JOINT INSTITUTE FOR NUCLEAR RESEARCH

Flerov Laboratory of Nuclear Reactions

FINAL REPORT ON THE INTEREST PROGRAMME

"Production and Spectroscopic Investigation of New Neutron-Rich Isotopes Near the Neutron N=126 Shell Closure Using the Multinucleon Transfer Reactions"

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Abstract

For studying masses super heavy elements we use the Mass Analyzer of Super Heavy Atoms (MASHA) setup which is located at (FLNR) in (JINR) Dubna, Russian Federation. It also provides an investigation about their decay process including alpha decay. Three reactions which are $40Ar$+$148Sm$, $40Ar$+$166Er$, and $48Ca$+$242Pu$ were performed using MASHA setup in FLNR. And an analysis for alpha decay energy for Hg and Rn isotopes was done using Origin Pro software. Giving peak analysis graphs, and heatmaps which obtained by silicon-strip detector.

1. Introduction

For on-line measurements of the physical properties of superheavy elements (SHE), such as decay energy and modes, mass and half-lives, MASHA was constructed at one of the beam outs of U-400M cyclotron based in Flerov Laboratory of Nuclear Reactions (FLNR) at Joint Institute for Nuclear Research (JINR), Dubna, Russia. Another possible application of the mass-separator MASHA would be related to studying the neutron-rich nuclei near the N=126 neutron shell. 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 aim of this project is to do the analysis on data obtained from the experiments of complete fusion reactions neutron evaporation residues $40Ar + 148Sm \rightarrow (188-x)Hg + xn$, $40Ar + 166Er \rightarrow (206-x)Rn + xn$ and multi-nucleon transfer reaction $48Ca + 242Pu$ using the α-decay chains from the position sensitive Si detector.

The data obtained was analyzed using Origin pro software. A peak analysis was done for every isotope giving alpha decay energy and half life of each isotope with the help of chart of nuclide. Furthermore, a heatmap for the product isotopes were obtained.

2. Experimental setup

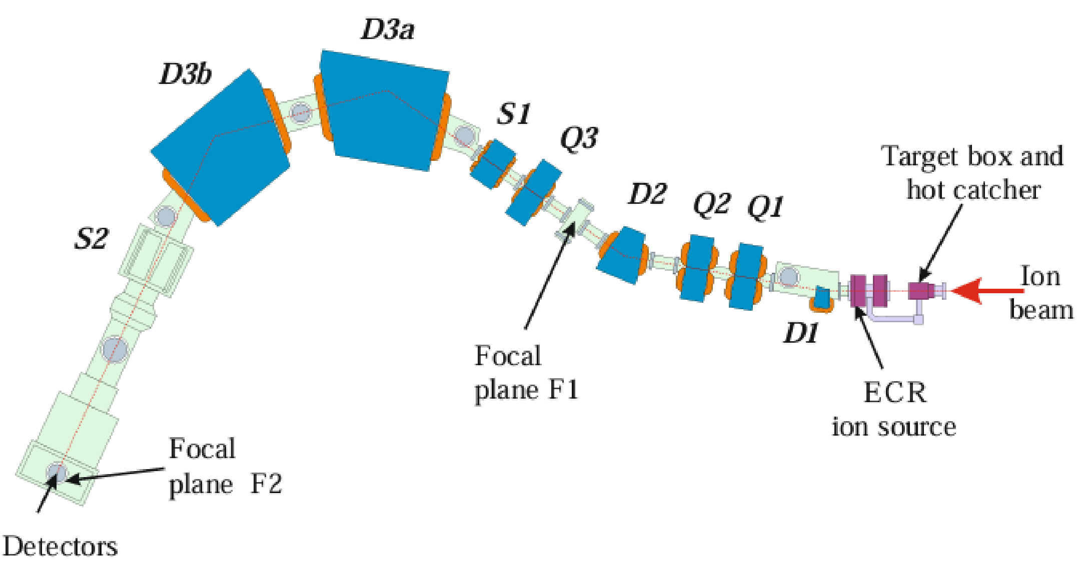

Figure 1: Scheme of the MASHA setup

In Figure 1 the scheme of the MASHA setup is shown. It consists of the target box with the hot catcher, the ECR ion source, the ion-optical transport system with a 192-strip silicon detector placed in the focal plane F2. The additional strip detector at the intermediate focal plane F1 registers permanently the products of the complete fusion reaction $^{48}Ca+^{nat}Nd$ which takes place due to the admixture of Nd in the target, providing the Cn nuclei must be detected in the focal plane detector.

