5 ms and the counted installation separation time using the polygraphene solid catcher is 1.8±0.3s.

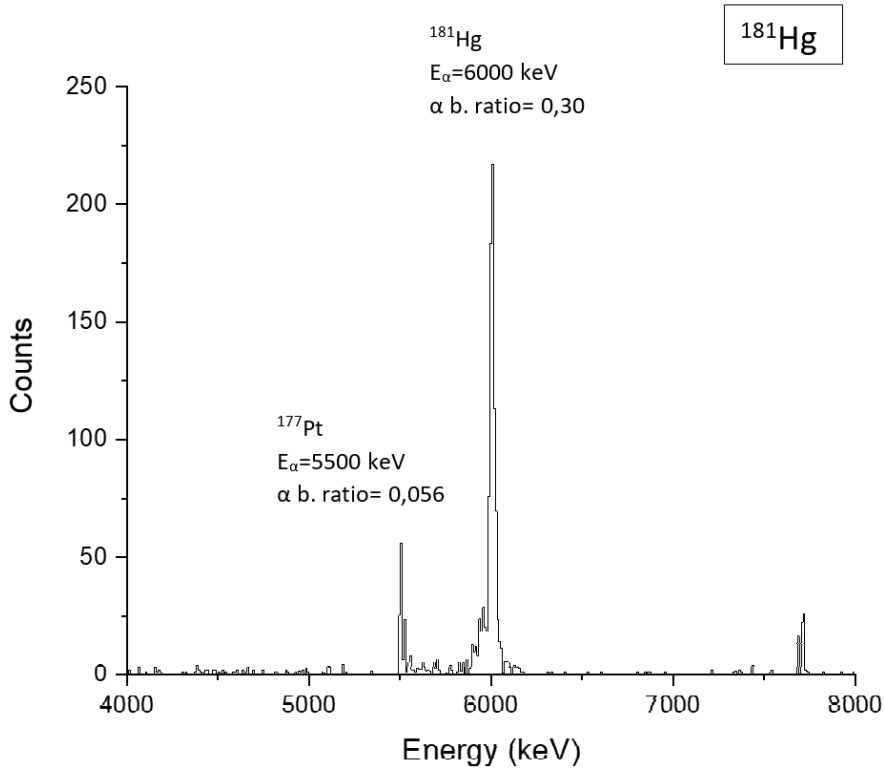
Task

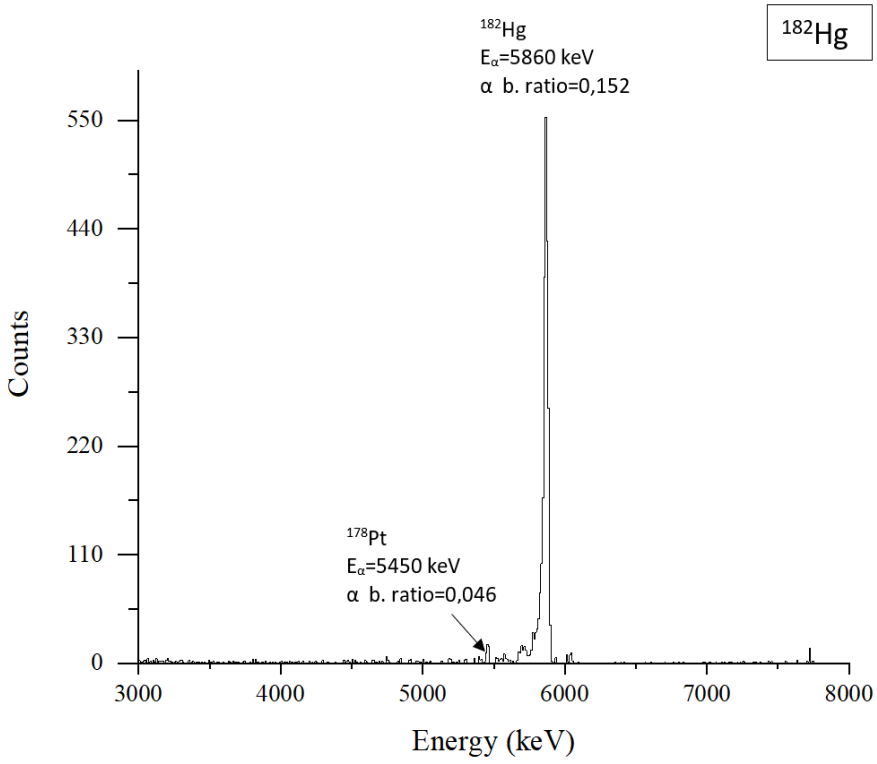
The task consists of plotting and analyzing data from the detectors. Data is obtained from 3 different reactions. The decay energy is obtained along with alpha branching ratio and the identification of the isotopes. The strip detector has been calibrated and the results are showed on the heat map.

