Joint Institute For Nuclear Research
Flerov Laboratory Of Nuclear Reactions

Report On Interest Programme Wave −03

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

Naman Sharma
Indian Institute Of Technology, Roorkee, India

Scientific Supervisor: **Mr. Vedeneev Vyacheslav Yurievich**
JINR, Dubna, Russia

Wave Period: 04/02/2021 – 19/03/2021

Abstract

Since last few decades an array of experiments has reported the existence of super heavy elements and attempts have been made to study them. Depending upon the properties of system, cyclotrons and accelerators are implemented. Experimental setup for MASHA (Mass Analyzer of Super Heavy Atoms) which has a mass resolution $\frac{m}{\Delta m} = 1700$, is explained in terms of its construction, installation and working along with the upgradations done in some of its components. The very purpose of MASHA is actually to identify superheavy elements by their masses. Detection of nuclei, near shell closure (N = 126) in MASHA setup is discussed. Alpha decay energies of different isotopes of Hg and Rn 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.

Contents

1. 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. In section 3 ISOL method has been described which is a technique to separate out the ion beams from SHEs. Alpha decay energy peaks have been identified for Hg and Rn isotopes and their respective first daughters also, if branching ratio is noticeable.

2. MASHA

MASHA facility, located at the beamline 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 fig. 1). Short-lived isotopes decays are being detected in the focal plane of the separator.

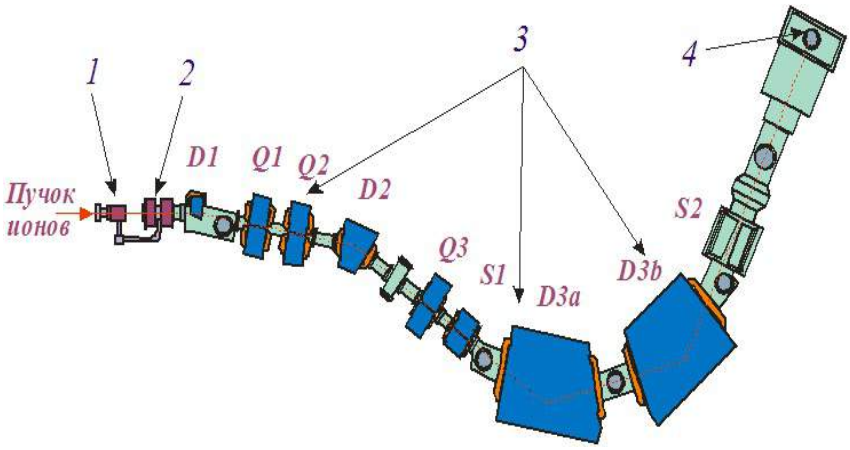
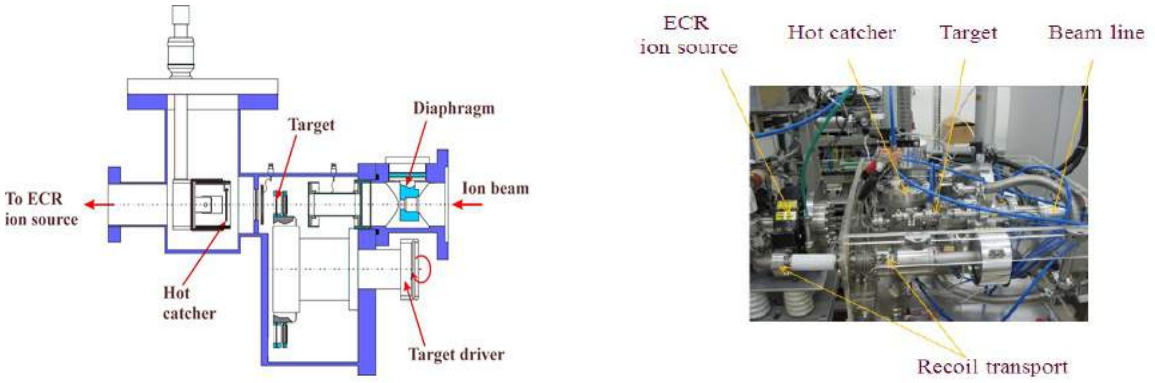


Figure 1: MASHA (Mass Analyzer of Super Heavy Atoms) [7]

2.1 Components

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



(a) Block diagram of setup [4]

(b) Actual figure of setup [4]

Figure 2

2.1.1 Ion Source

To ionize atoms of nuclear reaction products, ion source (fig. 2) 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 $(1-2)\times10^{-5}$ mbar and a microwave oscillator power of 30 W.

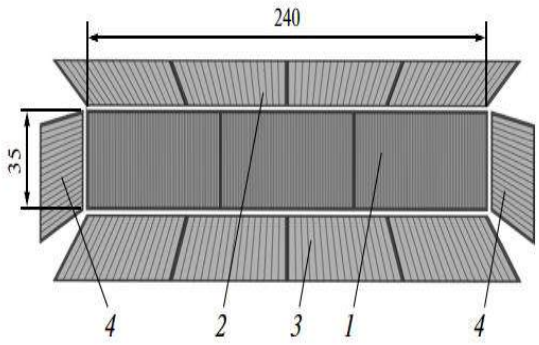
2.1.2 Target assembly and Hot Catcher

Hot catcher is a part of the target assembly shown in Fig. 2, it was used to inject products of complete fusion reactions into the ECR source in the first experiment to measure the masses of elements 112^{th} and 114^{th} elements. 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 during the experiments the temperature needed was set in terms of the heater current.

