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

Bc. Filippos Georgiadis

Palacky University
filippos.georgiadis01@upol.cz
Supervisor: Mr. Viacheslav Vedeneev
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Abstract

The MASHA (Mass Analyzer of Super Heavy Atoms) setup has been designed as a mass-separator with the resolving power of about 1700, which allows mass identification of superheavy nuclides. The setup uses the solid ISOL (Isotope Separation On-Line) method. The data analysis, which is collected from the experiments of complete-fusion reactions neutron evaporation residues and multinucleon transfer reaction $^{48}Ca + ^{242}Pu$ using the α-decay chains from the position sensitive Si detector. For detections is used a special hybrid pixel detector TIMEPIX with the MASHA setup for neutron-rich Rn isotopes identification.

I. Introduction

MASHA (Mass Analyzer of Super Heavy Atoms) is based on the beam line of Cyclotron U-400M at Flerov Laboratory of Nuclear Reactions (FLNR) at Joint Institute for Nuclear Research (JINR), Dubna, Russia. Was constructed as the mass-spectrometer in a large variety of masses (from 1 to 450 a.m.u.) and for on-line measurements of the physical properties of superheavy elements (SHE), such as decay energy and modes, mass and half- lives. MASHA is used for a fundamental investigations in nuclear physics. Here we will make an analysis of the data, which were obtained by accelerated ions. The data from fusion evaporation reaction were analysed and evalueted. From the experiments, that were performed in FLNR at JINR, were three different reaction (^{40}Ar + ^{148}Sm, ^{40}Ar + ^{166}Er, ^{48}Ca + ^{242}Pu) and the final product was Rn and Hg. [1, 2, 3]

II. Installation (Main Parts and Description)

1. **Ion-optical layout**

   A magneto-optical mass-to-charge ratio analyzer includes four dipole magnets (D1, D2, D3a, D3b), three quadrupole lenses (Q1, Q2, Q3), two sextupole lenses (S1, S2) and a focal plane detector system.

2. **ECR ion source**

   The ECR (Electron Cyclotron Resonance) ion source operates at the microwave generator frequency of 2.45 GHz. The incoming atoms of nuclear reaction products are ionized to the charge state Q=+1 and accelerated to 40 keV by a three-electrode electrostatic lens.

The ion beam formed is separated by the magneto-optical mass-to-charge ratio analyzer. With this ion source it is possible to get beam currents consisting almost entirely (100 %) of singly-charged ions. The ionization efficiency of about 90 % is obtained even for noble gases.

3. **Hot catcher**

   The injection of the complete fusion reaction products to the ECR ion source took place after it stopped inside polygraphene catcher unit. After emission from the target the reaction products passed through the separating foil and stopped in a graphite foil heated up to 1800-2000K. The nuclear reaction products diffused in the form of atoms from the graphite into the vacuum volume of the hot catcher. Moving along the vacuum pipe they reached the ECR ion source.

4. **Targed box**

   Target system represents a block of rotating targets, assembled into cassettes. The disc rotates at f = 25 Hz and the rotating target was used in this yields to higher efficiency and heat distribution. The ion beam collided with the target and then the reaction products are stopped in catcher.

5. **Detectors and control systems**

   For detection of nuclear reaction products a multiple detectors system at the focal plane of the mass-separator was installed. The front detector was a multi-strip silicon structure fixed on the surface of glass-cloth laminate. It had an area of 240x35 mm^2 and consisted of 192 strips with a pitch of 1,25 mm.The detectors on righ and left side had 16 strips and upper and lower detectors had 64 strips. The all detectors had 300 μm thickness. They were used to determine the energies of the α emmition and the spontaneous fission.

   The control of the ion-optical elements of the mass-separator, the vacuum system, the ECR ion source and the hot catcher was made on the base of the standard LabVIEW packet with personal computers located in the control room of the MASHA facility.

[1, 2]

III. Methods

The MASHA setup is a combination of the ISOL (Isotope Separation On-Line) method of synthesis and separation of radioactive nuclei with the classical magneto-optical mass analysis, allowing mass identification of the synthesized nuclides in the wid range of masses. MASHA would be related to study the neutron-rich nuclei near the N=126 neutron shell closure. These nuclei are planned to be produced in the multi-nucleon transfer reactions with mass-to-charge ratio separation of the target-like fragments. This has to be in favor of increasing the yield of newborn nuclei. It is also expected that a prior determination of masses of the nuclei under investigation will essentially facilitate the analysis of their decays with using the hybrid pixel detectors of the TIMEPIX type. These detectors have a high spatial and energy resolution and allow one to count a single β- or α-particle. [1, 2]

IV. Tasks

Make an analysis of the data, that were obtained from MASHA facility and create graphs. Determine α-decay energy and write down the isopes, that can be find in the specifics energy levels. Create a heatmap from isotopes matrixes and analyse it too.