2.1 Target box

The target box consists of a rotating disc divided into 6 sectors, which hold up target materials. The disc rotates at a frequency of 25Hz using Siemens electric engine. The target materials are bombarded and nuclear reaction occurs. The nuclear reaction products are stopped by the hot catcher.

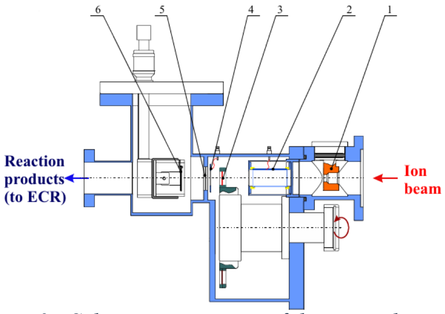

Figure 3: Schematic overview of the target-hot catcher system. Here: 1– diaphragm; 2– pick-up sensor; 3 target on the wheel; 4– electron emission beam monitor; 5– separating foil; 6– hot catcher.

Figure 2: The photo of the rotating target cassette in assembly. 6 packs, 2 windows at 14 mm width each. Target material– 242Pu in oxide state put on the Ti 2 µm thick foil

2.2 ECR Ion source

The ECR (electron cyclotron resonance) ion source is operated under ultra-high frequency conditions at about 2.45 GHz. The incoming atoms of nuclear reaction products are ionized to the charge state Q =+1and accelerated up to 38 keV by a three-electrode electrostatic lens. 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%.

2.3 Hot Catcher

The injection of the complete fusion reaction products to the ECR ion source took place after it stopped inside poly-graphene catcher unit. After emission from the target the reaction products passed through the separating foil and stopped in a graphite foil heated up to 2000K. 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.

2.4 Detection and control system

In this work Silicon semiconductor detector was used. This detector is made up of a 192-strip frontal detector. Each of the top and bottom planes is divided into 64 strips, and each of the left and right planes is divided into 16 strips. Operating at 40 V bias, with an energy resolution of around 30 keV, which is sufficient for precise alpha-spectroscopy. The application displays one-dimensional energy spectra for each strip as well as two-dimensional spectra for each crystal's energy dependent on strip number.

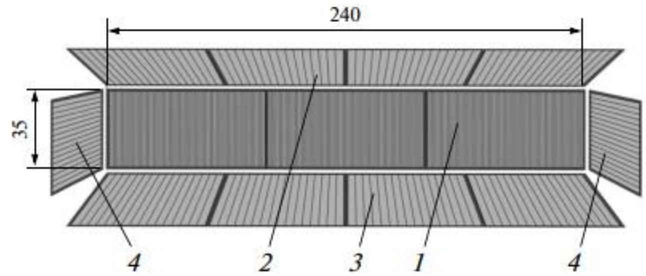

Figure 4: Silicon detector of the focal plane: (1) frontal part (192 strips), (2) top part (64 strips), (3) bottom part (64 strips), and (4) side parts (16 strips in each).

3. Experimental work

The experiment was carried out at U-400M cyclotron of FLNR JINR. Which is used to accelerate projectile particles to do these nuclear reactions. After that the collision between energetic particles and target materials occur at MASHA setup making the nuclear reactions.

Three nuclear reactions occurred (40Ar + 148Sm) with Hg isotopes as products and (40Ar + 166Er and 48Ca + 242 Pu) with Rn isotopes as products. The products are stopped in the hot catcher by the absorber material. Then alpha decay occurred and detected using Si detector.

After that peak analysis was done using Origin Pro software to get alpha decay energies and these energies were compared with data in chart of nuclides. Chart of nuclides used to get data for isotopes like isotopes masses, half-lives, energy of decay and decay schema. At the end a heatmap (two-dimensional energy-position graph) was made for each reaction to give a view on which isotope was detected at which strip number and energy.

