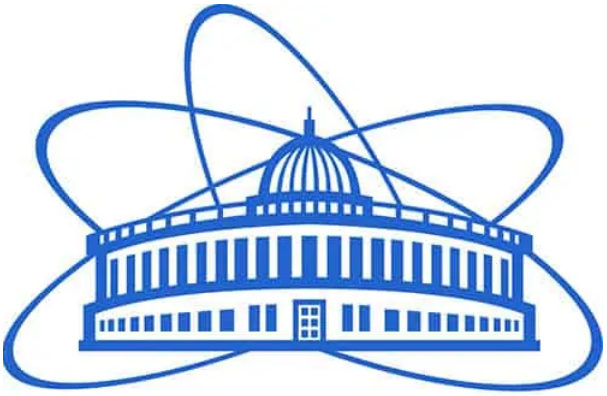

Determination of Masses of the Super Heavy Elements in the Experiments on Synthesis of Cn and Fl Using the Reactions $^{40}Ar +^{148} Sm$, $^{40}Ar +^{166} Er$ and $^{48}Ca +^{242} Pu$

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Contents

Abstract

Mass Analyzer of Super Heavy Atoms (MASHA) has been designed for direct mass measurements with mass resolution of about 1600 which is enough to determine superheavy isotopes in a range of A=250-300. The possible applications of this analyzer is to make on-line measurements of the super heavy elements physical properties, e.g. mass, decay energy, branching, etc. In this project, by using the data obtained from MASHA, Reactions $^{40}Ar +^{148} Sm$, $^{40}Ar +^{166} Er$, $^{48}Ca +^{242} Pu$ were studied by the isotopes identification.

1 Introduction

Studies of the Super Heavy Elements (SHE) production is one of the most important scientific improvements of the last decades. Together with the leading studies that performed in Joint Institute for Nuclear Research at Dubna, Russia; these studies lead to the recent discoveries of SHEs with atomic numbers Z=113-118 [1, 2].

Resulting nuclei of different collision dynamics such as complete fusion, elements such as Cn,Nh,Fl has been synthesized in Flerov Laboratory of Nuclear Reactions (FLNR) in Dubna, Russia. By using such dynamics, it is possible to obtain nuclei with relatively long decay time ($\sim 1s$) and hence, it is possible to perform independent chemical identification on these nuclei [3].

In order to identify such products, several mass-spectrometric techniques has been developed. One of the most important required attributes for such spectrometer is high separation efficiency and fast on-line separation of SHEs with short half-lives. In FLNR, Mass Analyzer of Super Heavy Atoms (MASHA) has been developed and used for such analysis. The unique advantage of MASHA is the possibility to measure the mass-to-charge ratios of SHE isotopes with the simultaneous detection of their α decays [1]. The reactions for studying in this project are:

$$^{40}Ar +^{148} Sm$$
$$^{40}Ar +^{166} Er$$
$$^{48}Ca +^{242} Pu$$

The first two reactions can be classified under head-on collision (complete fusion) and the latter as multinucleon transfer. It is decided to measure the efficiency and the separation time of MASHA by performing model experiments on mercury (Hg) that is produced by this full fusion reaction because mercury is the chemical analogue of the elements Cn and Fl. [2] In the second and third reaction, Radon nuclei is measured. The main difference between mercury and Radon is that, Radon does not

make any combinations with the coverings of the detector. Therefore, it is possible to perform different test measurements for different purposes.

Hence, in this project, the analysis is going to be performed on the reactions given above. By studying the α decay energies of the reaction products, It has been tried to identify the isotopes. Moreover, by studying the mass-energy spectra of the reaction products, mass-separation quality of the analyzer will be visualized.

2 Experimental Setup

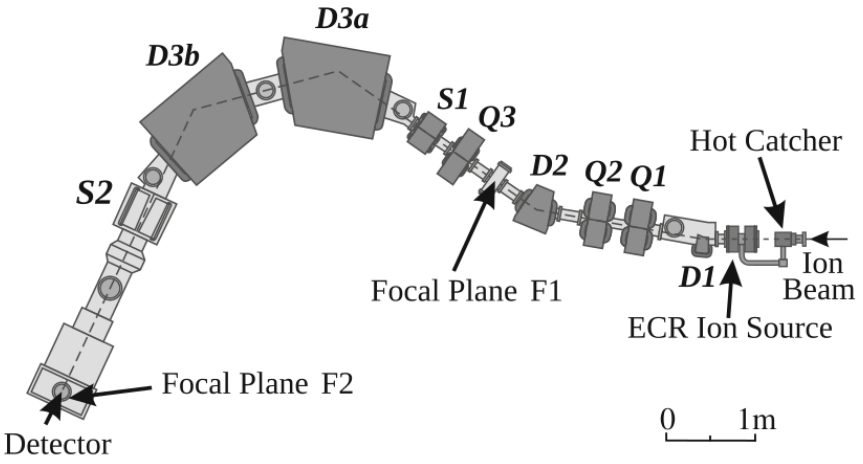

Figure 1: Schematic diagram of MASHA mass separator[1]

As can be seen from Fig. 1, the separator consists of 4 main parts: An ion source based on electron cyclotron resonance, a target assembly with a hot catcher, an ion optics (D,Q,S) and the detection systems.

2.1 Ion Source

In this part of the separator, the reaction products has been ionized with an ECR that contains a 2.45 GHz microwave oscillator. In the ion source, the atoms are ionized to charge state Q=+1. Then, these ions accelerated by the help of the electrode system and gathered into a beam. This beam is then separated with an optical system of the mass spectrometer [1].

