JOINT INSTITUTE FOR NUCLEAR RESEARCH
Flerov Laboratory of Nuclear Reactions

FINAL REPORT ON THE INTERST PROGRAMME

Production and spectroscopic investigation of new neutron-rich isotopes near the neutron N=126 shell closure using the multinucleon transfer reactions

Supervisor:
Viacheslav Vedeneev,
Joint Institute for Nuclear Research,
Dubna, Russia

Student:
Javlonbek Bakhromov,
Nationality University of Uzbekistan
named after Mirzo Ulugbek

Participation period:
October 30 – December 10,

Dubna 2023

Table of Contents

1.Abstract

The MASHA mass separator designed for identifying super-heavy elements by their masses is described. experiments have been carried out, in which α-active *Hg* and *Rn* isotopes produced in complete fusion reaction $^{40}Ar + {}^{144}Sm \rightarrow {}^{184-xn}Hg + xn$, $^{40}Ar + {}^{166}Er \rightarrow {}^{206-xn}Rn + xn$ have been detected in the focal plane of the mass spectrometer.. A calibration of position sensitive strip detector, located at the focal plane of separator was performed, using test reactions.

2.Introduction

The study of super-heavy nuclei is one of the most important studies in nuclear physics. This involves precise measuring of energy, mass, α-decay schemes and spontaneous fission with using statistics analysis methods.

The Mass Analyser of Super Heavy Atoms (MASHA) had been built at one of the beamline from U-400M cyclotron ~~that~~ based in Flerov Laboratory of Nuclear Reactions (FLNR) at Joint Institute for Nuclear Research (JINR), Dubna, Russia.

The setup could be used for direct measuring the masses in a wide range up to A=450 a.m.u. with mass resolution M/ΔM=1700 of the heaviest elements with simultaneous detecting its α-decays and/or spontaneous fission. For this in the U-400M cyclotron a beam of Ar^{40} or Ca^{48} ions accelerated to 5-7 MeV/nucleon irradiating an external targets of Sm^{148}, Er^{166} *and* Pu^{242}. The evaporation residue products stops in a hot catcher, from where they diffused into the ECR ion source, in which they were ionized to a charge state of +1. Then they got into the detector.

In experiments to study the chemical properties of superheavy elements, the element Copernicium (Cn, Z = 112) was found to have increased volatility compared to its chemical analogue mercury. At the MASHA facility the test experiments to measure the masses of radon and mercury isotopes were performed. Another important motivation for doing this work was studying the features of fusion reactions with target nuclei located near the magic number of neutrons N = 82.

The work is devoted to the calibration of a position-sensitive strip detector using the reactions Ar + Sm, Ar + Er and the reaction of multinucleon transfers calcium + plutonium - just for the synthesis of radons near a closed neutron shell N = 126

3. Experimental Setup

3.1 Target Assembly and Hot Catcher

The hot catcher is a part of the target assembly shown in Figure 2.2. Prior to hitting the target, the primary beam of heavy ions passes through the diagnostic system composed of a split type aperture of the electrostatic induction sensor and a Faraday cup. The split aperture is divided into four sectors each of which measures the fraction of the beam current that does not fall into the hole of the aperture. This system allows control of the beam position relative to the ion guide. The Faraday cup is fixed in place on the rotary vacuum tight feedthrough at a distance of 70 mm in front of the target. Behind the diagnostic system, there is a rotating target divided on 12 sectors assembled in cassettes and driven by electric engine. Nuclear reaction products escape from the target, pass through the separating foil, and are stopped in the graphite absorber. 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.

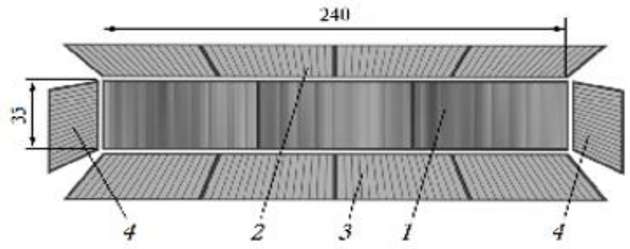


Figure 2.3: 1-frontal 192 strips; 2-top 64 strips; 3-bottom 64 strips; 4-side 16 strips