2.1.3 Detectors and Control System

An unique strip detector with a pitch of 1.25 mm and total 192 no. of strips is designed to estimate low direct current. It serves the job of controlling the operating modes of the ECR source. Calibrating the mass spectrometer, this detector is set in front of the silicon detector by the method of vacuum tight feedthrough. Extraordinary multichannel electronic module (a single module can be utilized for total 64 channels, with lower limit to be 60 pA and upper one to be 5 µA), mounted externally on the vacuum chamber with the

(a) Actual Picture



(b) Parts of silicon detector 1) fornt, 2) top, 3) bottom & 4) side [5]

Figure 3: Silicon multistrip detector

detectors are used to get an quantitative idea of low currents and information are sent straightforward to a PC through a specified serial interface board (PCI Board).

To recognize the decay of the products of nuclear reactions, a well-type silicon detector (fig. 3) is installed in the focal plane of the mass spectrometer. The plane of the frontal detector part (covering an area of 240 $\times$ 35 mm^2 of the focal plane) is oriented along the normal to the beam direction.

Besides this, to get an enhanced efficiency of detecting reaction product decays, some geometric manipulations are needed which are done by the installation of four side detectors around the frontal detector part (fig. 3(b)) containing 64 strips in both lower and upper planes and 16 strips in left and right planes.

This entire detector assembly is mounted into a single frame made up of metal. Standard value of the operating bias of the detectors is –40 V.

The above described setup allows detector to makes it possible to detect no less than 90 % alpha particles emitted in a single nuclear decay, at the center of the detector's frontal part.

3. ISOL Method

ISOL (Isotope Separation On-Line Method) is used to separate reaction products (basically SHEs) from the incident beam (fig. 4), obtained from heavy ion induced fusion evaporation reactions.

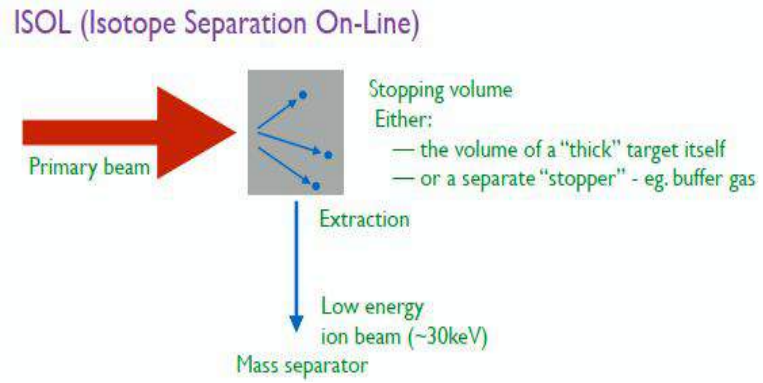


Figure 4: Demonstration of ISOL, Low energy ion beams are separated applying a stopping volume [8]

This technique to used to produce a range of radioisotopes. A combination of element selective and mass selective processes which result in a very pure, carrier-free batch of the isotope of interest is used in this technique. First a target material is irradiated with high energy protons. Afterwards, the target it heated to extract the produced isotopes. These isotopes are selectively ionized in the ion source, this allows the selective ionization of isotopes. This ion beam passes through a mass separating magnetic field to result in an ion beam which is very pure in mass. As a final step this ion beam will be collected in a metallic foil or a salt. Afterwards, the radioisotopes can be separated from the collection material using dissolution and simple radiochemical purifications.
In real practice it is difficult to separate pure ion beam since always there may be some isobars of different elements.

4. Results 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.

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

Histograms for Hg isotopes

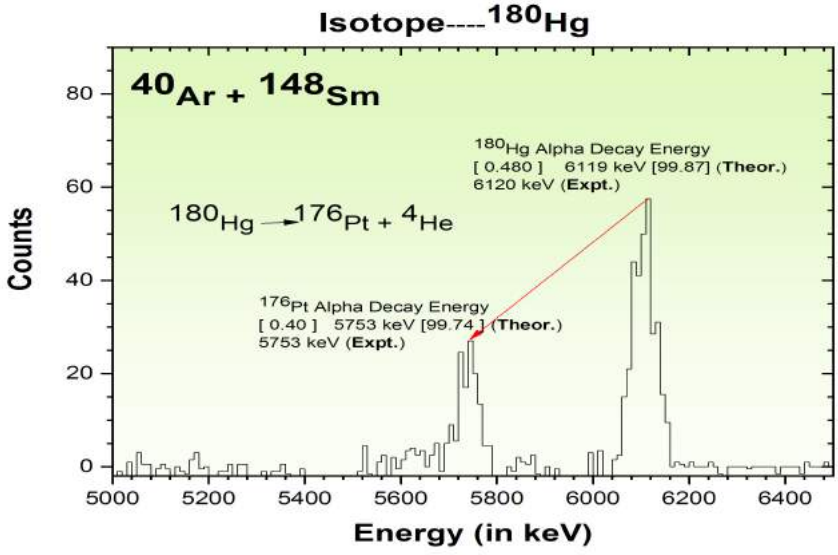


Figure 5: Expt. peaks of ^{180}Hg (6120 keV) & ^{176}Pt (5753 keV) are identified and both are in very good agreement with theoretical values.

