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

The Mass Analyzer of Super Heavy Atoms (MASHA), setup located at the Flerov Laboratory of Nuclear Reactions (FLNR) in the Joint Institute for Nuclear Research (JINR) in Dubna, Russian Federation, is a powerful mass spectrometer capable of studying superheavy elements. Using the Isotope Separation On-Line (ISOL) technique and the beamline of the Cyclotron U - 400 M, the setup was capable of reaching a resolving power of approximately 1700, allowing for the efficient separation and study of reaction products from multi-nucleon transfer and complete fusion reactions.

The reactions: $40Ar + 148Sm$, $40Ar + 166Er$, and $48Ca + 242Pu$ were experimented with and studied at the MASHA setup at FLNR for the reactions and the data was analyzed using Origin Software. The data was interpreted from the α-decay energy spectrum, showing insights about the properties of the product isotopes (mainly Mercury and Radon) of these mentioned reactions.

Table of Contents

List of figures

Introduction

The MASHA (Mass Analyzer of Super Heavy Atoms) setup has been designed as a mass-separator with a resolving power reaching 1700, which allows mass identification of superheavy nuclides. The setup uses the solid ISOL (Isotope Separation On-Line) method. This project is concerned about the analysis of data retrieved 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 experimental data of the reactions mentioned were analyzed to calculate the masses of identified isotopes (which are results of the above nuclear reactions), their half life, energy of α-decay (E_α) and their probability to decay with a specific amount of energy. A 1-D α-decay energy spectrum plot was done using Origin software and peak analysis was performed. Also, a heatmap was obtained (2-D energy-position graph) for the product isotopes of mentioned reactions.
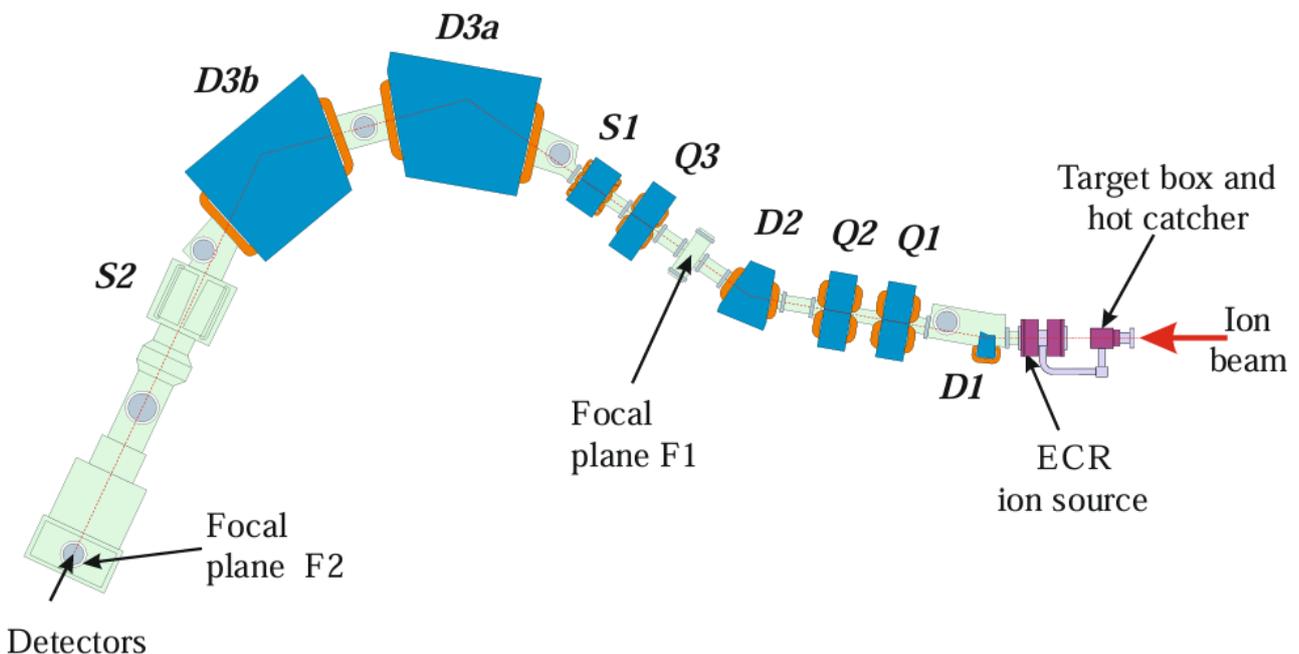
MASHA Setup Description

Figure 1: Scheme of the MASHA Setup

Ion-Optical Layout
The magneto-optical system separates the beam of ions on the basis of their mass to charge ratio. The magnetic separation of heavy nuclei is performed using four dipole magnets(D1, D2, D3a, D3b), three quadrupole lenses (Q1, Q2, Q3) and two sextupole lenses (S1, S2) as shown in fig 1 Once, the heavy nuclei gets separated they are then detected at different strips of position sensitive Si detector.

ECR Ion Source

The ECR (Electron Cyclotron Resonance) ion source with a microwave oscillation frequency of 2.45 GHz(Rodin, Belozerov, Chernysheva, et al., 2014), acts as an ionization chamber of MASHA spectrometer. It ionizes the atoms of gaseous isotopic products of nuclear reaction to a charge state Q=+1, and accelerates them to an energy of 48 KeV using three electrode system. The ionized atoms gets converted to beam and are then separated by magnetooptical system of the MASHA spectrometer.

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 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.

Target Box

The target box consists of a rotating disc divided into 6 sectors, which are sputtered with target material (or materials). The disc rotates with a frequency of 25Hz. The high energetic projectile particle ejected from U-400M cyclotron collides with the target material to induce some kind of nuclear reaction. The products of the nuclear reaction are stopped by the hot catcher.
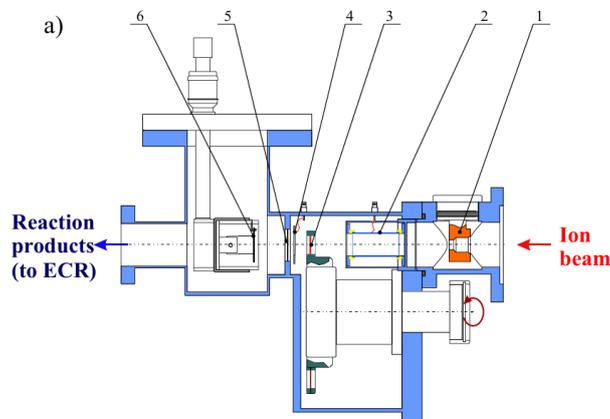
Figure 2: Schematic overview of the target-hot catcher system. Here: 1) diaphragm; 2) pick-up sensor; 3) target on the wheel; 4) electron emission beam monitor; 5) separating foil; 6) hot catcher.

Detection and Control System

There are many detectors available for detecting nuclear reaction products, such as gas filled tubes (e.g., Geiger Muller) or Scintillator detectors, as well as the most recent of these detectors, semi-conductor detectors. A well-known type of silicon semiconductor detector is used in this work, which is placed in the focal plane of the mass spectrometer. The Frontal detector component is made up of 192 strips that are perpendicular to the direction of the beam and form the detector's frontal sector. The detector is made up of side detectors divided into 16 and 64 strips.