The efficiency of the ion source reaches 90% for the noble gases. Therefore, the ions that are in the current are almost 100% singly ionized [4].

2.2 A Target Assembly and a Hot Catcher

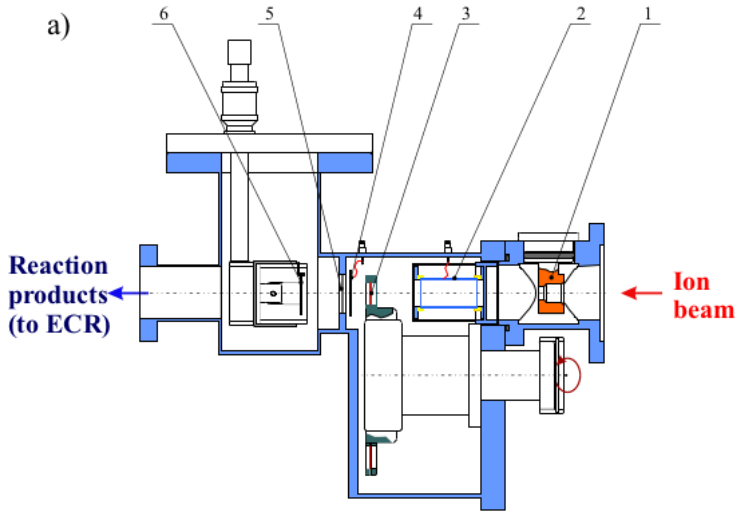

Figure 2: Target assembly with the hot catcher:1–diaphragm; 2–pick-up sensor; 3–target on the wheel; 4–electron emission beam monitor; 5–separating foil; 6 – hot catcher.[4]

When the ion beam enters this part, it incidents on a rotating target unit, consisting of 12 sectors, assembled in cassettes, revolving 25 rps via electric engine located right before the hot catcher unit. Prior to this collision, the energy and the intensity of the ion is being measured via pick-up detectors and a Faraday cups. After the collision, the injection of the fusion products to the ECR ion source takes place. Prior to this injection, fusion products hits on the pre-heated (up to 2000K) graphite foil. Fusion products hit to the graphite to stop and cool down. While cooling down, ions fill their electron orbitals and diffuse through in the form of atoms into the vacuum of the hot catcher. From this, they move along a pipe and reach to the ECR ion source [1].

2.3 Detector

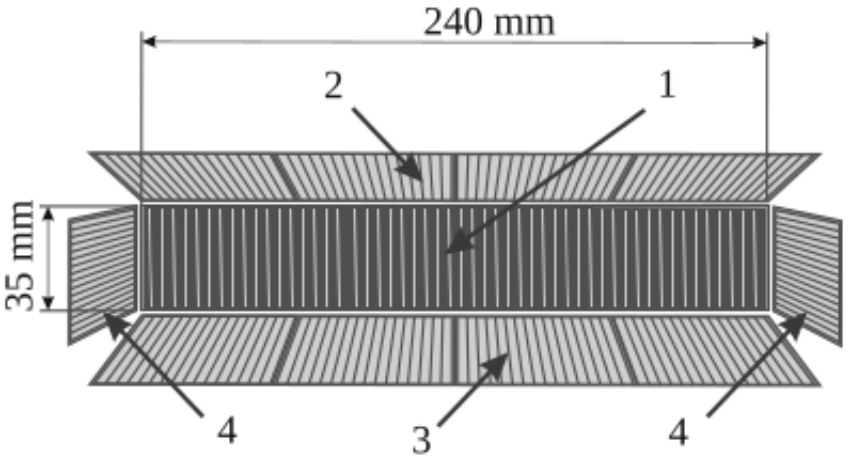

Figure 3: Detector system: 1- front detector, 2 3- side detectiors, 4- lateral detectors [1]

In order to detect the reaction products, a silicon strip detector system is used in the MASHA. In order to cover as much area as possible, the detector is a well-type detector that contains front, side and lateral detectors. The front detector consists of 192 strips with a 1.25 mm pitch. Side detectors on the other hand has 64 strips. The energy resolution of the detector is about 30 keV and It is possible to detect at least 90% of the decay products (α particles) if it occurs in the middle of the front detector [1].

The other detector in the system is TIMEPIX pixel detector and it is used for detecting the β^- and α particles. It is possible to detect even a single β^- and α particles with this detector together with the γ and X-rays. The detector consists of an full sensitive area of 14x14 mm^2 and has an array of 256x256 pixels on it [4].

2.4 Data Acquisition System

The signals from the detectors are collected with independent spectrometric channels and then, routed to the data acquisition system consists of charge-sensitive preamplifier with 16 preamplifiers that are outside of the vacuum chamber. From these preamplifiers, the signals are directed to the 8-channel driver amplifiers with a built-in multiplexer.

After these steps, three outputs are taken from the multiplexer: Alpha, fragment and

digital channels. The digital channels contain the information on the source of the input signal and these outputs are connected to the XIA multi-channel high-speed digitizers [4].

3 Results and Discussion

As discussed in the previous sections, in this project, the aim was to analyze three different nuclear reaction. In the analysis, a nuclei chart with the decay schemes was used and compared the observed energies of the α particles in order to classify the reaction products.

