Joint Institute for Nuclear Research

Project Report INTEREST Programme Wave-05

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

Project Supervisor: Mr. Vedeneev Vyacheslav Yurievich JINR, Dubna, Russia

Shubham Bangalia
Department of Physics Panjab University, Chandigarh

Abstract:

The MASHA (**M**asha **A**nalyser for **S**uper **H**eavy **E**lements) mass spectrometer designed for identifying superheavy elements which has a mass resolution $^{m}/\Delta m = 1700$, is explained in terms of its construction, installation and working along with the upgradations done in some of its components. Depending upon the properties of system type of accelerators are used such as Cyclotron, Linear accelerators are used. The main purpose of MASHA is to distinguish the superheavy elements on the basis of their mass. Detection of nuclei, near shell closure (N = 126) in MASHA setup is discussed. Alpha decay energies of different isotopes of Rn and Hg produced by heavy ion fusion evaporation reactions $^{40}Ar + ^{148}Sm$, $^{40}Ar + ^{166}Er$ and $^{48}Ca + ^{242}Pu$ have been identified. Calibration of detector using one-dimensional histograms have been performed and heat maps have been drawn using this calibration.

Introduction:

Drastic changes occurred in periodic table of elements with the discovery of actinides. After the production of first artificial superheavy element people started to look for the

new ones and definitely this era was initiated by the existence of closed shell. The primary experiments to produce these elements was performed at JINR, Dubna, Russia. To produce and investigate SHEs in FLNR two cyclotrons U400 and U400M are installed. In FLNR the SHEs are synthesized by complete fusion reaction of doubly magic ^{48}Ca and ^{40}Ca nucleus with neutron rich nuclei such as ^{238}U, ^{237}Np, ^{242}Pu, ^{244}Pu, ^{243}Am etc. In section 2 different components of MASHA have been described along with relevant features, working and their respective setup.

Superheavy Elements- Reaction Of Synthesis:

For the synthesis of superheavy nuclei with Z = 112–116 and 118 with large neutron excess we chose the fusion reactions: ^{238}U, ^{237}Np, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Cf + ^{48}Ca, which are characterized by evaporation residues with a maximal number of neutrons.

Before that for the synthesis of all heavy nuclei with Z = 107–112, fusion reactions of the magic nuclei ^{208}Pb and ^{209}Bi with a massive projectile (AP ≥ 50) were used .In this kind of reactions the compound nucleus has an excitation energy about Ex ≈ 12–15 MeV (cold fusion). The transition to the ground state takes place by the emission of only one neutron and γ-rays. As a result, the survivability of the compound nucleus significantly increases, this being the main advantage of the cold-fusion reactions. Together with this, as can be seen from the production cross-section of the evaporation products strongly decreases with the growth of ZCN . This indicates that the hindrances to fusion, leading to the formation of a compound nucleus, increase.

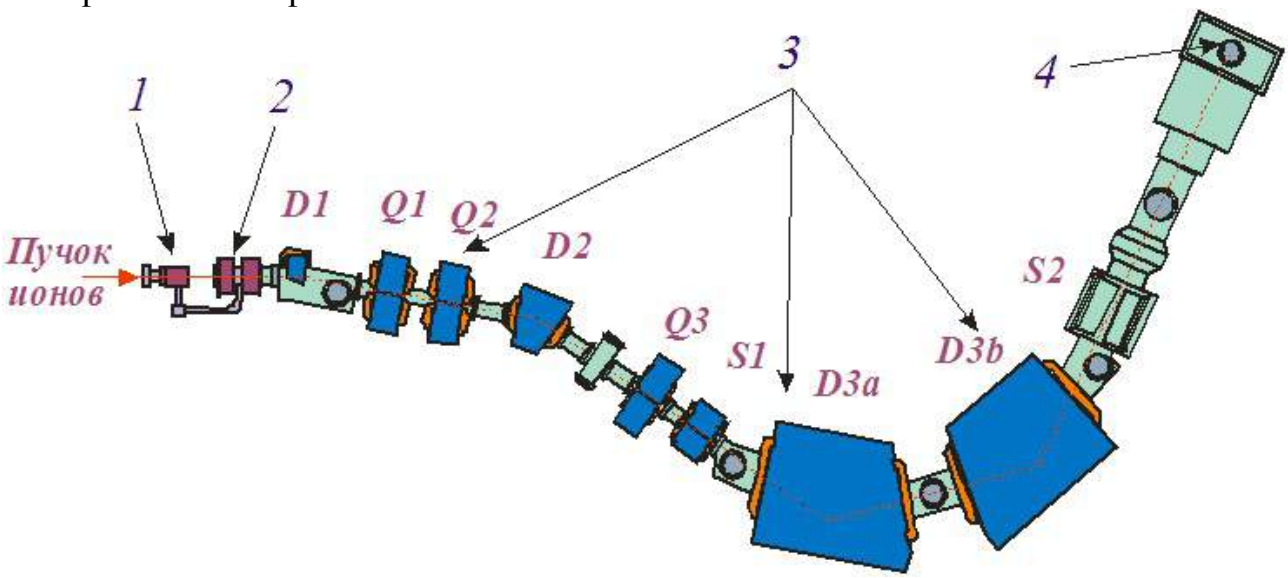
In reactions such as actinides + ^{48}Ca at excitation energies Ex ≈ 35–40MeV (hot fusion), the survivability of the compound nuclei is significantly lower. The two factors, the formation and survival of compound nuclei, lead to decreasing the cross section for the evaporation residues, formed in the reactions of cold and hot fusion However, the restrictions themselves arise because of different reasons.

Indeed, at fixed values of mass and charge of the target (^{208}Pb or ^{209}Bi) the increase of the atomic number of the projectile causes an increase in the Coulomb repulsion along the path of the collective motion of the system from the point of contact to the final configuration of the com- pound nucleus. For this reason, in cold-fusion reactions in the region of ZCN > 112, as well as at ZCN = 102–112, the cross-section σ1n (ZC N) will strongly decrease with increasing atomic number of the compound nucleus. In more asymmetric in mass/charge hot fusion reactions, of the type act. + ^{48}Ca, the forces hindering fusion are weaker. The main losses are due to fission of the heavy excited

nucleus in the process of its de-excitation by means of neutron evaporation. Thus, the survival probability of the nucleus is determined to a large extent by its fissility, which depends on the height of the fission barrier.

MASHA:

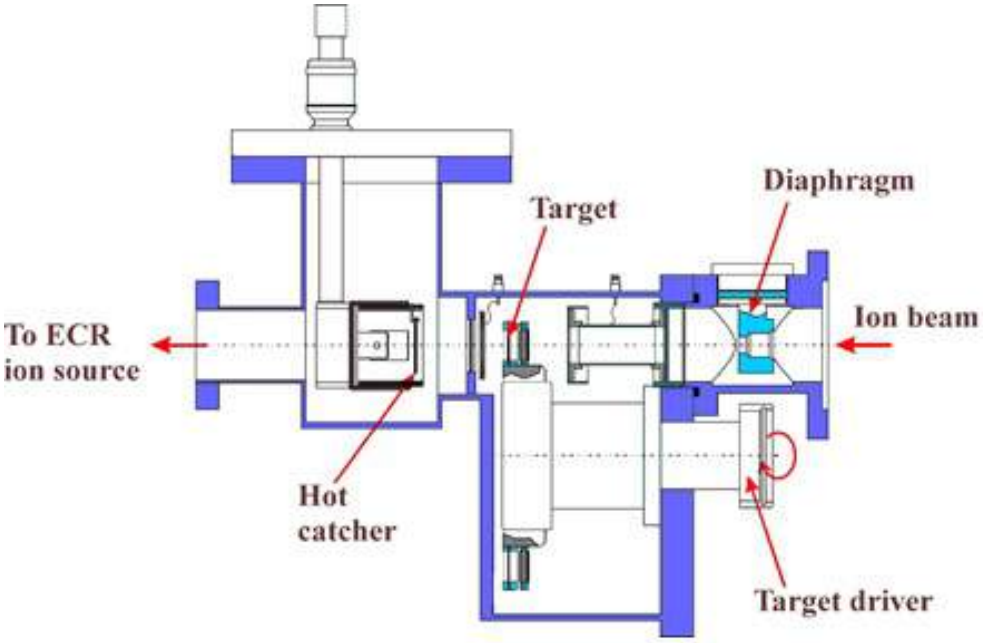
MASHA facility, located at the beam line of U400M cyclotron consisting of many components, is used to produce and investigate different elements.To identify and interrogate the synthesized isotopes MASHA uses the method of online analysis, based on the ISOL Method. Cyclotron ejects the projectile ions (such as ^{40}Ca, ^{48}Ca, ^{40}Ar, ^{36}Ar etc.) with a beam energy of the order of 5-7 MeV/nucleon. Basically products obtained from reaction get deposited on the absorber (placed after the target) made up of graphite, a porous poly-graphene structure with a porosity of 75 % absorber. Products are then injected in the ECR ion source where they get ionized and get transferred to the mass separator, consisting of dipole magnets, quadruple lenses and sextuple lenses (denoted as D, Q and S respectively in figure. Short-lived isotopes decays are being detected in the focal plane of the separator.



MASHA (Mass Analyzer of Super Heavy Atoms)

Components:

The setup consists of an ion source based on electron cyclotron resonance (ECR), target assembly located in- side the hot catcher unit, magnet system (made up of dipoles, quadruples and sextuples) and DAQ (Detection and Control) system.



Block Diagram of Setup

a) Ion Source:

To ionize atoms of nuclear reaction products, ion source based on the ECR with a 2.45 GHz frequency of its microwave oscillator is used where atoms ionized to charge state Q = +1 (almost 100 % singly ionized), accelerated with the aid of the three electrode system, gathered into a beam which thereafter separated by the magneto-optical system of the mass spectrometer. ECR source were optimized by means of buffer gas pressure in the ionization chamber. Helium was used as a buffer gas (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 %), and its pressure was regulated using a controlled piezoelectric valve. To obtain the optimal parameters of the source helium pressure is set in the range of (1 – 2) Ö10^{-5} mbar and a microwave oscillator power of 30 W.

B) Target Assembly and Hot Catcher:

In the first experiments aimed at measuring the masses of isotopes of the 112^{th} and 114^{th} elements, a hot catcher was used to inject products of complete fusion reactions into the ECR source. Physically, the hot catcher is a part of the target assembly prior to hitting the target, the primary beam of heavy ions passes through the diagnostic system composed of

a split type aperture of the electrostatic induction sensor and a Faraday cup. Behind the diagnostic system, there is a rotating target mounted on a wheel consisting of 12 sector assembled in cassettes and revolving 25rps. Nuclear reaction products escape from the target, pass through the separating foil which does not allow reaction products to go backward and thus being lost and then they are stopped in the graphite absorber, which is heated to a temperature of 1800–2000 K. 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. The temperature calibration of the graphite stopper was done before the irradiation via an infrared pyrometer disposed beyond the vacuum chamber of the target. The pyrometer measured the radiation going outside from the heated graphite through a sapphire window. Since the geometry of the hot catcher did not permit to check its temperature

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ISOL technique:

The ISOL technique was invented in Copenhagen over 50 years ago. The technique is today established as one of the main techniques for on-line isotope production of high intensity and high quality beams. The thick targets used allow the production of unmatched high intensity radioactive beam. The great advantage of the thick targets is the large total cross-section available for production of ions. Three main reaction channels are responsible for the bulk production of ions: spallation, fragmentation and fission facilities with neutrons as the “driver beam” the two first channels are suppressed leading to a lower cross section but a higher beam purity. The disadvantage with ISOL pro- : in general is the general difficulty to achieve high beam purity due to the many isobars of different elements produced simultaneously in the target. High beam purity can only be achieved with a combination of measures such as the right choice of target material, driver beam and ion source. Furthermore, refractory elements are in general difficult to produce due to the high temperatures required to make them volatile.

TIMEPIX Detector:

The Timepix is the next generation of pixel particle detector from the Medipix family. The semiconductor pixel detector Timepix is the single quantum counting detector. Each pixel can pro- vide independently one of three kinds of information from measurement. The first mode provides information about the count of detected particles. The second mode is the Time over Threshold (TOT) which provides information about energy of

particles in each pixel and the last mode pro- vides information about arrival time of particles in each pixel. The Timepix ASIC chip can be combined by the bump-bonding technology with different semiconductor sensors (i.e. different materials – e.g. Si, GaAs, CdTe, and thickness – e.g. 300, 700, 1000 μ m) which convert the ionizing radiation into electric signals. The sensitive area of the sensor contains an array of 256 × 256 square pixels with 55 μ m pitch.

The Timepix chip provides for each pixel of the sensor an independent electronic circuit in the chain. The electronic circuit is divided into an analogue and a digital part. Each pixel contains preamplifier, discriminator, 14-bit counter and shift register. Measured values are stored in counters and can be readout through shift registers. The Timepix chip provides two possibilities how to read data from the chip. The first approach is the serial readout through LVDS lines and the second approach is the parallel readout through 32-bit CMOS gate. Several Timepix detectors can be connected easily into the chain through LVDS serial interface. We obtain larger sensitive area by this approach. Thanks to the separated analogue and digital parts of the electronics, the Timepix detector has unique properties compared to the other detection technologies such as linearity and “infinite” dynamic range.

Data Analysis and Discussion:

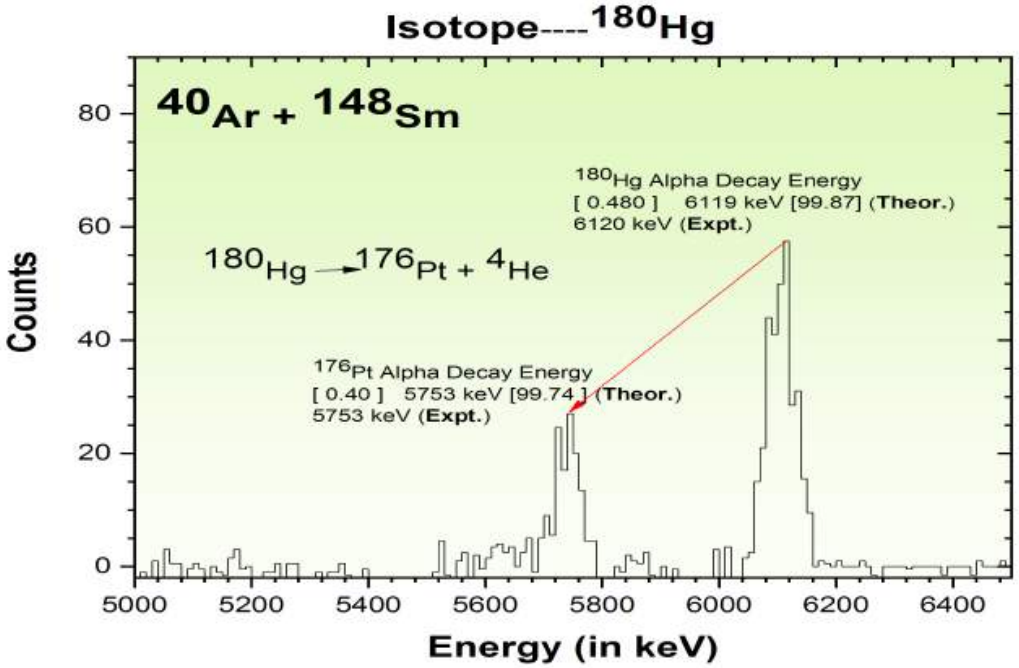
Different isotopes of Hg (mass no., A = 180, 181, 182, 183, 184 & 185) are produced via the fusion reaction $^{40}Ar + {}^{148}Sm = {}^{188-xn}Hg + xn$, Rn isotopes (mass no., A = 201, 202, 203, 204 & 205) are produced via the fusion $^{40}Ar + {}^{166}Er = {}^{206-xn}Hg + xn$ and Rn isotopes (mass no., A = 212, 218, & 219) are produces from the fusion evaporation reaction of ^{48}Ca & ^{242}Pu.