These detectors typically have an operating bias of 40V and an energy resolution of 30keV for particles from a 226Ra source. The detector assembly is designed so that at least 90% of the particles produced by the nuclear reaction are detected in the detector's frontal section. The signals from each detector strip are read out separately. The application makes use of two types of spectra: a one-dimensional spectrum for each strip and a two-dimensional spectrum for each crystal's energy dependence on strip number
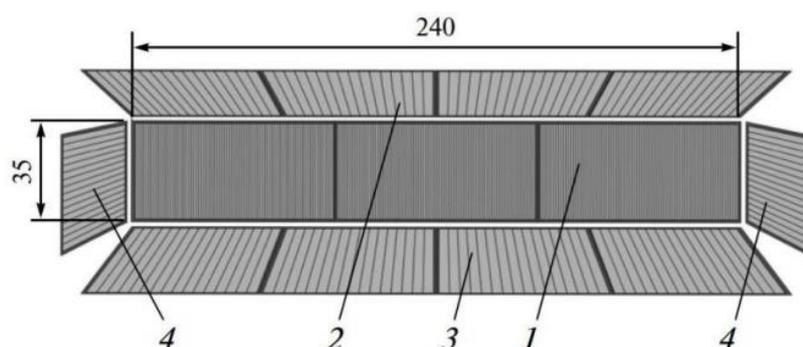
Figure 3: Positive Si Detector: (1) Frontal part (192 strips), (2) top part (64 strips), (3) bottom part (64 strips), and (4) Side Parts (16 strips in each)

Experimental Work

The U-400M cyclotron installed at FLNR, JINR is used to accelerate projectile particles in these reactions. The high energetic projectile particle enters into the MASHA setup and induce a nuclear reaction by colliding with target material sputtered in rotating disc present in target box of MASHA facility. The products of nuclear reaction are isotopes of Hg (for 40Ar + 148Sm) and Rn (for 40Ar + 166Er and 48Ca + 242 u) which are stopped by the absorber material of hot catcher.

The separated heavy nuclei undergoes α-decay to produce daughter nuclei and it's alpha particles (with different energies) given out by both parent nucleus and its daughter nuclei which are detected at unique strip numbers of position sensitive Si detector. The detector used is a hybrid pixel detector of the TIMEPIX type, with high resolution and sensitivity which can detect even a single α or β particle.