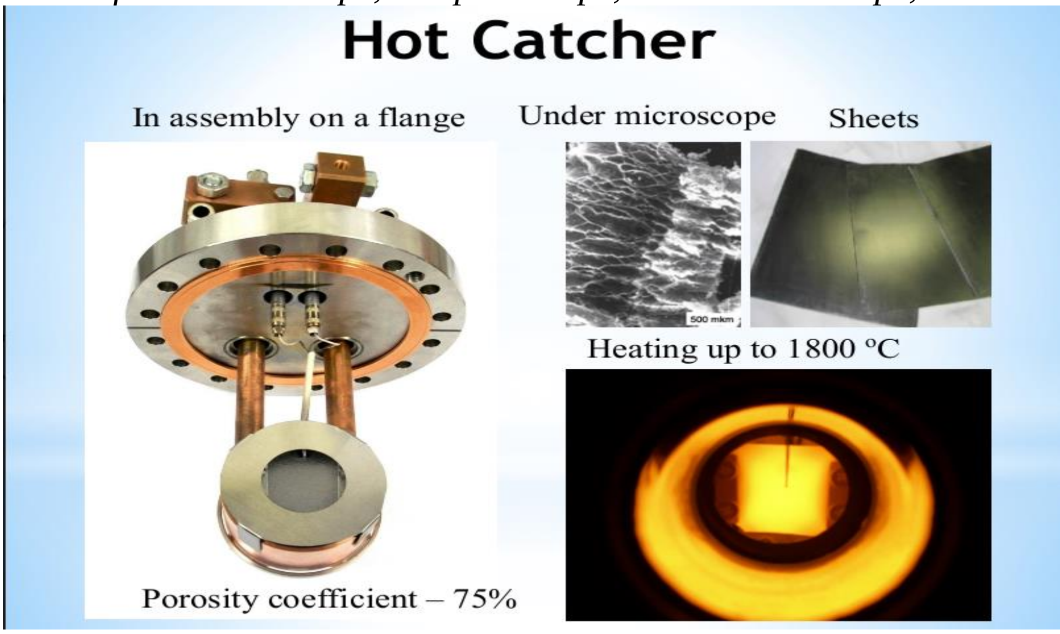


Figure 2.4: Hot catcher

3.2 MASHA Setup

The setup, the layout of which is shown in Figure 2.1, consists of the target assembly with a hot catcher; an ion source based on the electron cyclotron resonance phenomena (ECR); a magneto-optical analyzer (a mass spectrometer); a position sensitive strip detector at the focal plane.

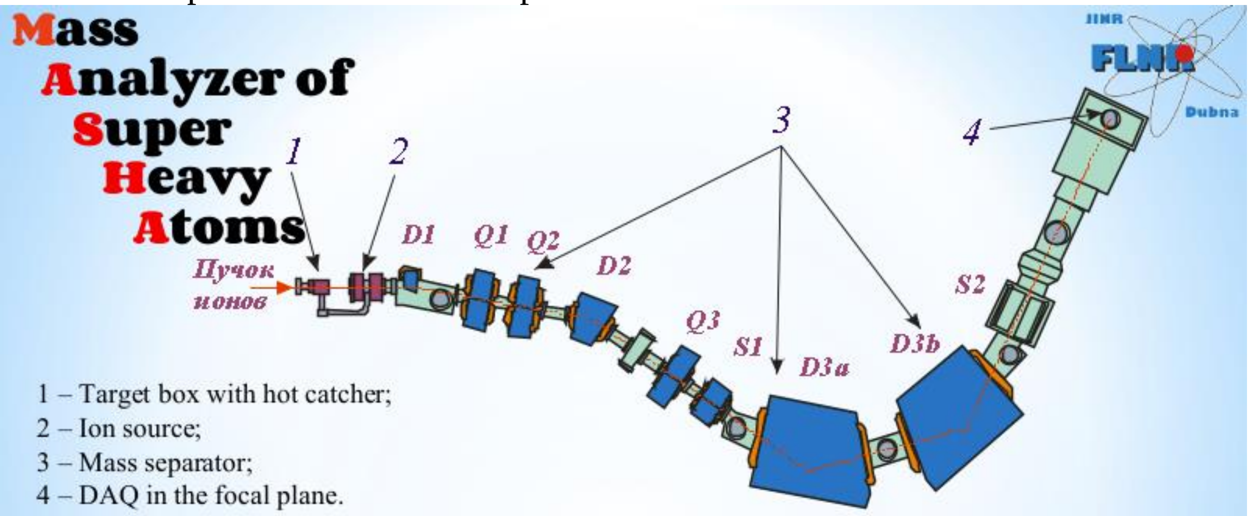


Figure 2.1: MASHA setup: (D1, D2, D3a, D3b) dipole magnets, (Q1, Q2, Q3) quadrupole lenses, and (S1, S2) sixtupole lenses. The detection system is in focal plane of the separator 4

3.3 Ion Source

An ion source based on the ECR (the ECR source) with a 2.45GHz frequency of its microwave oscillator is used for ionizing atoms of nuclear reaction products. 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.

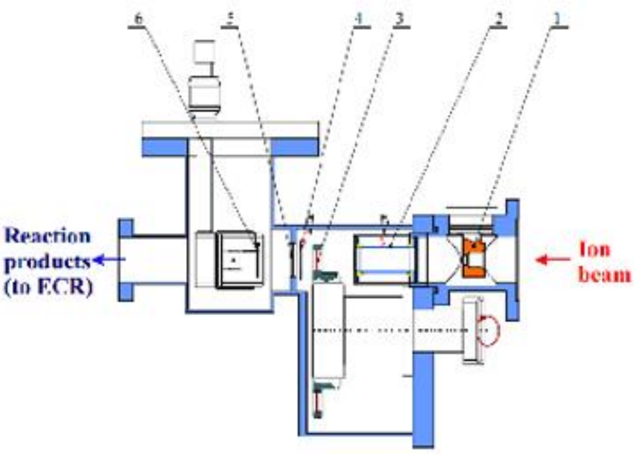


Figure 2.2: Target-hot catcher system. 1-diaphragm; 2-pick-up sensor; 3-target on the wheel; 4-electron emission beam monitor; 5-separatin foil; 6-hot catcher

3.4 Detection and Control System

To detect decays of nuclear reaction products, a well-type silicon detector is mounted in the focal plane of the mass spectrometer. ~~The~~ 192 strips make up the plane of the frontal detector component, which is positioned normal to the beam direction. Each of the side detectors is divided into 64 and 16 strips. The detectors have a conventional operating bias of 40V and a 25keV energy resolution for α-particles from a Ra^{226} source. The detector assembly's stated design allows it to detect not less than 90% of particles emitted in a single nuclear decay at the detector's frontal section. Each strip of the silicon detector's signals is read out separately. The application displays one-dimensional energy spectra for each strip as well as two-dimensional spectra for each crystal's energy dependency on strip number.