3.1 $^{40}Ar + ^{148}Sm$

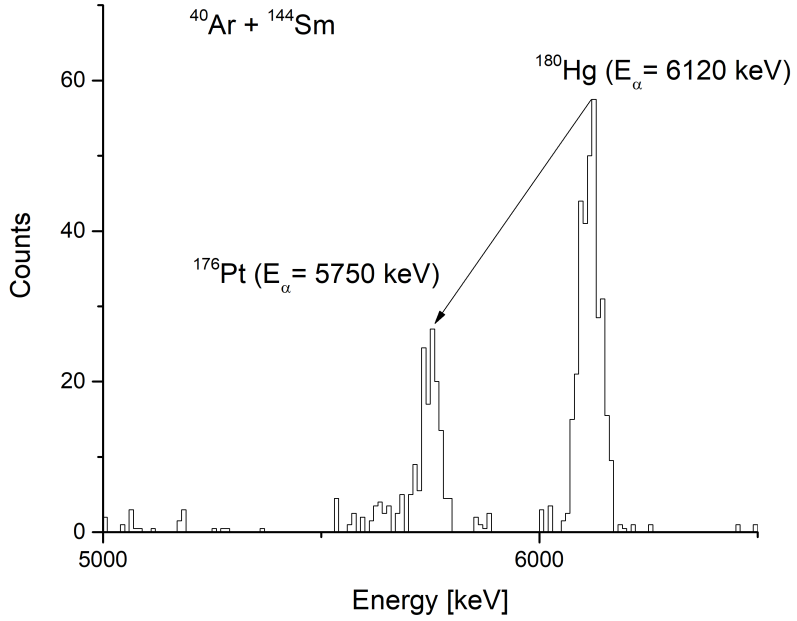

Figure 4: Energy spectrum of the α-particles from decays of ^{180}Hg

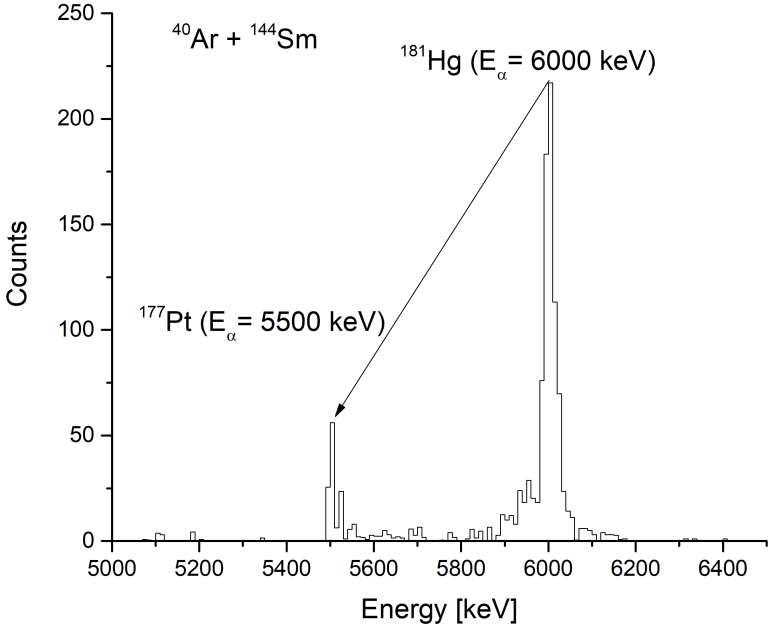

Figure 5: Energy spectrum of the α-particles from decays of ^{181}Hg

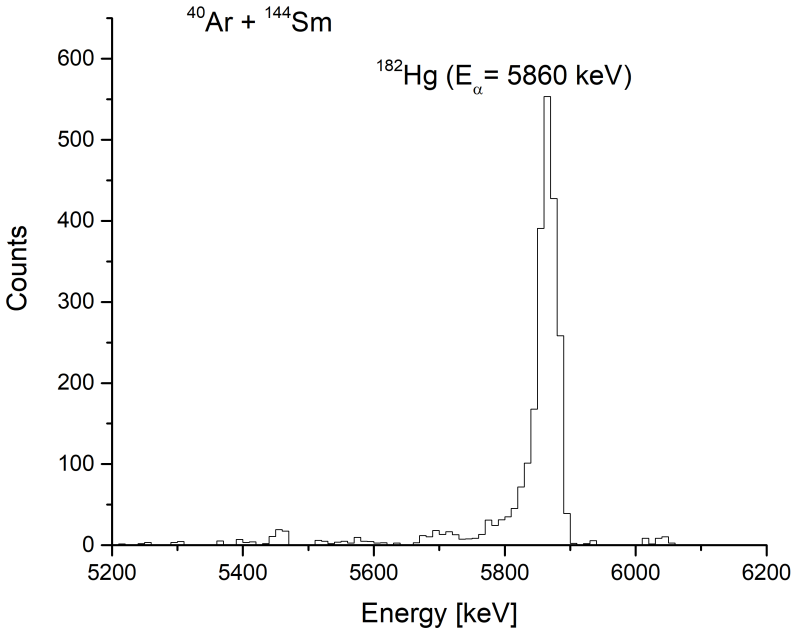

Figure 6: Energy spectrum of the α-particles from decays of ^{182}Hg

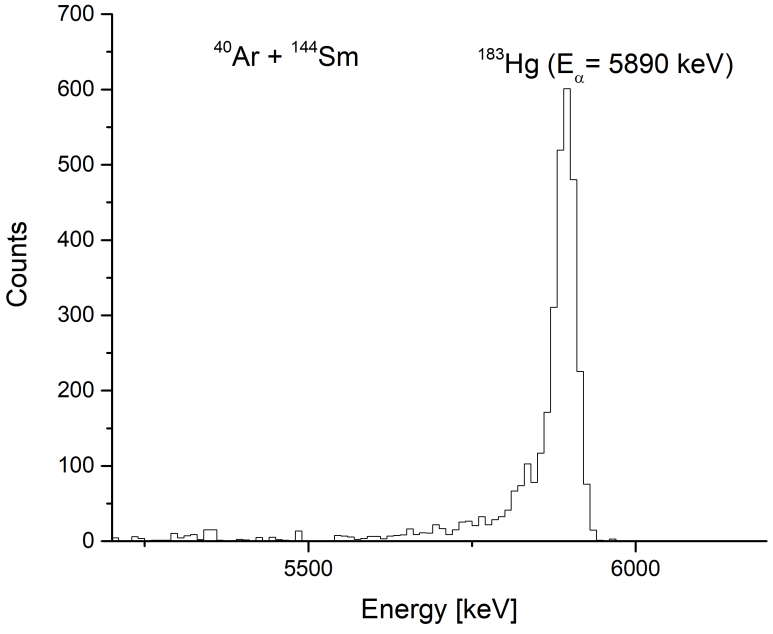

Figure 7: Energy spectrum of the α-particles from decays of ^{183}Hg

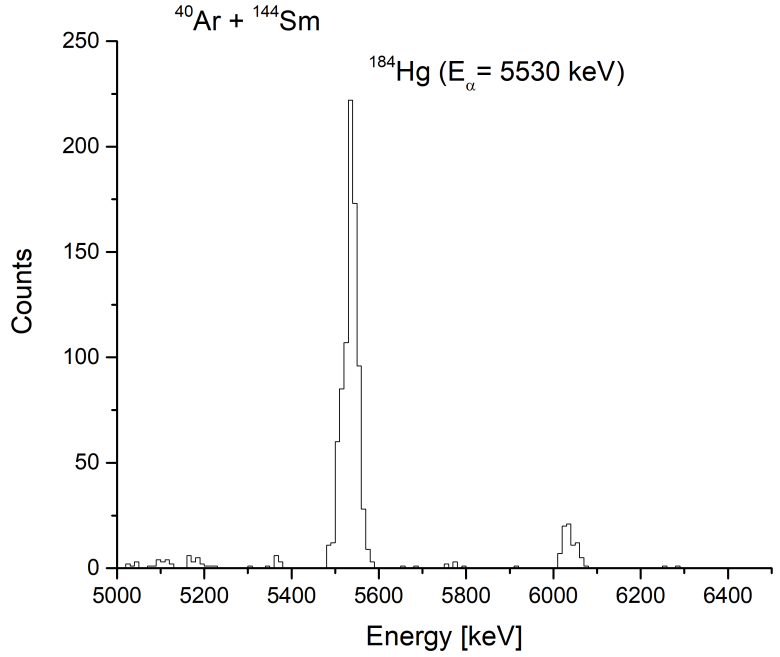