V. Results

i. $^{40}Ar + ^{148}Sm$

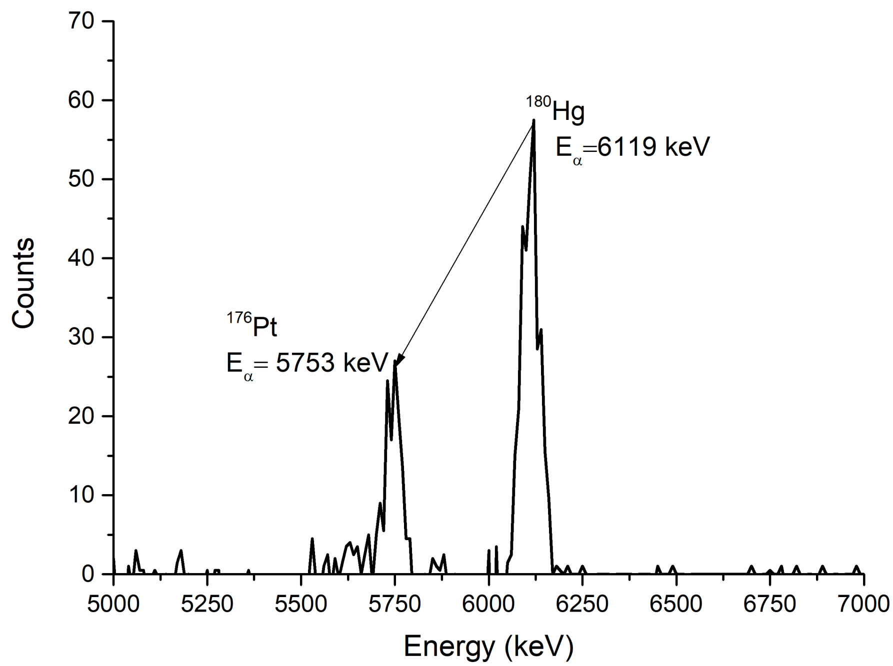

Figure 1: *Graph shows 1-D spectra of mercury isotopes*

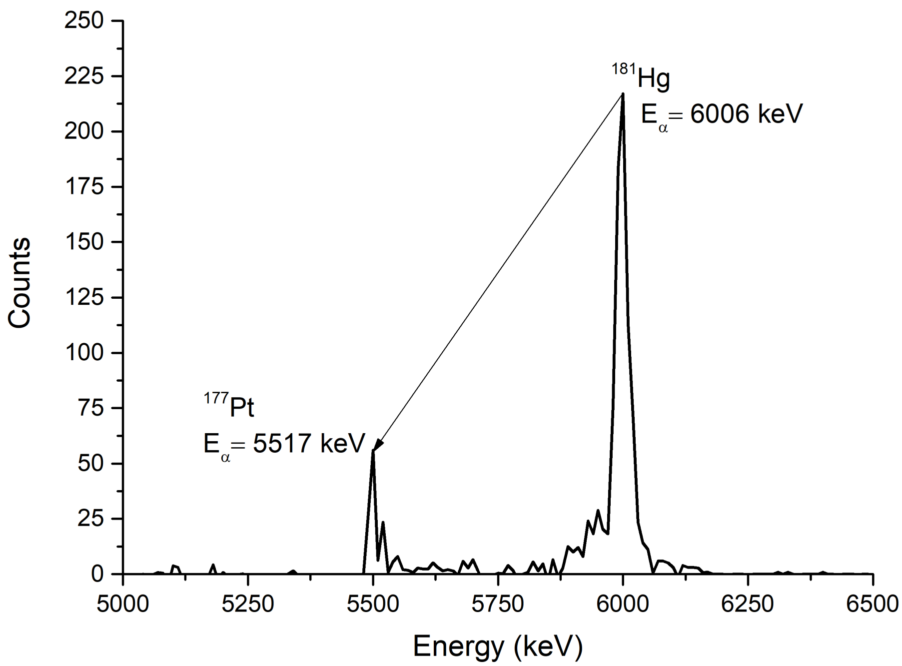

Figure 2: *Graph shows 1-D spectra of mercury isotopes*

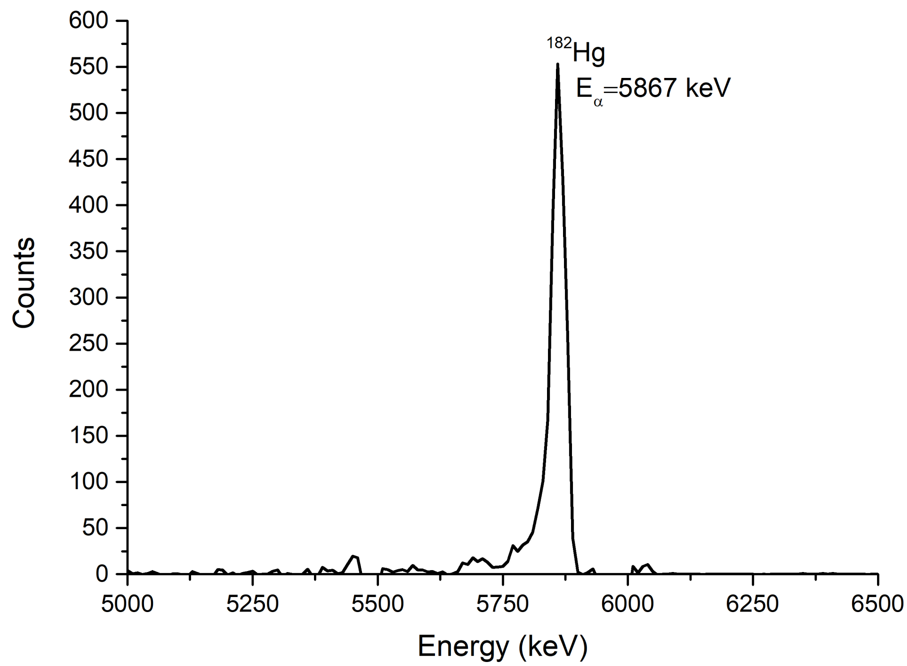

Figure 3: *Graph shows 1-D spectra of mercury isotopes*

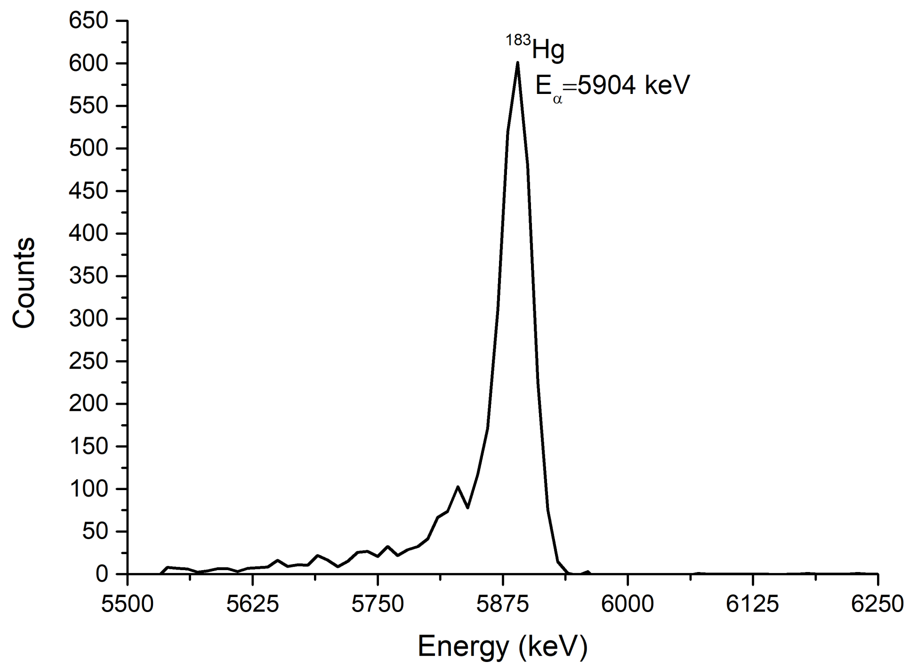

Figure 4: *Graph shows 1-D spectra of mercury isotopes*

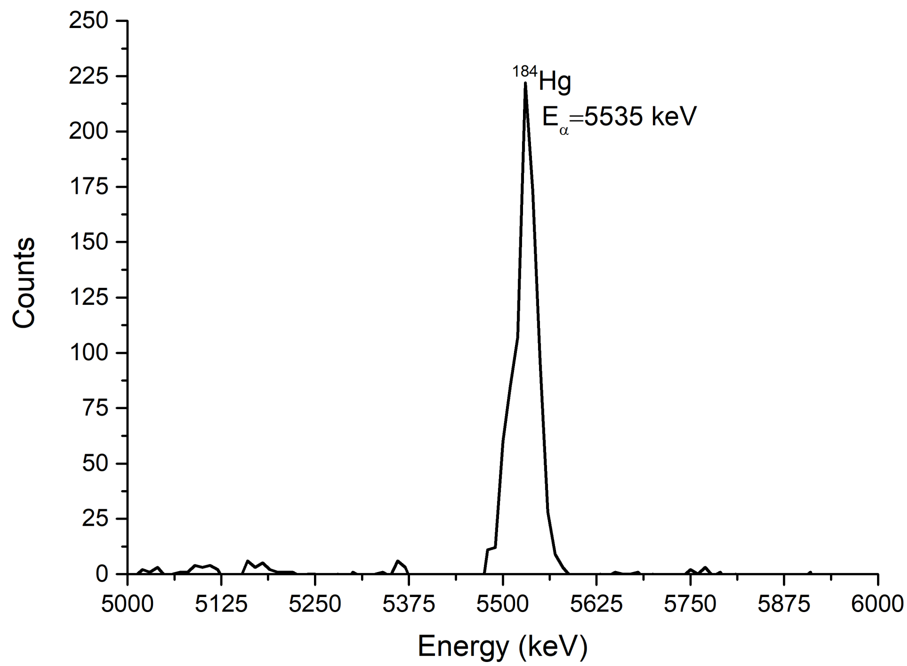

Figure 5: *Graph shows 1-D spectra of mercury isotopes*

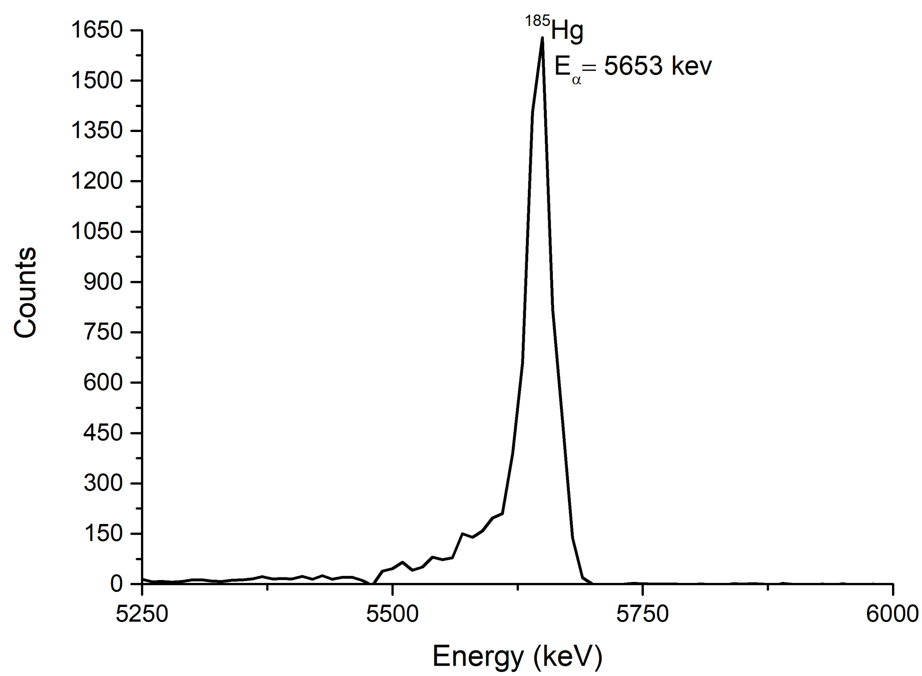

Figure 6: *Graph shows 1-D spectra of mercury isotopes*

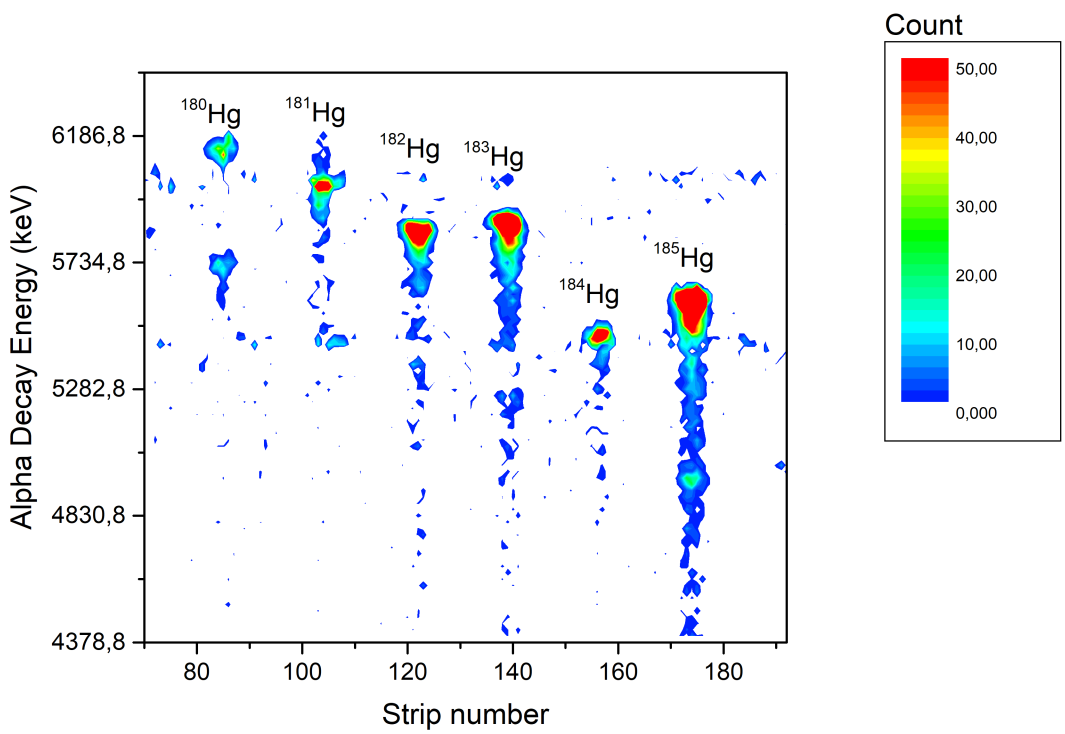