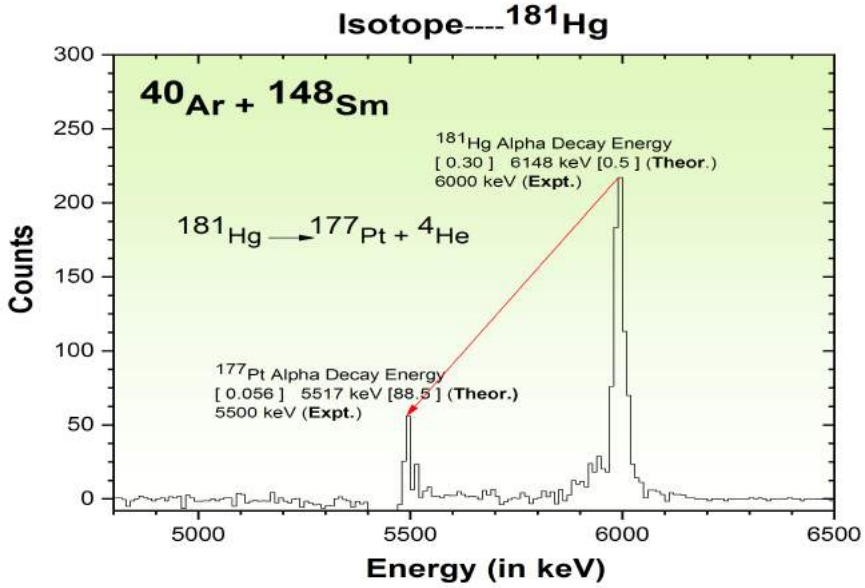


Figure 6: Expt. peaks of ^{181}Hg (6000 keV) & ^{177}Pt (5500 keV) are identified and both are approximately same to theoretical values.

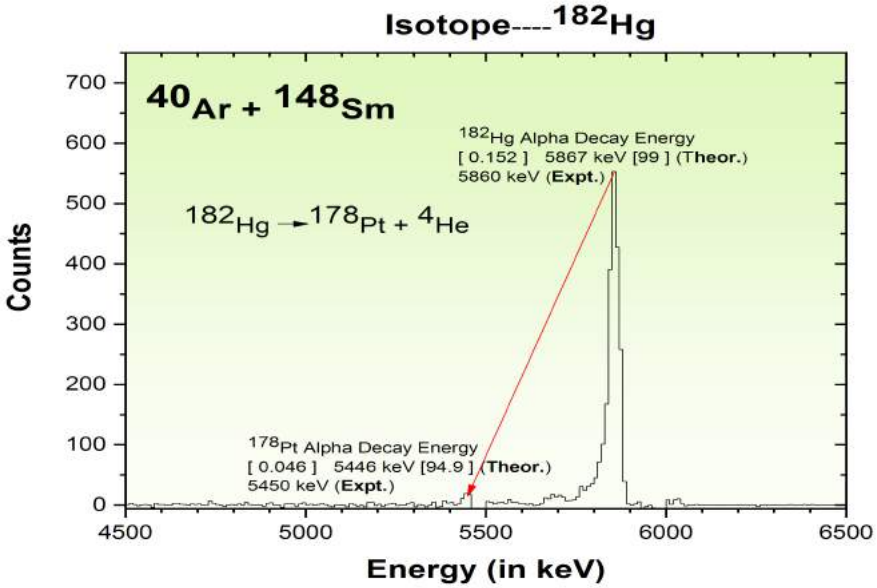


Figure 7: Expt. peaks of ^{182}Hg (5860 keV) & ^{178}Pt (5450 keV) are identified and both are nearly meeting with theoretical values.

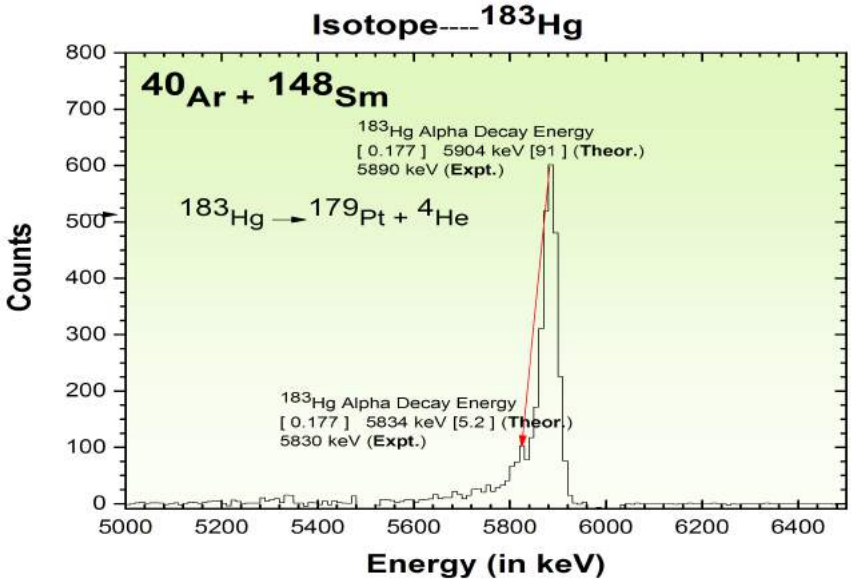


Figure 8: Expt. peaks of ^{183}Hg (5890 keV) & ^{176}Pt (5830 keV) are identified for ^{176}Pt it is approximately same as theoretical values whereas for ^{183}Hg it deviates little bit.

