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Flerov Laboratory of Nuclear Reactions

Interest programme - Wave 5

Optimization of the solid ISOL method for volatile reaction products of heavy ion beam reactions

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Abstract

During the last decades the discovery of *Super Heavy Elements* (SHE) with atomic number Z=113-118 was a major breakthrough of the scientific community. For the identification and research of those new nuclides the *Isotope Separator On-Line* (ISOL) method was developed and applied successfully. At FLNR, the *Mass Analyzer of Super Heavy Atoms* (MASHA) was deployed in order to measure accurately on-line the mass-to-charge ratio of the SHE isotopes and their respective α-decay. In this paper construction, working method and possible upgrades of the MASHA setup are discussed. Furthermore, alpha decay energies of different isotopes of Hg, Rn which are produced from heavy ion fusion evaporation reactions are examined thoroughly. Finally, one dimensional histograms and heatmaps have been created by modelling data from the experiments done in FLNR,JINR.

Contents

1 Introduction

After the first artificial synthesis of transuranium element *Neptunium* (Np) in 1940, scientists started to look for new superheavy elements and a new era began for nuclear physics. A pioneer for the development of SHE elements was JINR at Dubna Russia. U-400 and U-400M are two of the most used cyclotrons that are responsible to create SHEs by complete fusion of double magic nucleus (^{40}Ca and ^{48}Ca) with neutron rich nuclei (^{238}U,^{237}Np,^{242}Pu etc.). In the following chapters MASHA setup will be explained and ISOL method will be analyzed. The alpha decay energy peaks of Hg and Rn isotopes will be presented through diagrams.

2 Mass Analyzer for Super Heavy Atoms

MASHA setup is located at the beamline of U-400M cyclotron and uses the ISOL method in order to identify the synthesized isotopes. The incoming atom projectiles from cyclotron (^{40}Ca and ^{48}Ca) are forwarded to the absorber (placed after the target) with an energy of 5-7 MeV/nucleon. The absorber is made of graphite, a porous (75%) poly-graphene structured material. Moving on, the products are inserted in the ECR ion source where are being ionized and then transferred to the mass separator where the short-lived isotopes decays will be detected in the focal plane. The mass separator consists of dipole magnets, quadruple lenses and sextuple lenses (D,Q and S respectively in Figure 1).

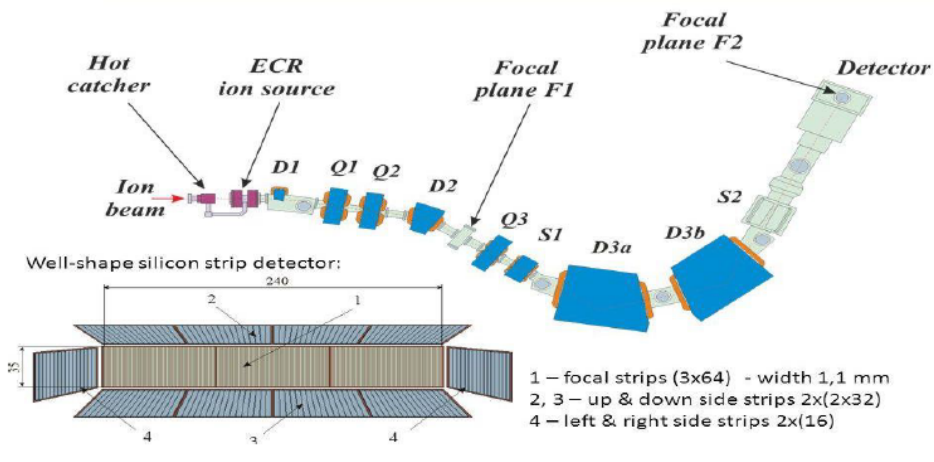

Figure 1: Mass Analyzer of Super Heavy Atoms (MASHA)

2.1 Components

2.1.1 Target assembly and Hot catcher

The Hot catcher as it's shown in figure 2 is used as a diagnostic system before the products of the cyclotron enter the ECR ion source. Prior to hitting the target, the beam of heavy ions passes through a split type aperture of electrostatic induction sensor and a Faraday cup. The rotating split aperture is divided into four sectors and each one measures the fraction of the beam current that does not fall into the hole of the aperture. Those nuclear reaction products escape from the target, pass through the separating foil (doesn't 't allow reaction products to go backwards) and finally are stopped in the graphite absorber, which is heated to 1800-2000 K. The atoms are then diffused from the graphite absorber to the hot catcher and afterwards reach the ECR source. The graphite stopper is being thermally calibrated through a sapphire window with an infrared thermometer in order to achieve maximum heat/beam current.