4. Results and discussion

Alpha-decay energies were measured for each reaction and summarized in the following tables. For each reaction we obtain a plot and heatmap to show energy and furthermore peak analysis was done to show this energy compared with chart of nuclide results.

3.1. First Reaction Results

$$40Ar + 148Sm \rightarrow (188-x)Hg + xn$$

In this reaction 6 isotopes of mercury which are: 180Hg, 181Hg, 182Hg, 183Hg, 184Hg and 185Hg were produced.

Table 1: 40Ar + 148Sm results

Isotope	Half-life (s)	Theoretical Energy (KeV)	Measured Energy (KeV)
180Hg	2.58	6119	6120
181Hg	3.54	6006	6000
182Hg	10.83	5867	5860
183Hg	9.4	5904	5890
184Hg	30.9	5535	5530
185Hg	49.1	5653	5650

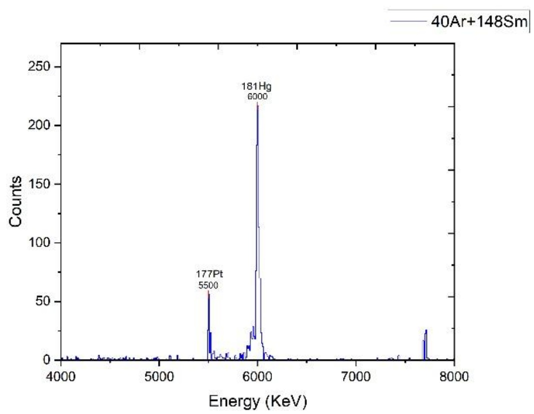

Figure 6: 181 Hg