3.5 Experimental Technique

MASHA was constructed at one of the beam lines of U - 400M cyclotron in order to conduct online measurements of the physical properties of super-heavy elements. The target was bombarded by beam of ^{48}Ca with energy E_{beam}=7,3MeV/n. Atoms diffuse from the graphite volume and, move along the vacuum pipe and reach the ECR ion source chamber where they are ionized. Faraday cup allows beam intensity control or target protection by periodically interrupting the beam. The separation efficiency and time were measured for Hg isotopes due to their similarity with element Z = 112 and Z = 114. A radioactive isotopes were obtained in the fusion reaction. A decay energy of the fusion products was measured as a function of the strip number.

4. Result and Discussion

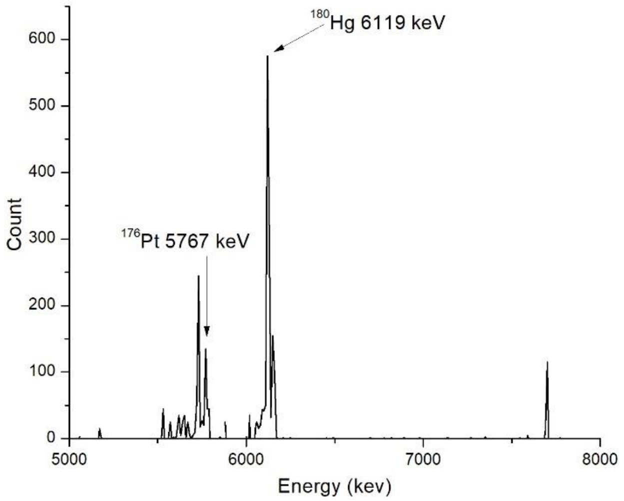
In this chapter will be represented and analyzed the results of the nuclear reactions taken from MASHA.

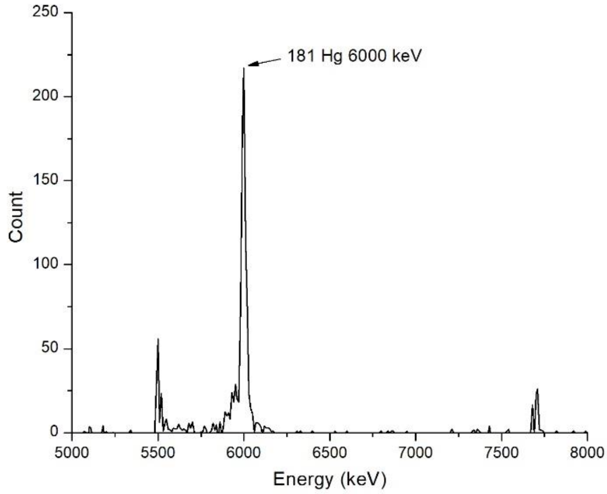
4.1 Reaction $^{40}Ar + ^{148}Sm$

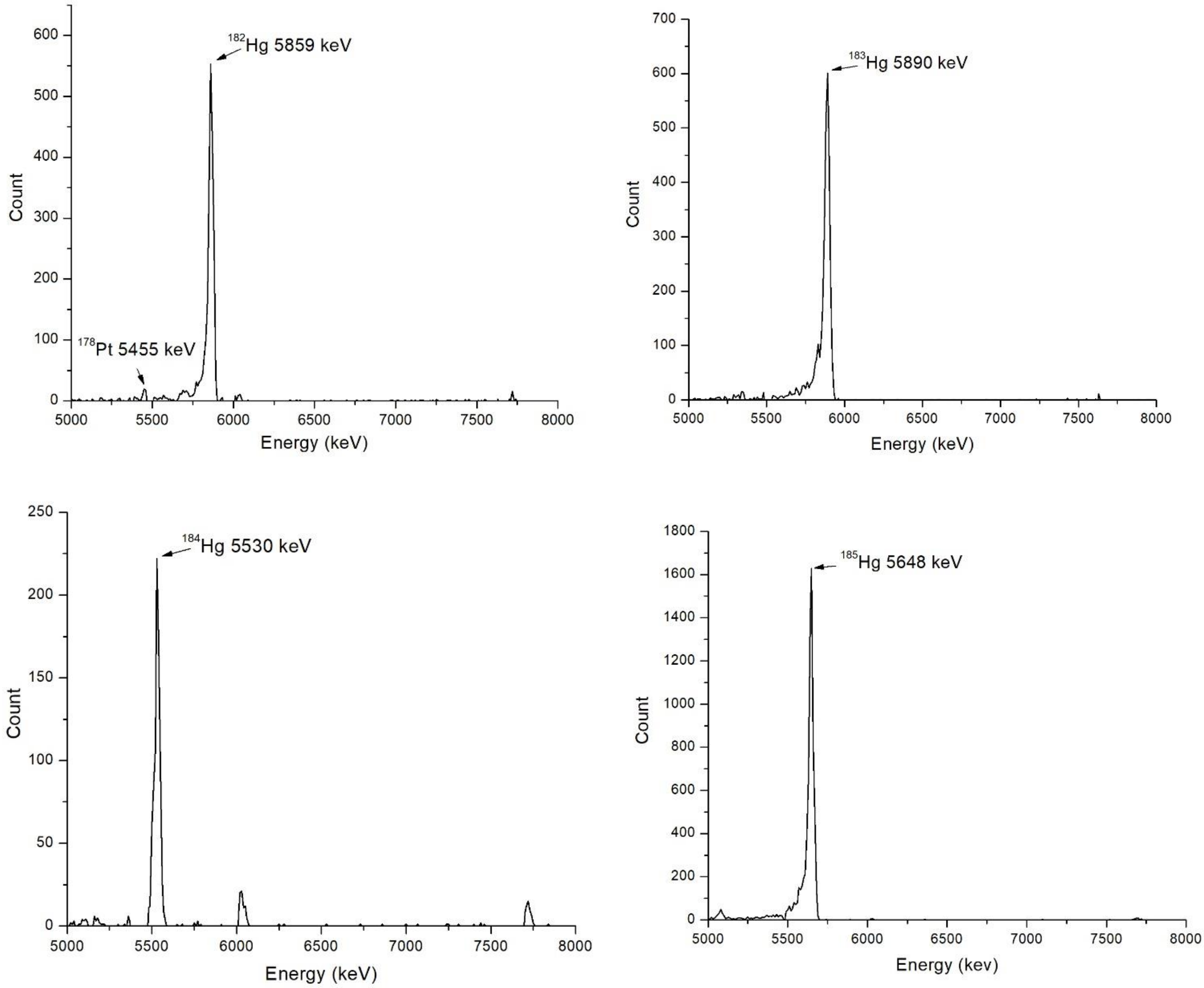
It is noticeable in Table 3.1, that the experimental and theoretical results are very close, and this indicates the accuracy of the mass analyzer MASHA. The magnetic system and detector have excellent resolution, distinguishing the various isotopes both in mass and energy.

