JOINT INSTITUTE FOR NUCLEAR RESEARCH

Flerov Laboratory of Nuclear Reactions

FINAL REPORT ON THE INTEREST PROGRAMME

Wave-03

Determination of masses of the super heavy elements in the experiments on synthesis of Cn and Fl using the reactions ^{48}Ca +^{242}Pu and ^{48}Ca +^{244}Pu

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ABSTRACT

The MASHA mass-separator is designed, which is used to identify super heavy elements based on their masses. The ISOL (Isotope Separation On-Line) method is used in this setup. The isotope separation on-Line method (ISOL) is an effective method of separation which is used to separate out the ion beams from SHEs. The separation efficiency has been measured in the autonomous mode using four calibrated leakages of noble gases. Some results of the first experiments for the production of mercury isotopes, and radon isotopes using the complete-fusion reactions and multi-nucleon transfer reactions are described in this report.

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1. Introduction

The discovery of new superheavy elements appeared to be the most promising research findings of the last decade. The study of superheavy elements aims to examine the nuclear interaction and shell structure to which these elements owe their existence. For on-line measurements of the properties of the super-heavy atoms, the mass-separator MASHA (Mass Analyzer of Super-Heavy Atoms) was constructed and put into operation. MASHA was designed at Joint Institute for Nuclear Research(JINR), Dubna, Russia at the cyclotron U-400M of the Flerov Laboratory of Nuclear Reactions (FLNR). The mass analyzer can be attributed to estimate the mass-to-charge ratios of the superheavy element isotopes to detect their α-decays energy peak and (or) spontaneous fission. The superheavy elements were synthesized via the complete fusion reactions of accelerated ^{48}Ca (doubly magic) ions with targets of ^{238}U, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, and ^{249}Cf and to synthesize SHEs, MASHA is useful to carefully measure the beam energy and beam intensity. The nuclei of superheavy elements appeared to mainly undergo α-decays until the decay chain ends with spontaneous fission (SF).
Another conceivable application of the mass-separator MASHA would be related to studying the nuclei close to the N=126 neutron shell. These neutron-rich nuclei are produced in the multi-nucleon transfer reactions with mass-to-charge ratio separation of the target-like fragments. In this type of reactions, the target+catcher system will be used, in which the target material is solved in the catcher material.
Here in section 2 the MASHA setup(Separate units of MASHA) is briefly described. In section 3 some results of this experiment using the complete fusion and multi-nucleon transfer reactions are explained.

2. MASHA Setup

MASHA stands for the Mass Analyzer of Superheavy Atoms[1]. This separator was developed to carry out precise measurements of atomic masses and spectroscopic studies of superheavy atoms. The mass analyzer includes four dipole magnets (D1, D2, D3a, D3b), three quadrupole lenses (Q1, Q2, Q3), two sextupole lenses (S1, S2), and a detection system located in the focal plane of the spectrometer[2]. The setup, the layout of MASHA is shown in Fig.1.

Here the separate units of the MASHA setup are described.

2.1 ECR ion source

The ECR source has been selected for ionizing atoms of nuclear reaction products. The atoms are ionized with charge state Q=+1 in the ECR and accelerated to 40 keV by a three-electrode electrostatic lens. The ion beam formed, which is thereafter separated by the magneto-optical system of the mass spectrometer. The ECR source aids in the generation of

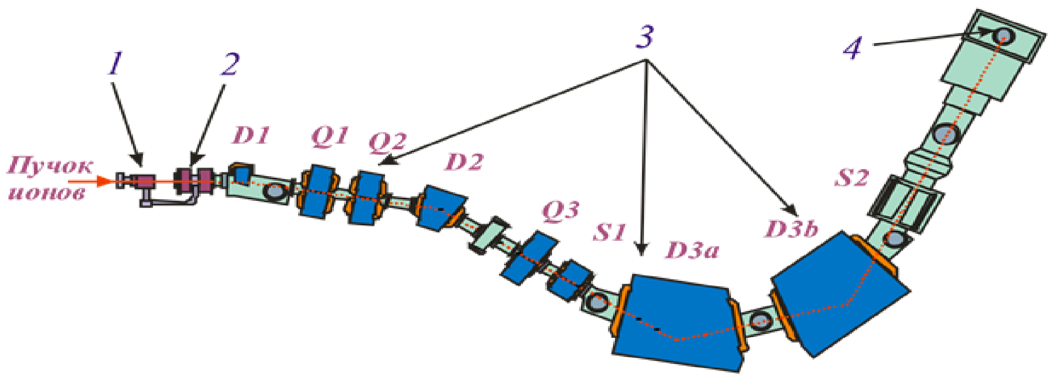

Fig. 1. Mass-separator MASHA: (1) Target box with hot catcher, (2) Ion source, (3) Mass separator, (4) DAQ in the focal plane[3]

ion currents that contain nearly 100 % of singly ionised atoms, and the ionization efficiency of noble gases is as high as 90 %.

2.2 Hot catcher

Hot catcher is a part of the target assembly shown in Fig. 2. Hot catcher was used to inject products of complete fusion reactions into the ECR source. Prior to hitting the target, a pick-up detector and a Faraday cup were used to determine the position and intensity of the heavy ion primary beam. In front of the pickup detector, a four-sector split collimator was installed. Each sector measures the fraction of the beam current that does not fall into the hole of the collimator. The beam position relative to the ion guide can be controlled using this method. Behind the diagnostic system, there is a rotating target mounted on a wheel consisting of 12 sector assembled in cassettes. After being emitted from the target, the reaction products passed through the separating foil and stopped in a graphite foil heated up to 1800-2000K. The products diffuse from the graphite absorber to the vacuum volume of the hot catcher as atoms and then to the ECR source through the pipeline.