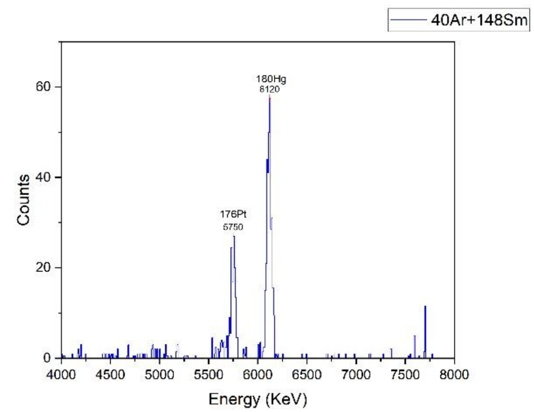

Figure 5: 180 Hg

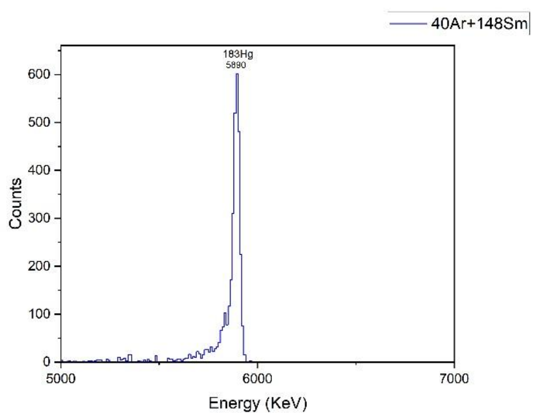

Figure 8: 183 Hg

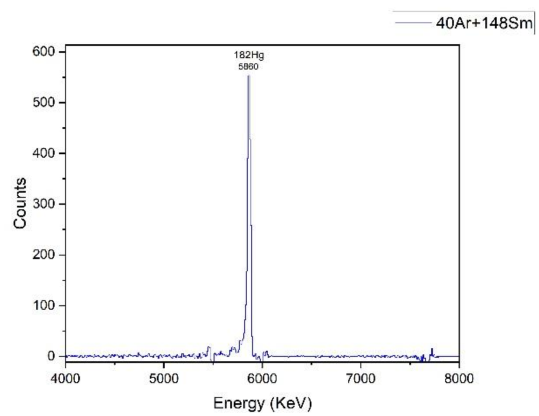

figure 7: 182 Hg

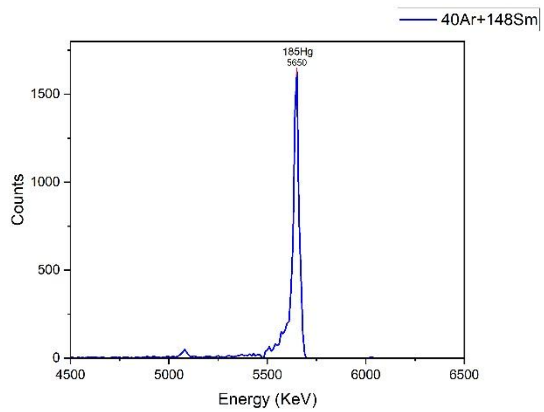

Figure 10: 185 Hg

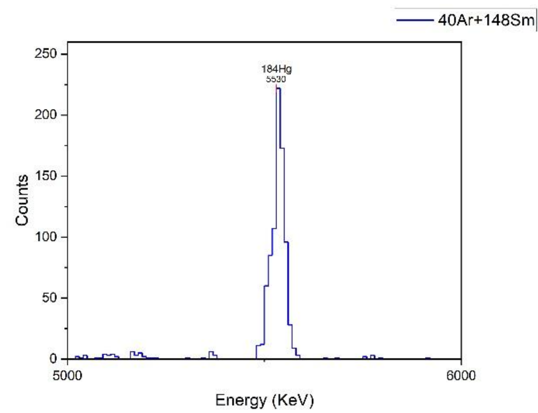

Figure 9: 184 Hg

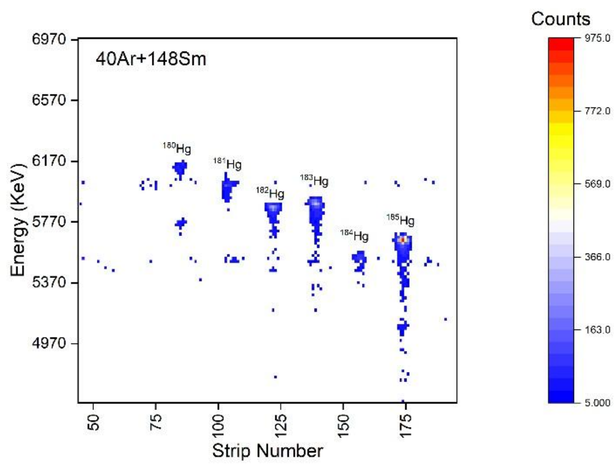

Figure 11: Hg isotopes heatmap

3.2. Second Reaction Results

$$40Ar{+}166Er{\rightarrow}(206{-}x)Rn + xn$$

In this reaction 5 isotopes of Radon were produced: 201Rn, 202Rn, 203Rn, 204Rn and 205Rn.

Table 2: 40Ar + 166Er results

Isotope	Half-life (s)	Theoretical Energy (KeV)	Measured Energy (KeV)
201Rn	7.1	6725	6760
202Rn	10.0	6639.5	6630
203Rn	28.0	6549	6550
204Rn	74.4	6418.9	6400
205Rn	170	6262	6270