Figure 7: *Graph shows 2-D plot of α decay energies (keV)*

ii. $^{40}Ar + ^{166}Er$

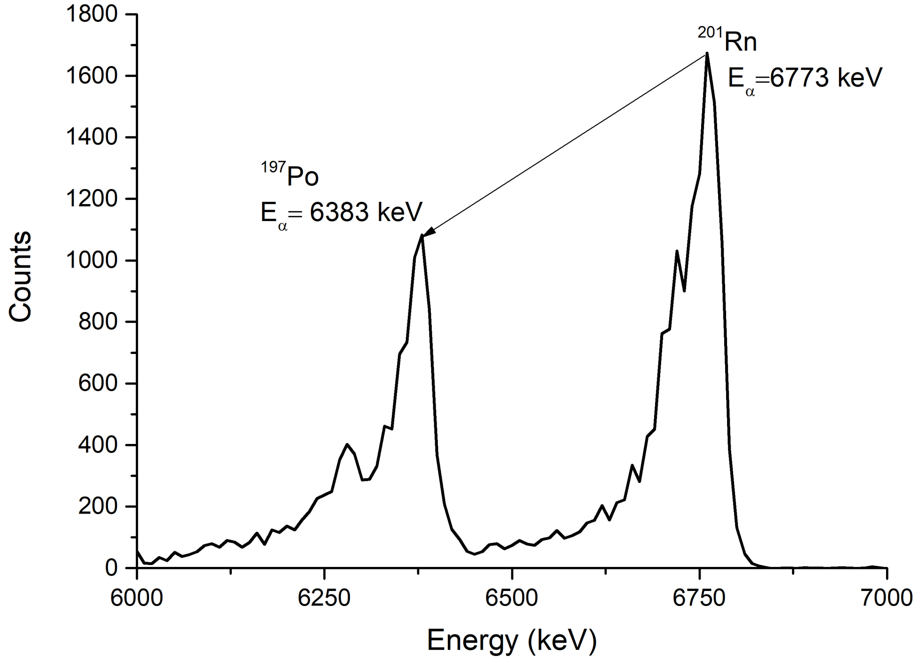

Figure 8: *Graph shows 1-D spectra of mercury isotopes*

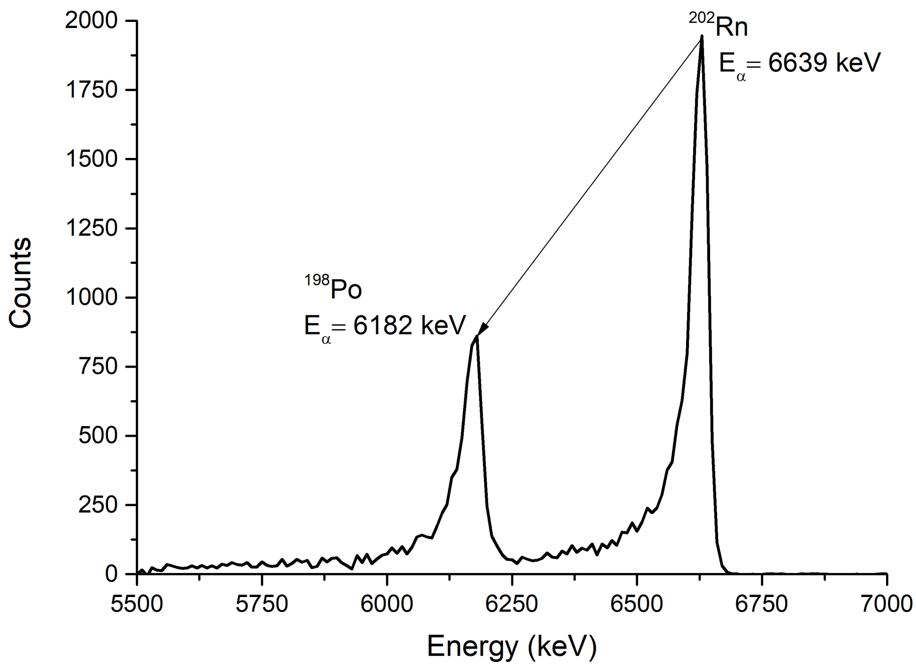

Figure 9: *Graph shows 1-D spectra of mercury isotopes*

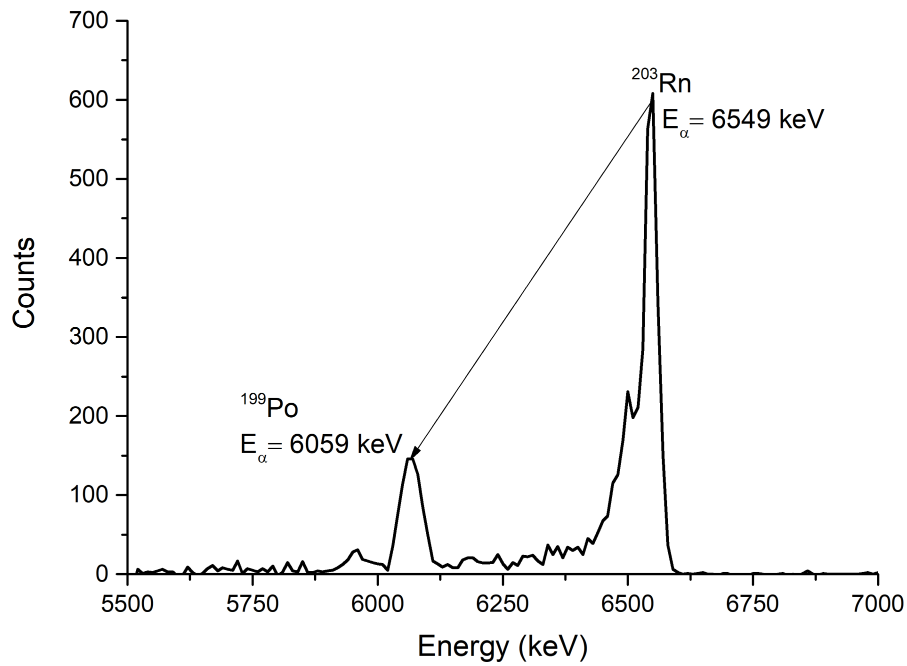

Figure 10: *Graph shows 1-D spectra of mercury isotopes*

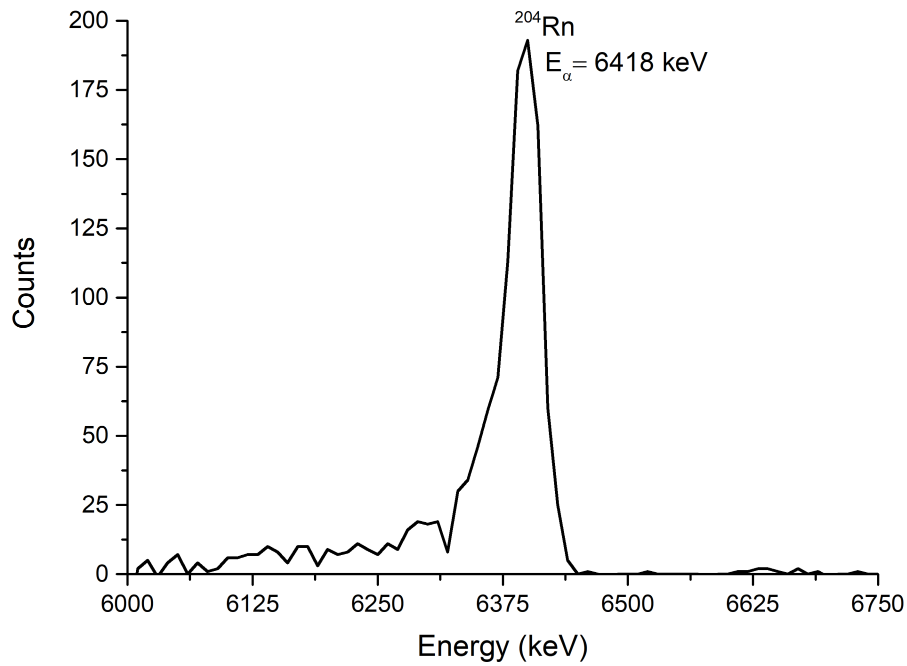

Figure 11: *Graph shows 1-D spectra of mercury isotopes*

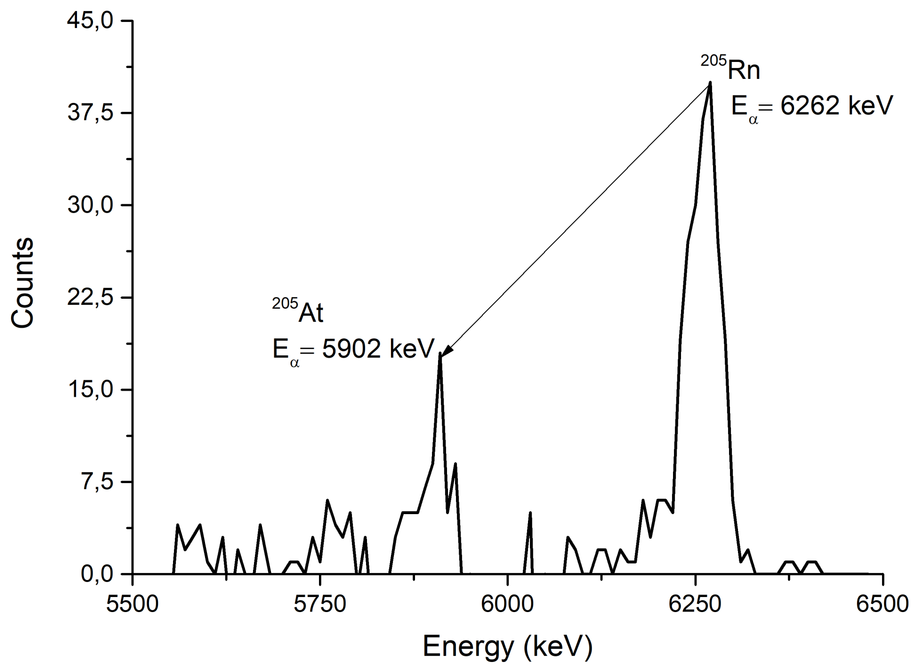

Figure 12: *Graph shows 1-D spectra of mercury isotopes*

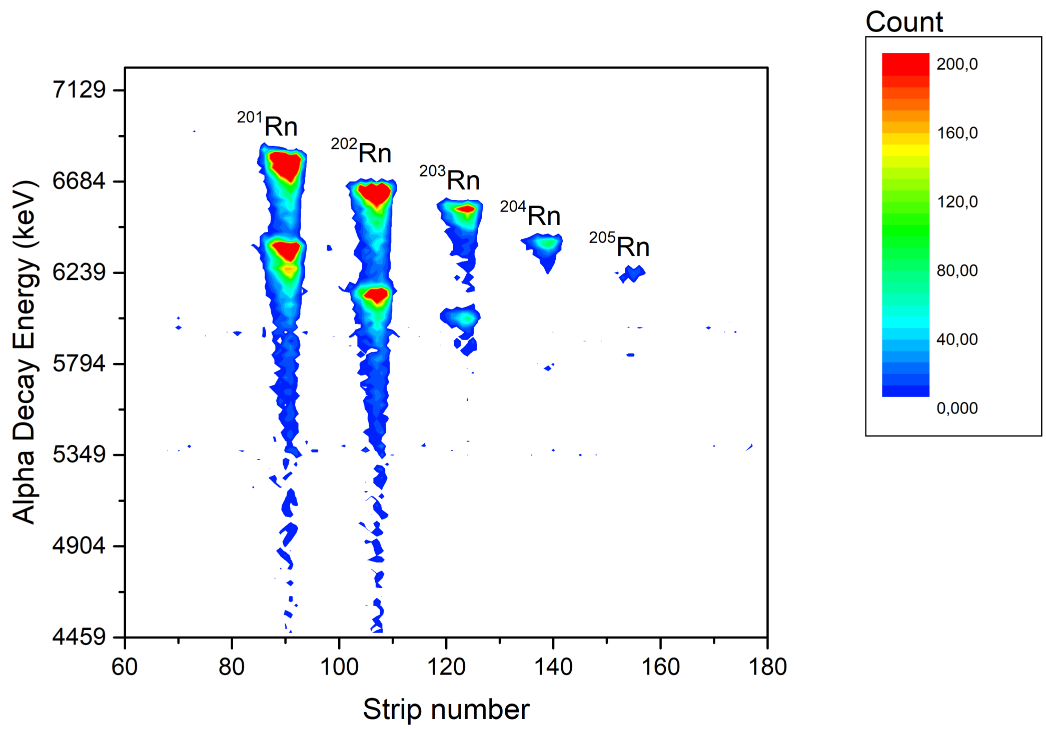

Figure 13: *Graph shows 2-D plot of α decay energies (keV)*