2.3 Detection and Control System

In the focal plane of the mass separator a silicon detector is installed to detect the nuclear reaction products. The diagram of the silicon detector system is shown in Fig.3. The frontal detector part occupies a focal plane area of $240 \times 35 mm^2$ and is made up of 192 strips with a 1.25 mm pitch. To improve the geometrical efficiency of detection of reaction product decays, four side detectors are installed around the frontal detector part. The side planes are divided into 64 strips each, and the latter planes are divided into 16 strips each. The detector assembly in the focal plane is mounted on a common metal frame. Energy resolution for α-particles from a ^{226}Ra source is $\sim$30 keV and the standard operating bias of the this detector is –40 V. The geometry of the detector assembly allowed to detect at least

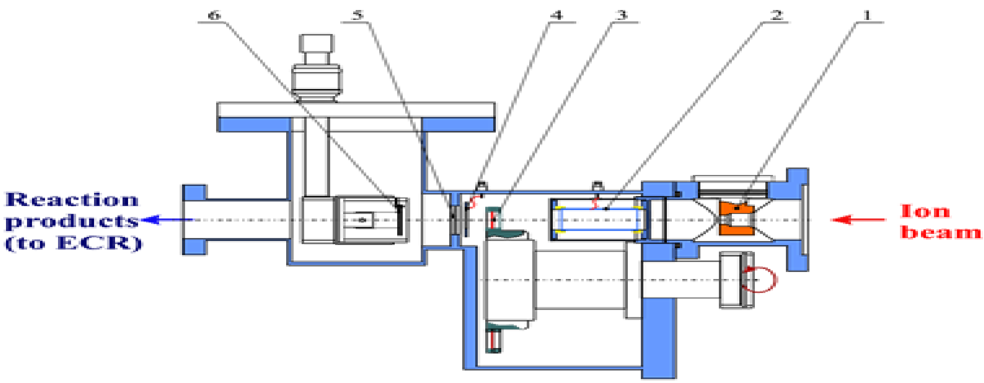

Fig. 2. Target-hot catcher system: (1) diaphragm, (2) pick-up sensor, (3) target on the wheel, (4)electron emission beam monitor, (5) separating foil, (6) hot catcher[4].

90% of the α-particles emitted from a single nucleus decay. Signals from the silicon de-

Fig. 3. Focal plane silicon multi strip detector

tector strips were recorded via independent spectrometric channels. The signals from each strip of the silicon detector are read out indiviusually. The signals arrive at the input of 16-channel charge-sensitive preamplifiers, they went from the preamplifier outputs to the inputs of 8-channel driver amplifiers with an embedded multiplexer. After amplification and multiplexing, the multiplexer outputs were used: alpha, fragment, and digital channels. These outputs were connected to the XIA 16-channel high-speed digitizers. The information from the digitizers was read and stored by the NI PXI controller – PXI-8119. A programme running on the multi-monitor PC at a control room read the stored data through the internal Ethernet network[4].

3. Experimental Results

3.1 Production of mercury isotopes in the reactions ^{40}Ar +^{148}Sm

Element 112 is a chemical analog of mercury[5], it was decided to perform model experiments to measure the efficiency and separation time of the mercury radioactive isotopes produced in the complete fusion reaction ^{40}Ar+^{148}Sm$\rightarrow^{188-xn}$Hg+xn[6]. The first stage of testing of the MASHA was applied on a beam of ^{40}Ar ions. The beam energy of ^{40}Ar ions was measured on a dedicated beamline by ions elastically scattered from a gold foil. Its energy was measured simultaneously by two independent detectors, first by A time-of-flight detector and then by a silicon detector in which A time-of-flight detector based on two microchannel plate sensors.

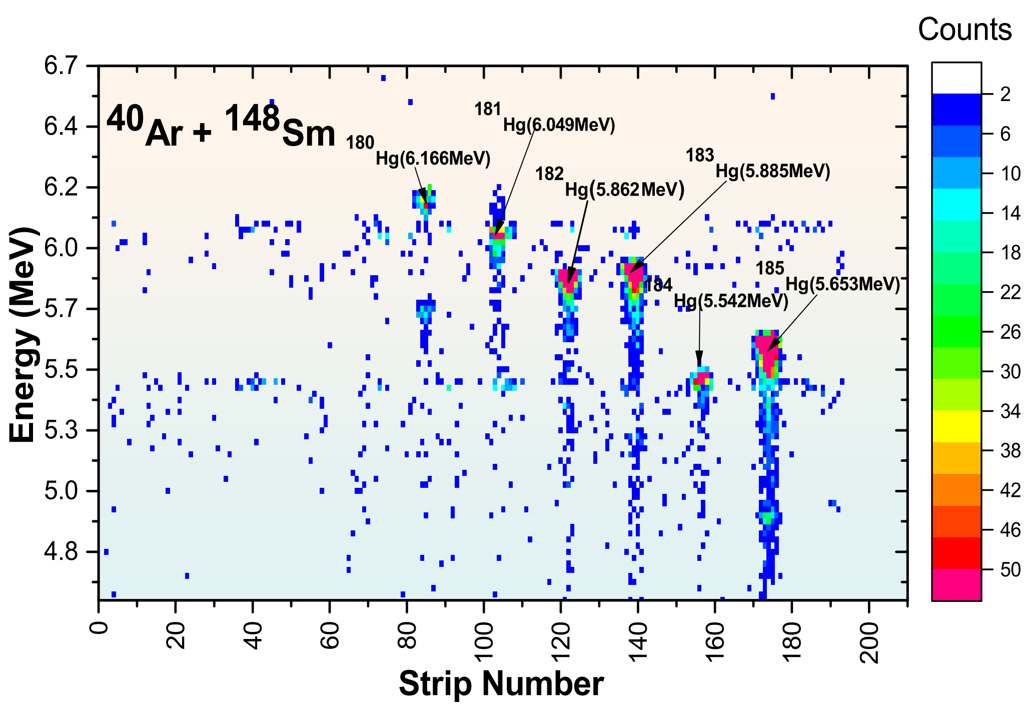

Fig. 4. Energy vs. strip number plot of the α-particles energies from decays of mercury isotopes

Figure 4 represents the α-particle decay energy spectrum of mercury isotopes as a function of the strip number in the frontal part of the silicon detector. The two-dimensional matrix of the α-particle energy vs. strip number was measured (Fig. 5) with a strong distinction by mass and energy.