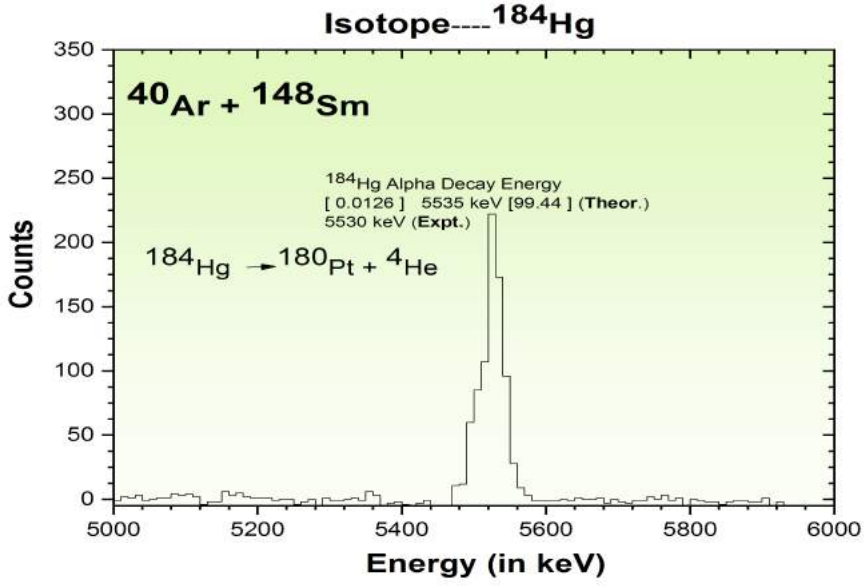


Figure 9: Expt. peak of ^{184}Hg (5530 keV) is identified and it is approximately same as theoretical values whereas for ^{180}Pt no peak is identified due to its really low intensity.

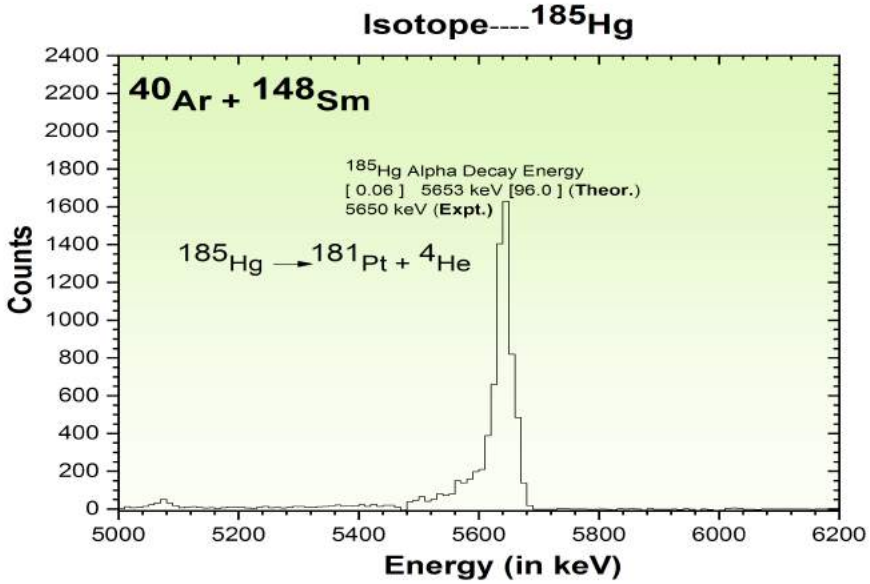


Figure 10: Expt. peak of ^{185}Hg (5650 keV) is identified and it is nearly same as theoretical values whereas for ^{181}Pt no peak is identified due to its really low intensity.

Heat map for Hg isotopes

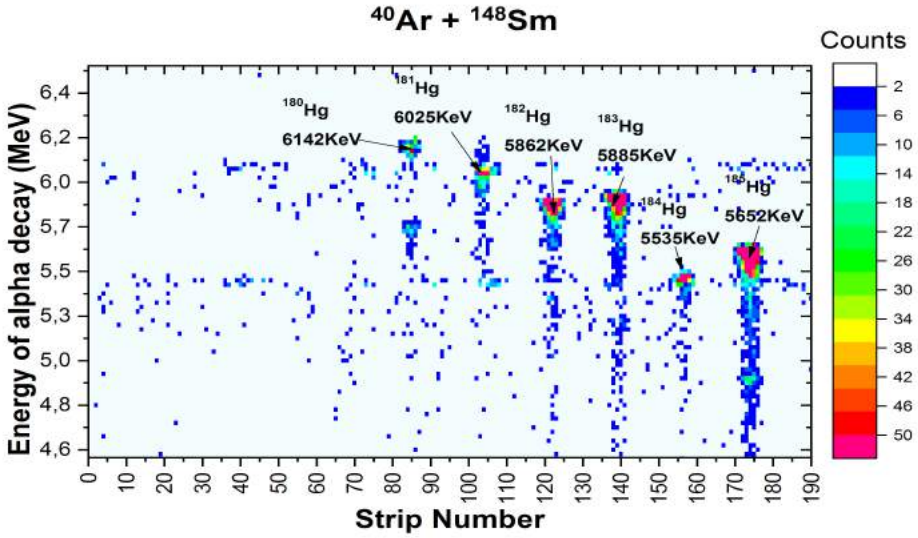


Figure 11: $E\alpha$ Vs strip no for Hg isotopes (A = 180 to 185).