iii. $^{48}Ca + {}^{242}Pu$

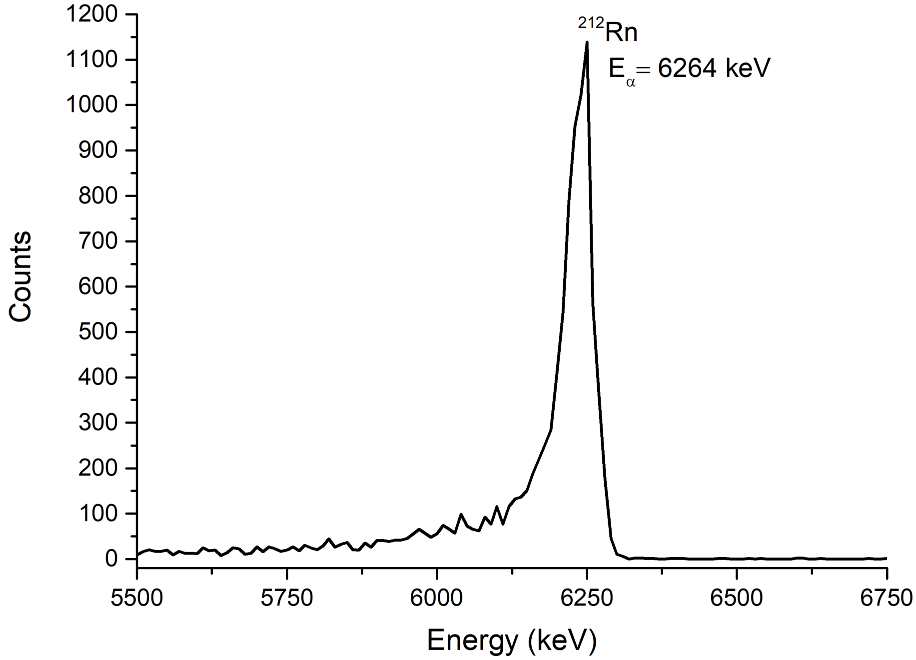

Figure 14: *Graph shows 1-D spectra of mercury isotopes*

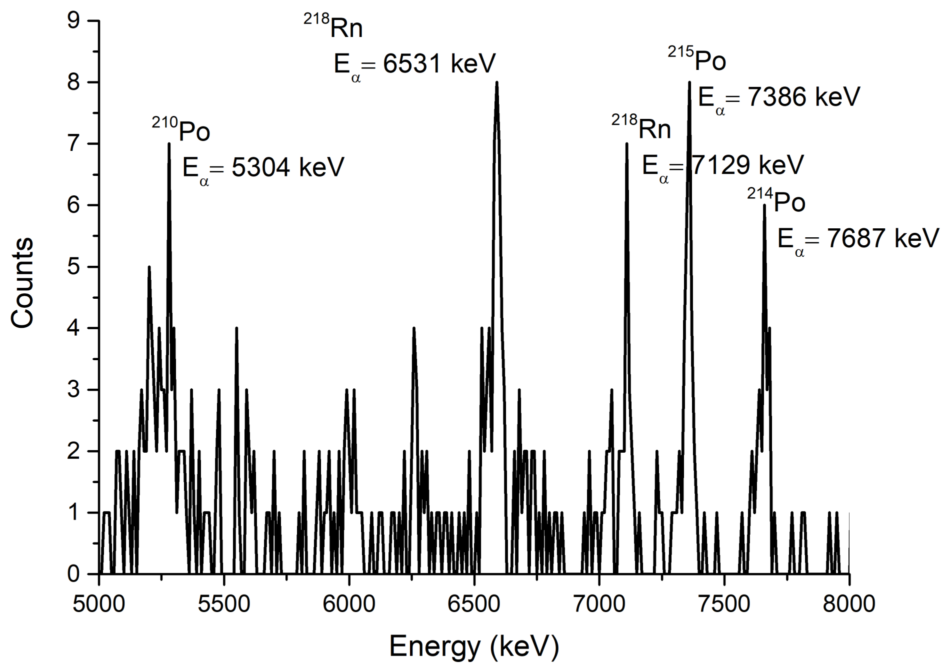

Figure 15: *Graph shows 1-D spectra of mercury isotopes*

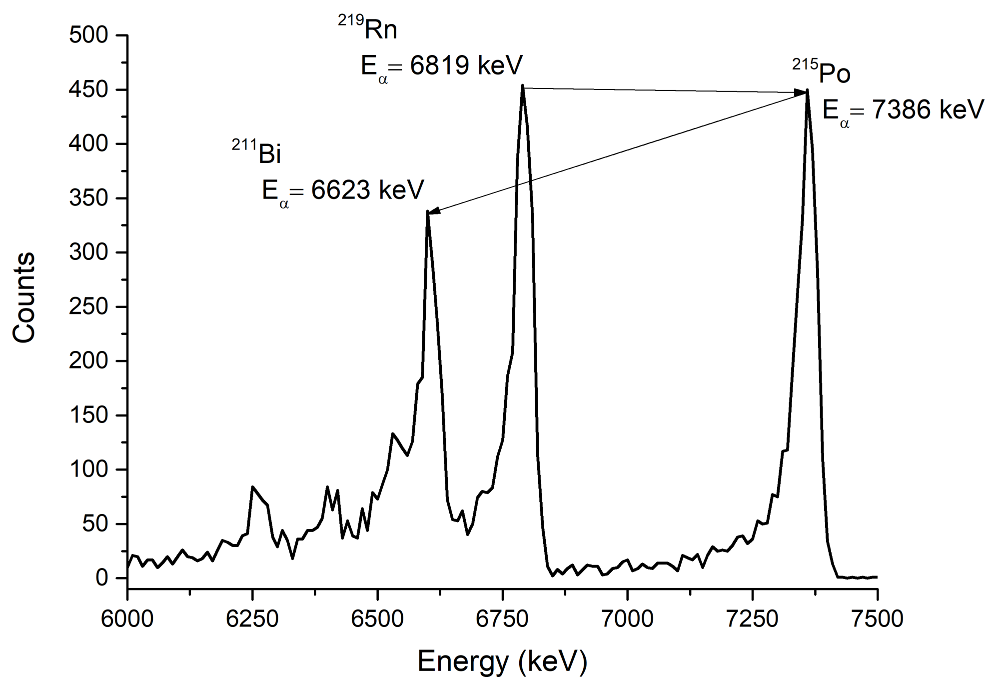

Figure 16: *Graph shows 1-D spectra of mercury isotopes*

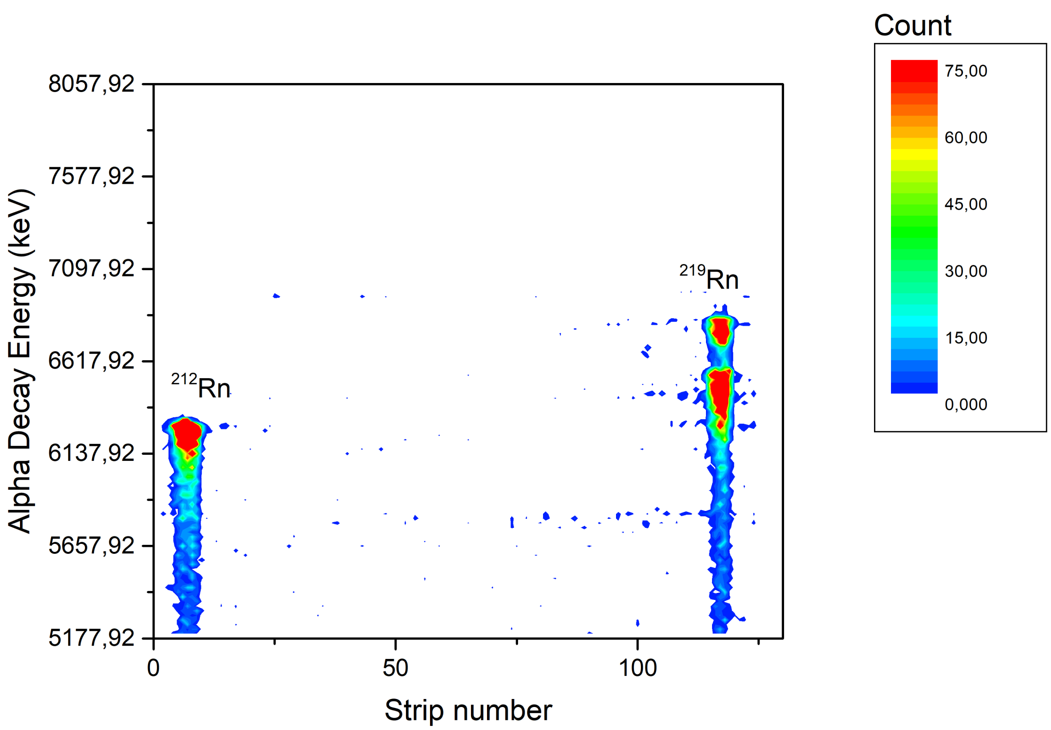

Figure 17: *Graph shows 2-D plot of α decay energies (keV), in this matrix* $^{213-217}Rn$ *doesnt't exist, because their half-lives are less than 0.5 ms. The weak α decay energy signal in the middle part of graph is created due to incomplete α emission energies. [2, 4]*

		Energy (keV)				