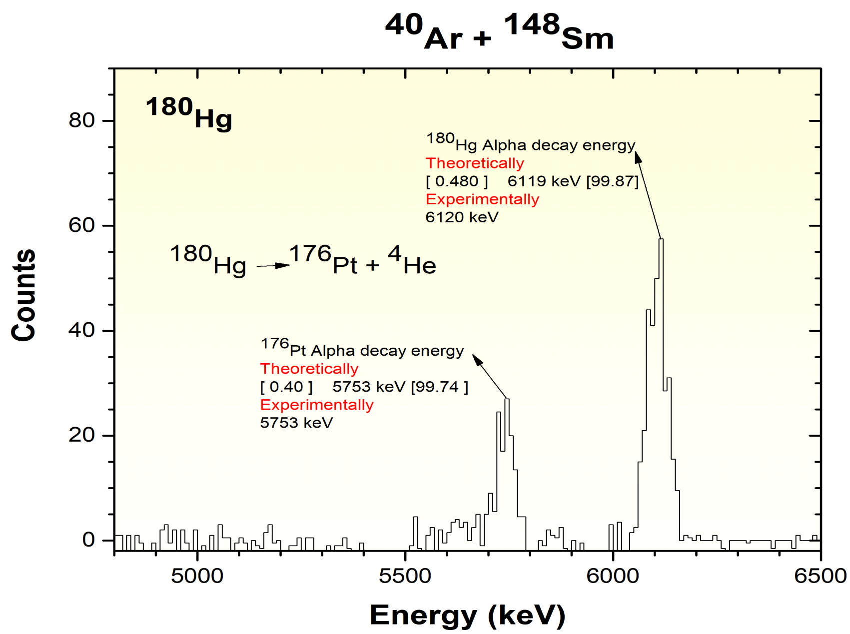

Fig. 5. Energy spectrum of α-particles from decays of ^{180}Hg

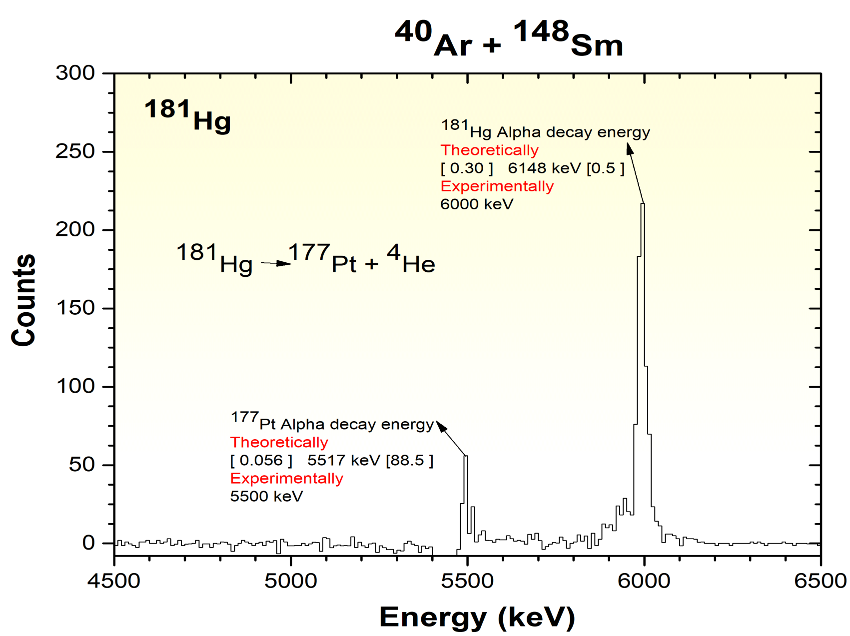

Fig. 6. Energy spectrum of α-particles from decays of ^{181}Hg

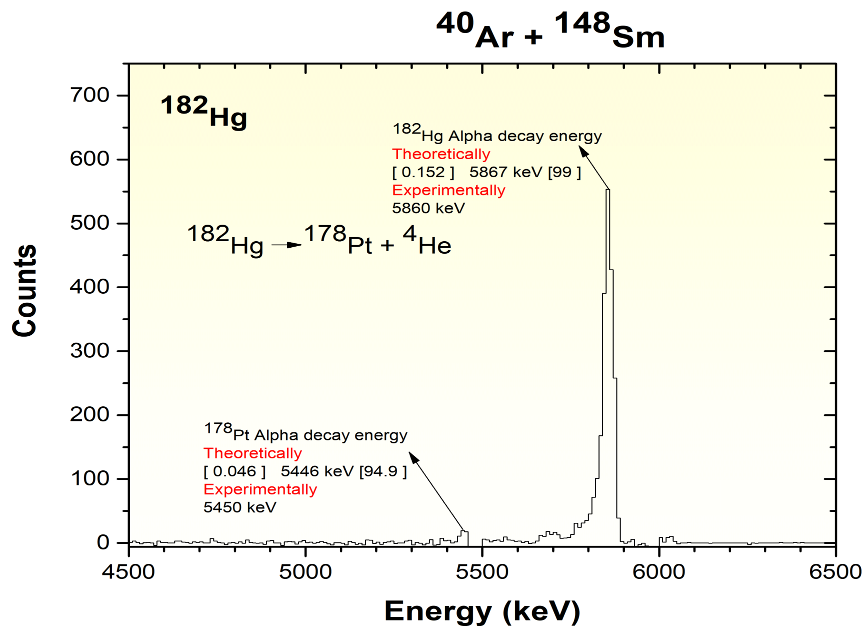

Fig. 7. Energy spectrum of α-particles from decays of ^{182}Hg

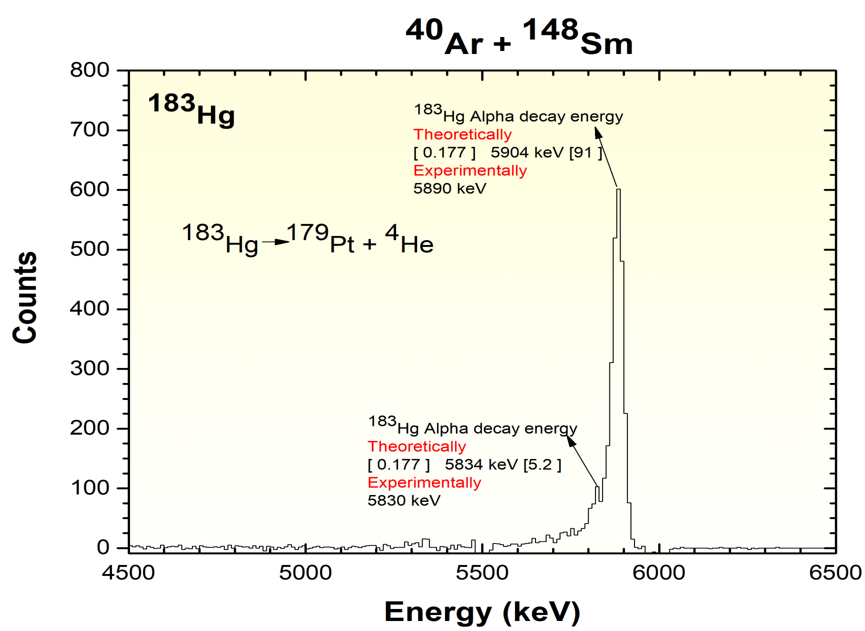

Fig. 8. Energy spectrum of α-particles from decays of ^{183}Hg

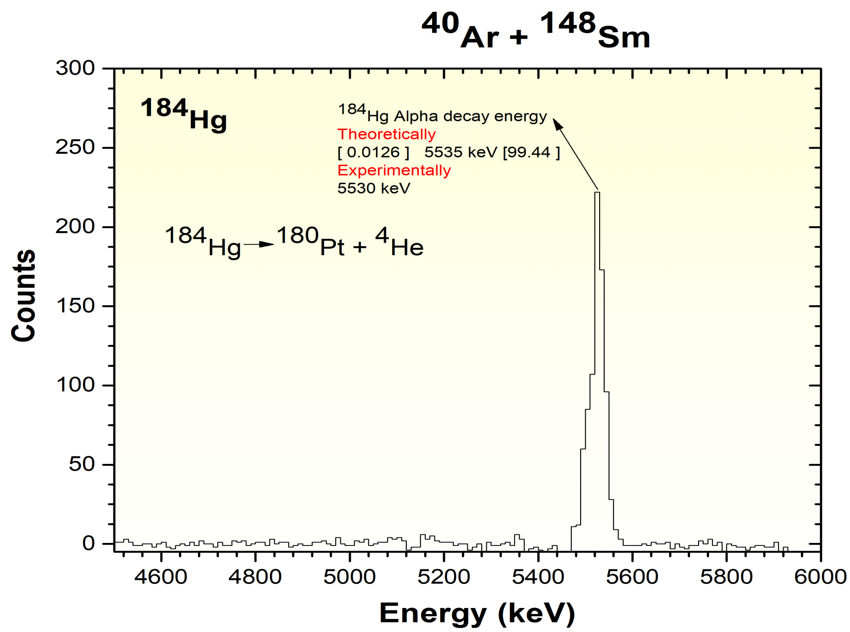