Alpha decay of the above said isotopes have been analyzed, their decay energy are indicated and a comparison has been made between the theoretical value and analyzed one. If peak is measurable for daughter nuclei, it is also shown along with corresponding decay energy and same type of comparison has been made as in the case of parent one.

Detector has been Calibrated using the histograms and chart of nuclides.

$$^{40}Ar + {}^{148}Sm = {}^{188-xn}Hg + xn$$

Histograms for Hg Isotopes



Experimental peaks of ^{180}Hg (6120 keV) & ^{176}Pt (5753 keV) are identified and both are in very good agreement with theoretical values

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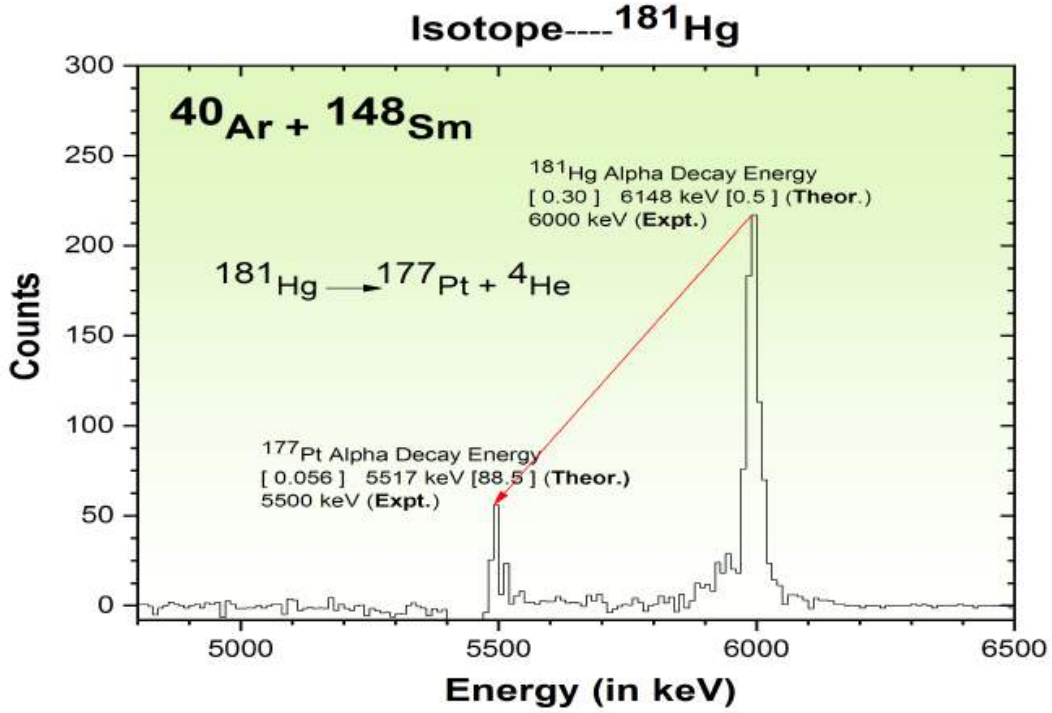
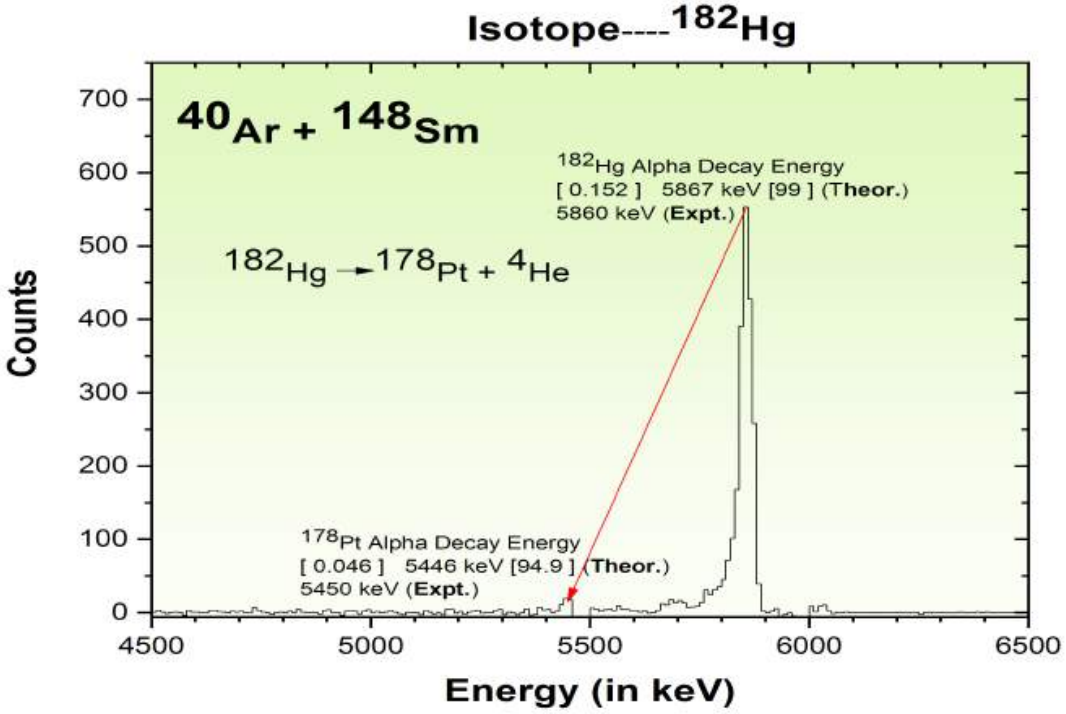
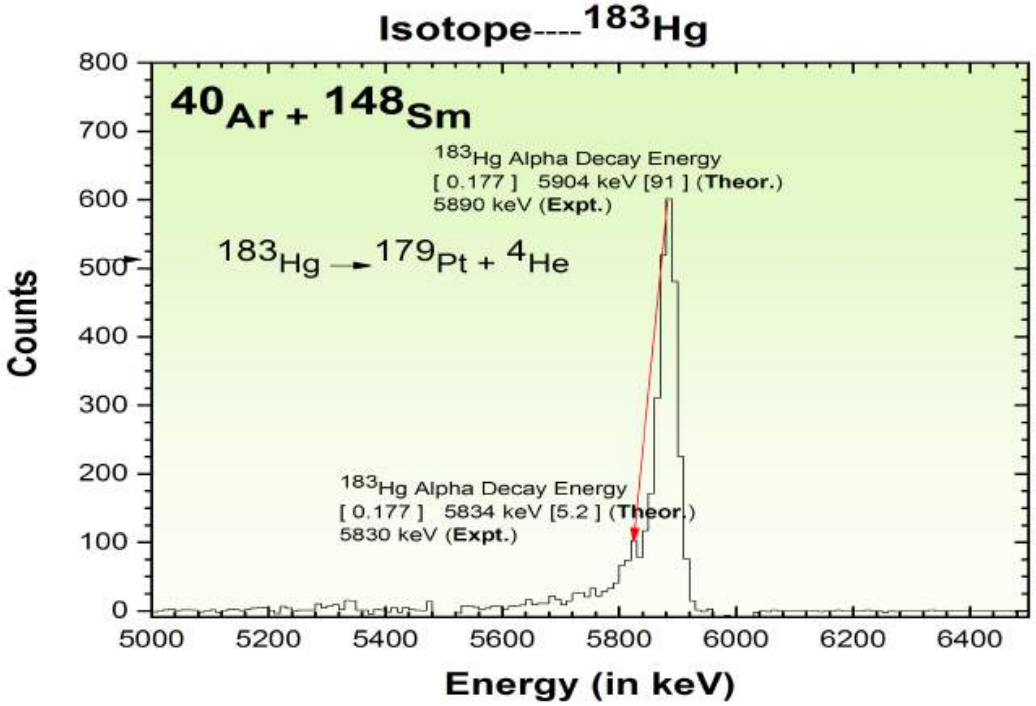