Isotope	**T ½, s**	**$E_{experiment}$, keV**	**E_{theory}, keV**
Hg180	2.58	6119	6119
Hg181	10.83	6000	6006
Hg182	9.4	5859	5867
Hg183	30.9	5890	5904
Hg184	49.1	5530	5535
Hg185	82.8	5648	5653
Pt176	6.3	5767	5753
Pt178	20.7	5455	5573

Table 3.1: comparison between experimental and theoretical table energy of the nuclei.

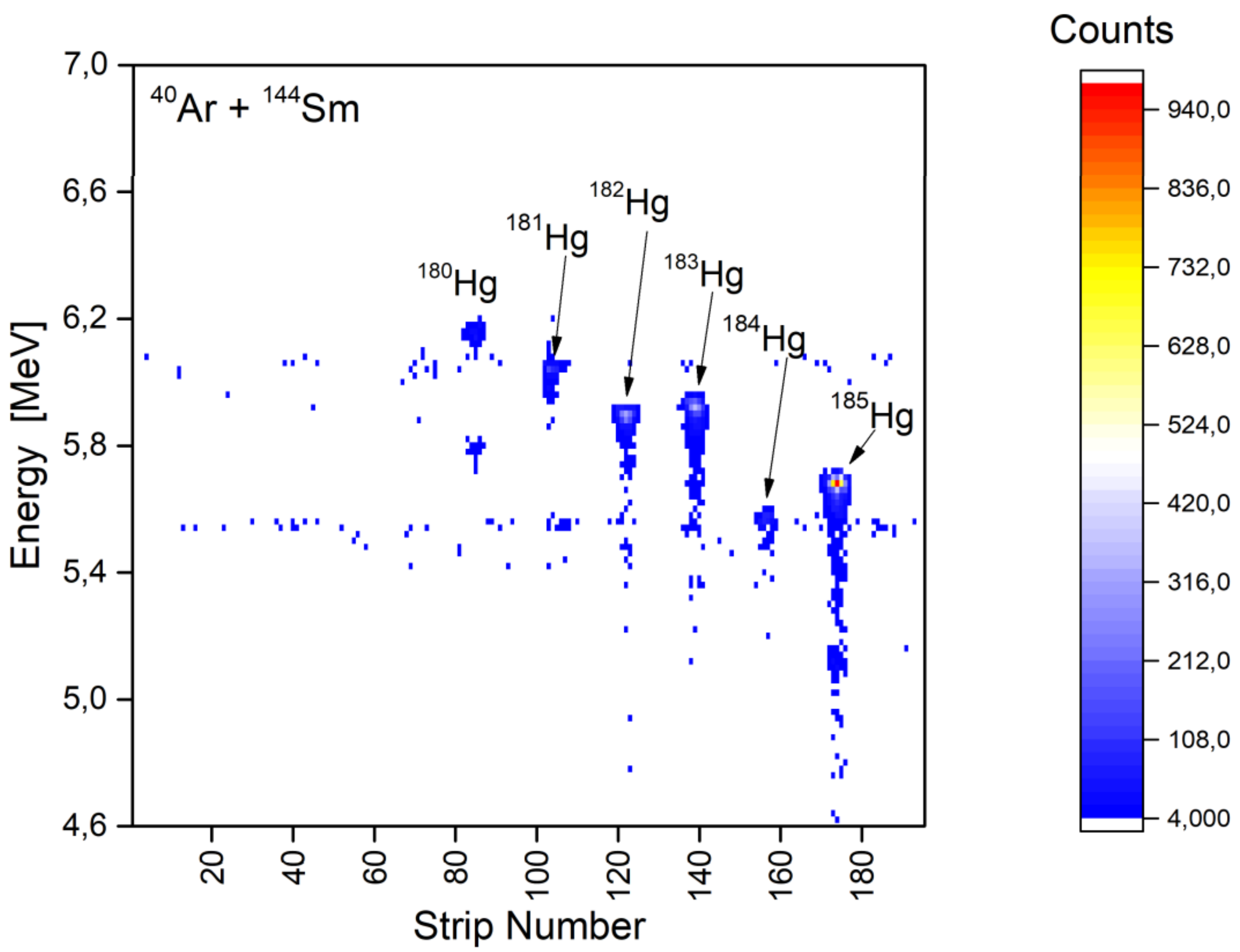






^{182}Hg 5859 keV
^{178}Pt 5455 keV
Count
Energy (keV)
^{183}Hg 5890 keV
Count
Energy (keV)
^{184}Hg 5530 keV
Count
Energy (keV)
^{185}Hg 5648 keV
Count