The experimental data is used to plot α-decay energy spectrum for those strips where an isotope was detected. From this spectrum peak analysis is done and calculate their α-decay energy (E_α) values. The base peak with maximum no. of α particles (with common energy) is our point of interest as it could be any one of the separated nuclei. By using the table of nuclides, the product isotopes can be determined because they undergo α-decay with energy very close to it (to data in table of nuclides). Also, the table of nuclides can also be used for getting the isotopes' masses, alpha branching ratio, and daughter nuclei.

A two-dimensional energy-position graph (called heatmap) is made for the three reactions. It gives a clear understanding that which isotope is detected at which strip number/region and corresponding to that particular isotope, how many alpha particles are detected with a common energy.

Results and Discussion

1. First Reaction Results

$$40Ar + 148Sm \rightarrow (188 - x)Hg + xn$$
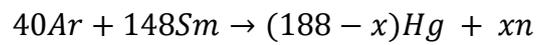
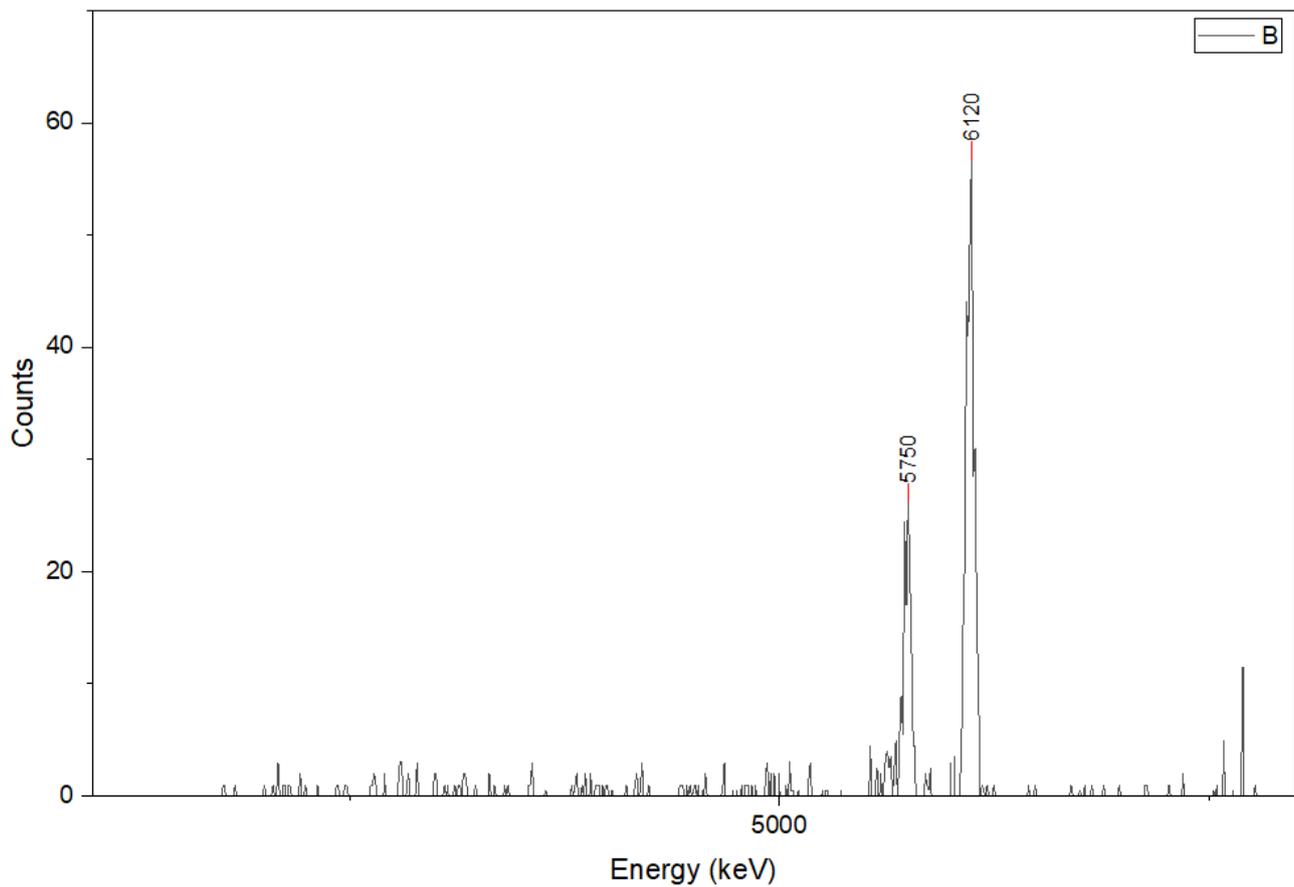This reaction leads to the production of 6 isotopes of mercury which are: 180Hg, 181Hg, 182Hg, 183Hg, 184Hg and 185Hg.
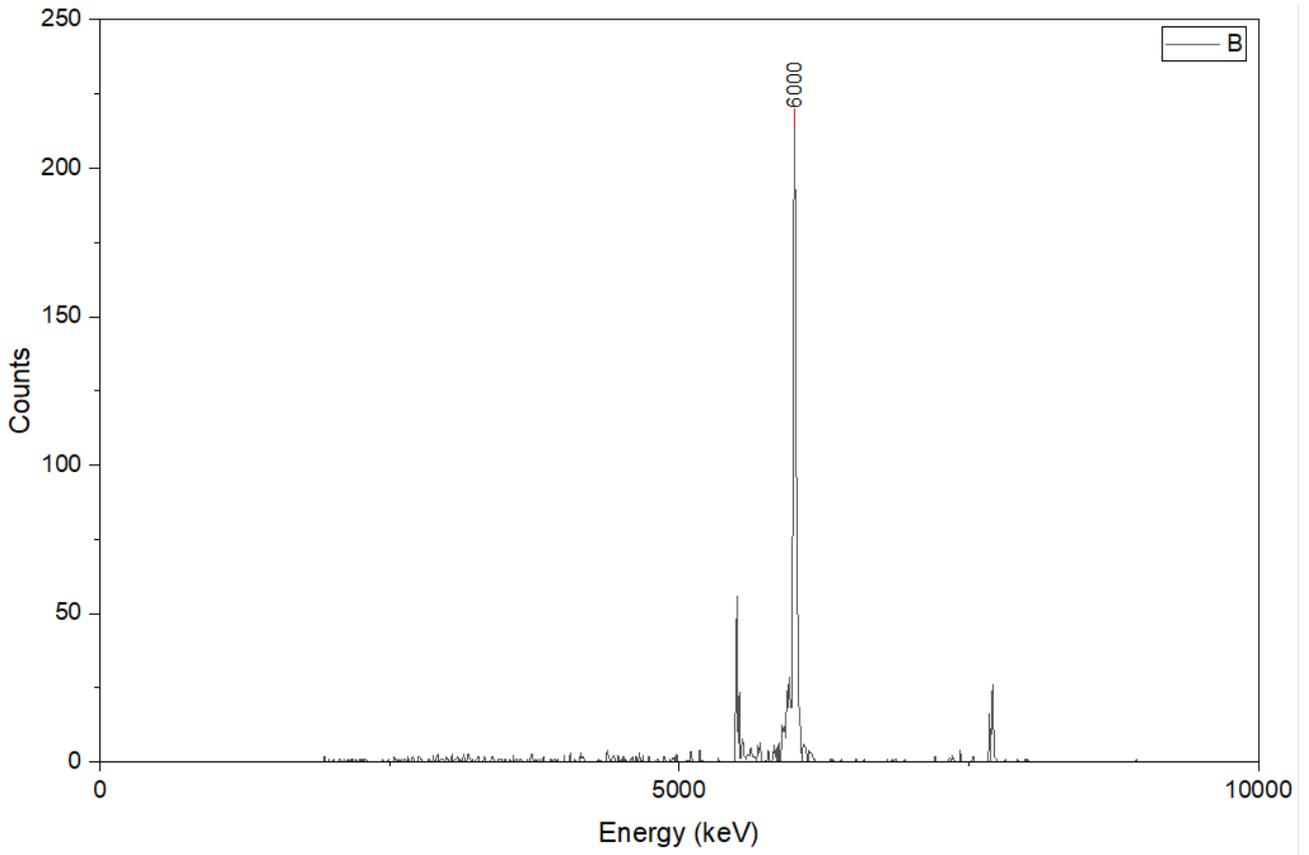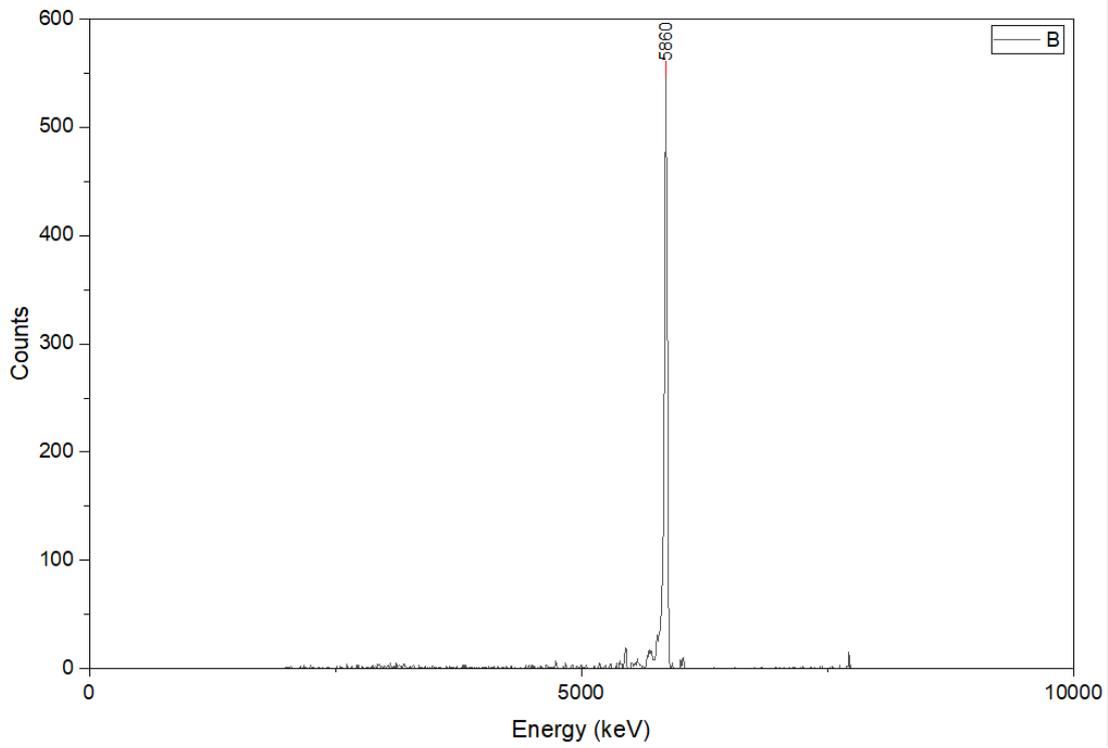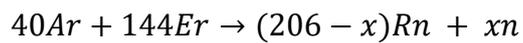