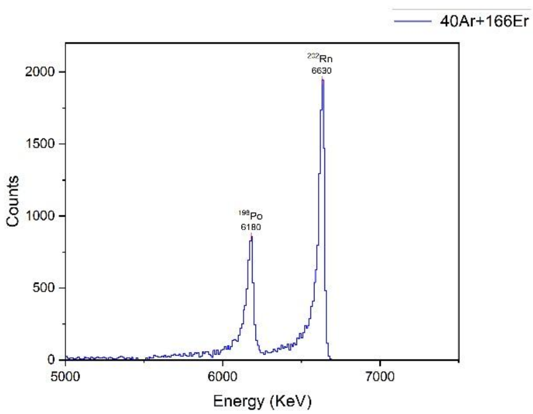

Figure 13: 202 Rn

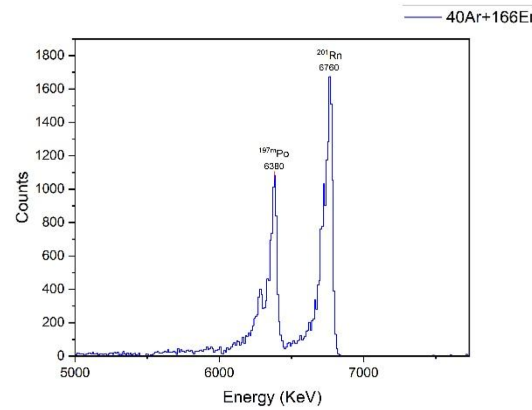

Figure 12: 201 Rn

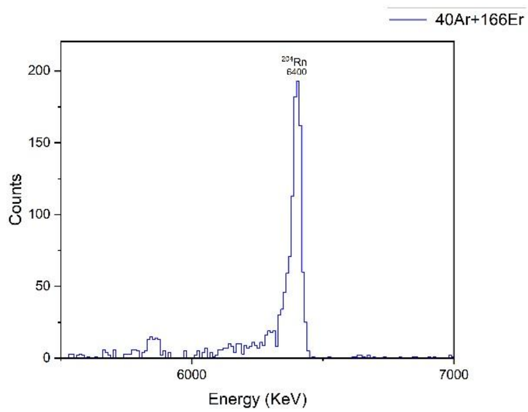

Figure 15: 204 Rn

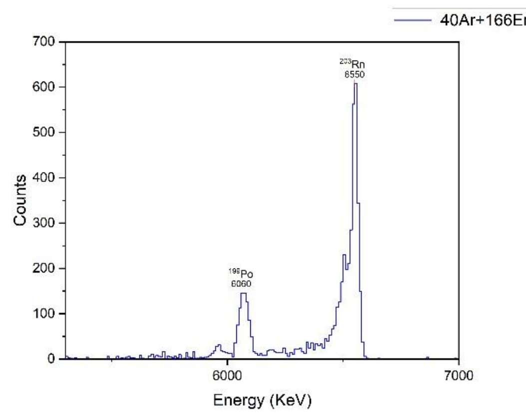

Figure 14: 203 Rn

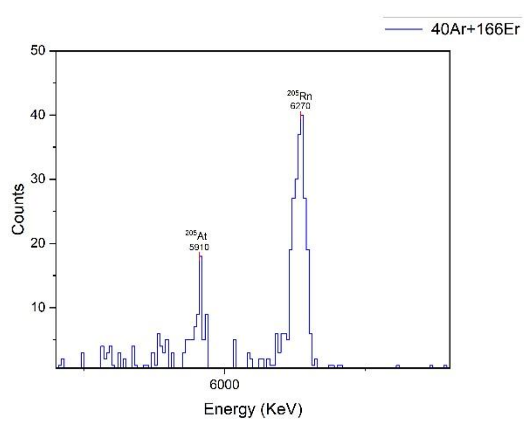

Figure 16: 205 Rn

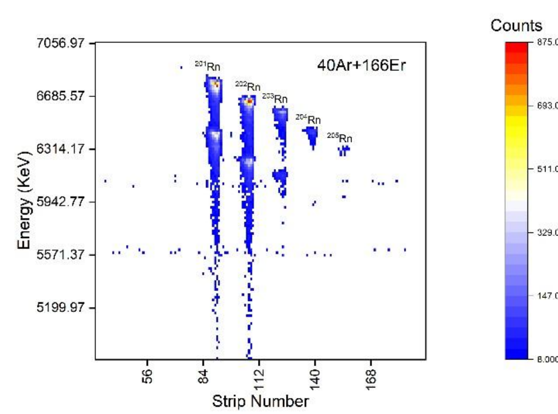

Figure 17: Rn isotopes heatmap

3.3. Third Reaction Results

$48Ca$+$242Pu$

In this reaction 3 isotopes of Radon produced which are: 212Rn, 218Rn, and 219Rn.