		Experimental Data	**Table Data**	**Probability (%)**	**Type of A decay**	**Peak Identification**
40Ar+148Sm	**180Hg**	6120	6119	99,87	*180HG A DECAY [0.480]*	180Hg
		5750	5753	99,74	*176PT A DECAY [0.40]*	176Pt
	181Hg	6000	6006	87,00	*181HG A DECAY [0.30]*	181Hg
		5500	5517	88,50	*177PT A DECAY [0.056]*	177Pt
	182Hg	5860	5867	99,00	*182HG A DECAY [0.152]*	182Hg
	183Hg	5890	5904	91,00	*183HG A DECAY [0.117]*	183Hg
	184Hg	5530	5535	99,44	*184HG A DECAY [0.0126]*	184Hg
	185Hg	5650	5653	96,00	*185HG A DECAY (49.1 S) [0.06]*	185Hg
40Ar+166Er	**201Rn**	6760	6773,0	100,00	*201RN A DECAY (3.8 S) [0.90]*	201Rn
		6380	6383,4	99,30	*197PO A DECAY (25.8 S) [0.84]*	197Po
	202Rn	6630	6639,5	99,99	*202RN A DECAY [0.90]*	202Rn
		6180	6182,0	99,99	*198PO A DECAY [0.57]*	198Po
	203Rn	6550	6549,0	100,00	*203RN A DECAY (28 S) [0.80]*	203Rn
		6060	6059,0	100,00	*199PO A DECAY (4.17 M) [0.39]*	199Po
	204Rn	6400	6418,0	*not specified*	*204RN A DECAY [0.73]*	204Rn
	205Rn	6270	6268,0/**6262,0**	*1,80/* ***98,20***	*205RN A DECAY [0.23]*	205Rn
		5910	5902,0	100,00	*205AT A DECAY [0.10]*	205At
48Ca+242Pu	**212Rn**	6250	6264,0	99,95	*212RN A DECAY [1.0]*	212Rn
	218Rn	5280	5304,3	100,00	*210PO A DECAY [1.0]*	210Po
		6590	6531,2	0,13	*218RN A DECAY [1.0]*	218Rn
			6609,8	0,00006	*214PO A DECAY [1.0]*	214Po
		7110	7129,2	99,87	*218RN A DECAY [1.0]*	218Rn