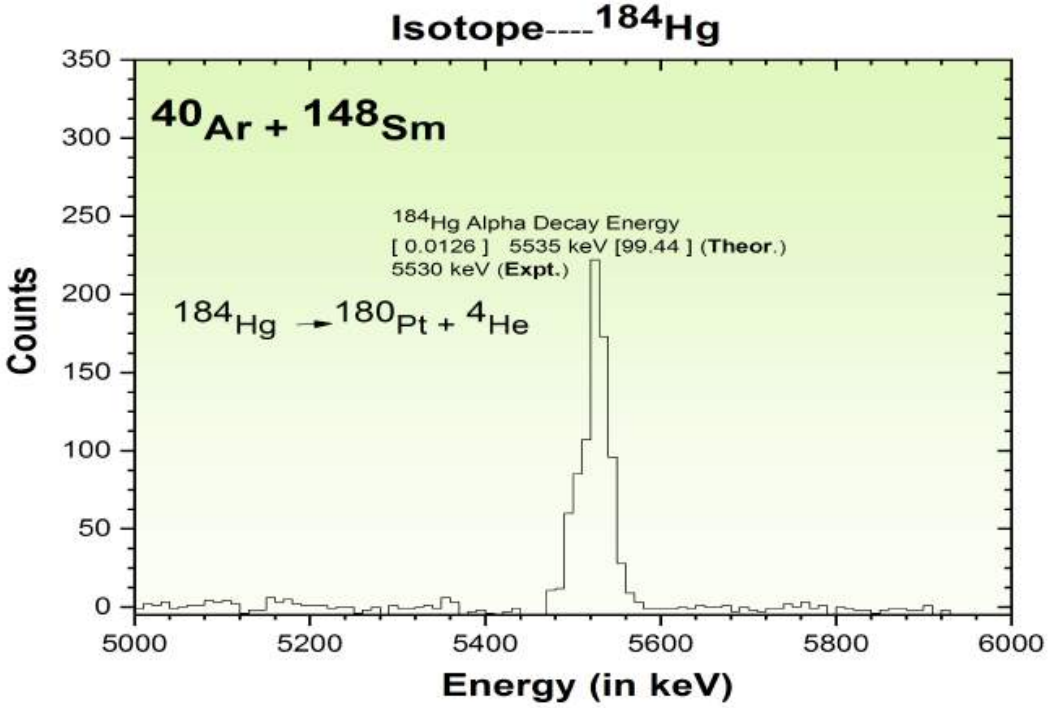
Experimental peaks of ^{181}Hg (6000 keV) & ^{177}Pt (5500 keV) are identified and both are approximately same to theoretical values



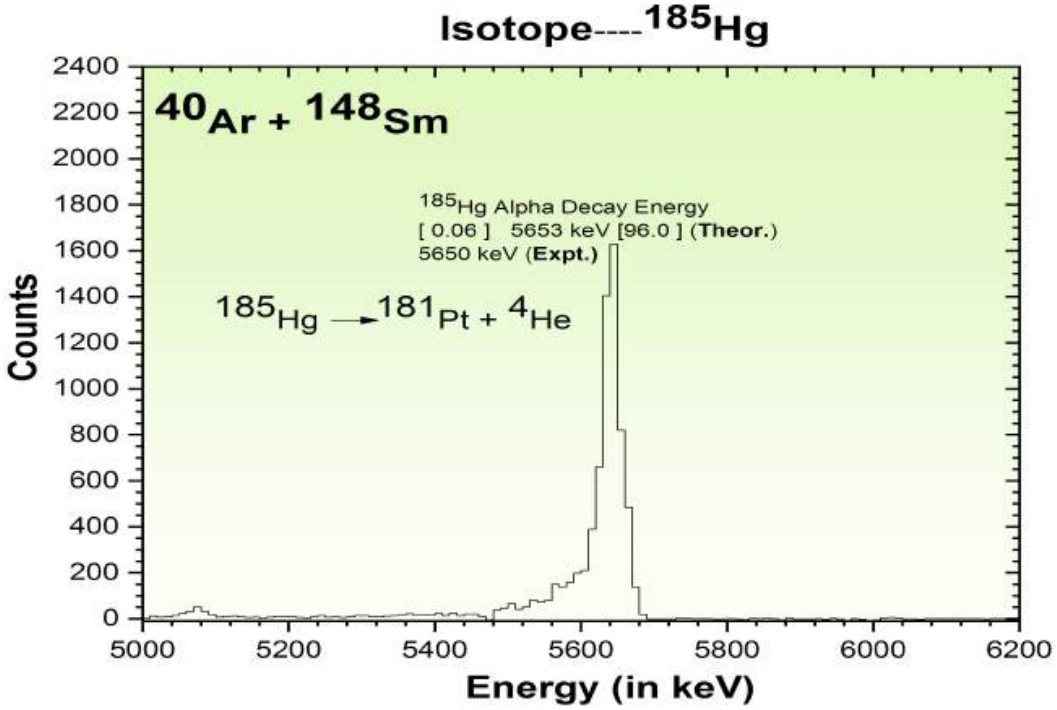
Experimental peaks of ^{182}Hg (5860 keV) & ^{178}Pt (5450 keV) are identified and both are nearly meeting with theoretical values.



Experimental peaks of ^{183}Hg (5890 keV) & ^{176}Pt (5830 keV) are identified for ^{176}Pt it is approximately same as theoretical values whereas for ^{183}Hg it deviates little bit.