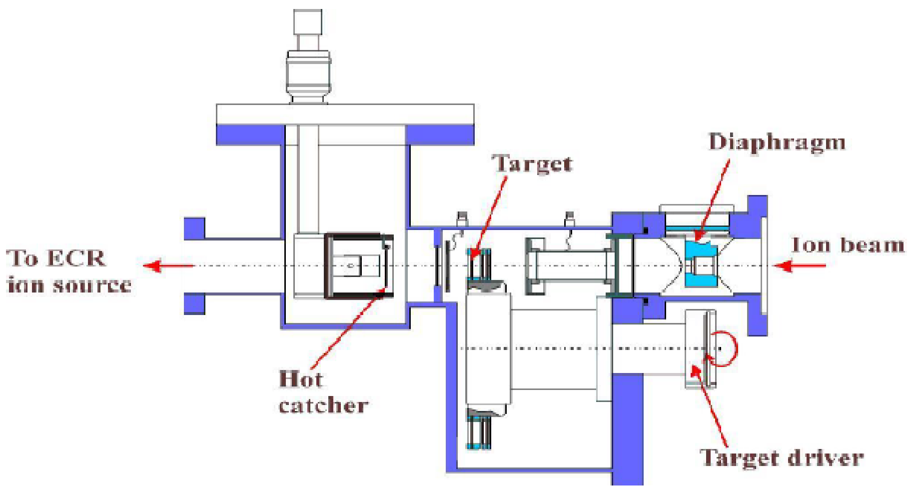

Figure 2: Target assembly and Hot catcher

2.1.2 Ion source

In order to ionize the incoming atoms, the ECR source is used at 2.45 GHz as a microwave oscillator. The atoms are ionized to charge state $Q = +1$ and are accelerated as a beam with the help of an electrode system. For the next step the beam of nucleus will be separated at the magnetic-optical system of the mass spectrometer. The ECR source uses an ionization chamber which is filled with buffered gas (Helium). ECR source is capable of producing almost fully single ionized atoms and its pressure is regulated through a piezoelectric valve. By setting the pressure of Helium at $(1-2)10^{-5}$ mbar the ECR provides 30 W of power (38 keV ion beam).

2.1.3 Detectors and Control System

It utilizes a strip detector with a pitch of 1.25 mm and a total of 192 focal strips and 160 backside strips to estimate low direct current. This detector is controlling the operator mode of the ECR source which was describes before. The control system uses multichannel (64 channels, 60pA-5μA) electronic modules to collect information from the beam and forward it to a computer. Through the use of a Silicon sensor (300μm width), in the focal plane of the mass spectrometer, this setup can recognize the decay of the products of nuclear reactions with a total efficiency no less than 90%.

3 ISOL Method

Isotope Separation On-Line method is used to remove reaction products (SHEs) from the incident beam from heavy ion induced fusion evaporation reactions. The low energy ion beam is separated by using buffer gas (Helium). The Super Heavy Isotopes are then studied. This method is capable of producing a range of pure radioisotopes. The process is the following:

1. Target material is irradiated with high energy protons.
2. The target is heated to extract the isotopes.
3. The isotopes are being selectively ionized in the ion source.
4. The produced ion beam passes through a mass separator using magnetic fields.
5. The finalized ion beam is collected in a metallic material (foil).
6. The radioisotopes can be extracted using radiochemical purification (charged state breeding).

However, it should be noted that in practice it is quite difficult to have a pure ion beam because there will always be some contamination from isobars of different elements.

4 Experiment Results

In this chapter isotopes of Hg are produced through fusion reaction

$$^{40}Ar +^{148} Sm \rightarrow^{188-xn} Hg + xn.$$

Rn isotopes are produced through fusion reaction

$$^{40}Ar +^{166} Er \rightarrow^{206-xn} Rn + xn$$

and fusion evaporation reaction

$$^{48}Ca +^{242} Pu \rightarrow^{21x} Rn.$$

Alpha decays of the above isotopes are presented below. Decay energies are then analyzed in histograms and the experimental values are being compared to the theoretical expected values. In some charts the decay energy of the daughter nuclei is also observed. The last figure for each reaction resembles the heat map which is created by the silicon sensor after calibration with the respective energies from the histograms and chart of nuclides.

$$^{40}\boldsymbol{Ar} +^{148}\boldsymbol{Sm} \rightarrow^{188-xn}\boldsymbol{Hg} + \boldsymbol{xn}$$

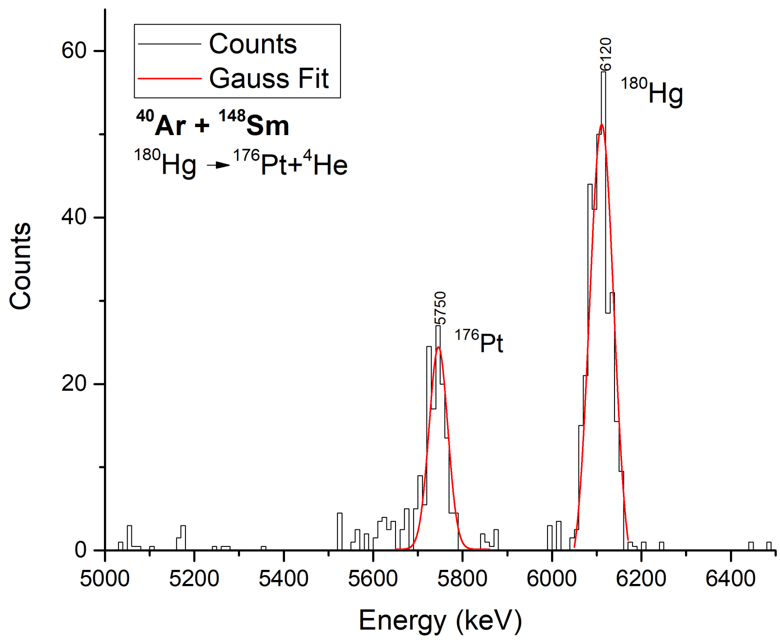

Figure 3: ^{180}Hg [2.58 s] decays with alpha energy 6120 keV [theor. 6119 keV - 99,9%].