		7360	7386,1	100,00	*215PO A DECAY [.9999977]*	215Po
		7660	7686,8	99,99	*214PO A DECAY [1.0]*	214Po
	219Rn	6600	6622,9	83,77	*211BI A DECAY [0.99724]*	211Bi
			6636,0	0,0003	*215PO A DECAY [.9999977]*	215Po
		6790	6819,1	79,40	*219RN A DECAY [1.0]*	219Rn
		7360	7386,1	100,00	*215PO A DECAY [.9999977]*	215Po

Figure 18: *Table shows value of measured energies and table energies (keV), probability of specific isotopes, type of A decay energies and peak identification*

VI. Conslusion

MASHA (Mass Analyzer of Super Heavy Atoms) is mass-separator for identification the SHE (superheavy elements) by mass-to-charge ratio and could show additional information about isotpes by using the detector system. Between the beam and target, that is placed in the hot catcher, happened fusion reaction. The energy spectra of the α decay energy were measured at the focal plane by silicon detector system. The reaction products become ionized and were diffused in the vacuum tube until they reached the detector.

VII. Acknowledge

I want to thank the team of the JINR Interest training program for joining me to work on the project. I gained newest information about MASHA setup and new knowledge about software OriginPro and it helped me to decide doing my masters thesis and to continue a colaboration with JINR.

References

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