Figure 4: Hg180

Figure 5:Hg181

Figure 6: Hg182
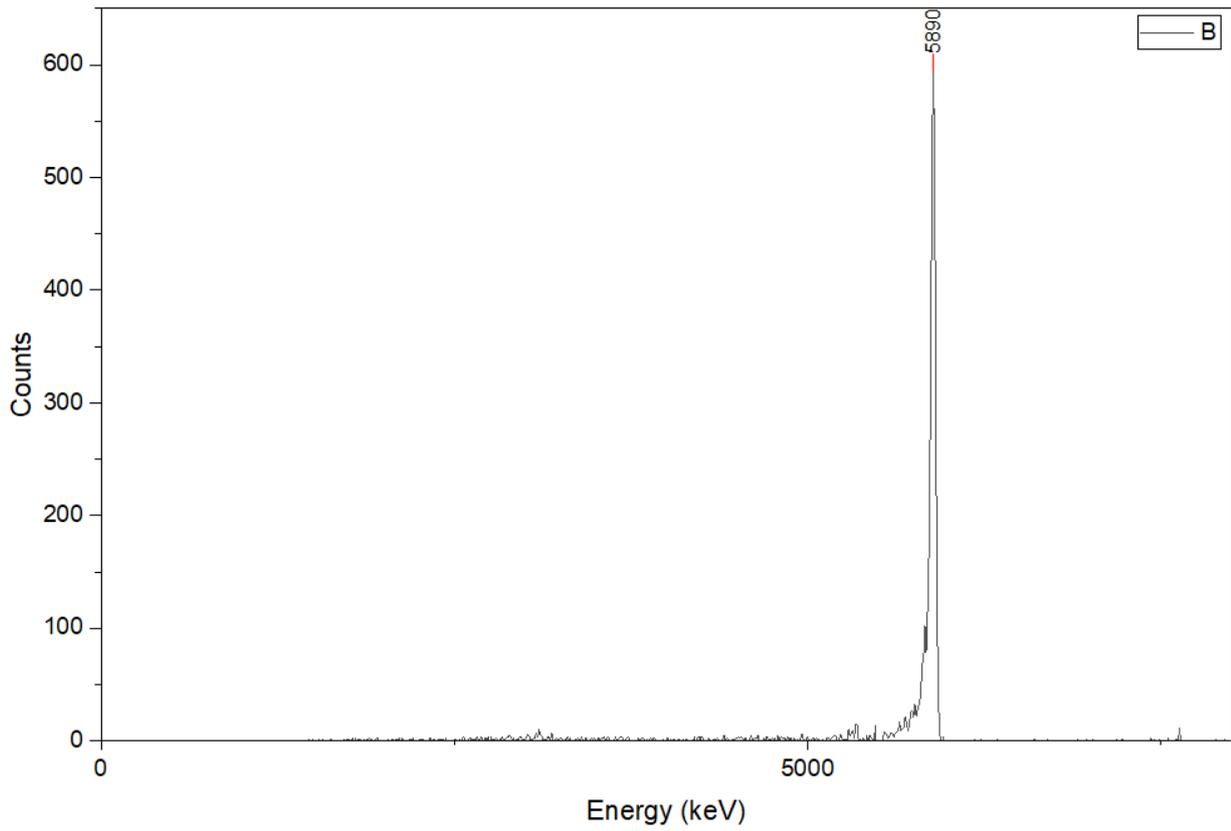
Figure 7: Hg183
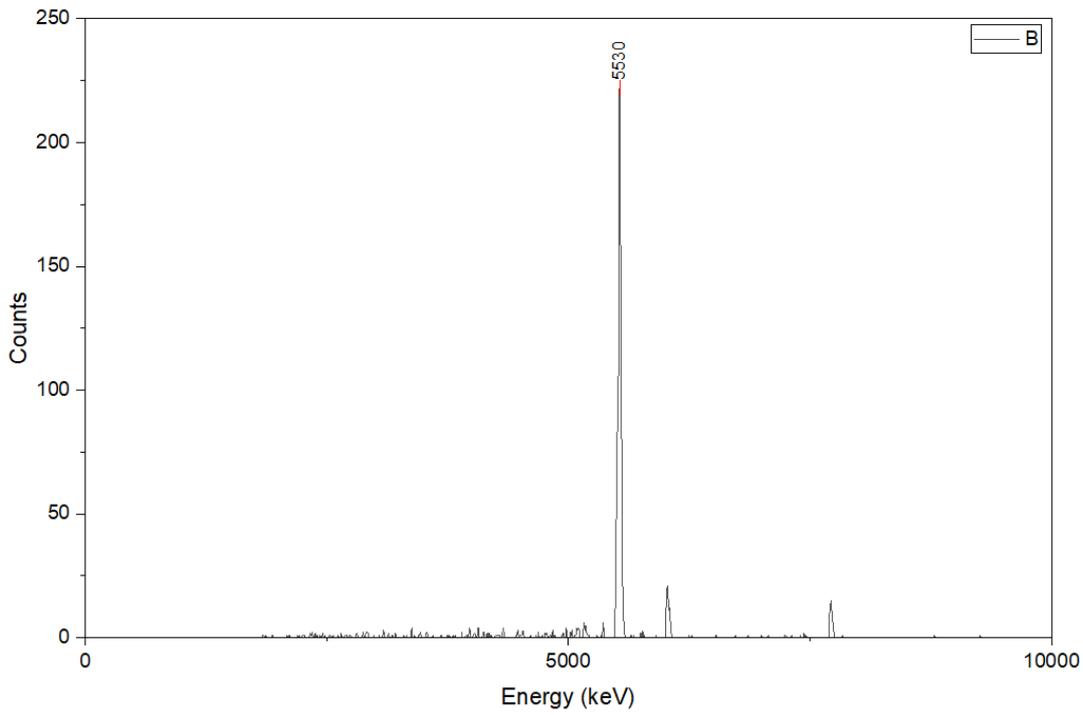
Figure 8: Hg184
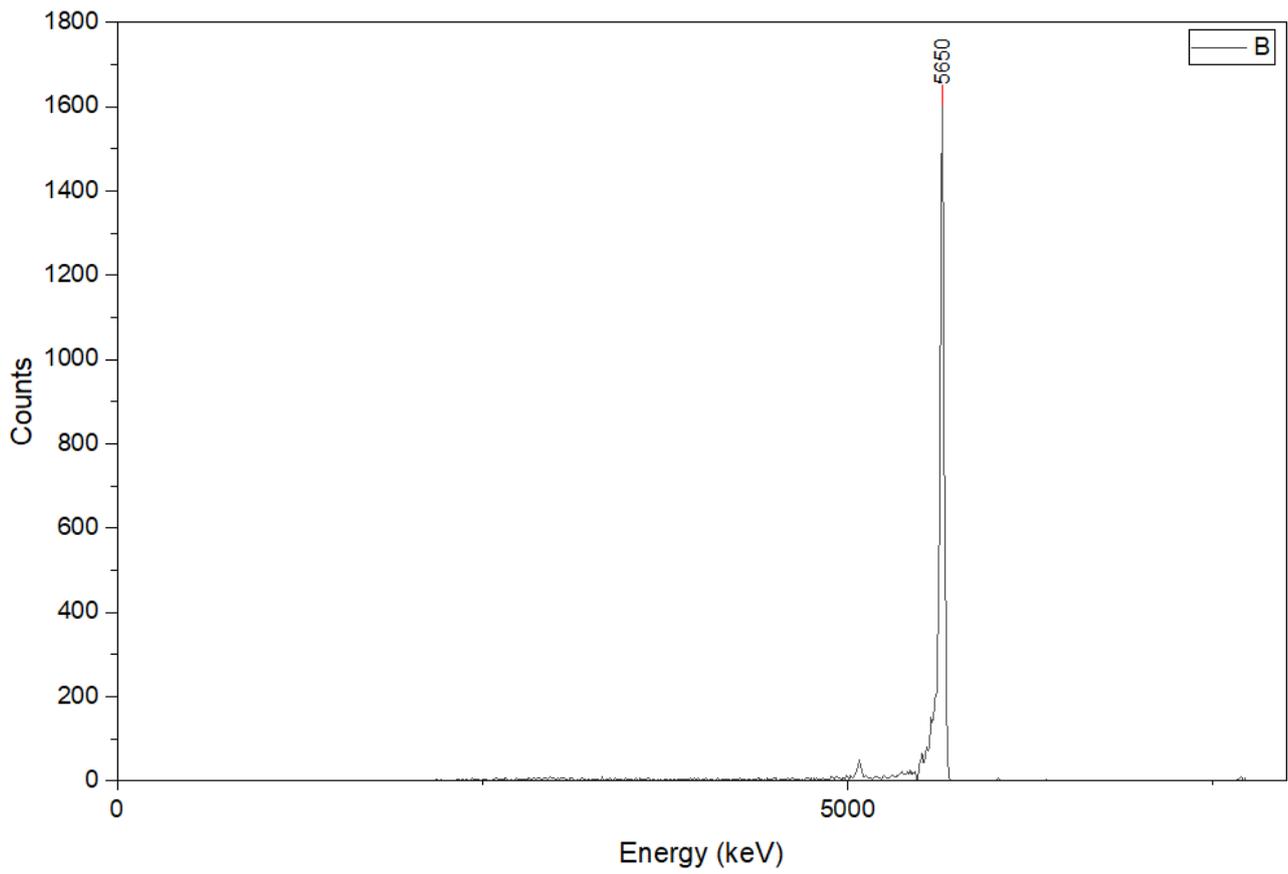
Figure 9: Hg185