Figure 8: Energy spectrum of the α-particles from decays of ^{184}Hg

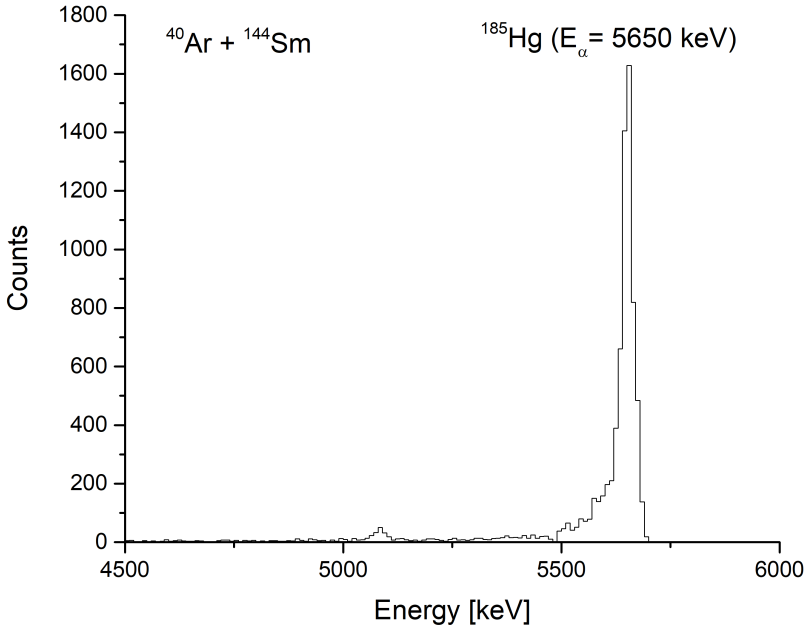

Figure 9: Energy spectrum of the α-particles from decays of ^{185}Hg

Isotope	E_α [keV]	$E_{\alpha-l}$ [keV]	Half Life [s]
^{180}Hg	6120	6199	2.58
^{181}Hg	6000	6006	3.54
^{182}Hg	5860	5867	10.83
^{183}Hg	5890	5904	9.4
^{184}Hg	5530	5535	30.9
^{185}Hg	5650	5653	49.1

Table 1: Comparison of the α decay energies (E_α) of the produced isotopes with the literature values ($E_{\alpha-l}$).