Fig. 9. Energy spectrum of α-particles from decays of ^{184}Hg

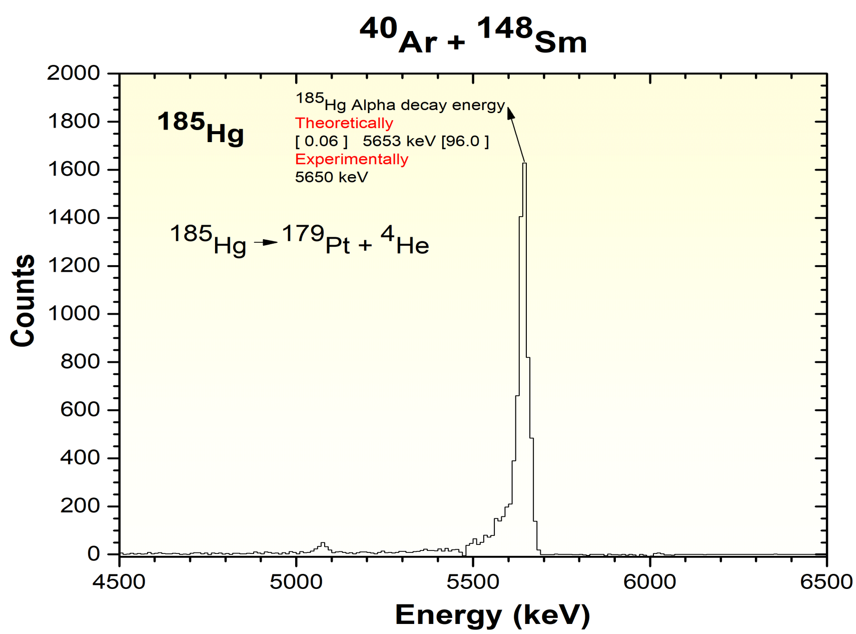

Fig. 10. Energy spectrum of α-particles from decays of ^{185}Hg

The energy spectrum of α-particles for mass number A=180, 181, 182, 183, 184, 185 is shown in above Figures. The peak associated with 180,181,182Hg decay and the peak corresponding to decay of their daughter nuclei 176,177,178Pt is recognizable in this spectrum. Whereas for 183,184,185Hg only the peak associated with its decay appears.