2. Second Reaction Results

$$40Ar + 144Er \rightarrow (206 - x)Rn + xn$$

This reaction produces 5 isotopes of Radon: 201Rn, 202Rn, 203Rn, 204Rn and 205Rn.
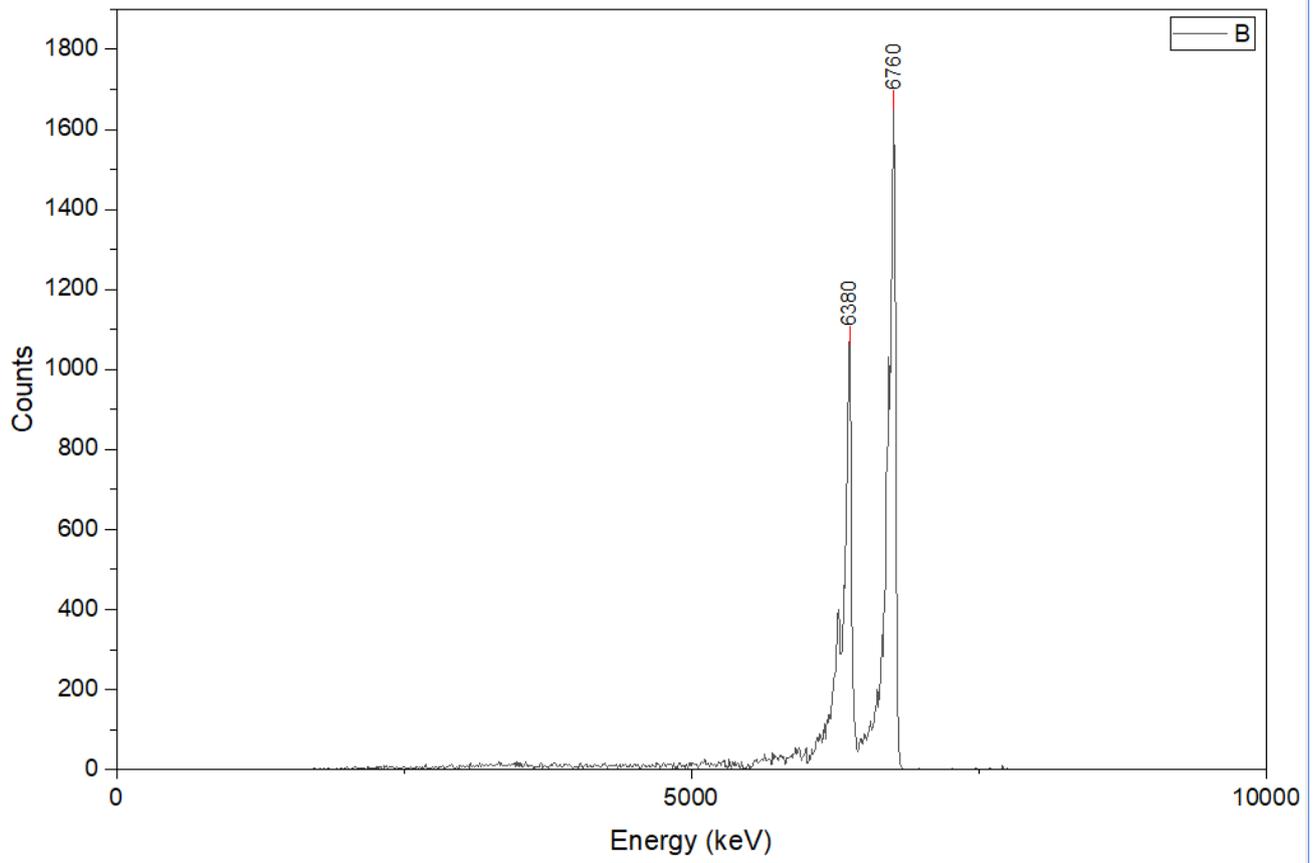
Figure 10: Rn201
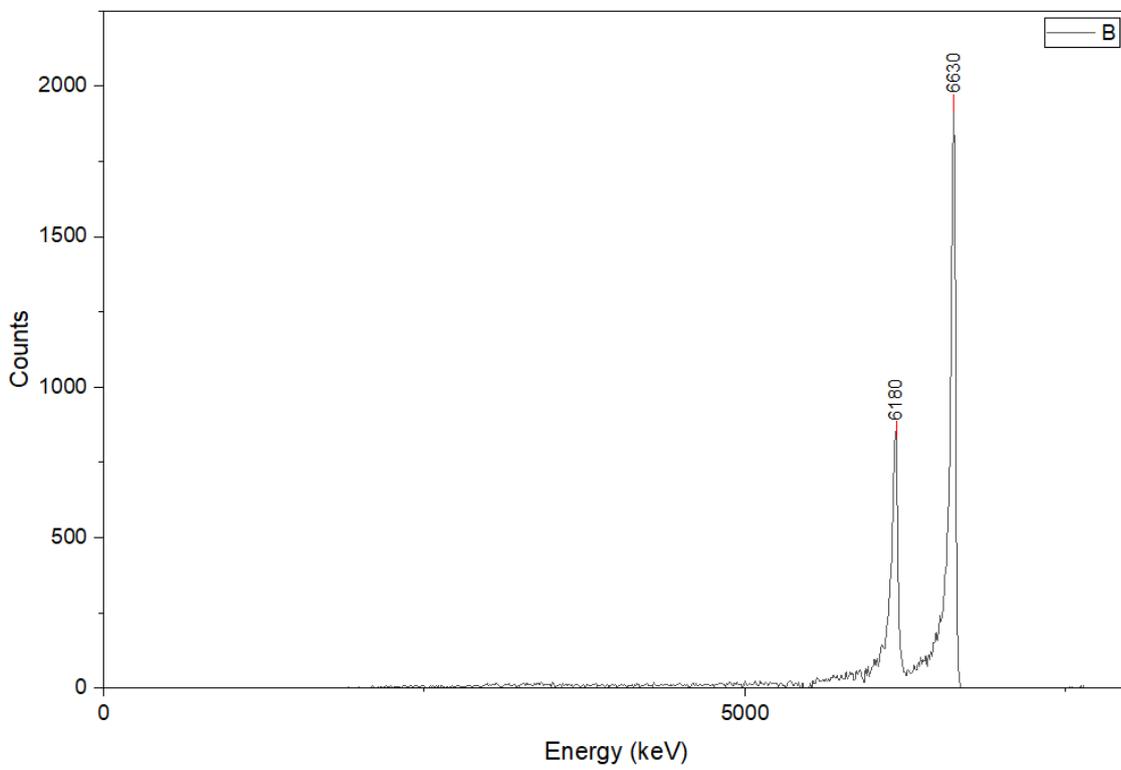