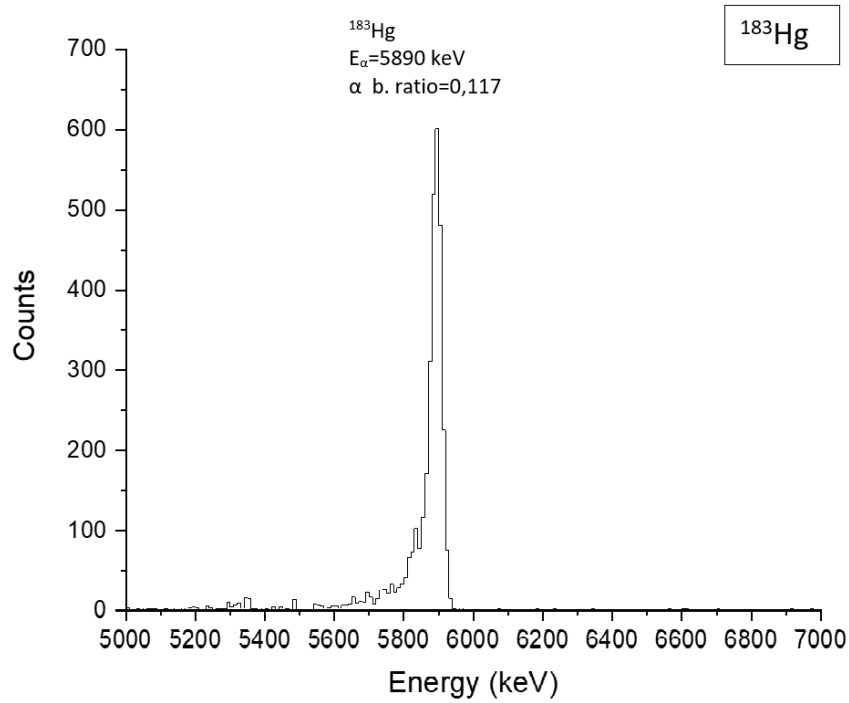
Results

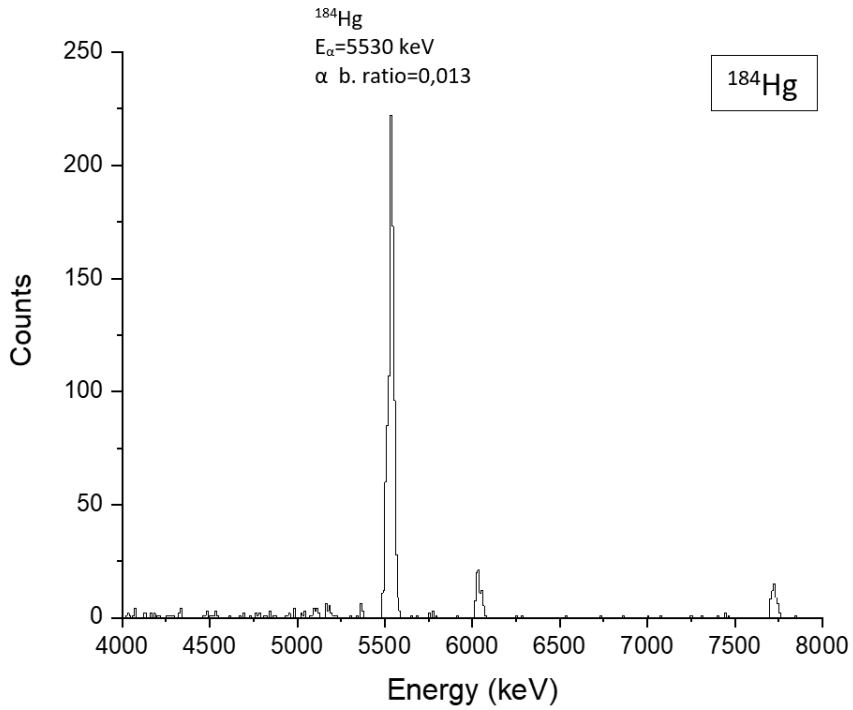
1. $^{40}Ar + {}^{148}Sm \rightarrow {}^{188\text{-}xn}Hg + xn$