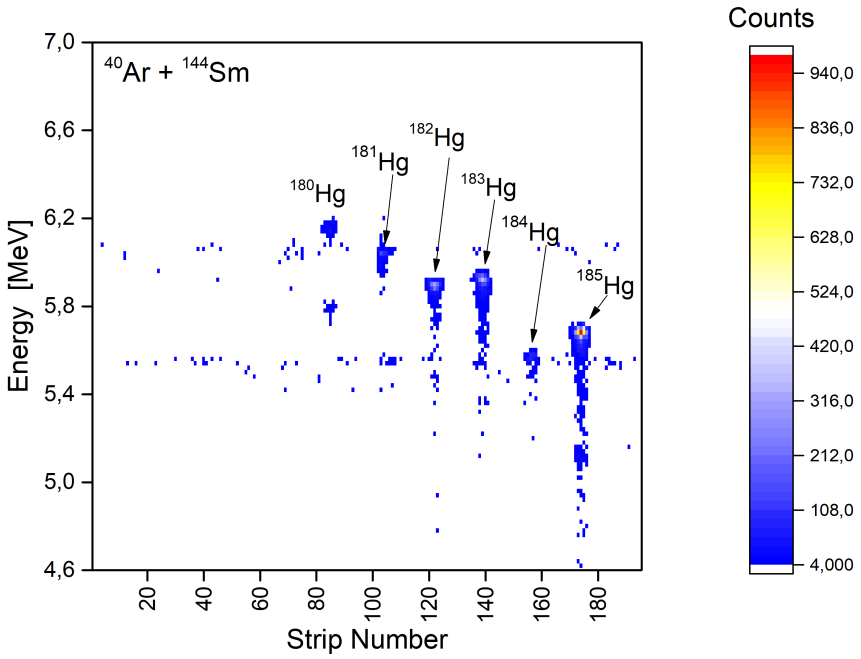

Figure 10: Energy vs. strip number plot of the α-particles from decays of mercury isotopes

The secondary peaks in the Figures 4-9 are mainly the decays of the daughter products. However, some of the secondary peaks are the remaining (undecayed) isotopes from the previous runs.