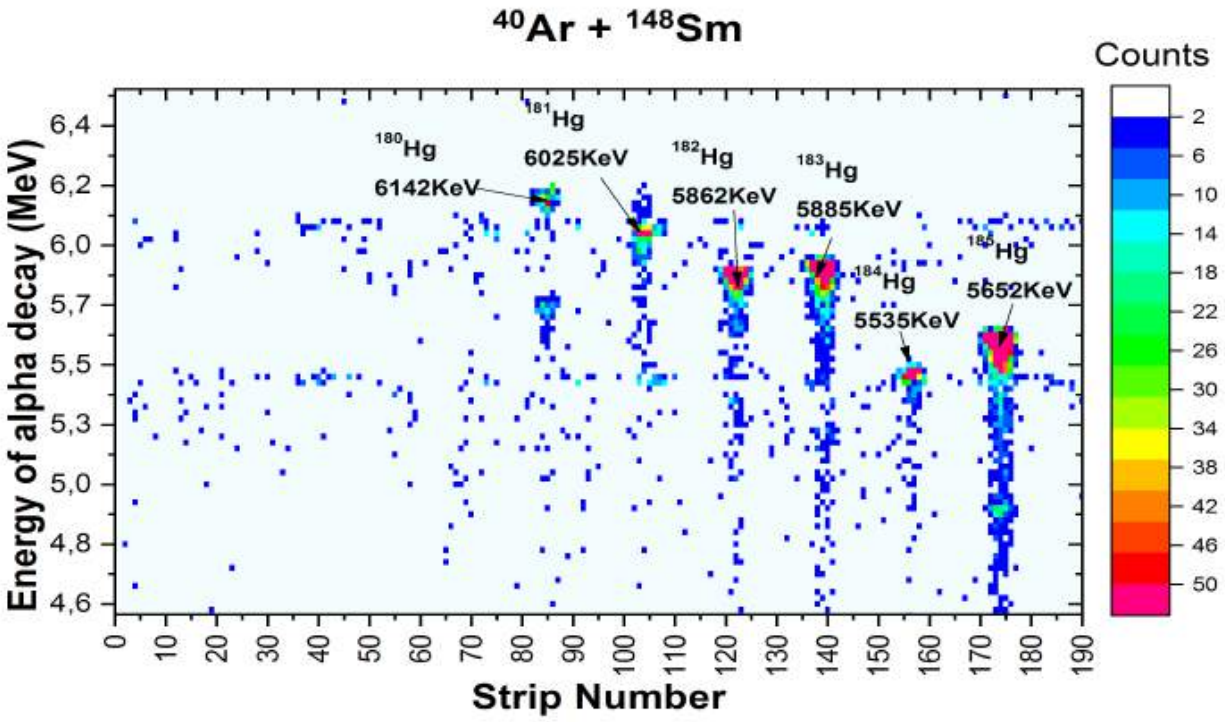


Experiment peak of ^{184}Hg (5530 keV) is identified and it is approximately same as theoretical values whereas for ^{180}Pt no peak is identified due to its really low intensity.



Experimental peak of ^{185}Hg (5650 keV) is identified and it is nearly same as theoretical values whereas for ^{181}Pt no peak is identified due to its really low intensity.

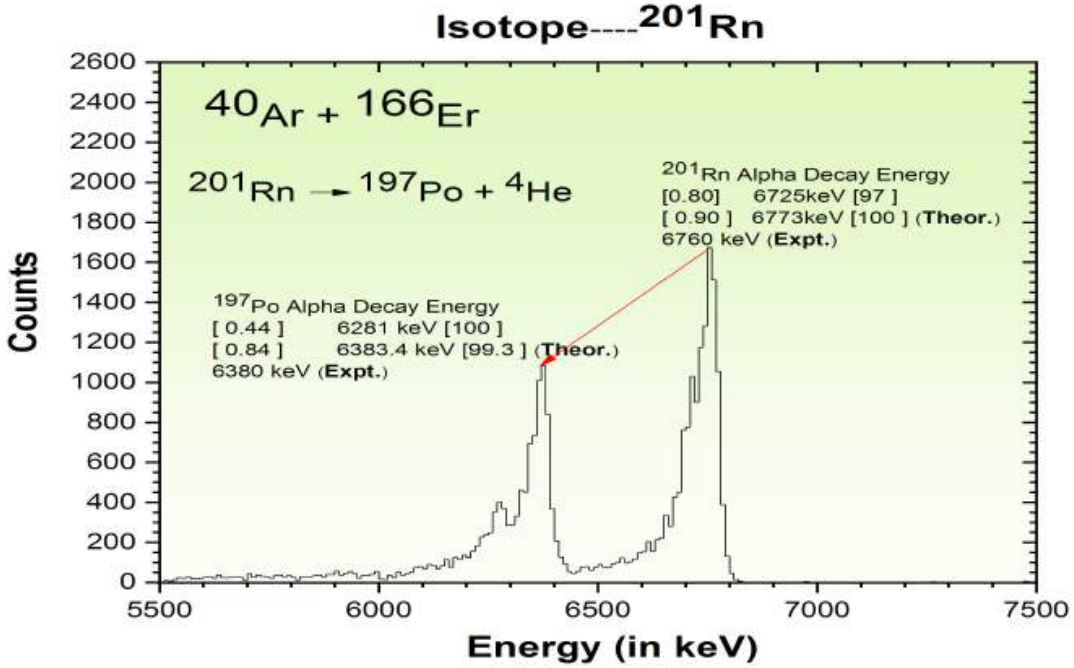
Heat map for Hg Isotopes



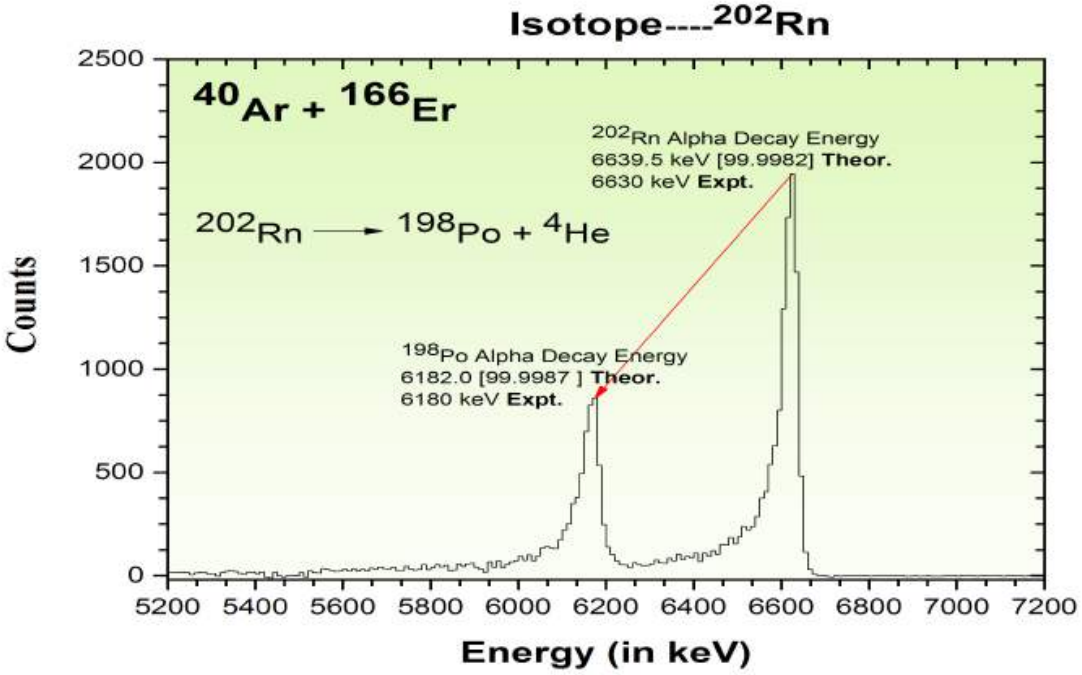
Eα Vs strip no for Hg isotopes (A = 180 to 185).