3.2 Production of radon isotopes in the reactions ^{40}Ar +^{166}Er

For production of radon isotope experiment is done with fusion reaction ^{40}Ar +^{166}Er.The two-dimensional matrix of the α-particle energy vs. strip number was measured (fig.11) with a good separation by mass and energy. Figure 11 represents the α- particle decay

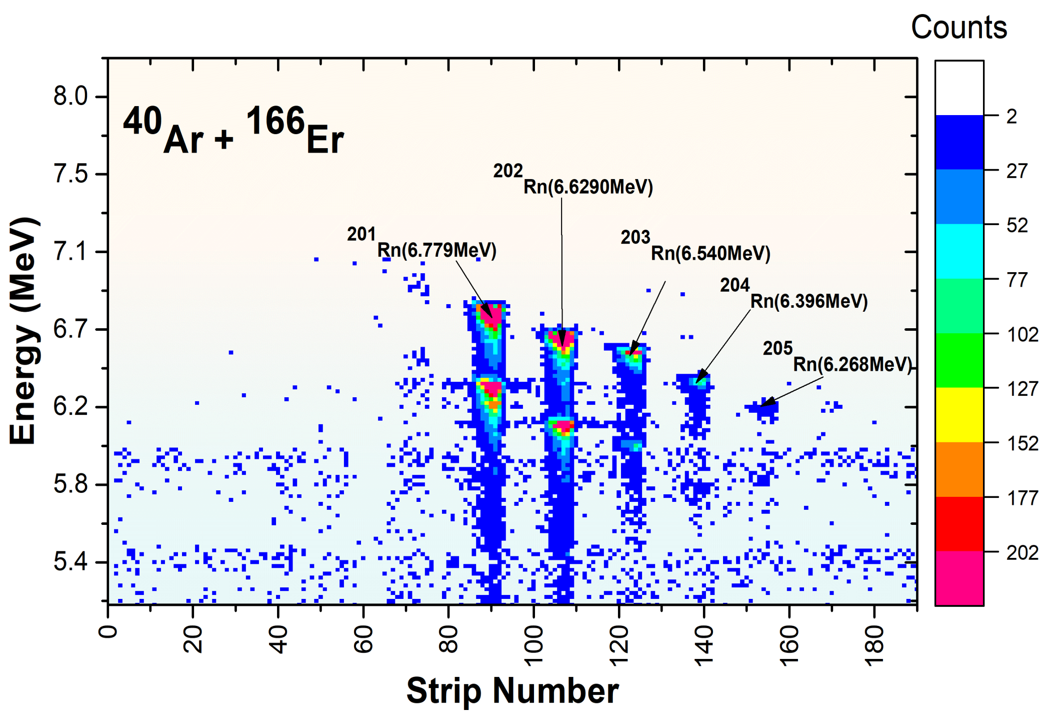

Fig. 11. Energy vs. strip number plot of the α-particles energies from decays of radon isotopes

energy spectrum of Radon isotopes ^{201}Rn,^{202}Rn, ^{203}Rn ,^{204}Rn and ^{205}Rn as a function of the strip number. All the α-decay energy peaks are clearly visible.