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

Histograms for Rn isotopes

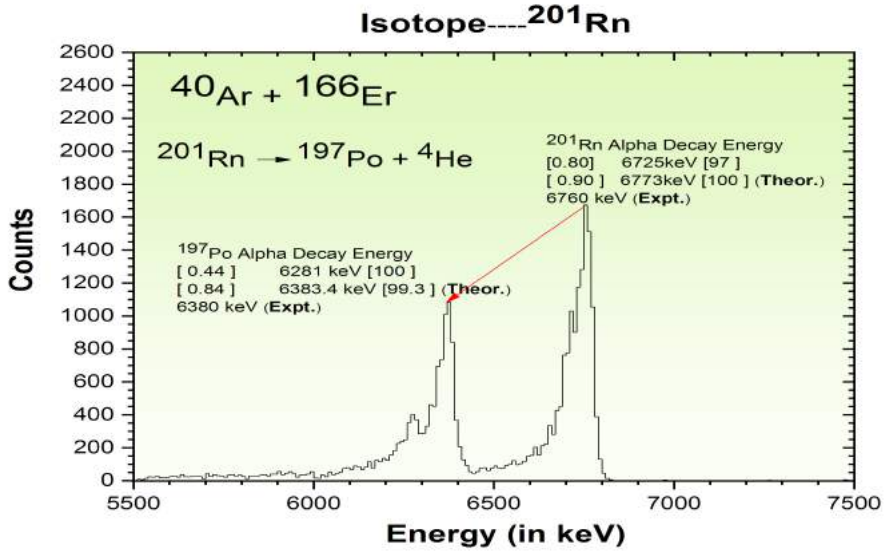


Figure 12: Expt. peaks of ^{201}Rn (6760 keV) & ^{197}Po (6380 keV) are identified which are nearly same as theoretical ones. Please note that for both the isotopes there are two theoretical possible peaks.

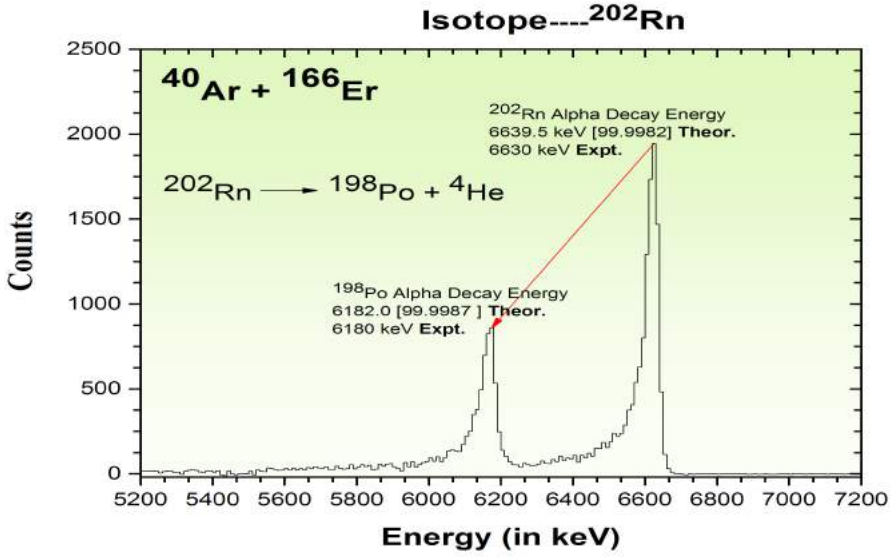


Figure 13: Expt. peaks of ^{202}Rn (6630 keV) & ^{198}Po (6180 keV) are identified which are in very good agreement with theoretical ones.

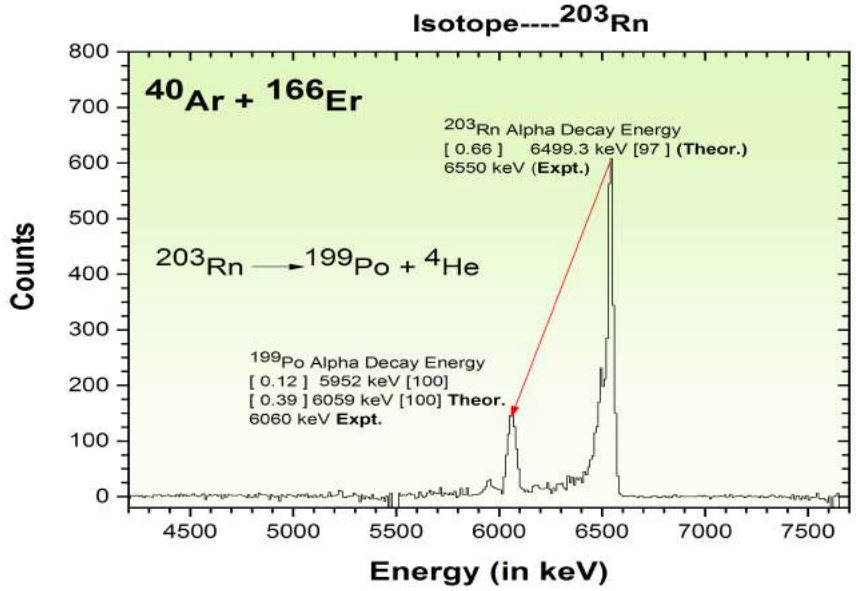


Figure 14: Expt. peaks of ^{203}Rn (6550 keV) & ^{199}Po (6060 keV) are identified which are nearly same as theoretical ones. For ^{199}Po there are two theoretical possible peaks with same intensity.