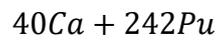*Figure 11:Rn202*
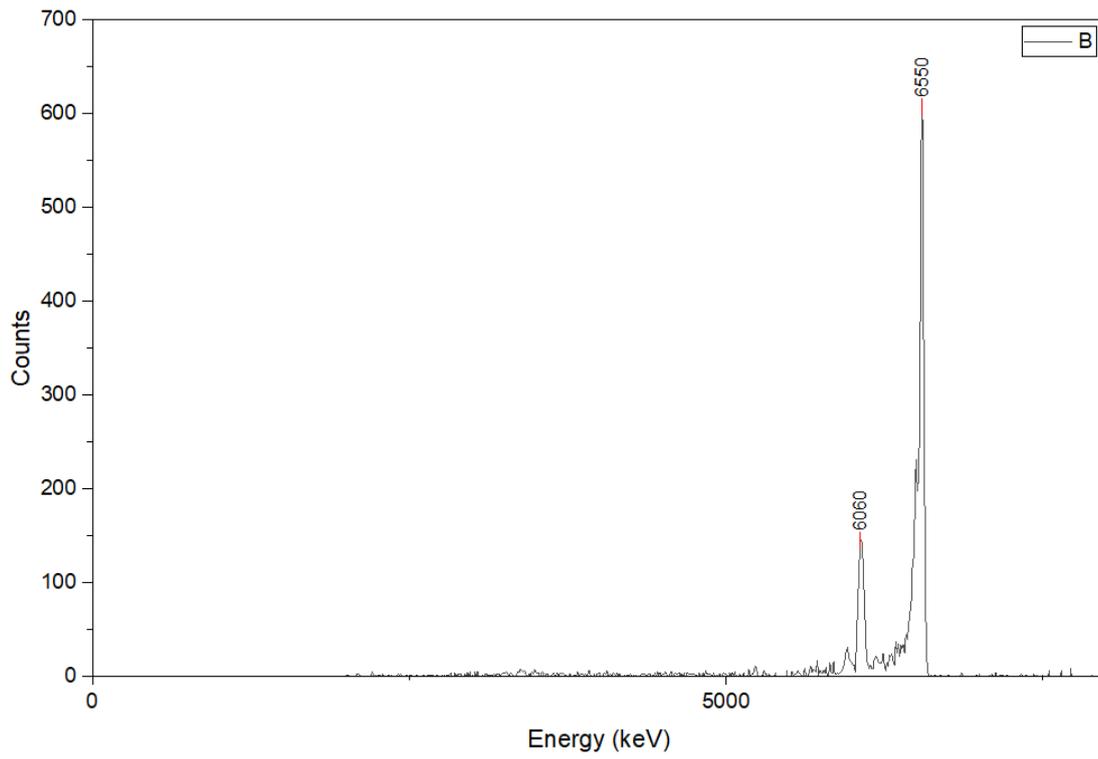
Figure 12: Rn203
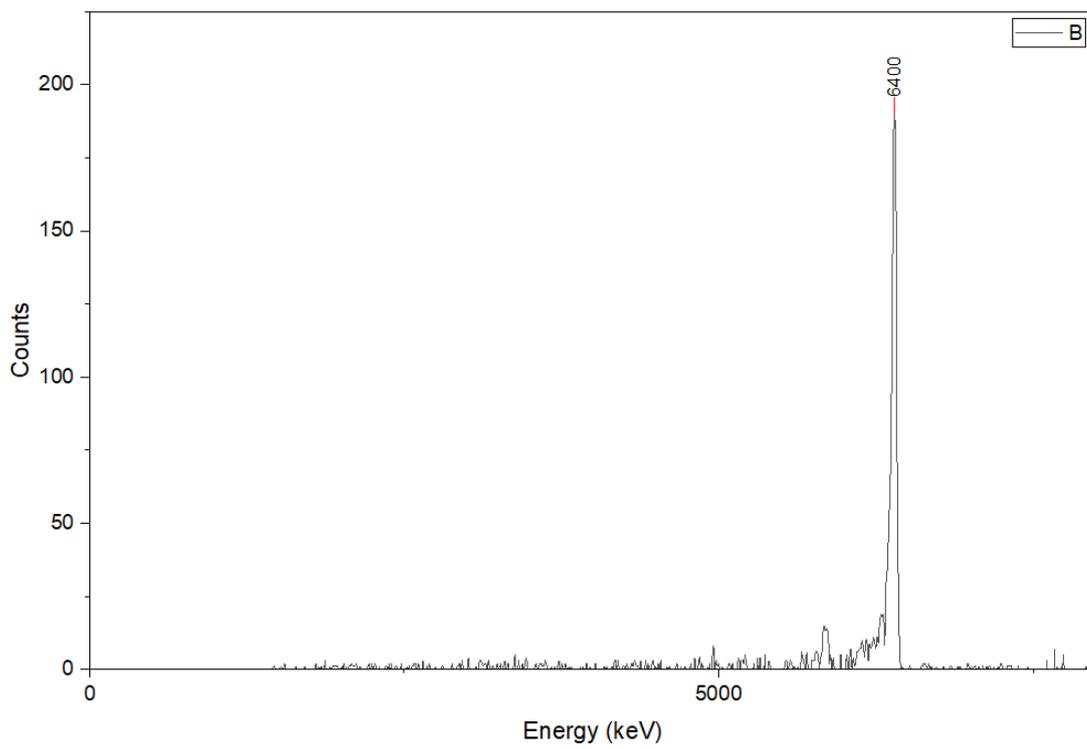
Figure 13: Rn204
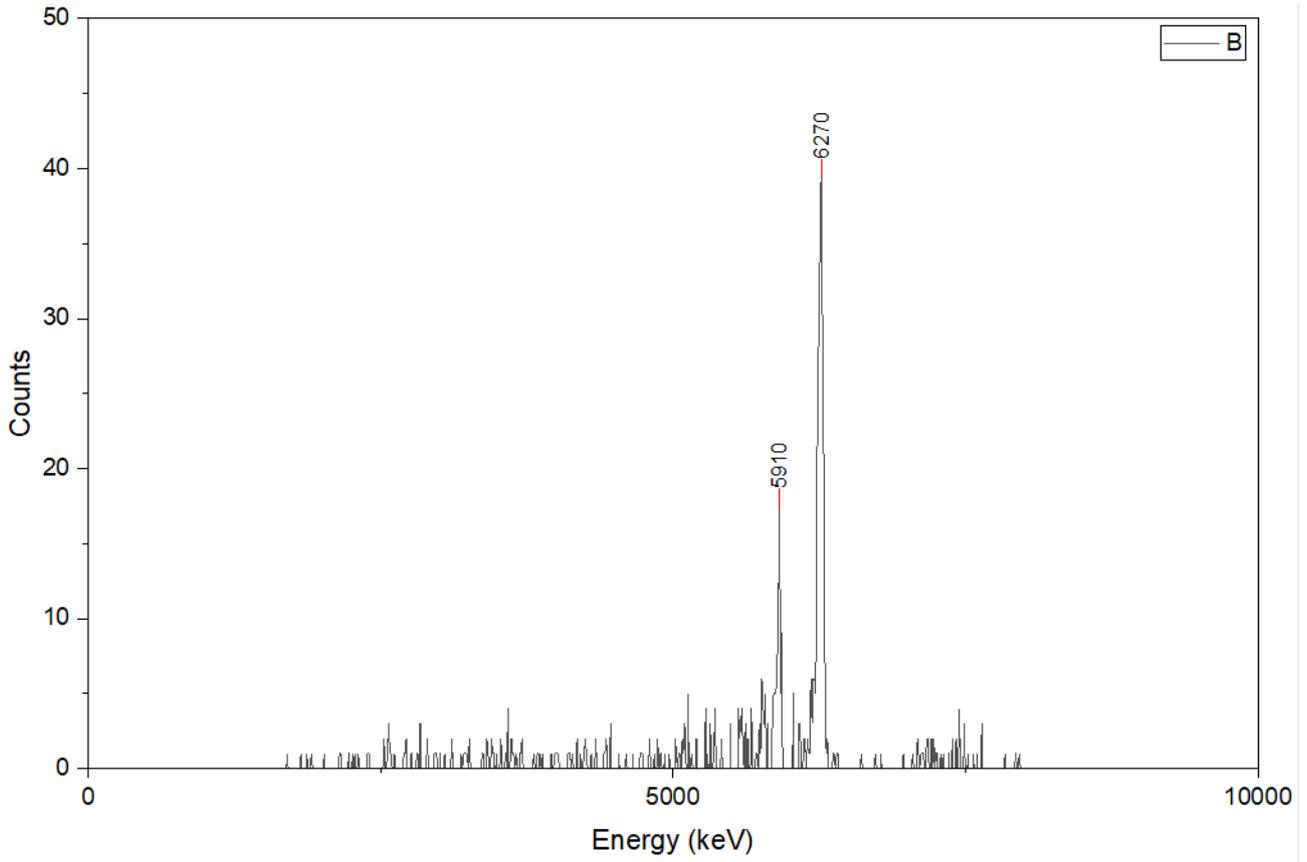
Figure 14: Rn205