Energy (kev)

Figure 3.1



Counts
940,0
836,0
732,0
628,0
524,0
420,0
316,0
212,0
108,0
4,000
7,0
6,6
6,2
5,8
5,4
5,0
4,6
Energy [MeV]
40Ar + 144Sm
180Hg
181Hg
182Hg
183Hg
184Hg
185Hg
20
40
60
80
100
120
140
160
180
Strip Number

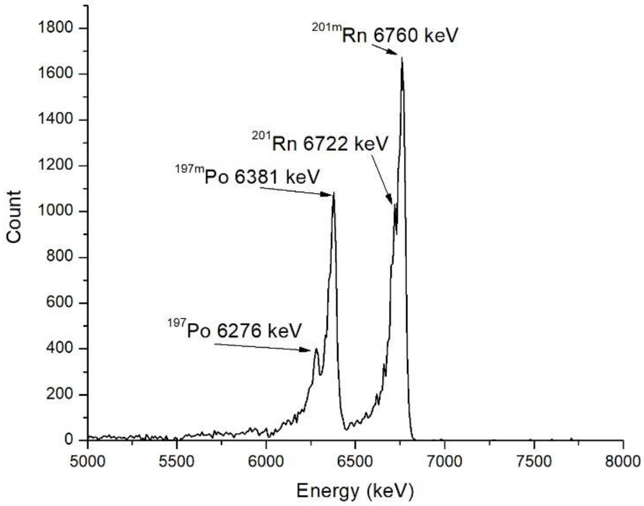
Heat map 3.3

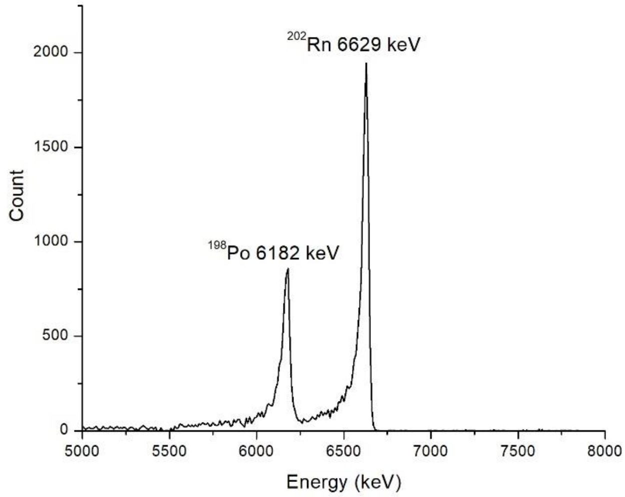
4.2 Reaction $^{40}Ar + ^{166}Er$

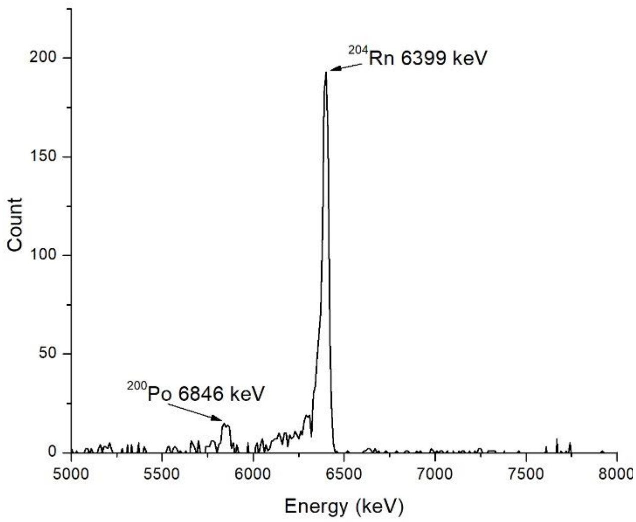
In below the peaks are clearly shown whether they are Rn or Po nuclei. The decays which ~~we~~ can extract are:

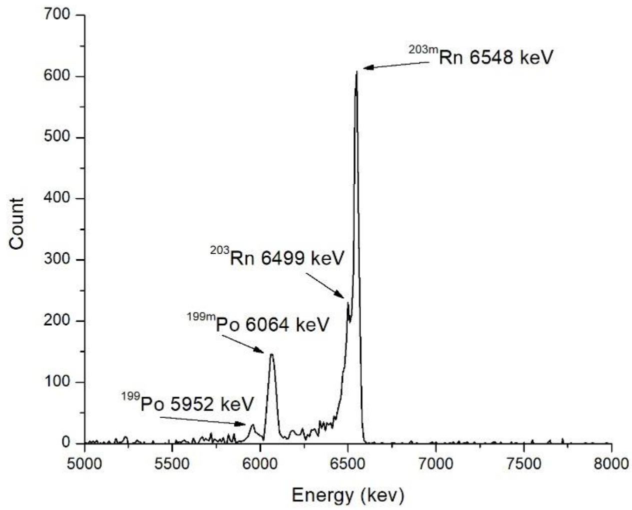
Isotope	T ½, s	E_{exp}, keV	E_{theor}, keV
Rn201	7.1	6722	6725
Rn202	10	6629	6639
Rn203	28	6499	6549
Rn204	74.4	6399	6419
Rn205	170	6269	6262
Po197	25.8	6276	6383
Po198	106.2	6182	6182
Po199	250.2	5952	6059

Table 4.2: comparison between experimental and theoretical table energy of the nuclei.









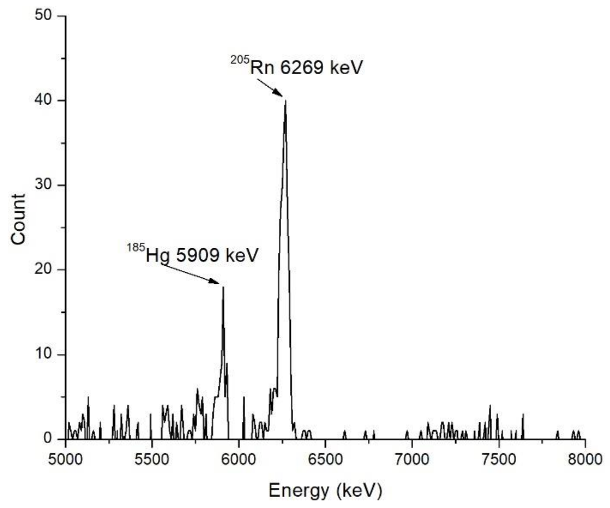
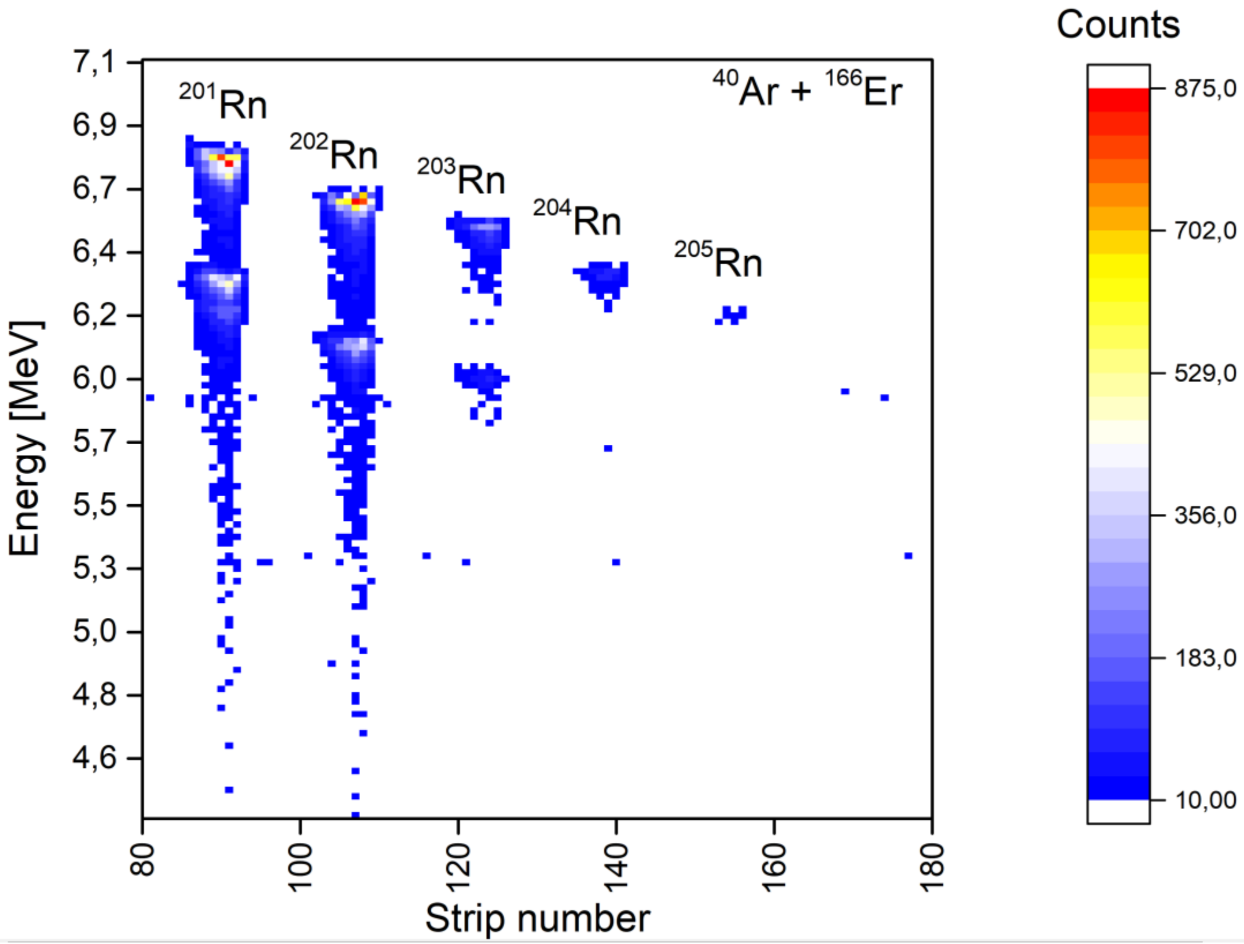