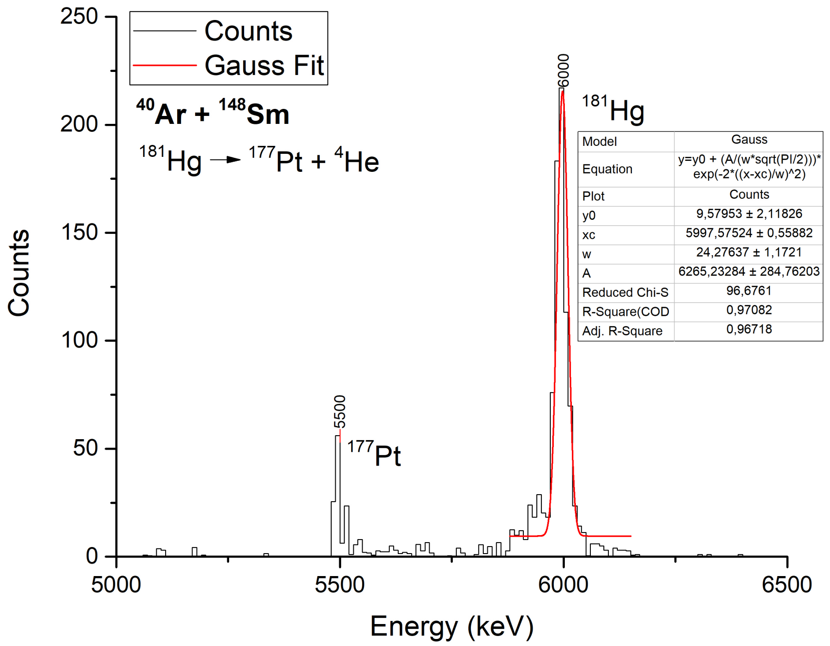

Figure 4: ^{181}Hg [3.54 s] decays with α-energy 6000 keV [theor. 6006 keV - 87%].

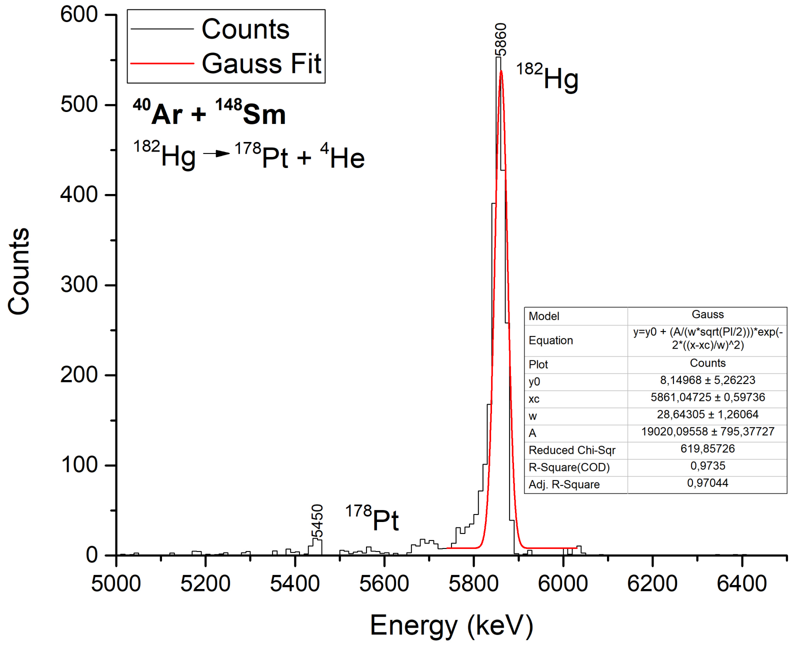

Figure 5: ^{182}Hg [10.83 s] decays with α-energy 5860 keV [theor. 5867 keV - 99%].

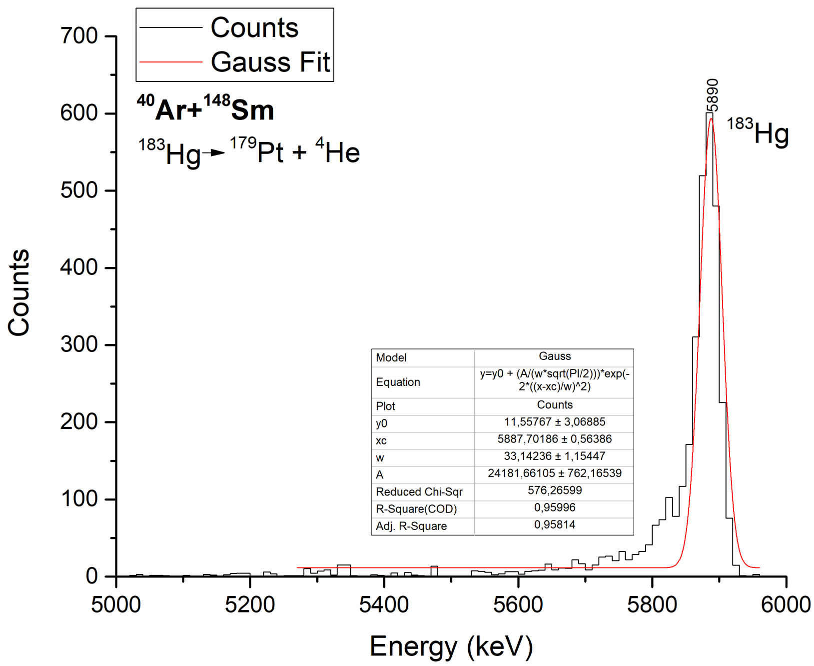

Figure 6: ^{183}Hg [9.4 s] decays with α-energy 5890 keV [theor. 5904 keV - 91%].