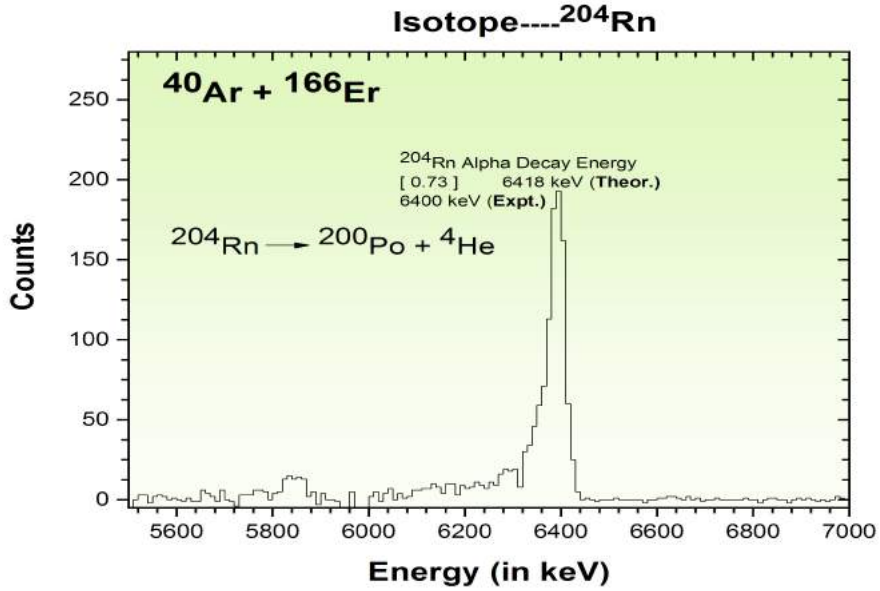


Figure 15: Expt. peaks of ^{204}Rn (6400 keV) is identified which is approximately same as theoretical value. For ^{200}Po no peak is identified due to its really low intensity.

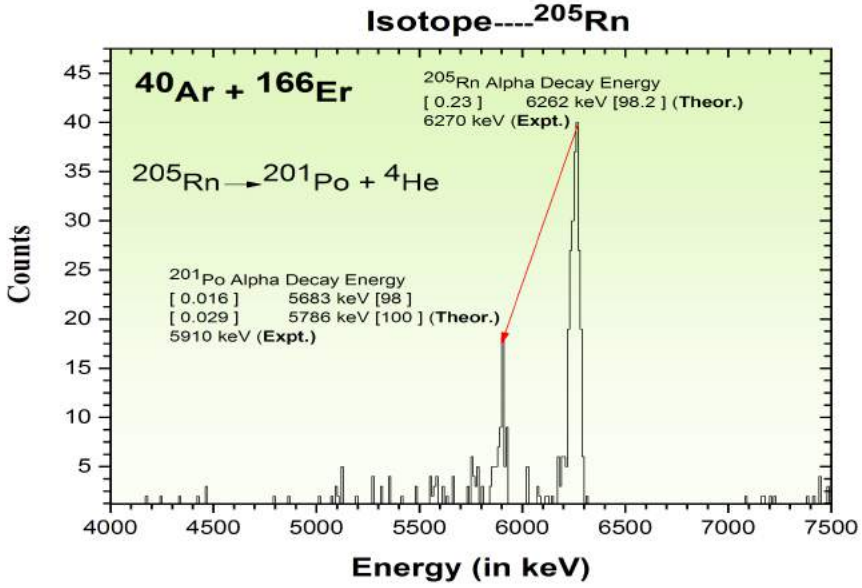


Figure 16: Expt. peaks of ^{205}Rn (6270 keV) & ^{201}Po (5910 keV) are identified for ^{205}Rn it is matching with theoretical value but for ^{201}Po it is showing something higher then expected by theory.