3. Third Reaction Results

$$40Ca + 242Pu$$

This reaction produces 3 isotopes of Radon which are: 212Rn, 218Rn, and 219Rn.
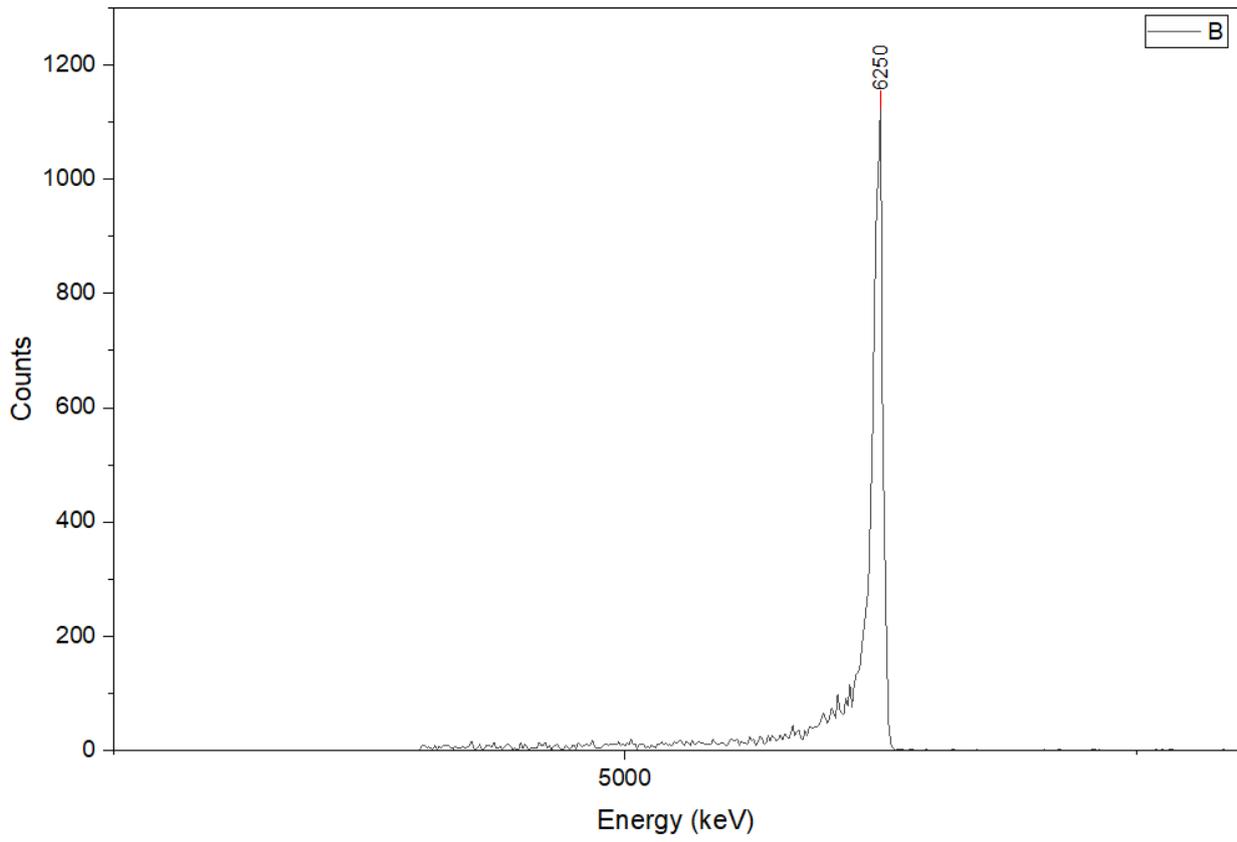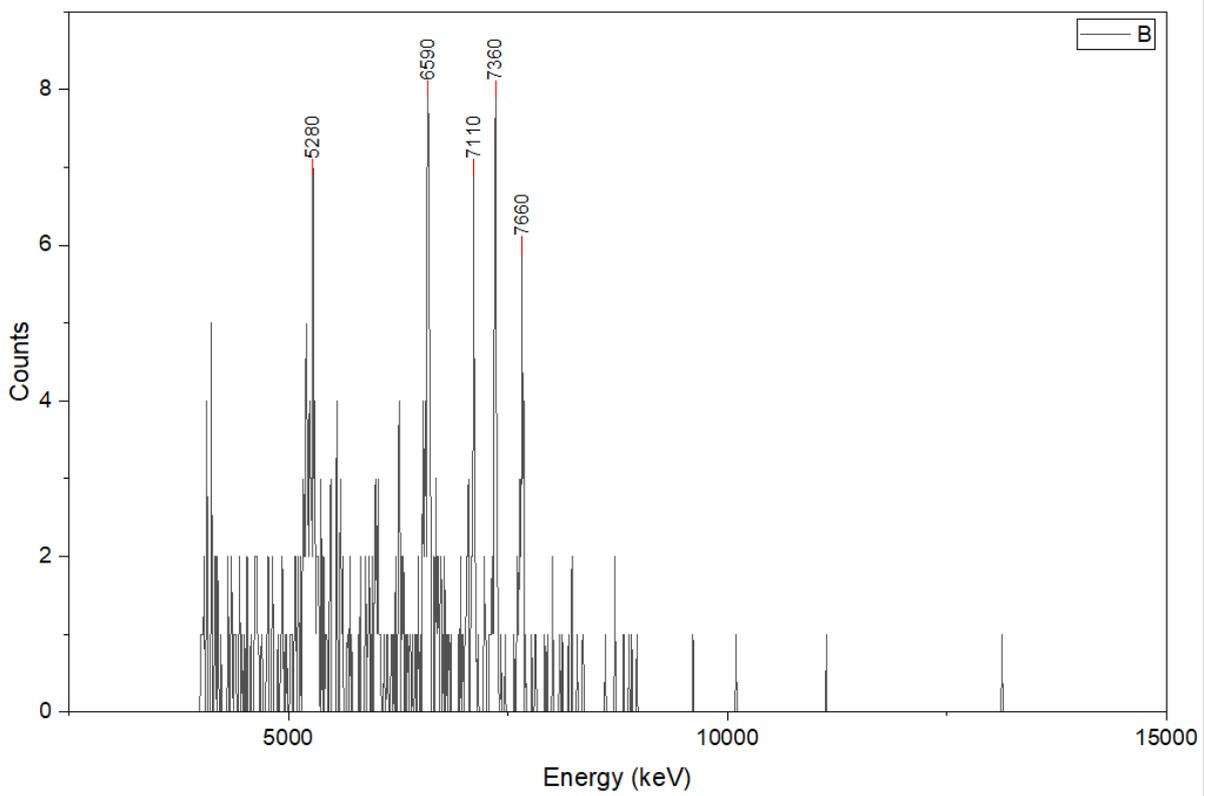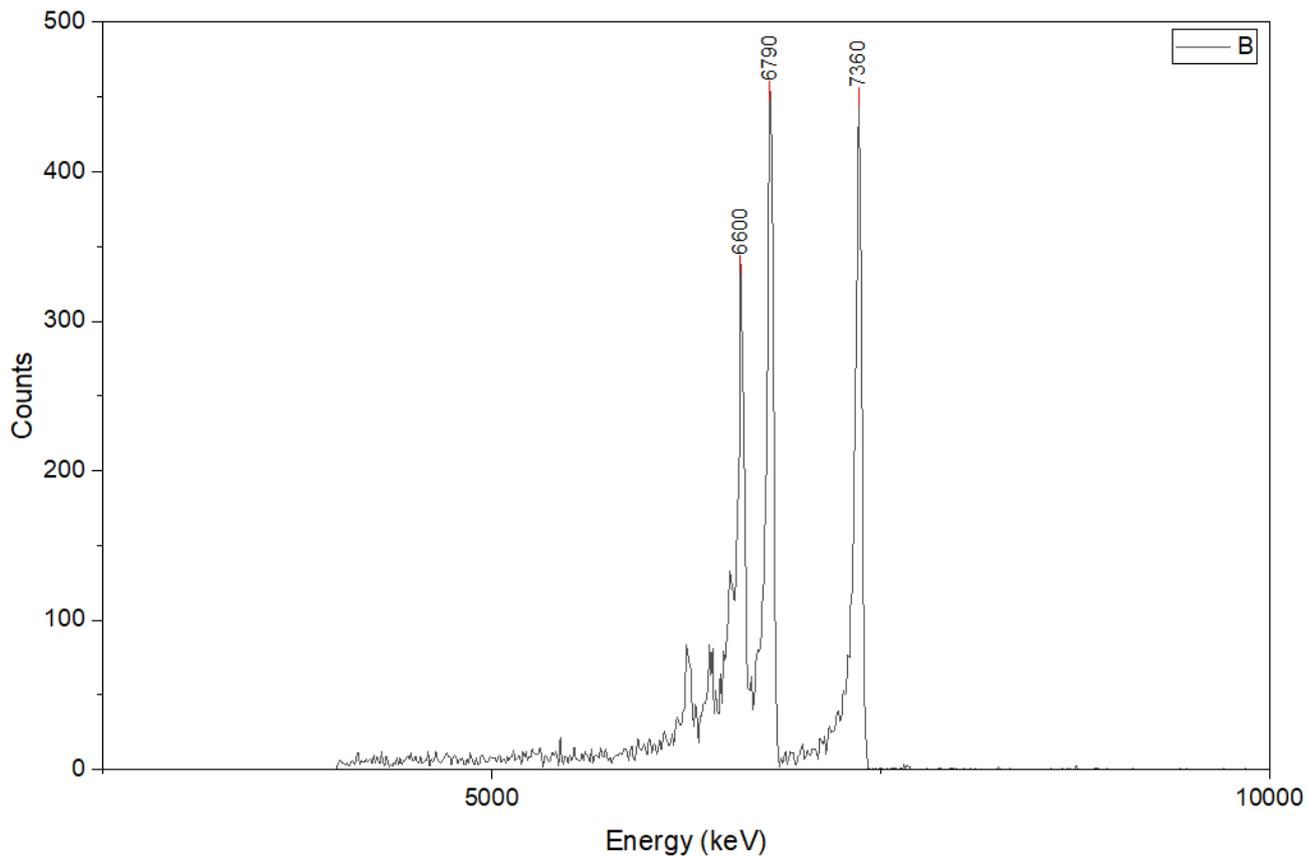
Figure 15: Rn212