3.2 $^{40}Ar + ^{166}Er$

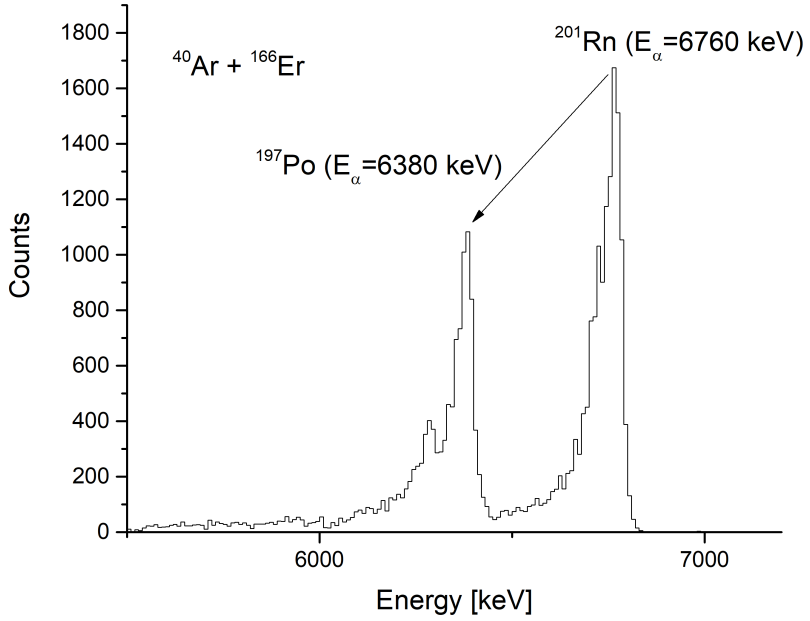

Figure 11: Energy spectrum of the α-particles from decays of ^{201}Rn

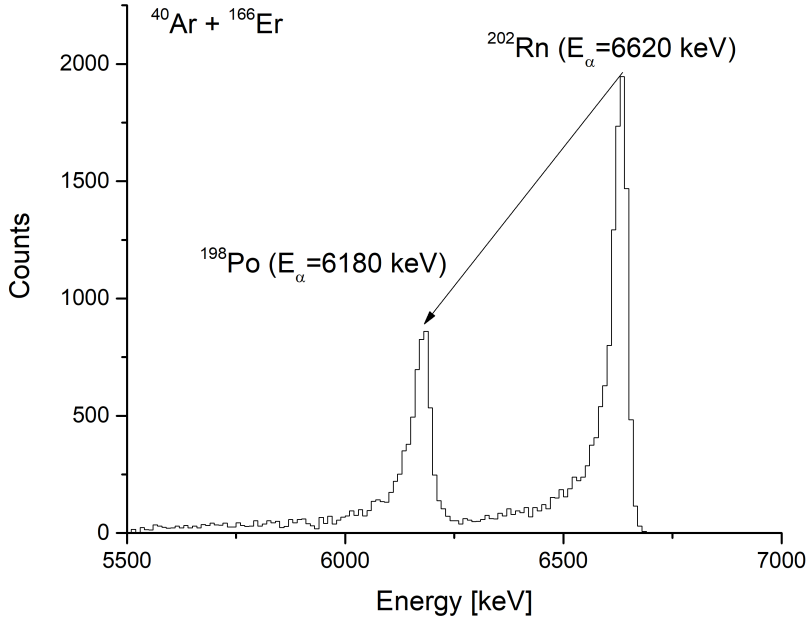

Figure 12: Energy spectrum of the α-particles from decays of ^{202}Rn

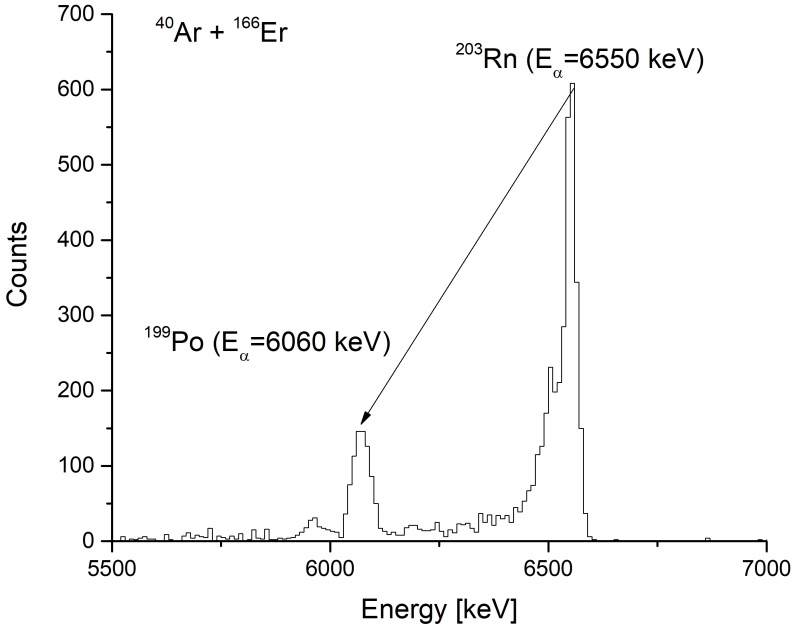

Figure 13: Energy spectrum of the α-particles from decays of ^{203}Rn

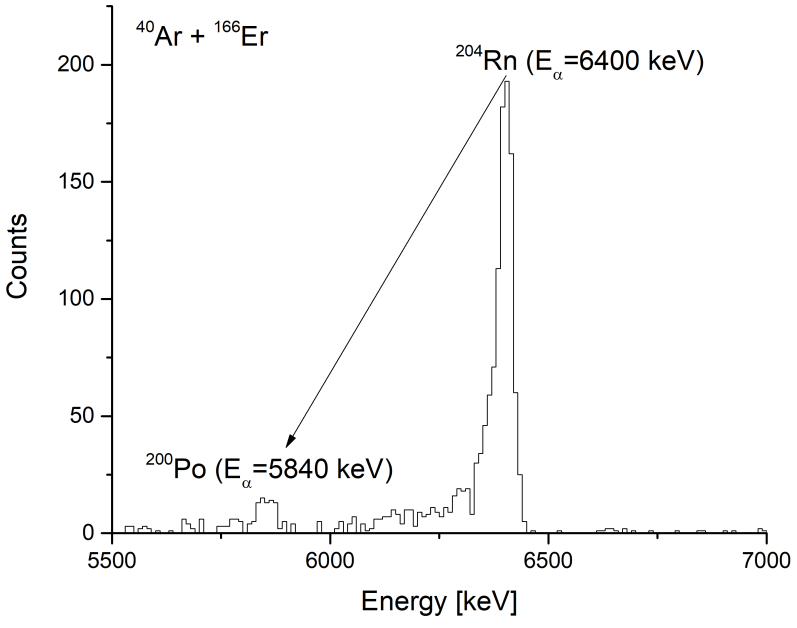

Figure 14: Energy spectrum of the α-particles from decays of ^{204}Rn

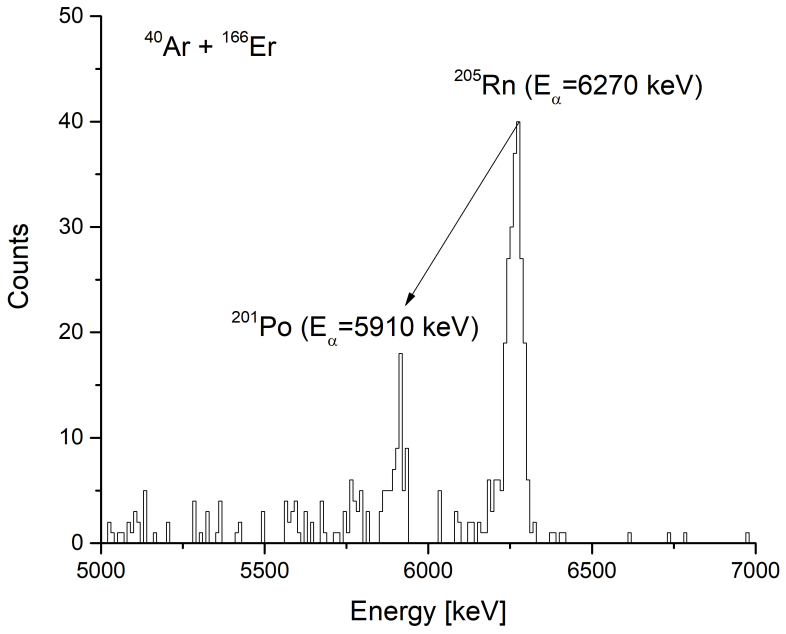

Figure 15: Energy spectrum of the α-particles from decays of ^{205}Rn

Isotope	E_α [keV]	$E_{\alpha-l}$ [keV]	Half Life [s]
^{201}Rn	6760	6725	7.1
^{202}Rn	6620	6639	10
^{203}Rn	6550	6499	45
^{204}Rn	6400	6418	75.4
^{205}Rn	6270	6262	170

Table 2: Comparison of the α decay energies (E_α) of the produced isotopes with the literature values ($E_{\alpha-l}$).