Heat map for Rn isotopes

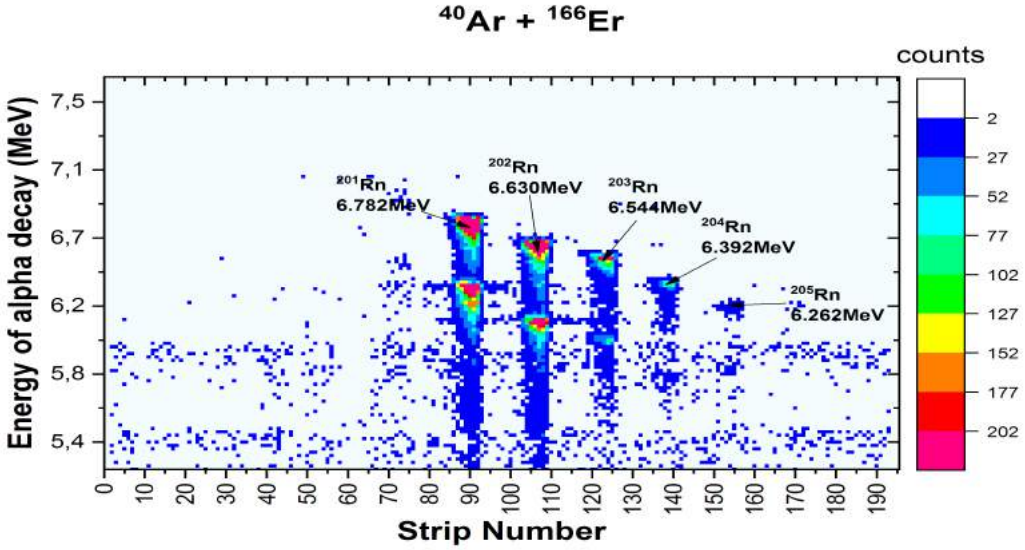


Figure 17: $E\alpha$ Vs strip no for Rn isotopes (A = 201 to 205).

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

Histograms for Rn isotopes

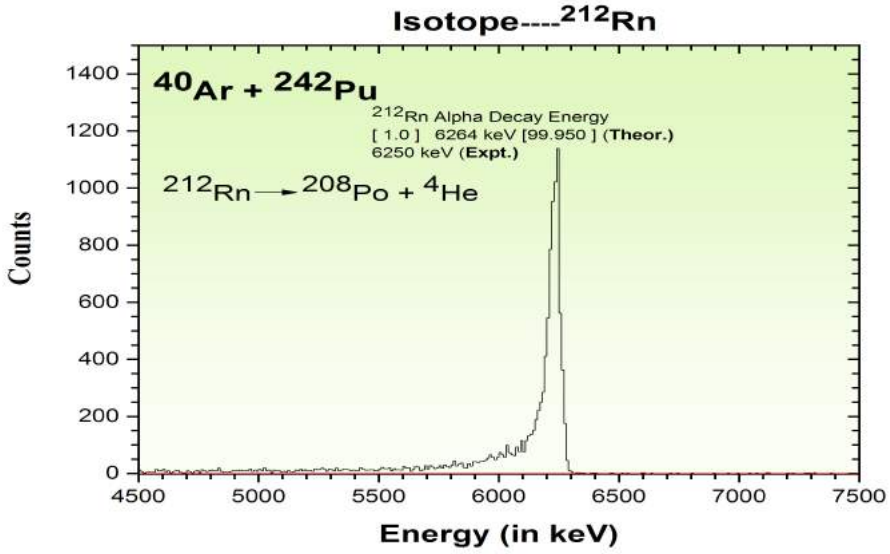


Figure 18: For ^{212}Rn expt. peak is obtained at 6250 keV which is nearly same as theoretical value but for ^{208}Po it couldn't be identified.

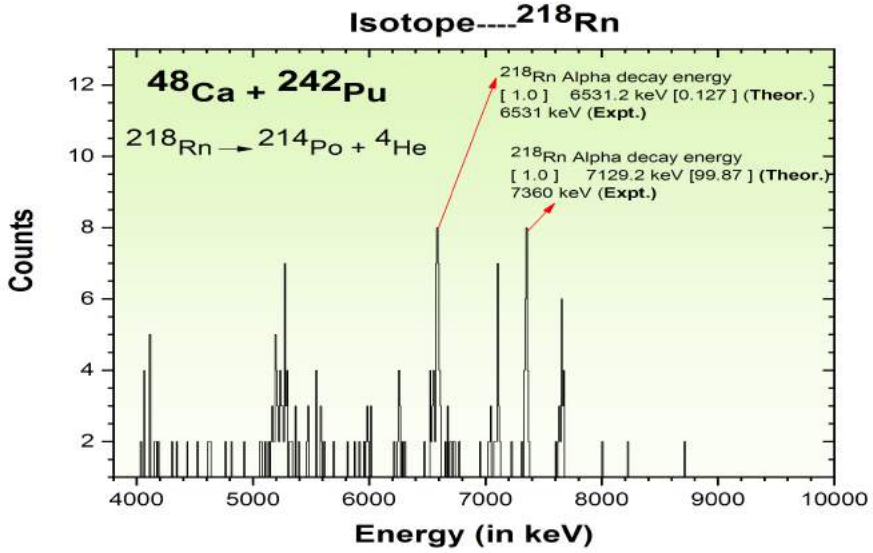


Figure 19: Two peaks for same isotope ^{218}Rn with different energies are identified at 6531 keV & 7360 keV where first one is exactly same as theory suggested but second one is somewhat deviated but for daughter product ^{214}Po no peak is identified.