Figure 16: Rn218

Figure 17: Rn219

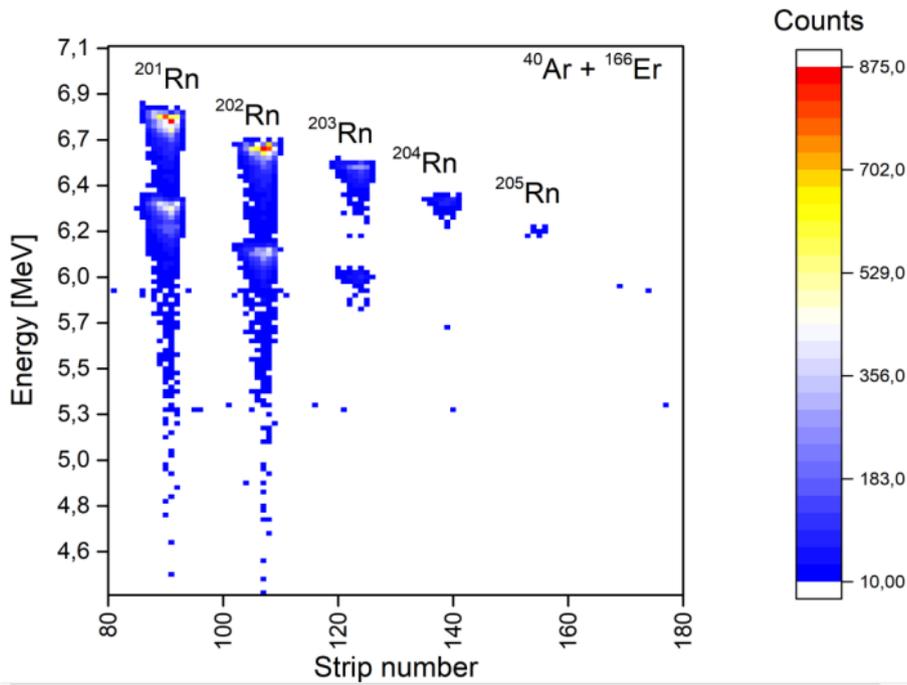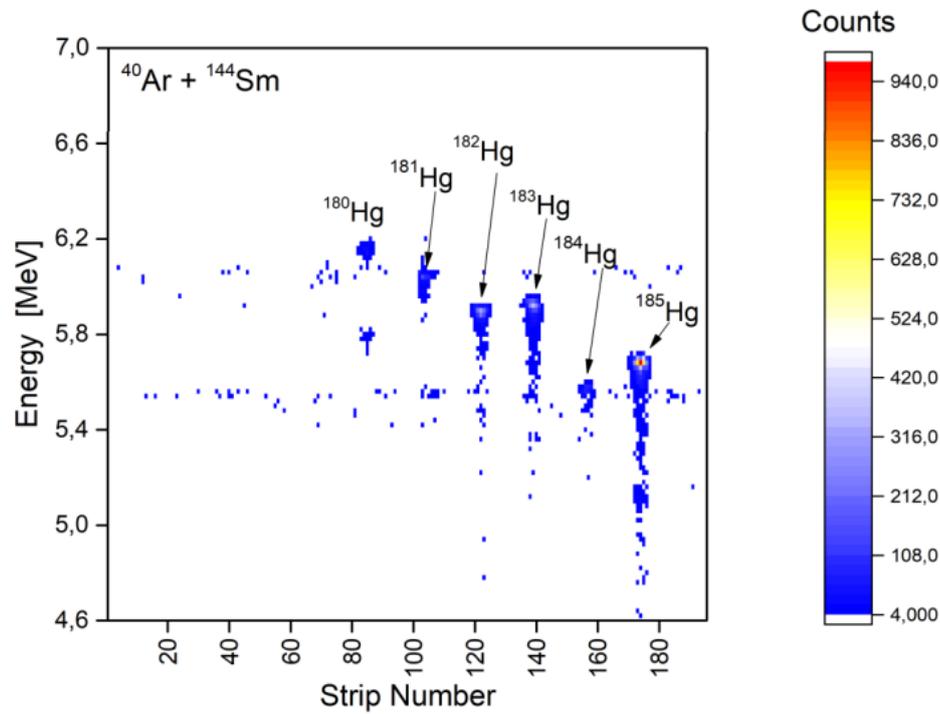# Heatmaps (respective of the mentioned order of the reactions)
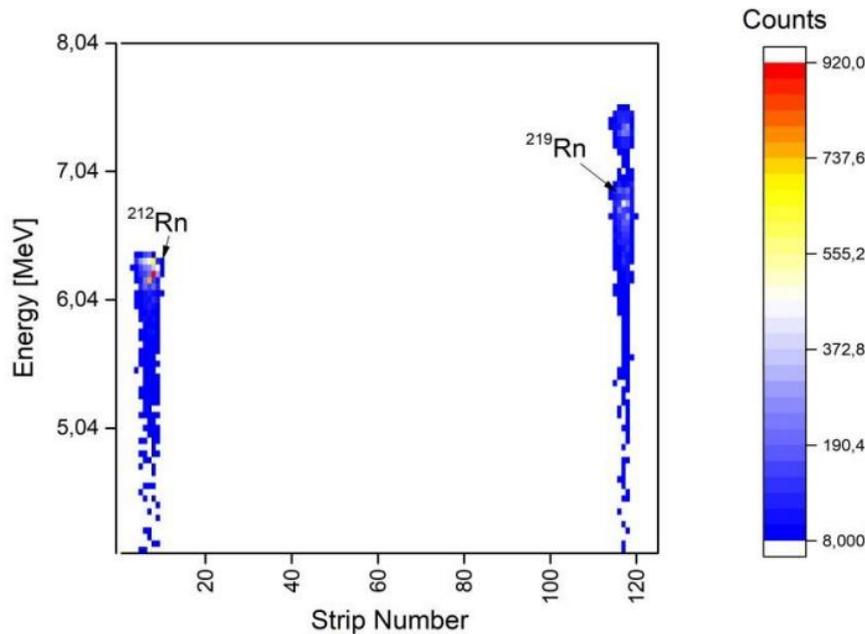

Figure 18: Heatmap 2

Figure 19: Heatmap 1

Figure 20: Heatmap 3

Conclusion

It is determined from the study of these experiments that the 40Ar+144Sm fusion reaction is sufficiently producing mercury isotopes, and the MASHA mass spectrometer setup was capable of detecting the masses and energies of the alpha-particles emitted by the residual products of this reaction. Also, the 40Ar+166Er has shown good separation efficiency of radon isotopes. The analysis of the alpha particle energy spectrum has assured the accuracy of measurements, consistently with tabulated parameters and a Full Width at Half Maximum (FWHM) within the expected range.

The production of Rn isotopes through the multinucleon transfer reaction 48Ca+242Pu has shown correlation between the separation efficiency of 212Rn-219Rn isotopes and their half-lives. The separation and detection of isotopes 212Rn and 219Rn was the most efficient due to their relatively high cross sections and half-lives.

Acknowledgements

References

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