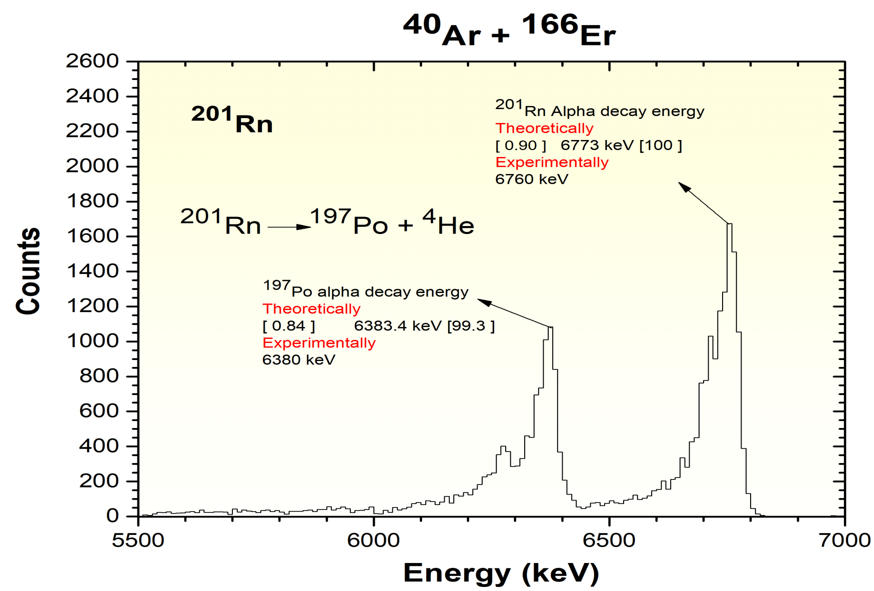

Fig. 12. Energy spectrum of α-particles from decays of ^{201}Rn

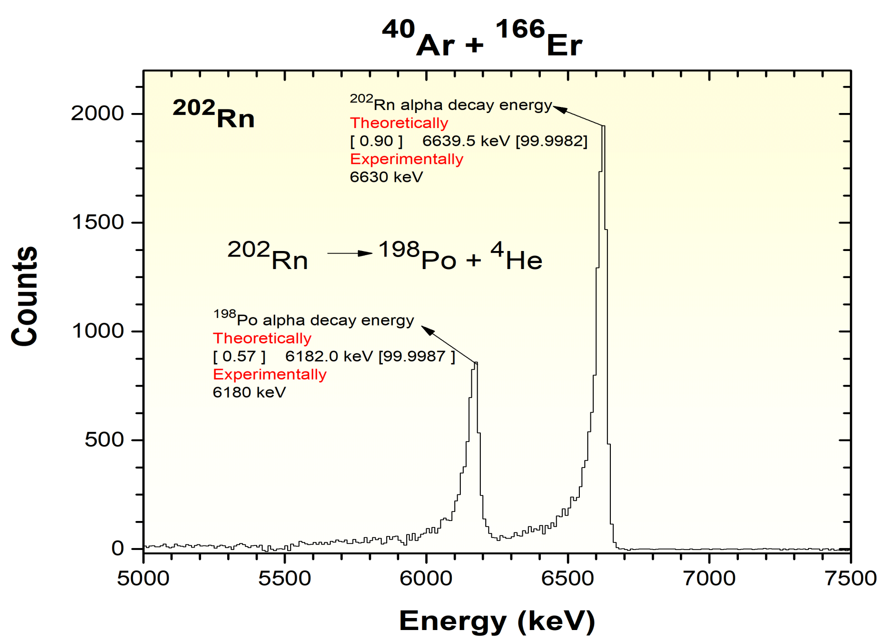

Fig. 13. Energy spectrum of α-particles from decays of ^{202}Rn

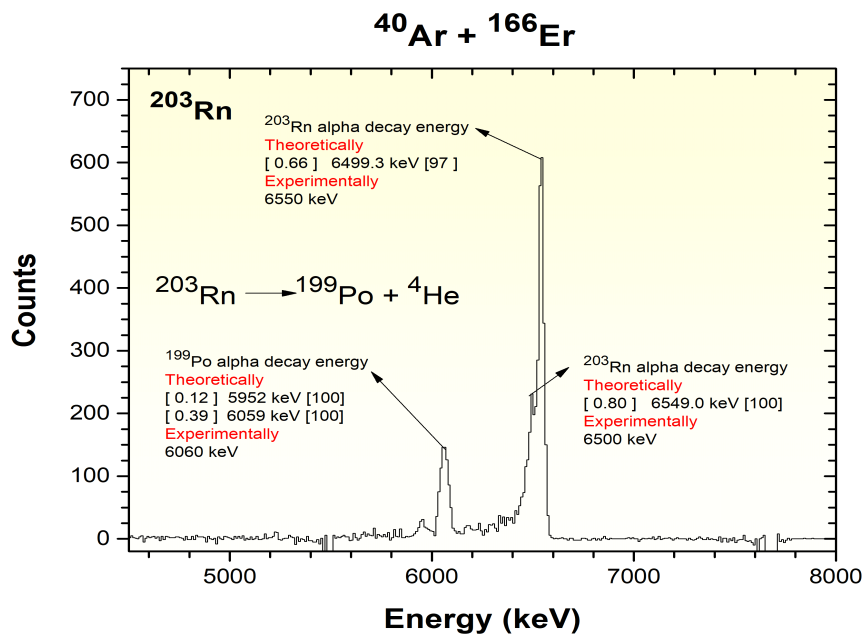

Fig. 14. Energy spectrum of α-particles from decays of ^{203}Rn

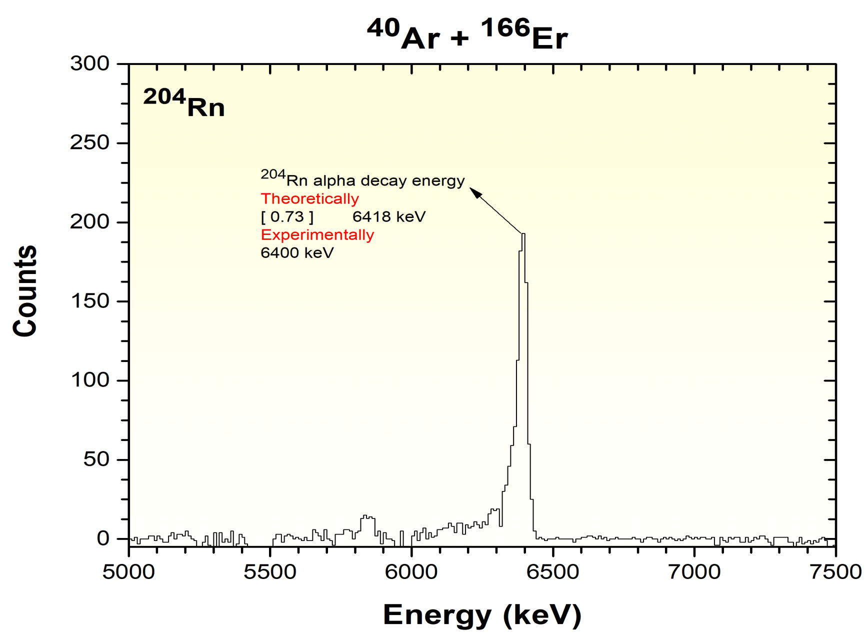

Fig. 15. Energy spectrum of α-particles from decays of ^{204}Rn

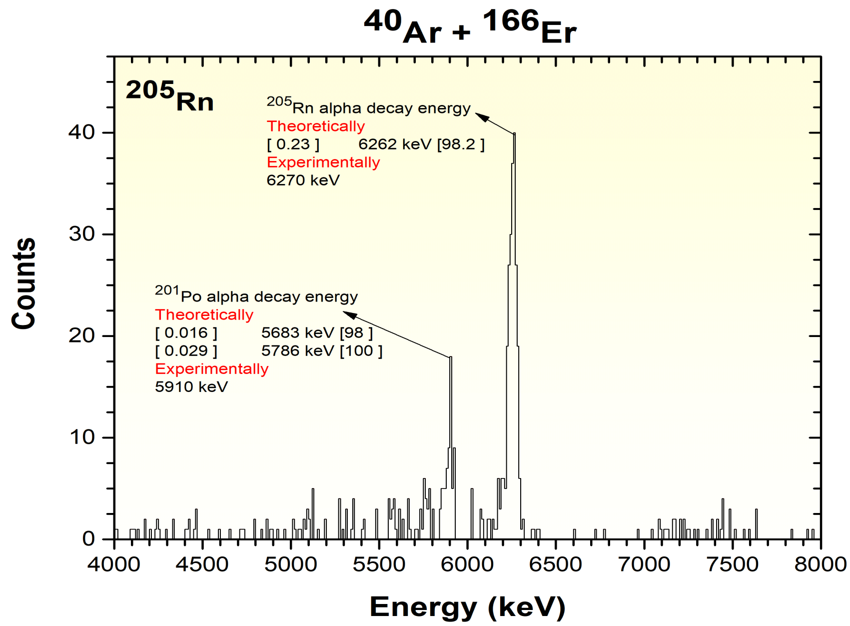

Fig. 16. Energy spectrum of α-particles from decays of ^{205}Rn

α-decay energy spectrum for radon isotope of mass no. A=201, 202, 203, 204, 205 is shown in above figure. In Radon decay the peak associated with 201, 202, 203, 205 Rn decay and the peak corresponding to decay of their daughter nuclei 197,198,199,201Po is visible in the spectrum. In case of ^{204}Rn only peak associated with ^{204}Rn decay is visible.