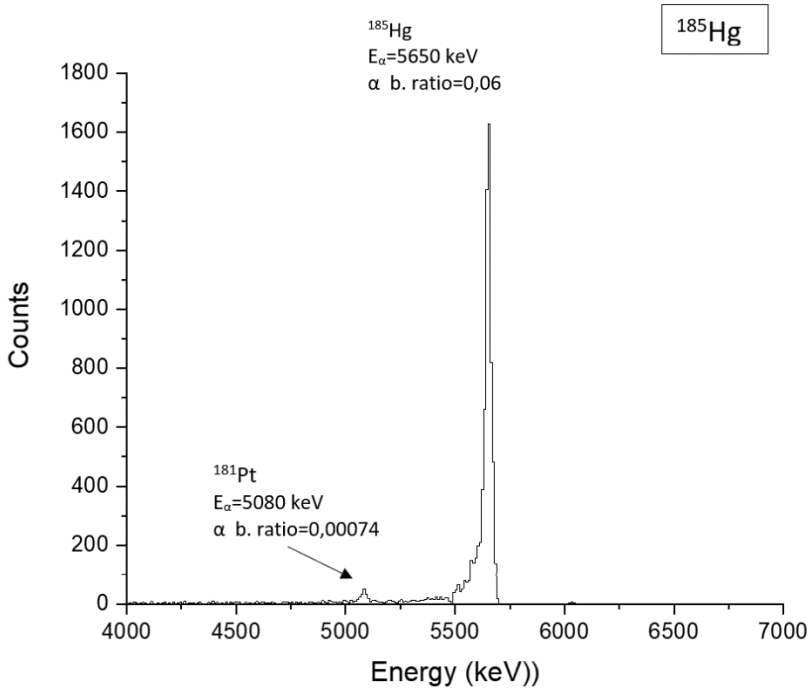


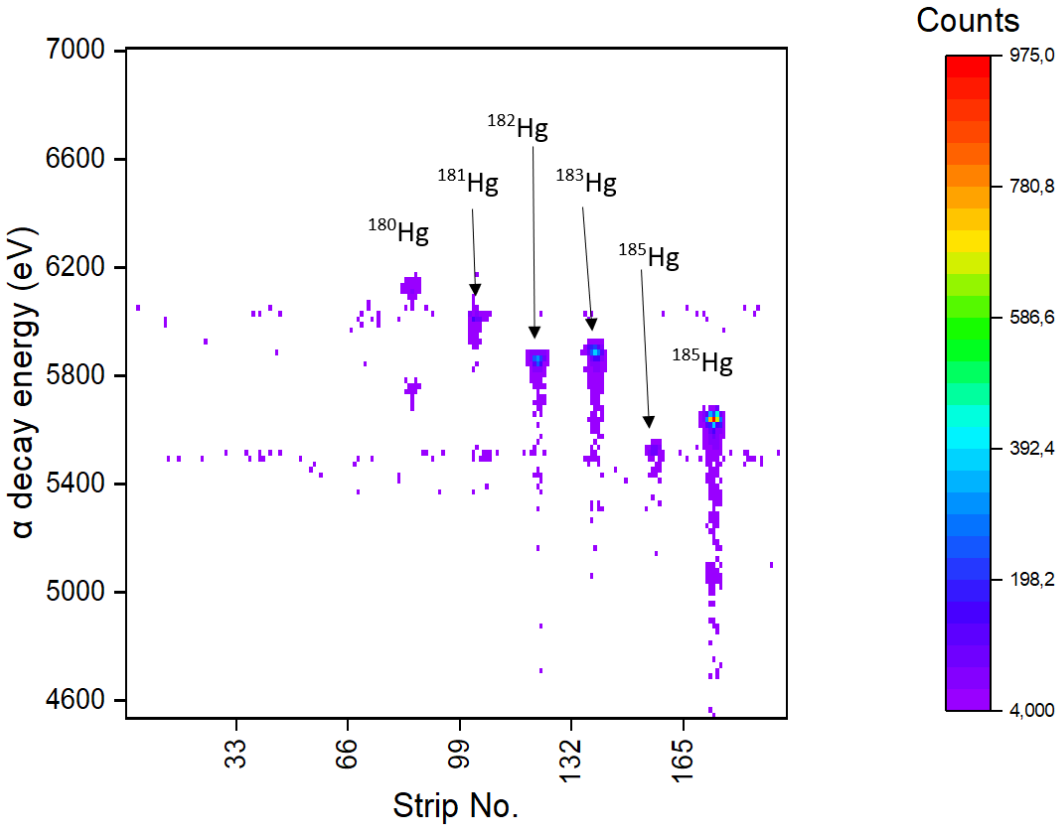

181Hg
181Hg
Eα=6000 keV
α b. ratio= 0,30
177Pt
Eα=5500 keV
α b. ratio= 0,056
Counts
Energy (keV)
0
50
100
150
200
250
4000
5000
6000
7000
8000


182Hg
182Hg
Eα=5860 keV
α b. ratio=0,152
178Pt
Eα=5450 keV
α b. ratio=0,046
Counts
Energy (keV)
0
110
220
330
440
550
3000
4000
5000
6000
7000
8000