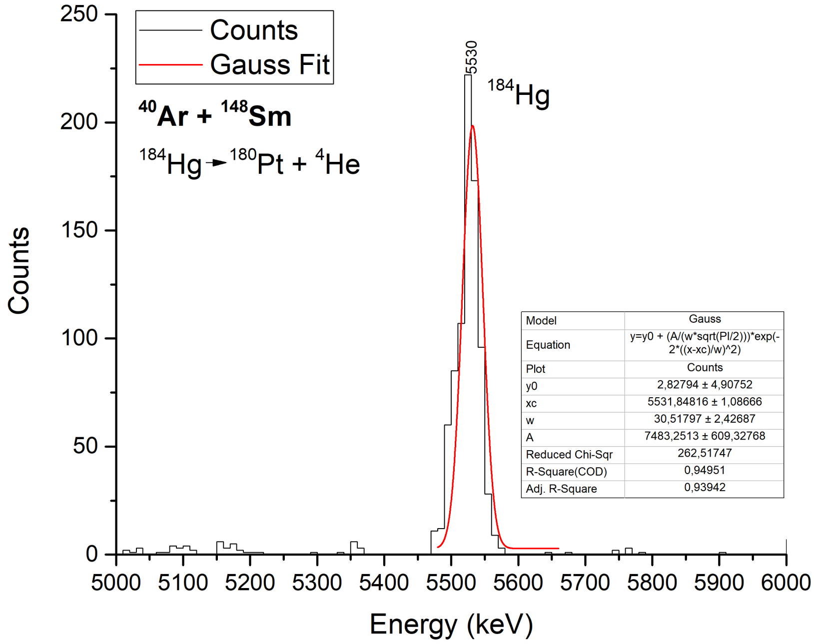

Figure 7: ^{184}Hg [30.9 s] decays with α-energy 5530 keV [theor. 5535 keV - 99.4%].

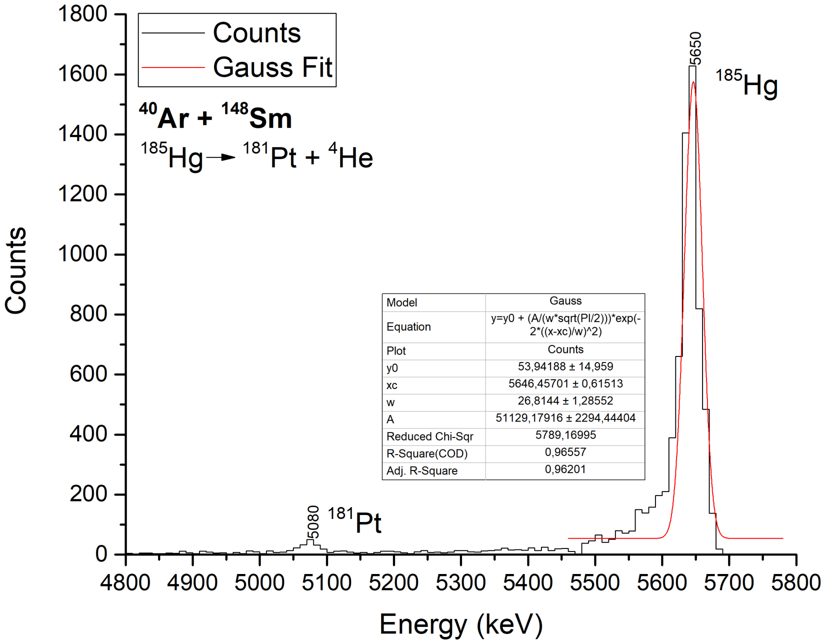

Figure 8: ^{185}Hg [49.1 s] decays with α-energy 5650 keV [theor. 5653 keV - 96%].