$$^{40}Ar + ^{166}Er = ^{206-xn}Hg + xn$$

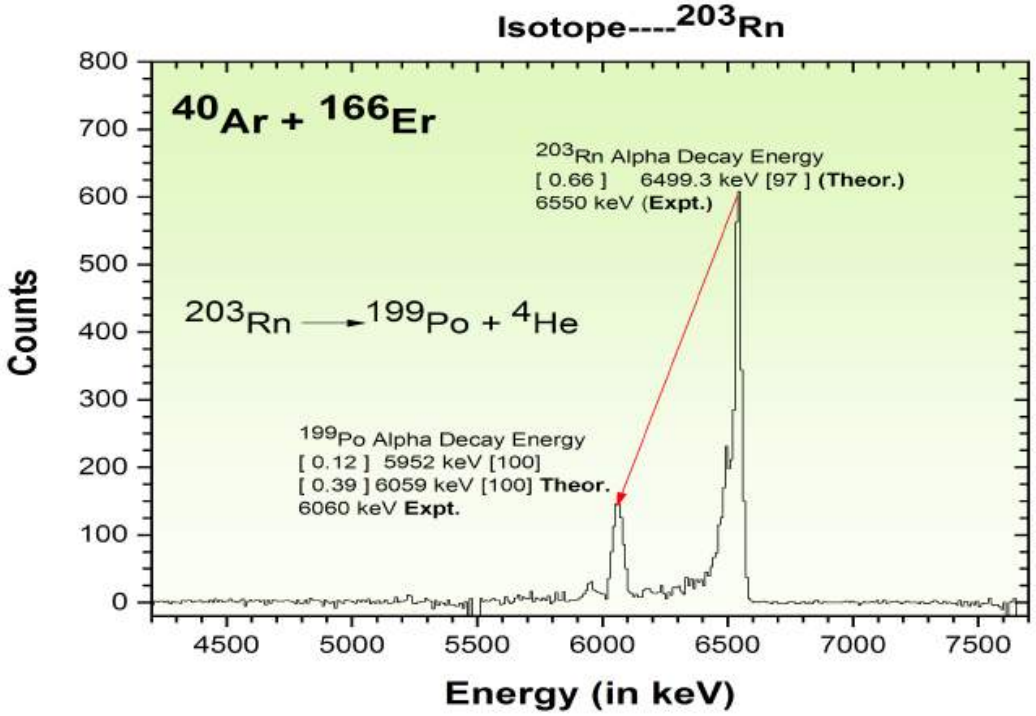
Histograms for Rn isotopes



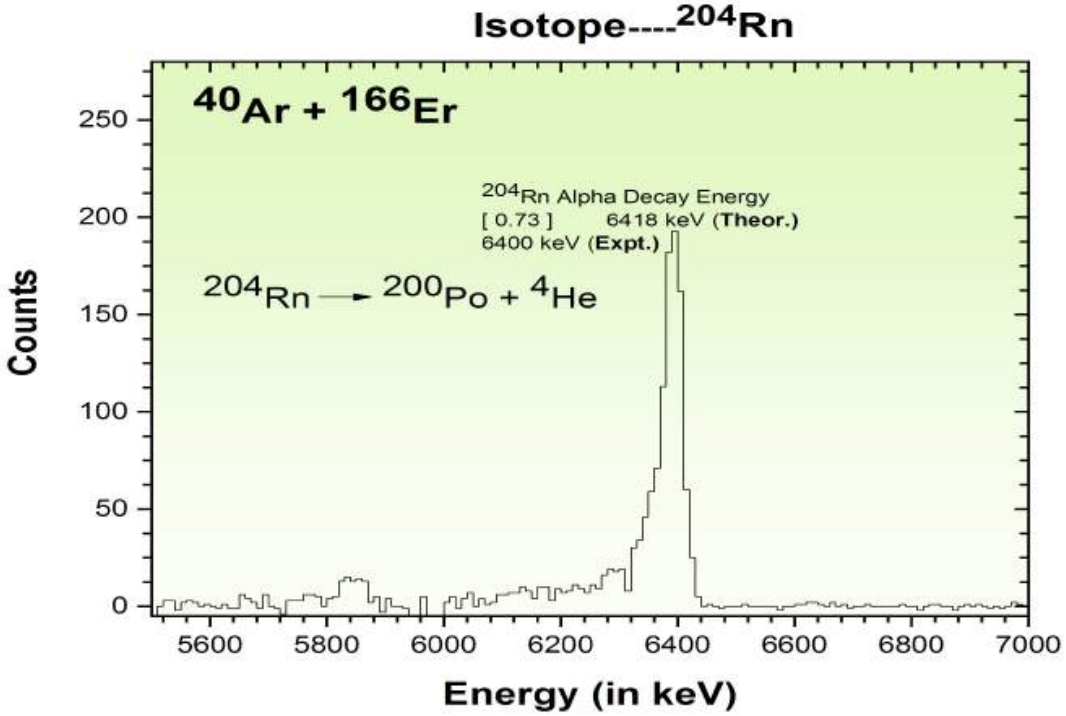
Experimental peaks of ^{201}Rn (6760 keV) & ^{197}Po (6380 keV) are identified which are nearly same as theoretical ones. Please note that for both the isotopes there are two theoretical possible peaks.



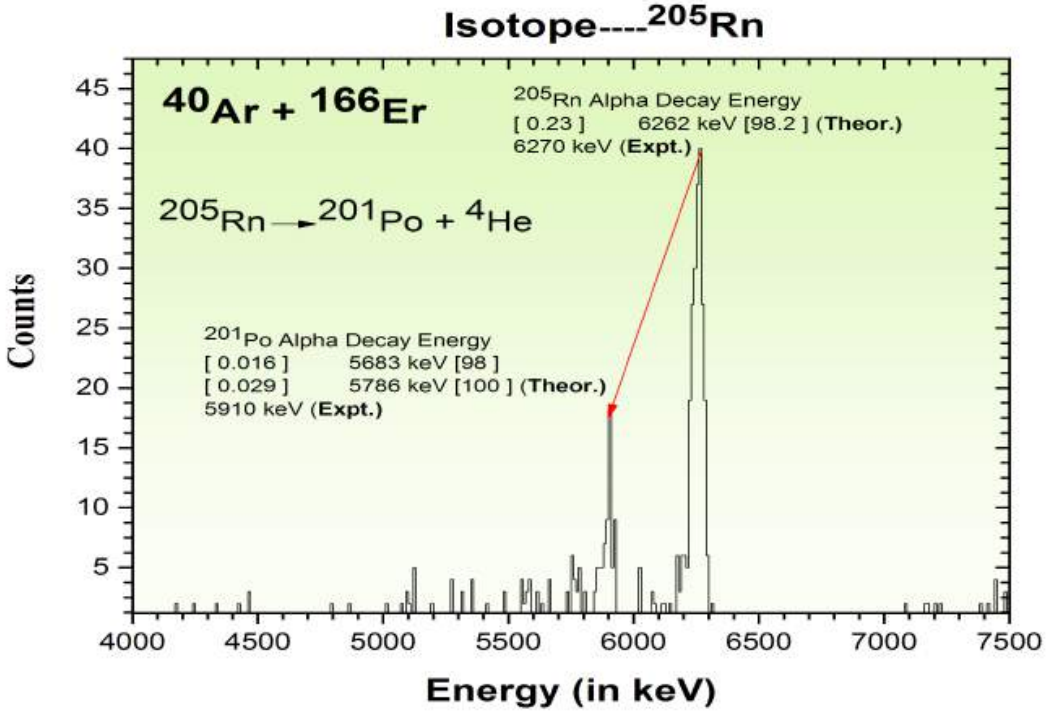
Experimental peaks of ^{202}Rn (6630 keV) & ^{198}Po (6180 keV) are identified which are in very good agreement with theoretical ones.