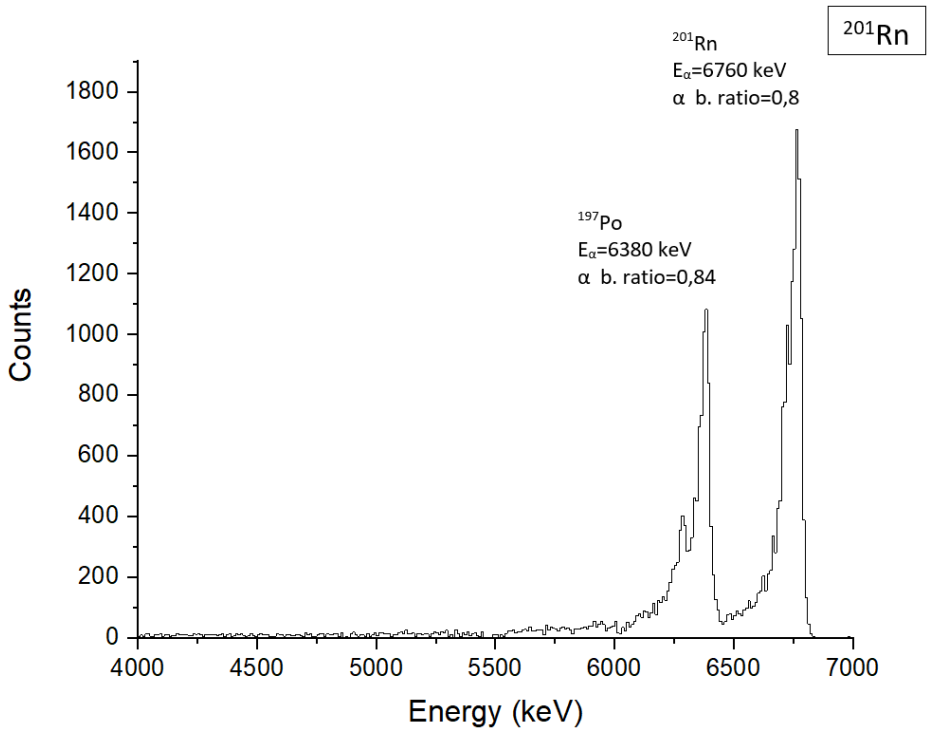

183Hg
Eα=5890 keV
α b. ratio=0,117
183Hg
Counts
Energy (keV)
0
100
200
300
400
500
600
700
5000
5200
5400
5600
5800
6000
6200
6400
6600
6800
7000

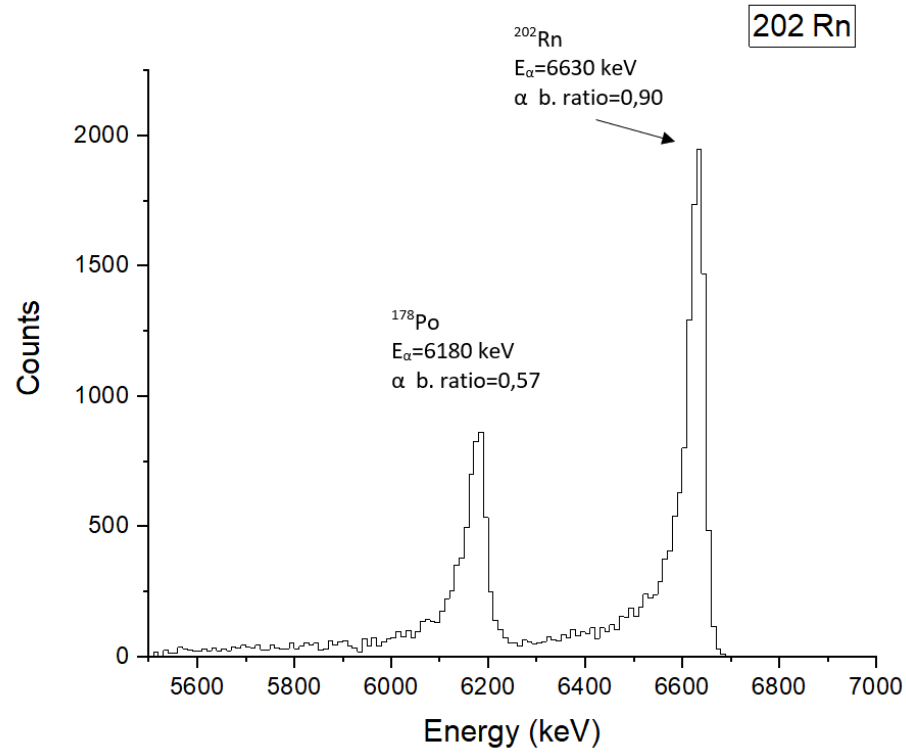

184Hg
Eα=5530 keV
α b. ratio=0,013
184Hg
Counts
Energy (keV)
0
50
100
150
200
250
4000
4500
5000
5500
6000
6500
7000
7500
8000

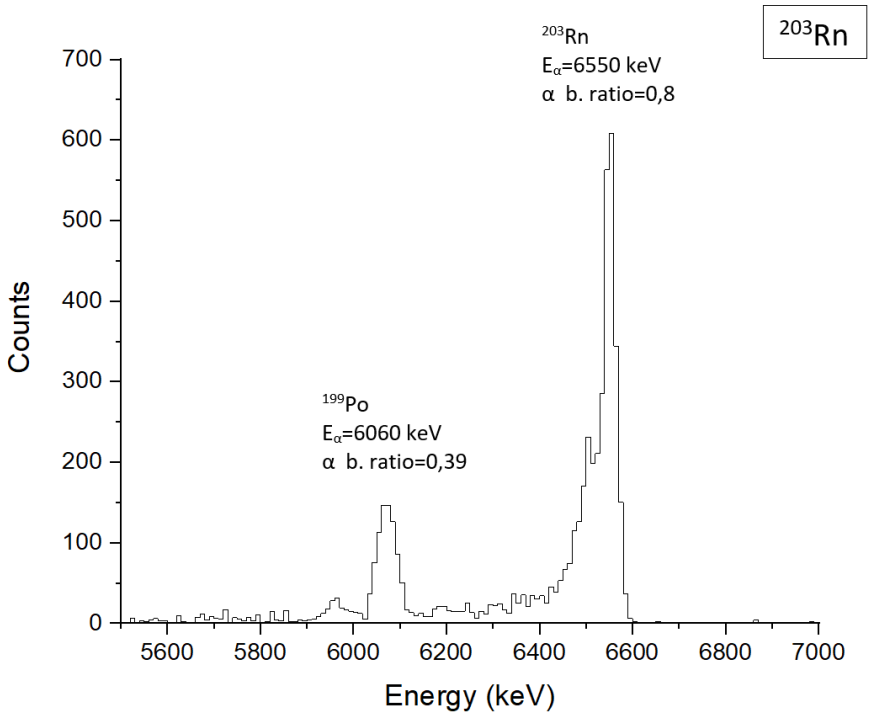

185Hg
185Hg
Eα=5650 keV
α b. ratio=0,06
181Pt
Eα=5080 keV
α b. ratio=0,00074
Counts
Energy (keV))
1800
1600
1400
1200
1000
800
600
400
200
0
4000
4500
5000
5500
6000
6500
7000