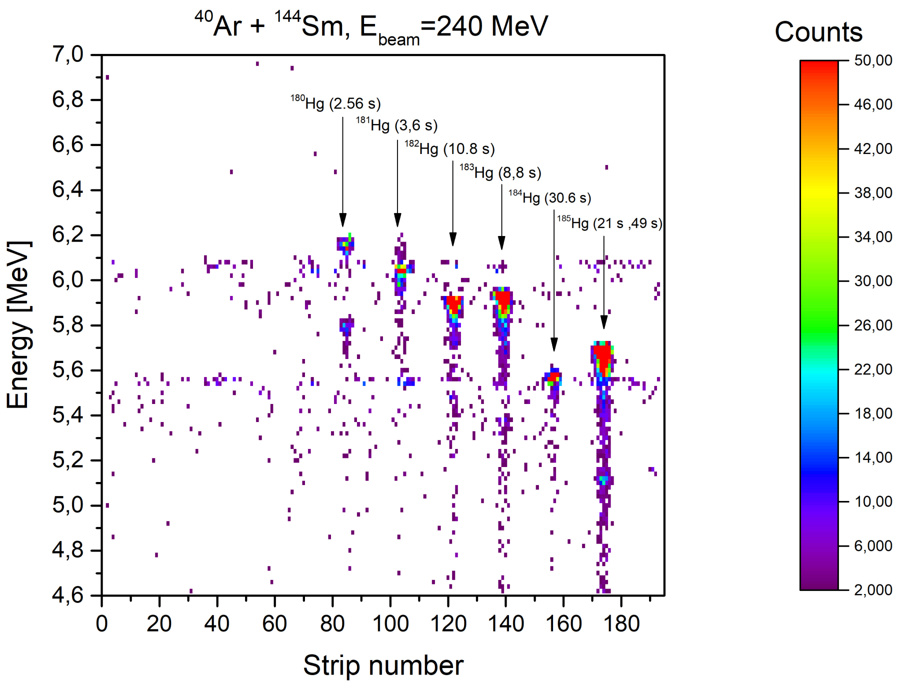

Figure 9: Heat map of Counts, $E_{\alpha-decay}$ and Strip number.

$$^{40}Ar +^{166}Er \rightarrow^{206-xn} Rn + xn$$

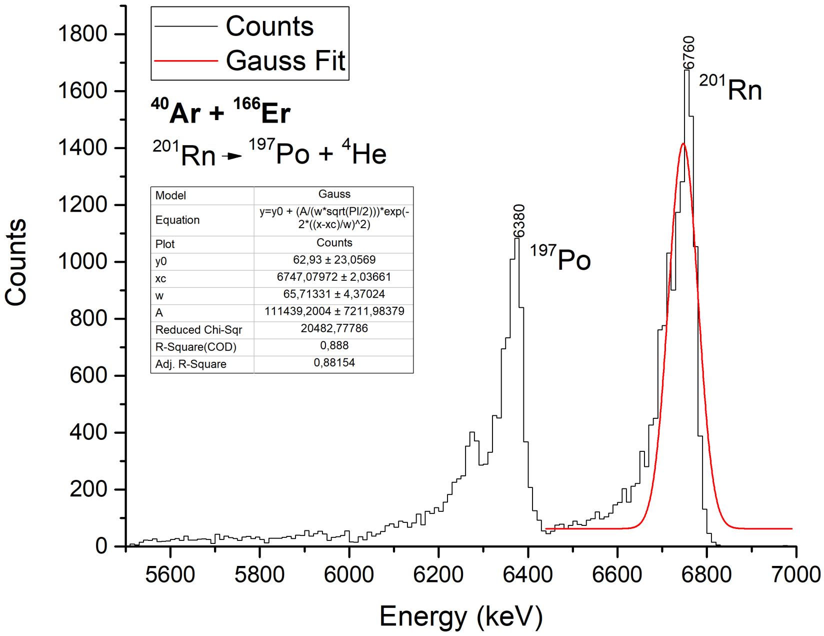

Figure 10: ^{201}Rn [7.1 s] decays with α-energy 6760 keV [theor. 6725 keV]

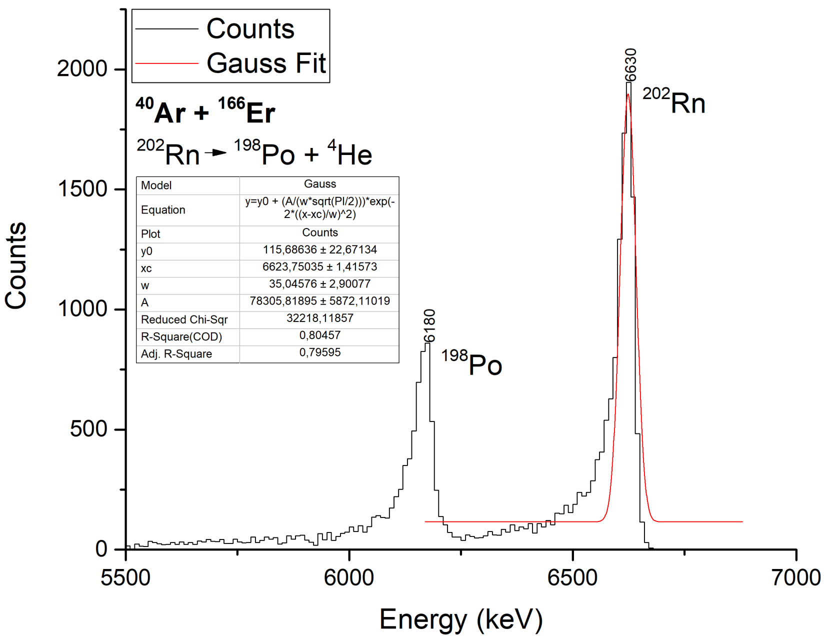

Figure 11: ^{202}Hg [10 s] decays with α-energy 6630 keV [theor. 6639 keV]