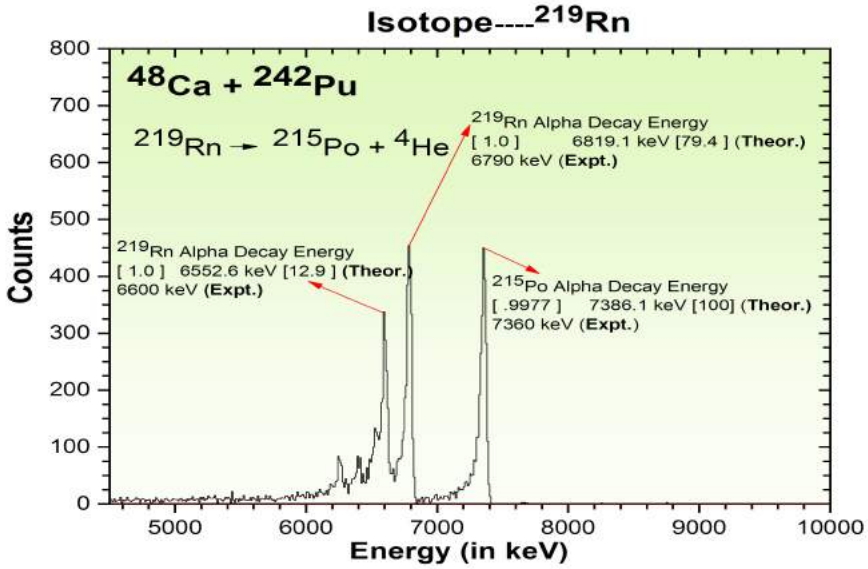


Figure 20: Two peaks for same isotope ^{219}Rn with different energies are identified at 6790 keV & 6600 keV both are somewhat deviated and for daughter product ^{215}Po peak is identified at 7360 keV which meets with theoretical value upto some extent.

Heat map for Rn isotopes

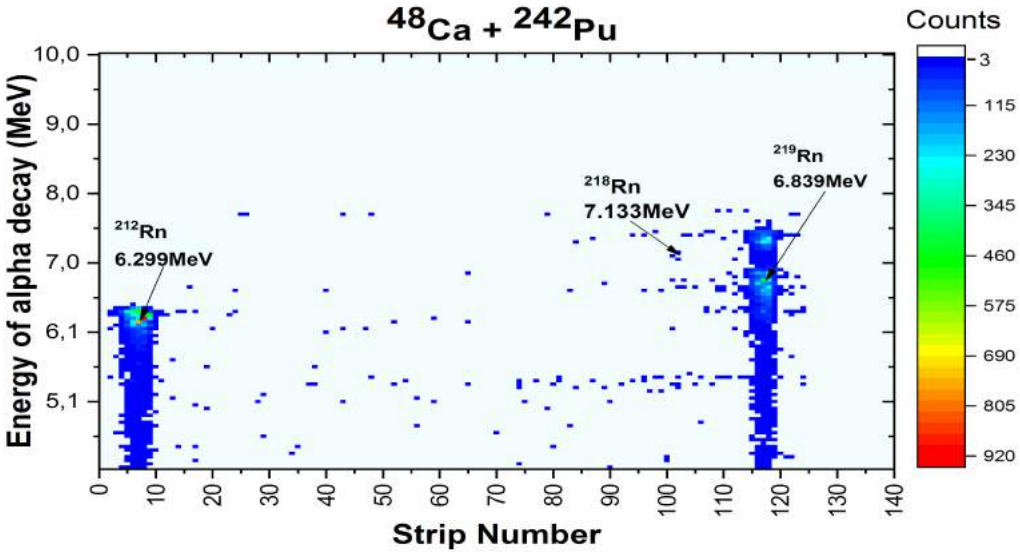


Figure 21: $E\alpha$ Vs strip no for Rn isotopes (A = 212, 218 & to 219).

5. 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.

6. Acknowledgement

I am grateful to the people in JINR institute and INTEREST team for organizing this programme and allowing me to participate. 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. Rinku Prajapat, PhD Scholar at IITR for informing, stimulating and suggesting me about this project.

7. References

1) Heinz W G¨aggeler. Mendeleev's principle against einstein's relativity: news from the chemistry of superheavy elements. Russian Chemical Reviews, 78(12):1139, 2009.
2) Dockx, K., Elias Cocolios, T., Stora, T. (2019). ISOL Technique for the Production of 225Ac at CERN-MEDICIS. Journal of Medical Imaging and Radiation Sciences, 50(1), S23. 2019.03.072.
3) Yu Ts Oganessian, VA Shchepunov, SN Dmitriev, MG Itkis, GG Gulbekyan, MV Khabarov, VV Bekhterev, SL Bogomolov, AA Efremov, SV Pashenko, et al. The project of the mass separator of atomic nuclei produced in heavy ion induced reactions. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 204:606613, 2003.
4) AM Rodin, AV Belozerov, EV Chernysheva, SN Dmitriev, AV Gulyaev, AV Gulyaeva, MG Itkis, J Kliman, NA Kondratiev, L Krupa, et al. Separation efficiency of the masha facility for short-lived mercury isotopes. Hyperfine Interactions, 227(1):209221, 2014.
5) AM Rodin, AV Belozerov, DV Vanin, V Yu Vedeneyev, AV Gulyaev, AV Gulyaeva, SN Dmitriev, MG Itkis, J Kliman, NA Kondratiev, et al. Masha separator on the heavy ion beam for determining masses and nuclear physical properties of isotopes of heavy and superheavy elements. Instruments and Experimental Techniques, 57(4):386393, 2014.
6) Domenico Rosaci and Giuseppe ML Sarn´e. Masha: A multi-agent system handling user and device adaptivity of web sites. User modeling and user-adapted interaction, 16(5):435462, 2006.
7) V Yu Vedeneev, AM Rodin, L Krupa, AV Belozerov, EV Chernysheva, SN Dmitriev, AV Gulyaev, AV Gulyaeva, D Kamas, J Kliman, et al. The current status of the masha setup. Hyperfine Interactions, 238(1):19, 2017.
8) Bradley cheal-2 laser spectroscopy.