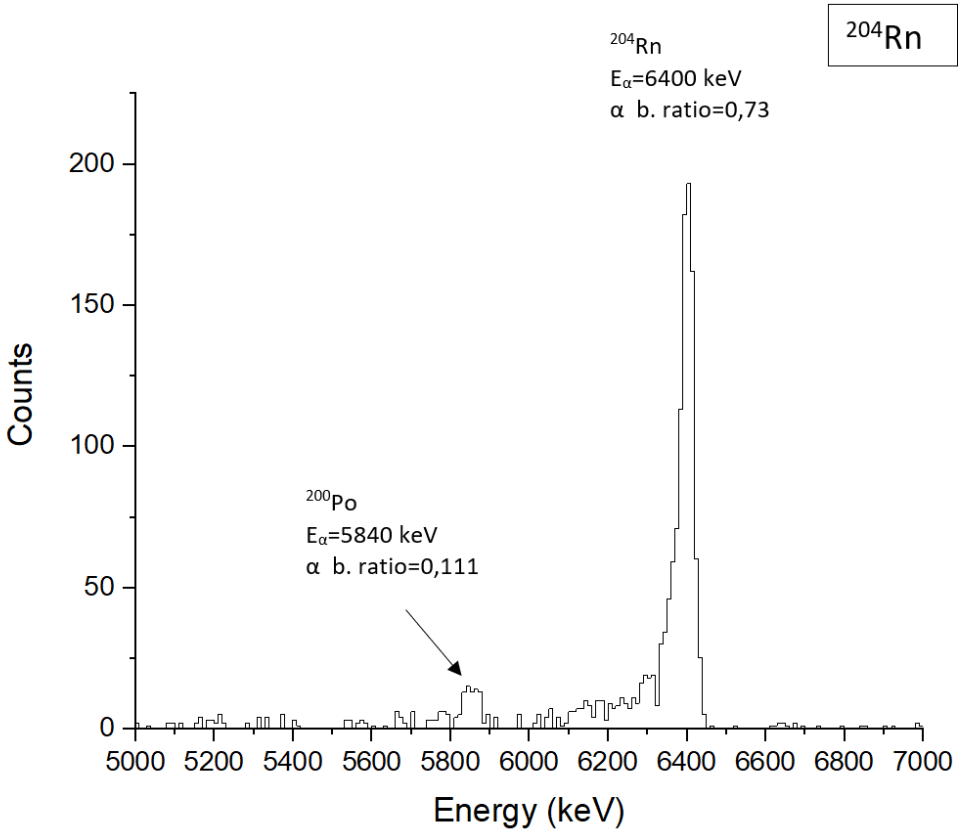

Counts
975,0
780,8
586,6
392,4
198,2
4,000
α decay energy (eV)
Strip No.
180Hg
181Hg
182Hg
183Hg
185Hg
185Hg
7000
6600
6200
5800
5400
5000
4600
33
66
99
132
165

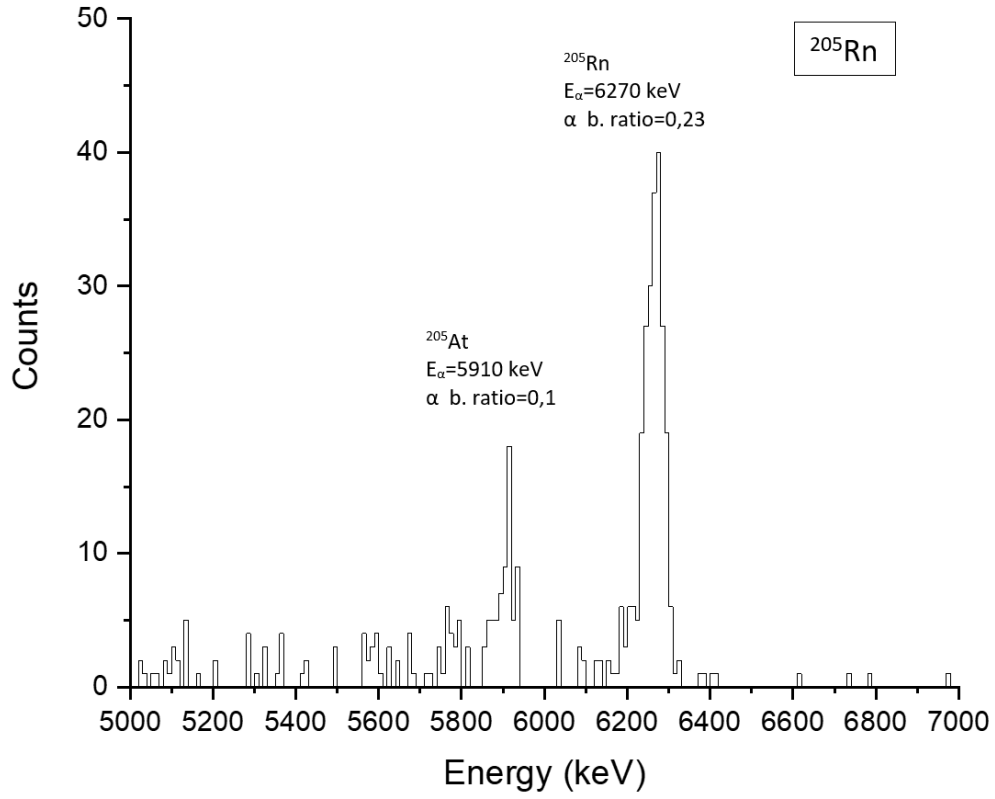
2. $^{40}Ar + {}^{166}Er \rightarrow {}^{206\text{-}xn}Rn + xn$