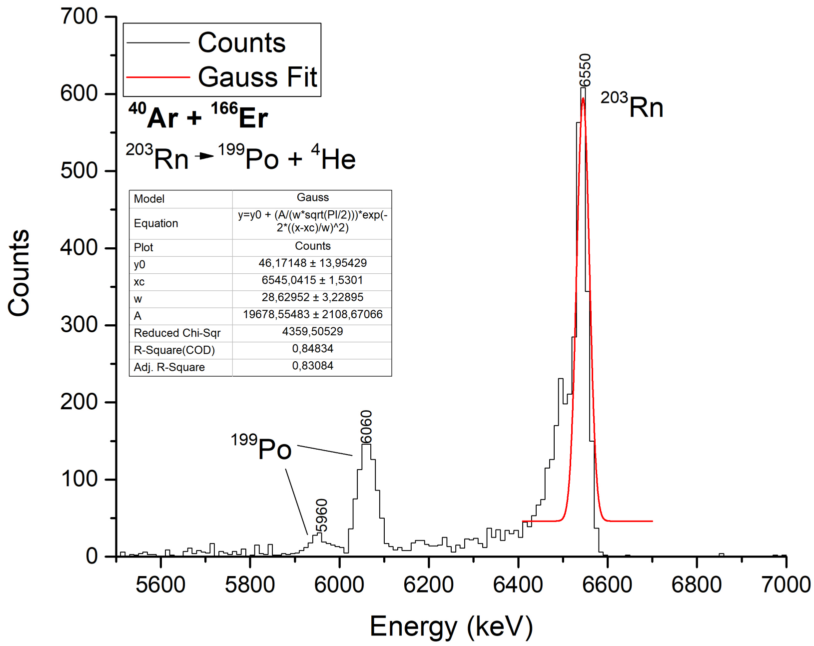

Figure 12: ^{203}Hg [45 s] decays with α-energy 6550 keV [theor. 6499 keV - 99%].

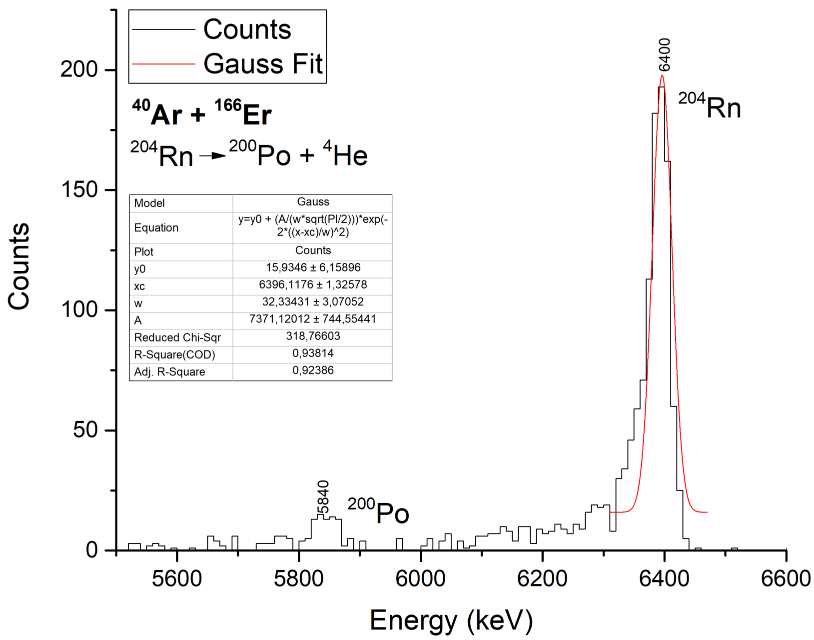

Figure 13: ^{204}Hg [74 sec] decays with α-energy 6400 keV [theor. 6419 keV].

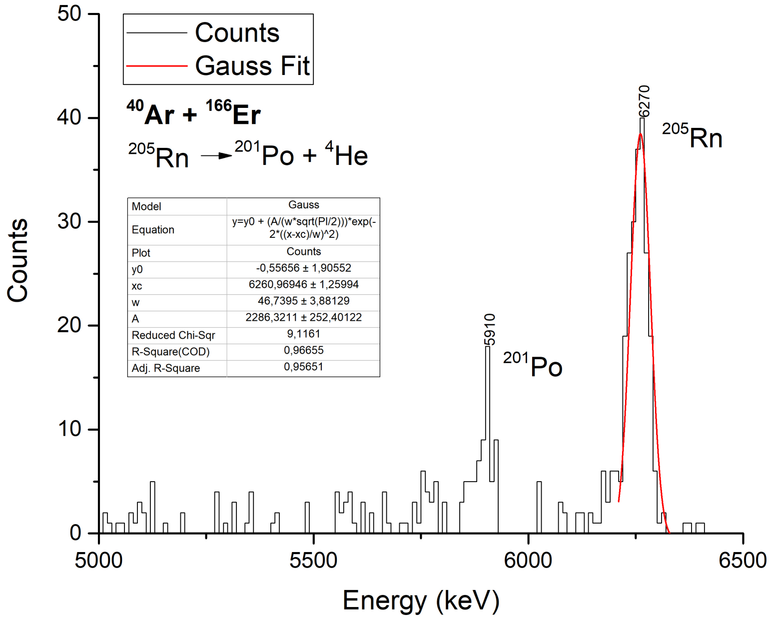

Figure 14: ^{205}Hg [170 s] decays with α-energy 6270 keV [theor. 6262 keV - 98.2%].