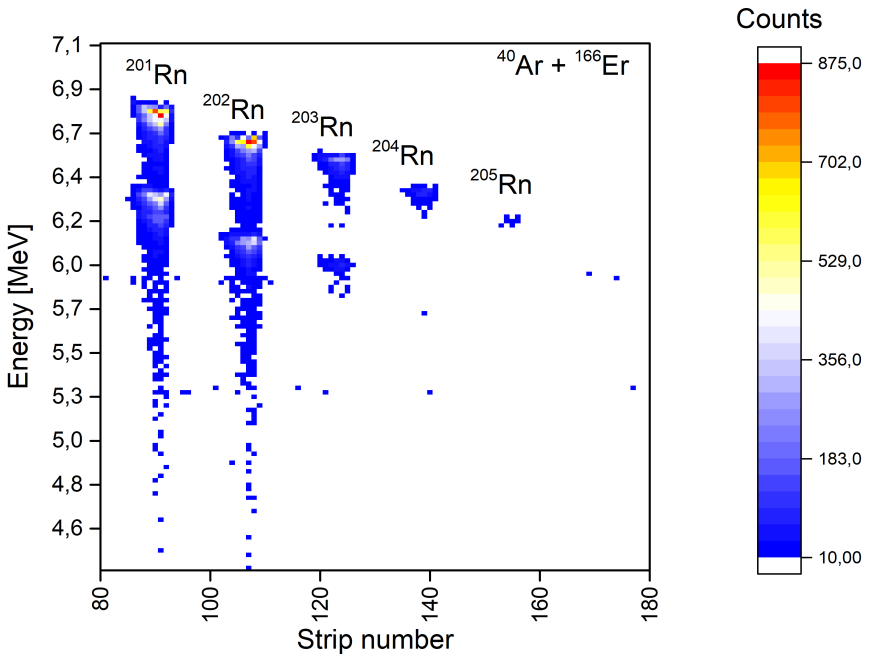

Figure 16: Energy vs. strip number plot of the α-particles from decays of Radon isotopes

As in the previous part, the secondary peaks in the spectra are mostly coming from the decays of the daughter nuclei. The most important point while considering these secondary peaks are of course seeking for alpha decays. Therefore, while studying the secondary peaks, we studied possible decay products of the Rn isotopes that make alpha decay from the literature.

Therefore, as in the previous part, the values from the literature are in good agreement both with Rn isotopes and its decay products.