Table 3: 48Ca+242Pu results

Isotope	Half-life (s)	Theoretical Energy (KeV)	Measured Energy (KeV)
212Rn	1434	6264	6250
218Rn	0.00035	7129.2	7110
219Rn	3.96	6819.1	6790

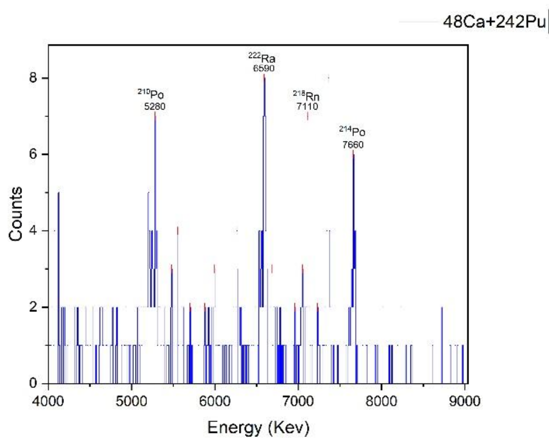

Figure 19: 218 Rn

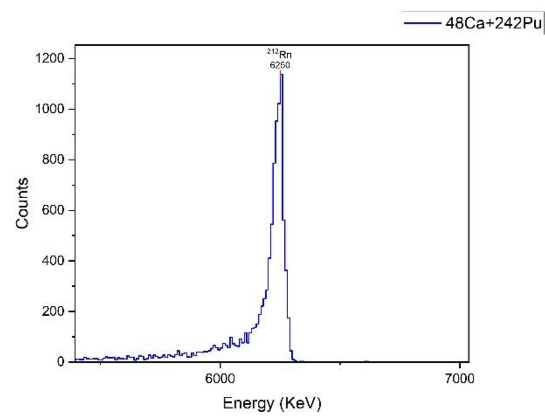

Figure 18: 212 Rn

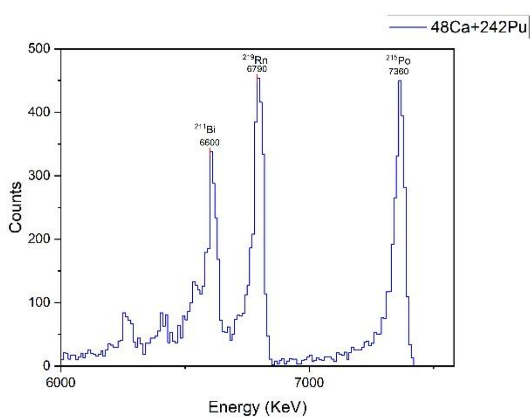

Figure 20: 219 Rn

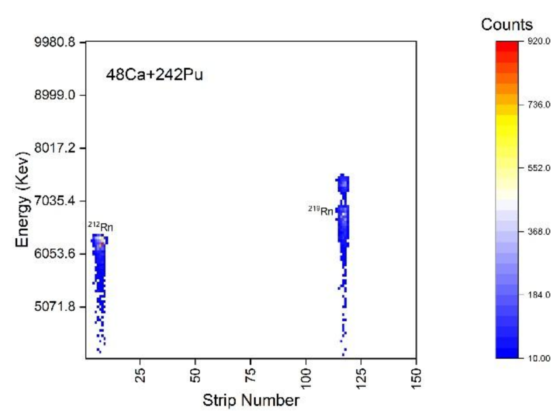

figure 21: Rn isotopes heatmap from third reaction

5. conclusion

This study success to validate the experimental data for three reactions by the comparison between the measured data analyzed using Origin Pro software and theoretical data obtained from chart of nuclides which shows reliable energy calibration. Peak analysis histograms and heatmaps were shown to give indication of alpha decay energy and isotopes production for each reaction. The 40Ar+144Sm reaction Produces mercury (Hg) isotopes, 40Ar+166Er and 48Ca+242Pu give radon (Rn) isotopes. The MASHA mass spectrometer setup was capable of detecting and separate between isotopes in these three reactions which was short half-lives.

References

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[2] A. M. Rodin *et al.*, "Features of the Solid-State ISOL Method for Fusion Evaporation Reactions Induced by Heavy Ions," *Exotic Nuclei*, pp. 437–443, Nov. 2019, doi: https://doi.org/10.1142/9789811209451_0062.

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