Experimental peaks of ^{203}Rn (6550 keV) & ^{199}Po (6060 keV) are identified which are nearly same as theoretical ones. For ^{199}Po there are two theoretical possible peaks with same intensity.



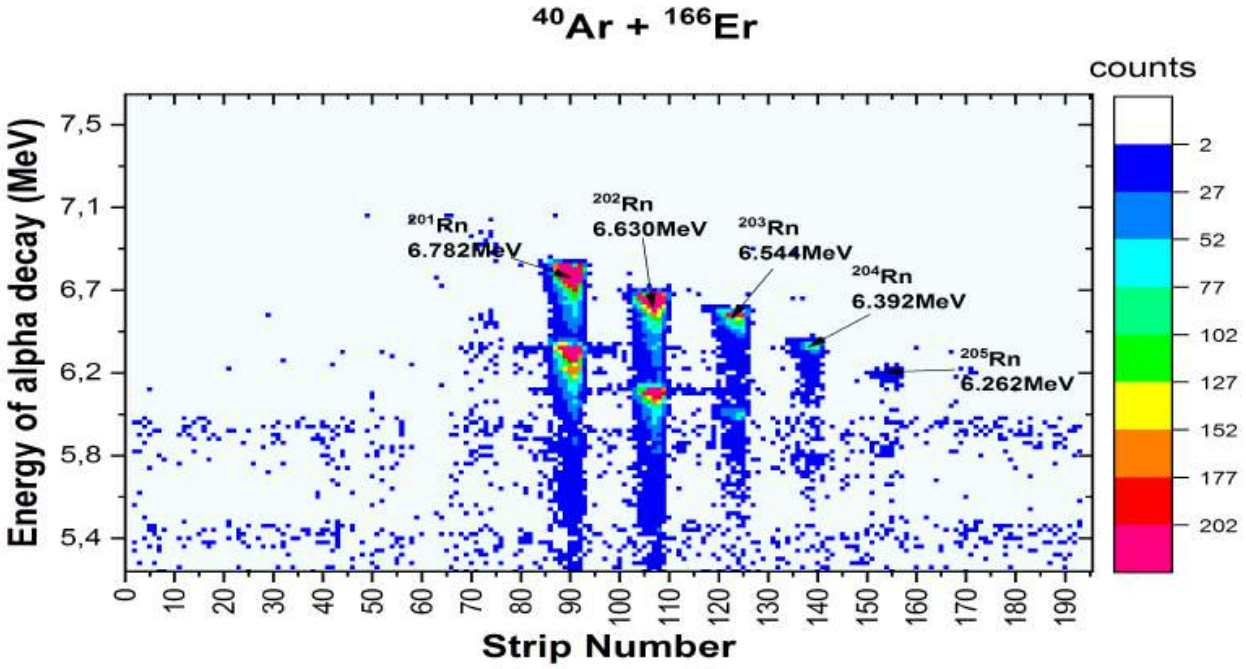
Experimental peaks of ^{204}Rn (6400 keV) is identified which is approximately same as theoretical value. For ^{200}Po no peak is identified due to its really low intensity.



Experimental peaks of ^{205}Rn (6270 keV) & ^{201}Po (5910 keV) are identified for ^{205}Rn it is matching with theoretical value but for ^{201}Po it is showing something higher then expected by theory.

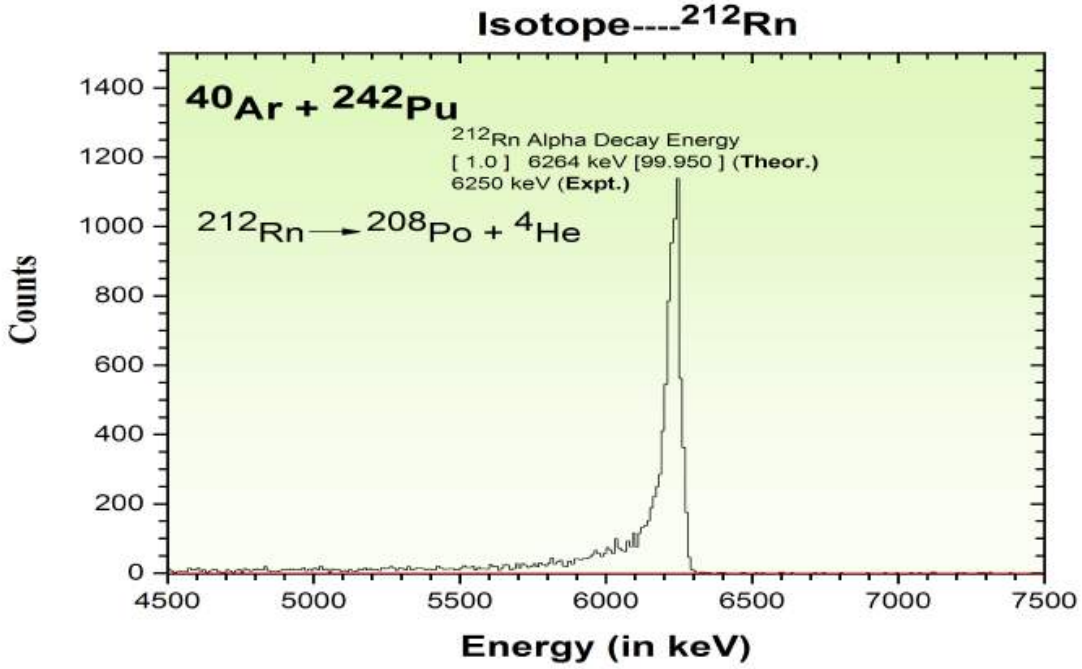
$$^{40}Ar + ^{166}Er = ^{206-xn}Hg + xn$$

Heat map for Rn isotopes

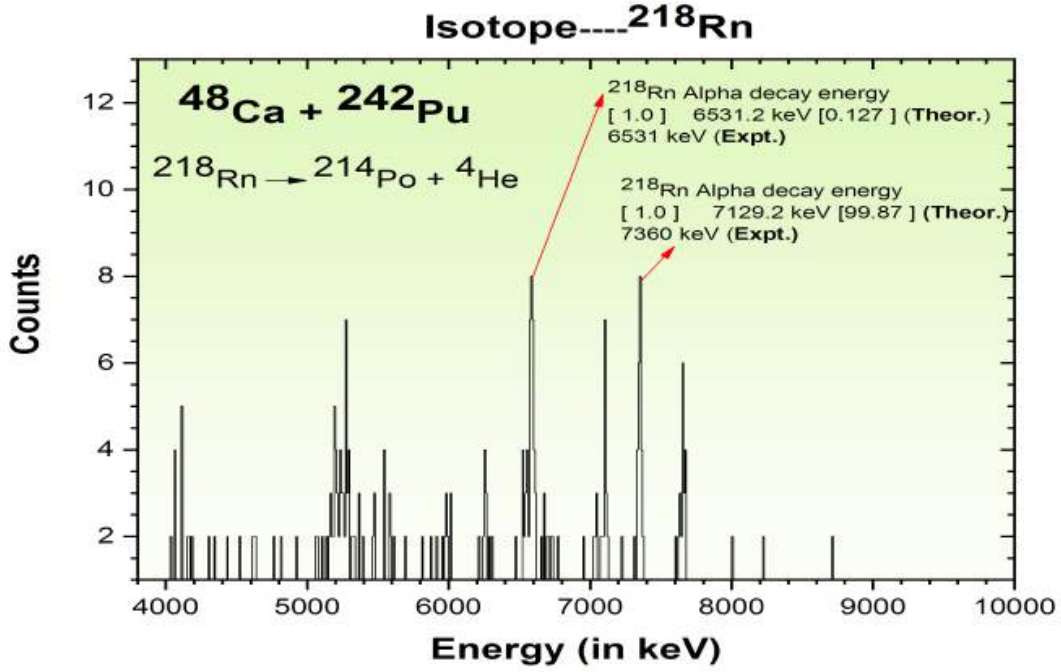


Eα Vs strip no for Rn isotopes (A = 201 to 205).