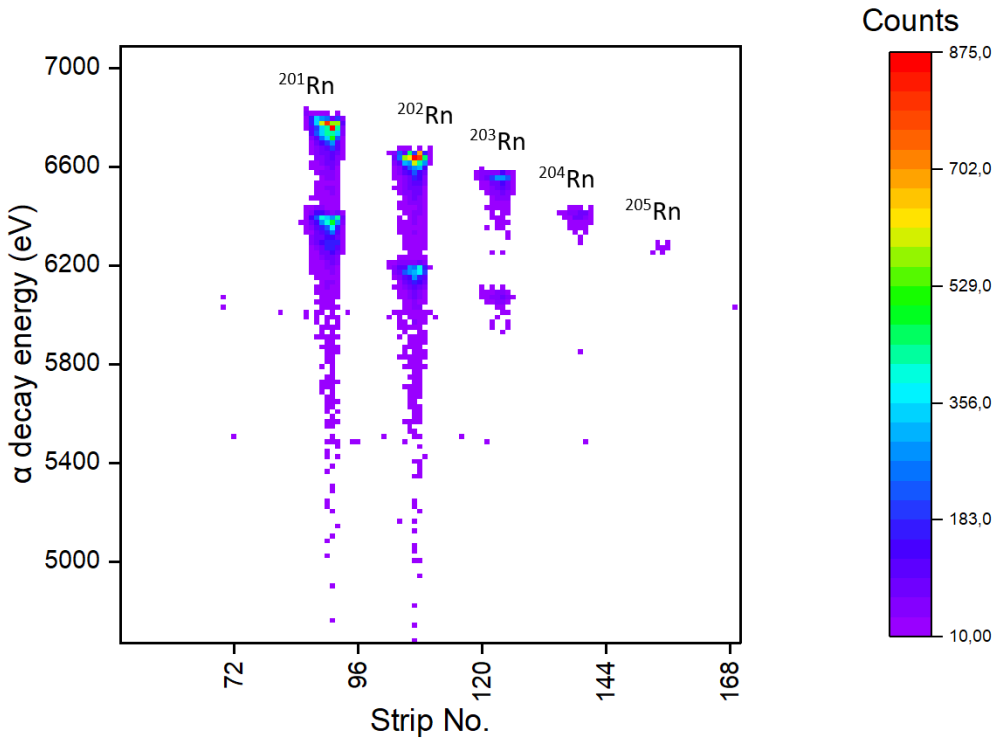




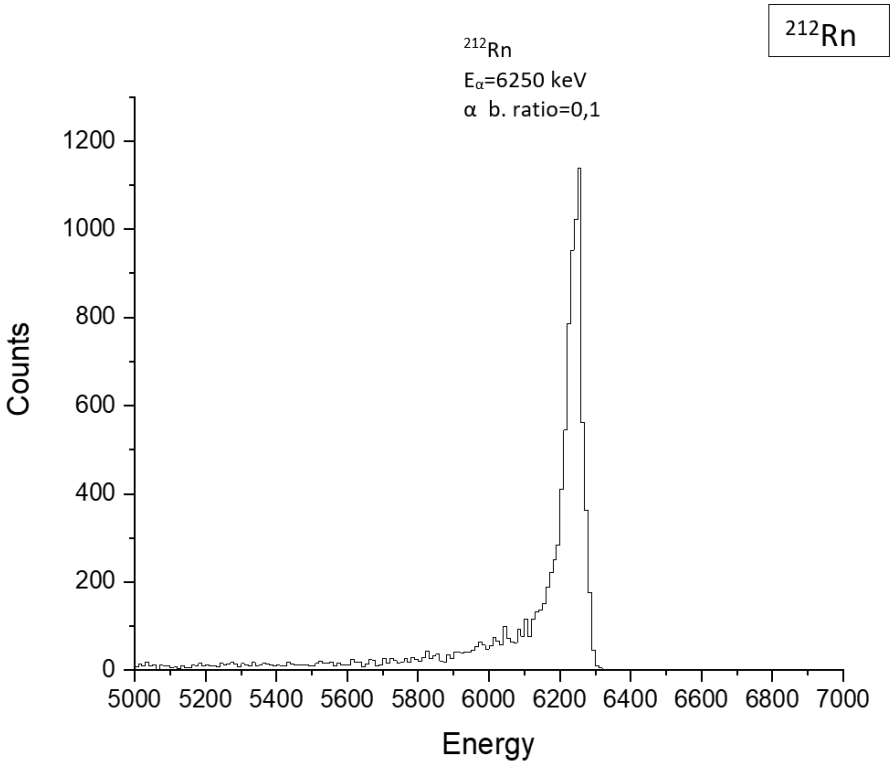

203Rn
203Rn
Eα=6550 keV
α b. ratio=0,8
199Po
Eα=6060 keV
α b. ratio=0,39
Counts
Energy (keV)
0
100
200
300
400
500
600
700
5600
5800
6000
6200
6400
6600
6800
7000