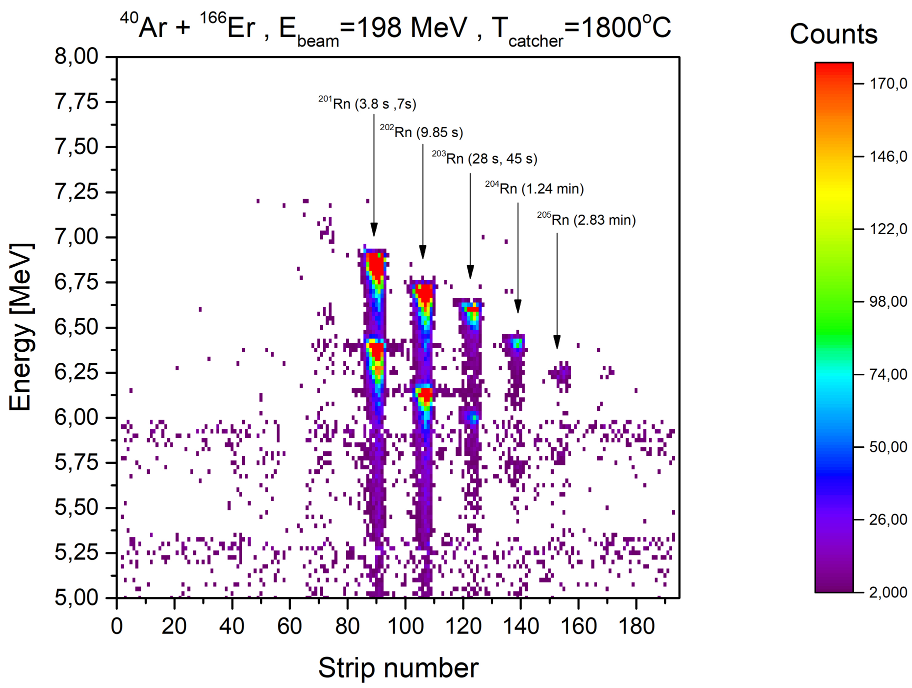

Figure 15: Heat map of Counts, $E_{\alpha-decay}$ and Strip number.

$$^{48}Ca +^{242} Pu \rightarrow ^{21x} Rn$$

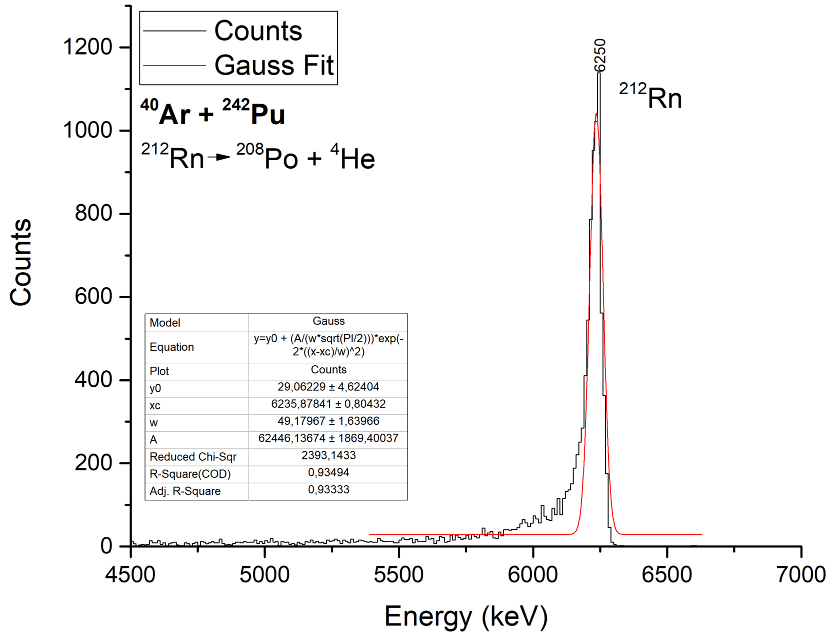

Figure 16: ^{212}Rn [23.9 min] decays with α-energy 6250 keV [theor. 6264 keV].

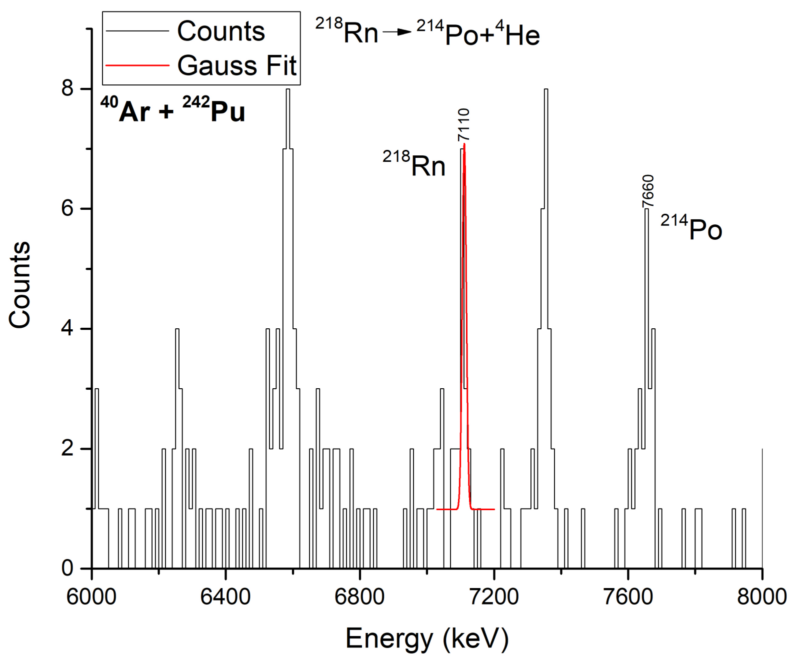

Figure 17: ^{218}Hg [35 msec] decays with α-energy 7110 keV [theor. 7129 keV].