Figure 4.2



Heat map 4.2

4.3 Reaction $^{48}Ca+^{242}Pu$

Isotope	T ½, s	E_{exp}, keV	E_{theor}, keV
Rn212	1434	6249	6264
Rn218	0.00035	7110	7129
Rn219	3.96	6789/6405	6819/6425
Rn222	36.17	6591	6559
Po210	138 days	5277	5304
Po214	0.000163	7658	7686
Po215	0.0001781	7357	7386
Bi210	5 days	4117	4100
Bi211	128.4	6602/6250	6622/6250

Table 4.3 comparison between experimental and theoretical table energy of the nuclei.

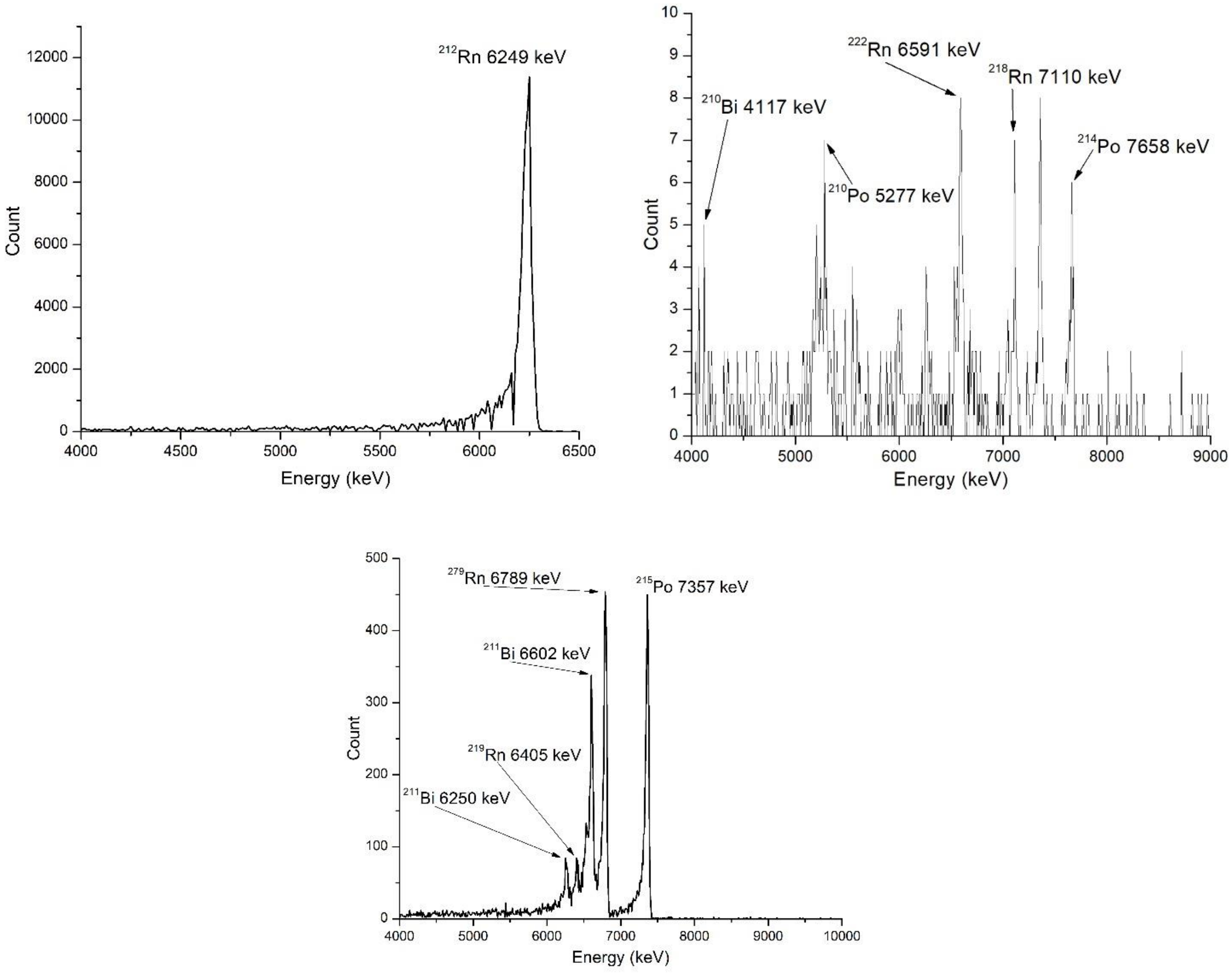
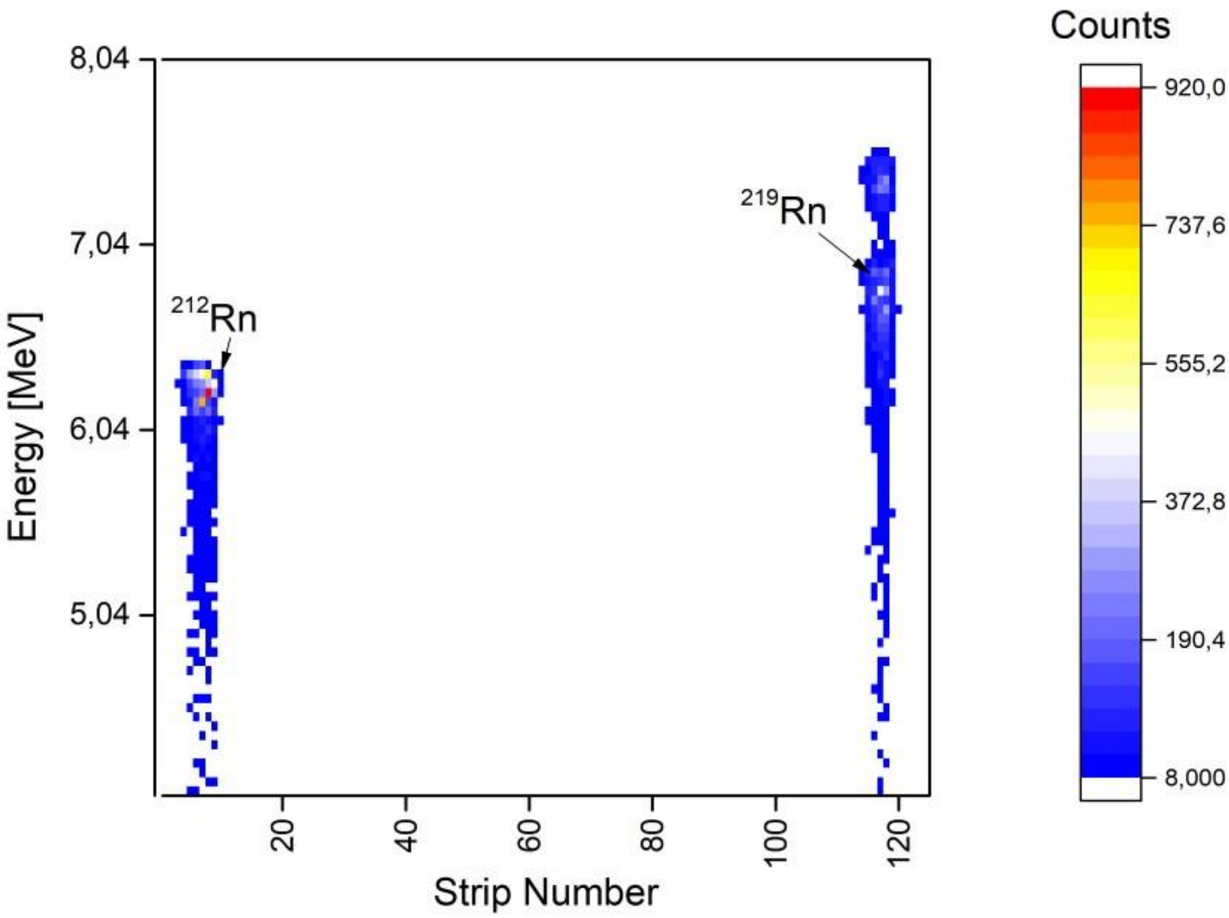