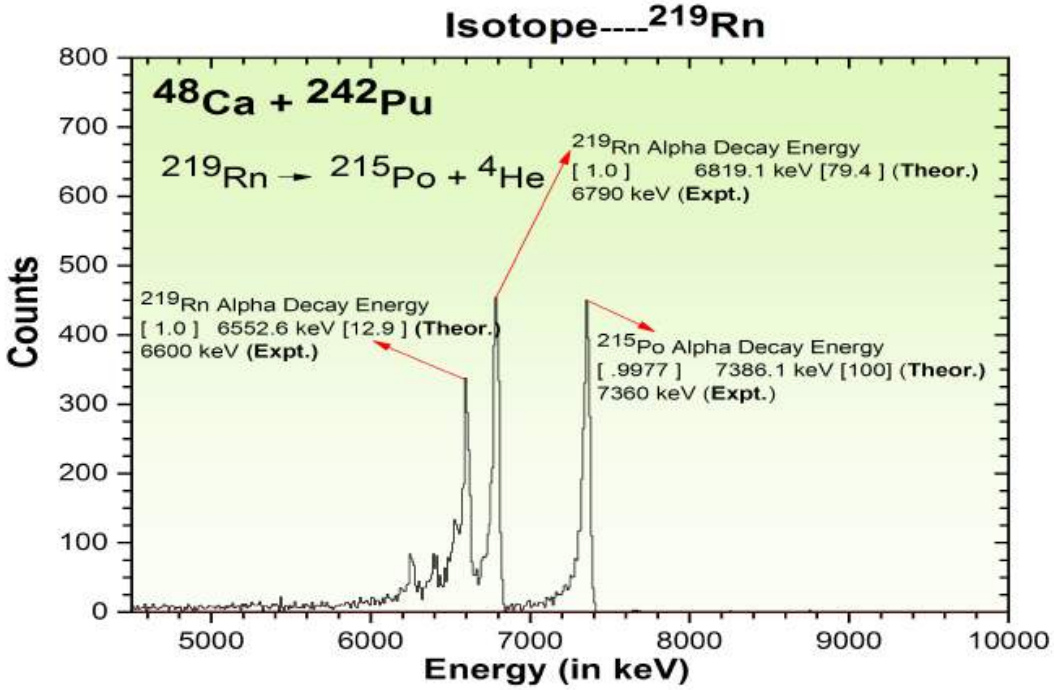
Histograms for Rn isotopes



For ^{212}Rn experiment peak is obtained at 6250 keV which is nearly same as theoretical value but for ^{208}Po it couldn't be identified.

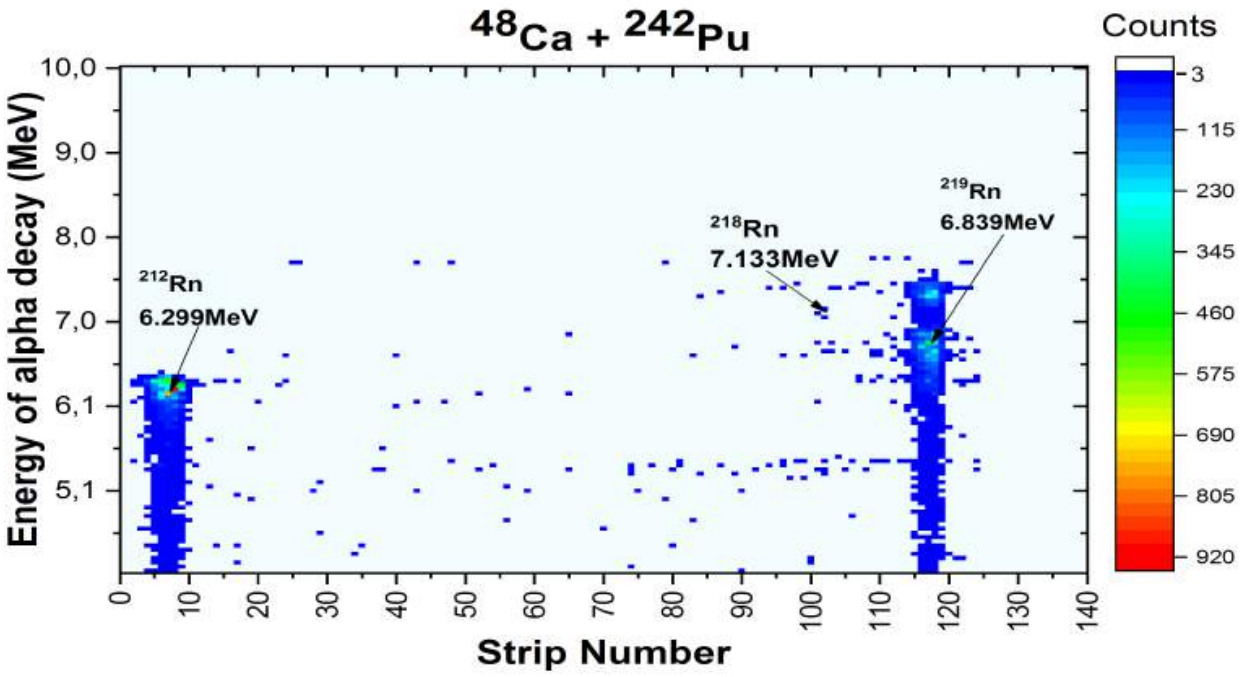


Two peaks for same isotope ^{218}Rn with different energies are identified at 6531 keV & 7360 keV where first one is exactly same as theory suggested but second one is somewhat deviated but for daughter product ^{214}Po no peak is identified.



Two peaks for same isotope ^{219}Rn with different energies are identified at 6790 keV & 6600 keV both are somewhat deviated and for daughter product ^{215}Po peak is identified at 7360 keV which meets with theoretical value upto some extent.

Heat map for Rn isotopes



Eα Vs strip no for Rn isotopes (A = 212, 218 & to 219).

Conclusion:

Here working on this report MASHA facility and its different components are described obviously some modifications can be done to get better energy & time resolution (which is definitely an area of interest for short-lived isotopes), to reduce as much noise as possible and get more information about atoms. Energies of alpha decay of different isotopes of Hg & Rn are identified. An idea of ISOL method is given where to interrogate the nuclei, they are taken away from the place of their production to an environment of organised experimental facilities where a large background from nuclear reactions is available to them.

Acknowledgment:

I am grateful to the people in JINR institute and INTEREST team for organizing this programme and allowing me to participate in the same. I am really grateful to my project supervisor Mr. Vedeneev Vyacheslav Yurievich, for addressing all my queries, providing enough material for this project and giving a lot of time to me to made me understand the things. I would really like to thank Mr. Naman Sharma, INTEREST Participant at JINR for providing the necessary information and guiding me to use Origin Pro software.

References:

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3) Yu. Oganessian Eur. Phys. J. A 42, 361–367 (2009) DOI 10.1140/epja/i2009-10861-y