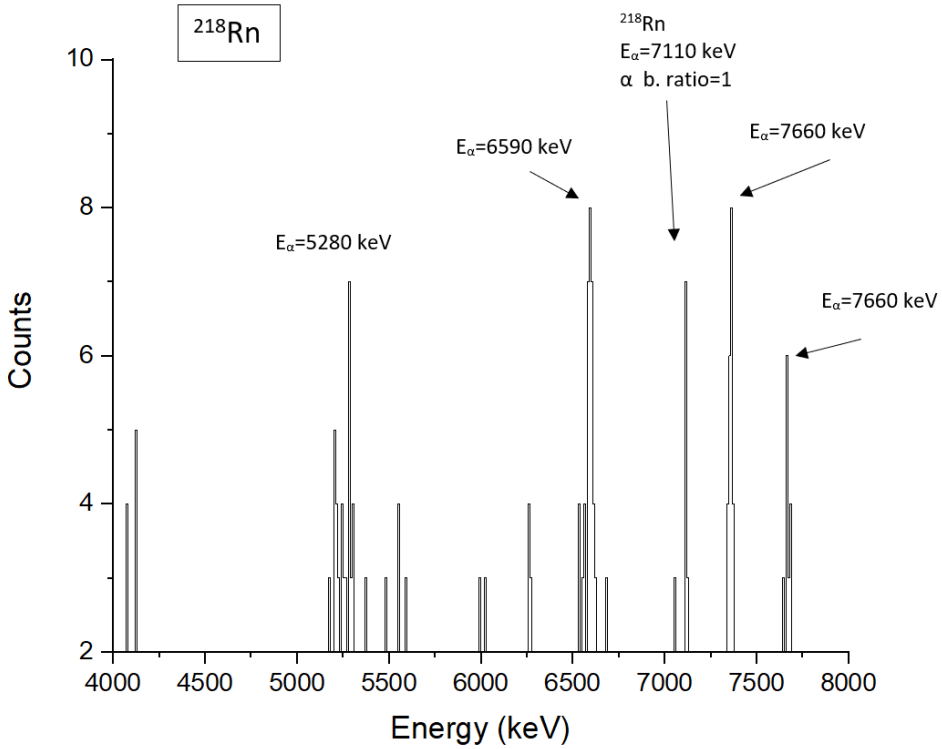

204Rn
204Rn
Eα=6400 keV
α b. ratio=0,73
200Po
Eα=5840 keV
α b. ratio=0,111
Counts
Energy (keV)
0
50
100
150
200
5000
5200
5400
5600
5800
6000
6200
6400
6600
6800
7000