3.3 $^{48}Ca +^{242} Pu$

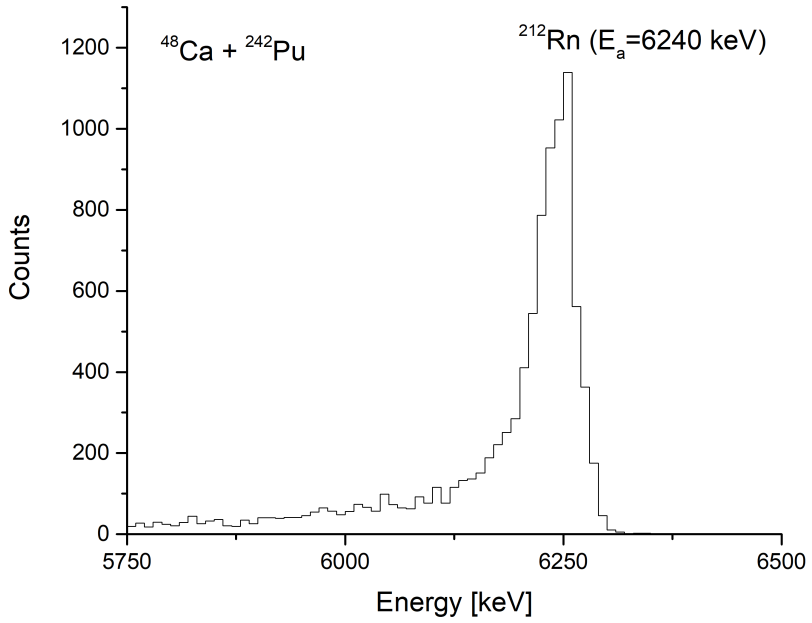

Figure 17: Energy spectrum of the α-particles from decays of ^{212}Rn

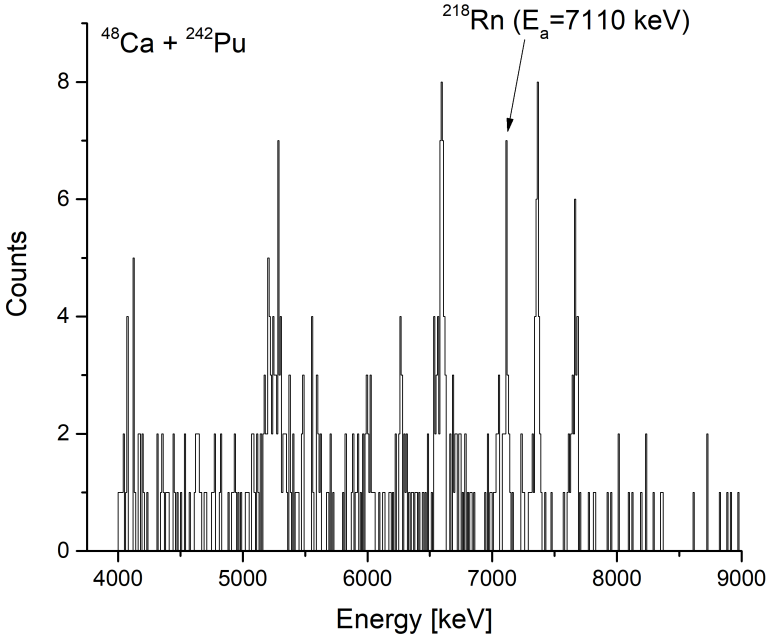

Figure 18: Energy spectrum of the α-particles from decays of ^{218}Rn

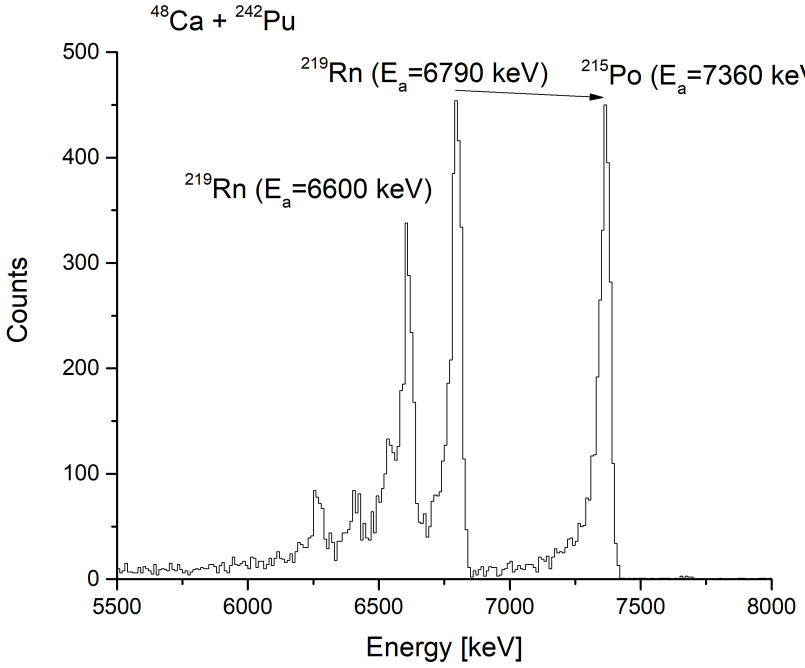

Figure 19: Energy spectrum of the α-particles from decays of ^{219}Rn

Isotope	E_α [keV]	$E_{\alpha-l}$ [keV]	Half Life [s]
^{212}Rn	6240	6264	1434
^{218}Rn	7110	7129	2100
^{219}Rn	6790	6819	3.96
^{219}Rn	6600	6552	3.96

Table 3: Comparison of the α decay energies (E_α) of the produced isotopes with the literature values ($E_{\alpha-l}$).

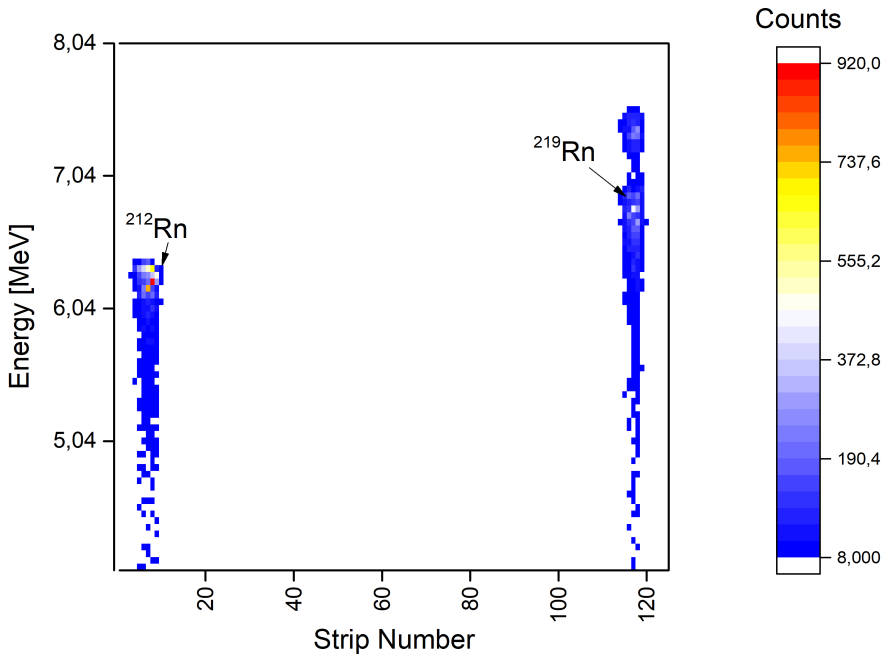

Figure 20: Energy vs. strip number plot of the α-particles from decays of Radon isotopes

As in the previous parts, the determination of the produced isotopes is accomplished. The only problem encountered in this part is that, the ^{218}Rn isotope has a very long half life and as can bee seen from the Figure 18, the activity of the isotope is much smaller than the others. Therefore, it was not easy to determine the isotope from the energy spectrum. Due to its low activity, it is not possible to observe ^{218}Rn in the energy vs. strip number graph.

Moreover, in the energy spectrum in Fig. 19, there are two ^{219}Rn isotopes. The reason for that is, the branching ratio of the ^{219}Rn with 6819 keV energy is 79% and with 6552 keV is 13%. Due to this relatively high probability, the peak at 6600 keV can be explained with this decay.

4 Conclusion

The MASHA mass-separator located at the Flerov Laboratory of Nuclear Research allows the on-line measurements of the produced isotopes from several reactions. In this project, by using the data obtained from MASHA, isotopes that are produced

in $^{40}Ar +^{148} Sm$, $^{40}Ar +^{166} Er$, $^{48}Ca +^{242} Pu$ reactions were identified by a detailed analysis on the Energy spectra of the alpha particles from the decays of the isotopes and comparing them with the literature

5 Acknowledgements

I would like to express my sincere gratitude to Mr. Viacheslav Vedeneev for giving me the privilege to participate this project. Moreover, I would like to thank him for his guidance and his valuable support. I would like to thank the INTEREST team for their valuable motivation and support throughout the wave.

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