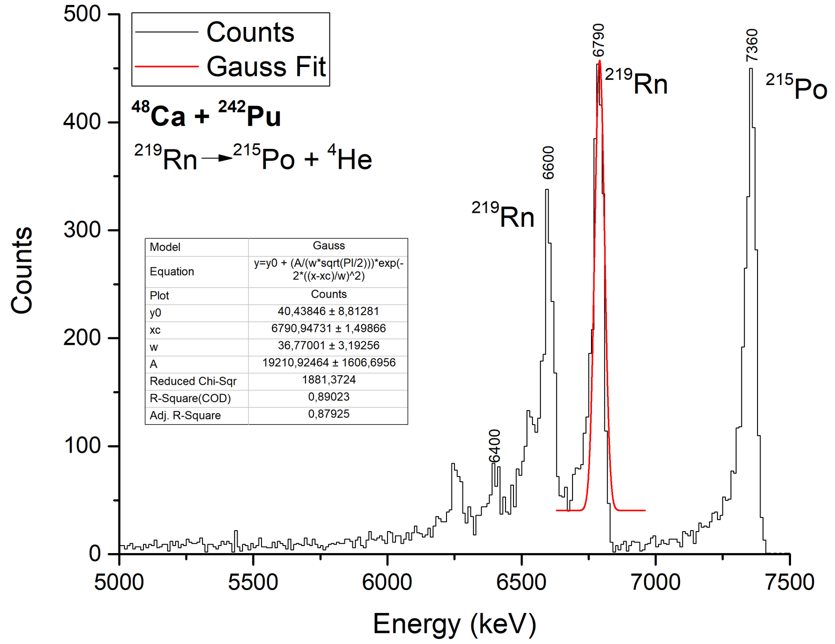

Figure 18: ^{219}Hg [3.96 s] decays with α-energy 6790 keV [theor. 6819 keV - 79.4%].

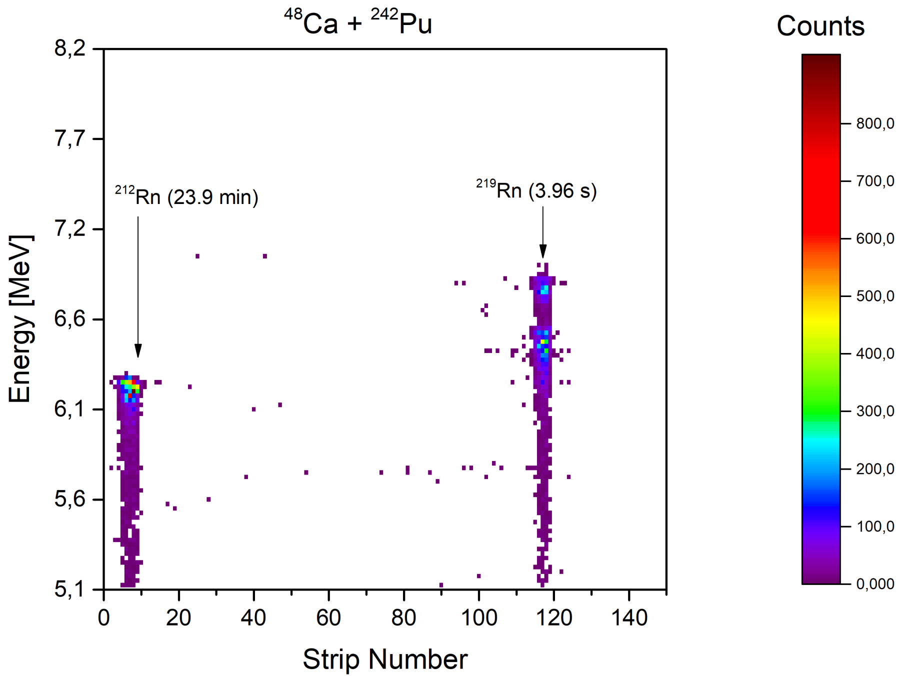

Figure 19: Heat map of Counts, $E_{\alpha-decay}$ and Strip number.

5 Conclusion

In this paper the main parts and working order of MASHA was described. Since its installation it's constantly being improved. By studying SHEs scientist in JINR hope to prove the theoretical idea of an existing "Island of Stability" with super heavy elements with longer half-lives than the rest. ISOL method was used to get a pure beam of nuclei and then through a well-shielded and monitored set-up the nuclear properties were observed. The mass analysis is performed MASHA set up and leads to the separation of the ions. Until this day the whole facility is being improved through numerous advancements. For instance, the rotating target has been upgraded to carbon graphene nanotube to be more effective at the separation procedure and heat dissipation. The data analysis of the nuclear fusions and multinucleon transfer agreed with the theoretical values that were predicted. The deviation error that was presented was at the scale of 1-10 keV which is normal.

6 Acknowledgments

I would like to thank the JINR institute and INTEREST team who organized this program as it was a great opportunity for me to extend my knowledge and enhance my experience regarding nuclear physics. I am grateful to my project supervisor Mr. Viacheslav Vedeneev for his help through this workshop. His knowledge and attitude have inspired me to continue to try and become better at my field. I hope for an equally wonderful collaboration in a future project.

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