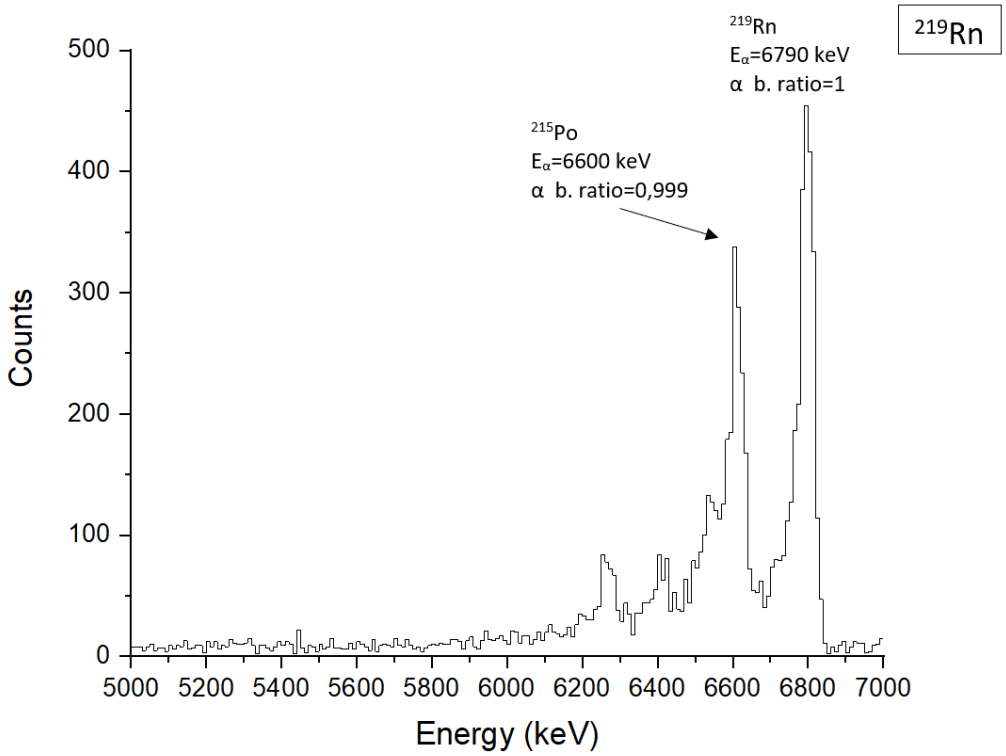

205Rn
205Rn
Eα=6270 keV
α b. ratio=0,23
205At
Eα=5910 keV
α b. ratio=0,1
Counts
Energy (keV)
0
10
20
30
40
50
5000
5200
5400
5600
5800
6000
6200
6400
6600
6800
7000

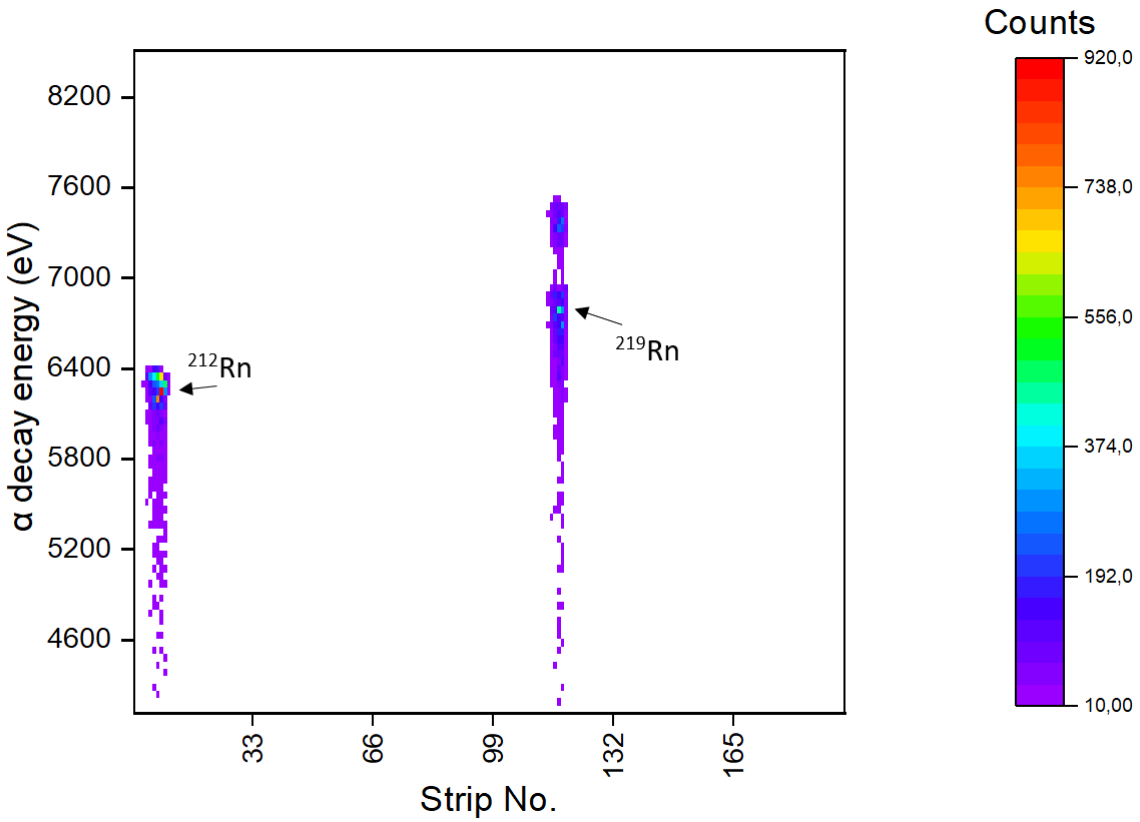

201Rn
202Rn
203Rn
204Rn
205Rn
α decay energy (eV)
Strip No.
Counts
875,0
702,0
529,0
356,0
183,0
10,00
5000
5400
5800
6200
6600
7000
72
96
120
144
168

3. $^{48}Ca + ^{242}Pu$ – multinucleon transfer reaction leading to Rn isotopes






219Rn
219Rn
Eα=6790 keV
α b. ratio=1
215Po
Eα=6600 keV
α b. ratio=0,999
Counts
Energy (keV)
0
100
200
300
400
500
5000
5200
5400
5600
5800
6000
6200
6400
6600
6800
7000


Counts
920,0
738,0
556,0
374,0
192,0
10,00
α decay energy (eV)
Strip No.
212Rn
219Rn
4600
5200
5800
6400
7000
7600
8200
33
66
99
132
165

Conclusion

The energy spectra of the escaped α-particles were measured at the focal plane via the silicon detector system during the experiment. The separation efficiency and time were determined for mercury and radon isotopes resulting from the reactions $^{40}Ar +^{144} Sm$, $^{40}Ar +^{166} Er$ and $^{48}Ca +^{242} Pu$. Data showed agreement within 7-9 keV between the experiment and the tabulated values, σ was obtained to be in the range of 20-50 keV.

Aknowledgements

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References

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