Figure 4.3


Counts
920,0
737,6
555,2
372,8
190,4
8,000
8,04
7,04
6,04
5,04
Energy [MeV]
212Rn
219Rn
20
40
60
80
100
120
Strip Number

Heat map 4.3

Conclusions

Total synthesis reactions $^{40}Ar+^{148}Sm$, $^{40}Ar+^{166}Er$ and multinucleon transfer reaction of $^{48}Ca+^{242}Pu$ with their products were analyzed on using OriginPro software. Comparison with corresponding literary values has proven correct response of the silicon detector with a relative deviation from the real one values for most nuclides are no more than 3%. As a result, a two-dimensional matrix of the dependence of α-energy on the position of the zone number was compiled for all reactions. manufactured to demonstrate very good mass and energy separation capabilities multi-band detector. The existence of an "Island of Stability", which is a predicted group of isotopes of superheavy elements that may have much longer half-lives than the known isotopes of those elements, is discovered through detailed study of superheavy elements. During the experiment, alpha decay energy spectra were measured at the focal plane using a silicon detection system. By analyzing the interaction data, we were able to identify mercury and radon nuclei and compare their experimental results with the theoretical results studied. The comparison showed the similarity of experimental and theoretical results for mercury nuclei, but in the case radon nuclei, there was a clear difference between the results.

Literature

1. MATTHIAS SCHÄDEL//The Chemistry of Superheavy Elements // Kluwer Academic Publishers, 2003

2. V. Yu. Vedeneev and oth, The current status of the MASHA setup, Hyperfine Interact (2017) 238: 19

3. H W Gäggeler, Mendeleev's principle against Einstein's relativity: news from the chemistry of superheavy elements,Russian Chemical Reviews 78 (12) 1139 - 1144 (2009)

4. R. Eichler and oth, Chemical characterization of element 112, NATURE| Vol 447| 3 May 2007

5. В. Ю. Веденеев и др, СЕЧЕНИЯ ОБРАЗОВАНИЯ ИСПАРИТЕЛЬНЫХ ОСТАТКОВ РЕАКЦИЙ ПОЛНОГО СЛИЯНИЯ ^{144}Sm(^{40}Ar, *xn*)$^{184-X}$Hg, ^{148}Sm(^{36}36Ar, *xn*)$^{184-X}$Hg, ^{144}Nd(^{40}Ca, xn)$^{184-X}$Hg, ИЗВЕСТИЯ РАН. СЕРИЯ ФИЗИЧЕСКАЯ, 2020, том 84, No 4, с. 611–615