3.3 Production of radon isotopes in the reactions ^{48}Ca +^{242}Pu

For production of radon(Rn) isotopes first test experiments is done with multinucleon transfer reaction ^{48}Ca +^{242}Pu.The cross-sections of these type of reactions are large, so use these reactions to obtain good statistics. In this only 212^{th} and 219^{th} and 218^{th} radon isotopes are visible.

Figure 17 represents the α-particle decay energy spectrum of Radon isotopes as a function of the strip number. In two-dimensional energy-position graph the isotope ^{218}Rn is barely visible rather than ^{212}Rn and ^{218}Rn isotopes.

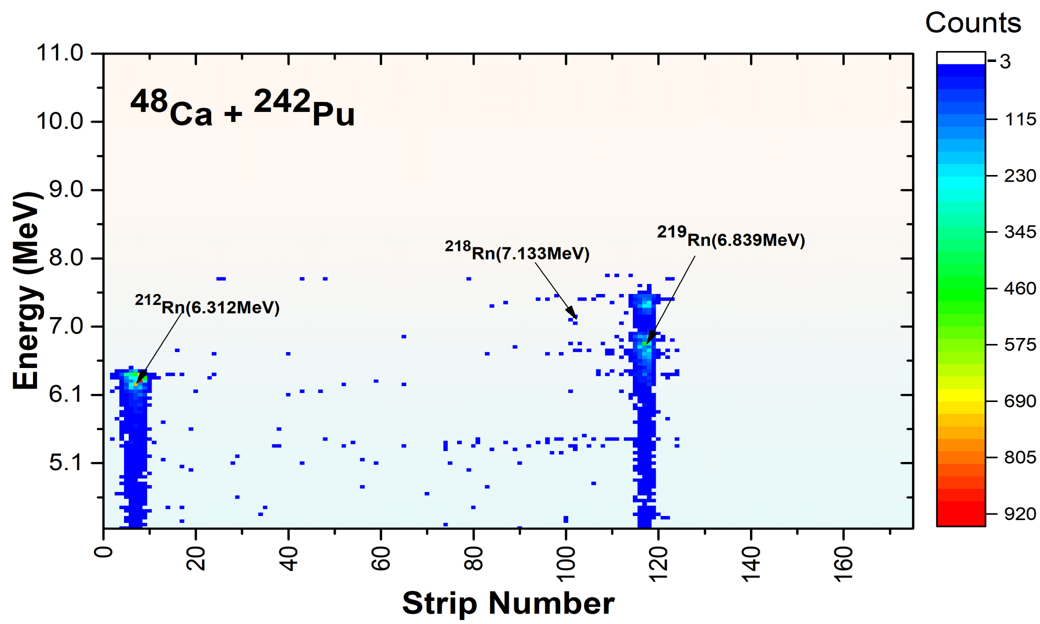

Fig. 17. Energy vs. strip number plot of the α-particles energies from decays of radon isotopes

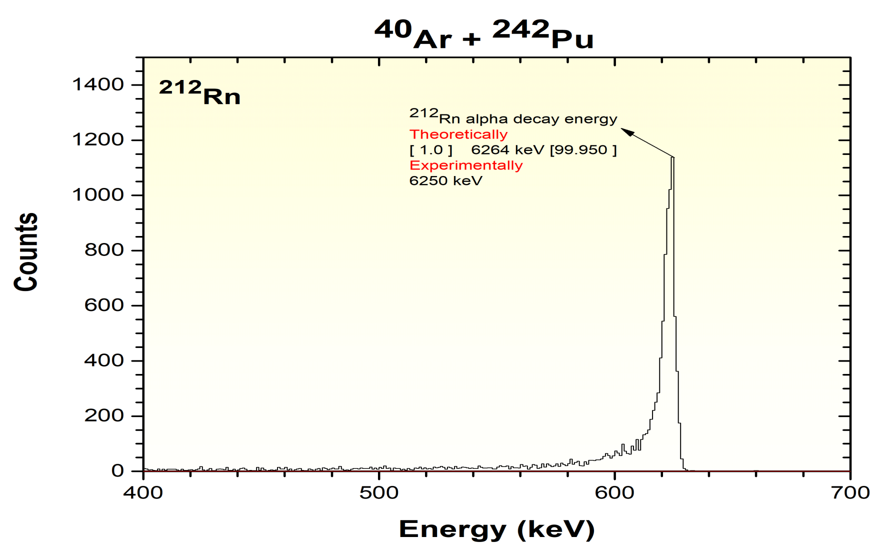

Fig. 18. Energy spectrum of α-particles from decays of ^{212}Rn

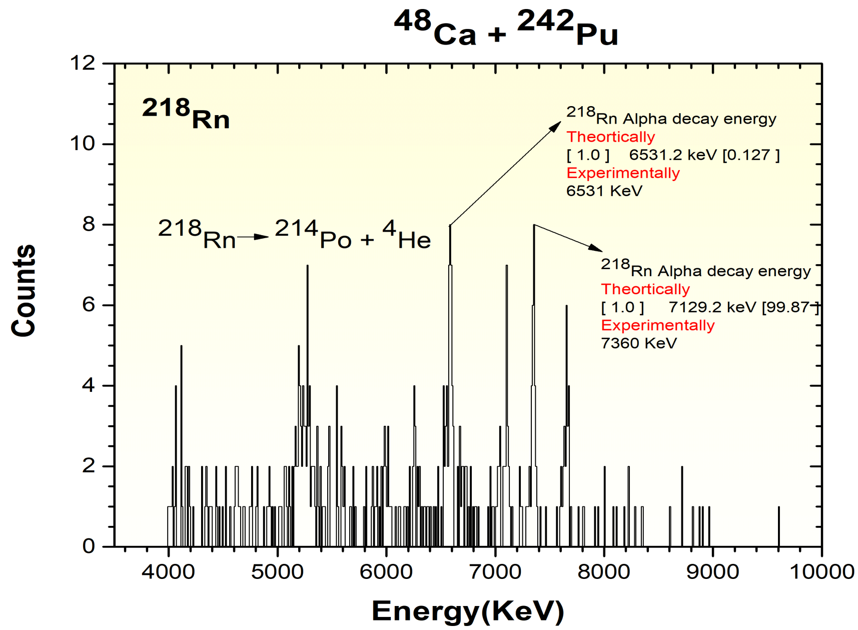

Fig. 19. Energy spectrum of α-particles from decays of ^{218}Rn

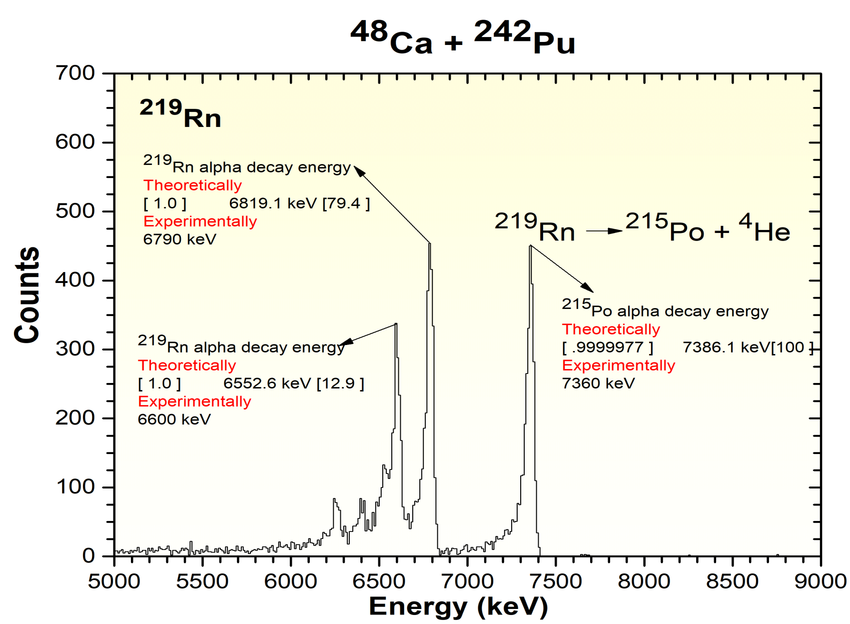

Fig. 20. Energy spectrum of α-particles from decays of ^{219}Rn

The α-decay energy spectrum for ^{212}Rn,^{218}Rn and ^{219}Rn is shown in above figures. From this, observed that for ^{212}Rn only one α decay Energy peak is available whereas for ^{218}Rn two α decay Energy peaks are visible of the approximately same height. In case of ^{219}Rn two α decay Energy peak for parent nuclei and one energy peak for daughter nuclei is visible.

4. Conclusion

The mass analyzer for superheavy elements (MASHA) was described, which is continuously improved. Mercury isotopes 180,181,182,183,184,185Hg have been synthesized in complete-fusion reaction ^{40}Ar +^{148}Sm, Radon isotopes 201,202,203,204,205Rn and 212,218,219Rn have been synthesized respectively in complete fusion reaction and multi nucleon transfer reaction ^{40}Ar +^{166}Er & ^{48}Ca +^{242}Pu. Measuring the masses of all elements which is produced in these reactions will be a near-future task for the MASHA facility. In the focal plane of the silicon detector, products of the above given complete fusion reactions and multi-nucleon transfer reactions were detected. A two-dimensional matrix of the α-particle energy vs. strip number was measured with a good separation by mass and energy. The energy spectrum of α-particles for all the mercury and radon isotopes was detected in the focal plane of the well-type silicon detector.

5. Acknowledgments

I would like to take this opportunity to express my sincere gratitude, sense of indebtedness to my Supervisor Mr.Viacheslav Yurievich Vedeneev, for his inspiring guidance and meticulous supervision throughout my project work, providing all the information related to this project and answers all my queries. I am extremely grateful to the interest team and university center of JINR to start this program and allow me to participate in this.

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