Experimental study of evaporation residue of Hg and Rn isotopes in complete fusion and multinucleon transfer reactions.

Joint Institute for Nuclear Research
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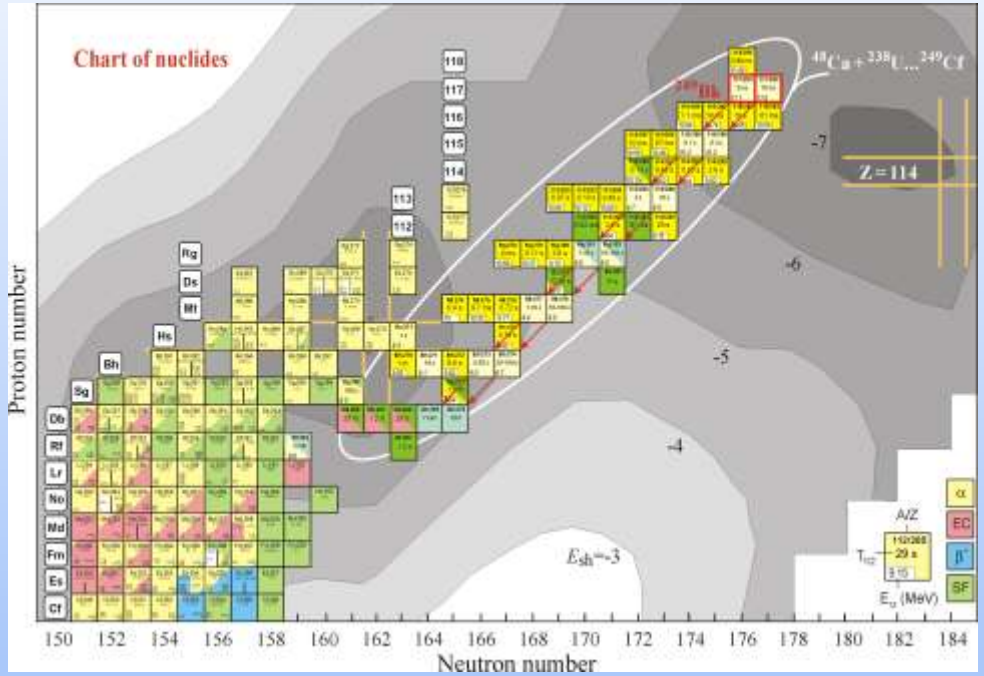
Outline

- Motivation
- Physical installation description
- Aim and Objectives
- Methodology
- Results

Motivation



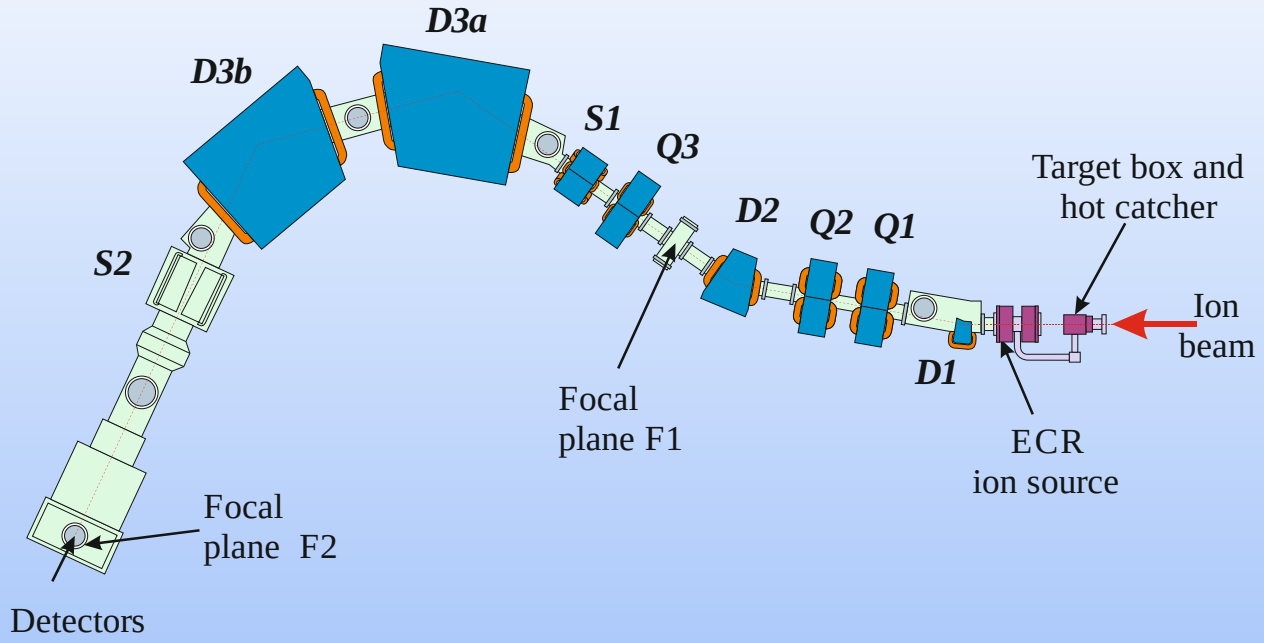
- The mass analysis is the crucial “stone” for the understanding the fundamentals of nuclei with its help we could determine the whole binding energy of the nucleus – the integral characteristic of all atomic and nuclear forces which is a key of fundamental physics from nuclear to symmetry and astrophysics.
- For superheavy elements mass determination the mass-separator was built.

MASHA

- The mass-spectrometer MASHA (Mass Analyzer of Supper Heavy Atoms) was designed for determination of the masses of super heavy elements.
- The unique property of this mass spectrometer is its ability to measure masses of the synthesized super heavy isotopes ($m/\Delta m \sim 1300$) simultaneously with registration of their α-decay and/or spontaneous fission.
- The synthesis of the new super heavy elements stimulated works on the development of methods of their identification by means of the technique called Isotope Separation On-Line (ISOL), which a method of making effectively ion beams, which are created in nuclear processes at high energies with huge emittance, into low-energy beams with minimal emittance and low energy spread.

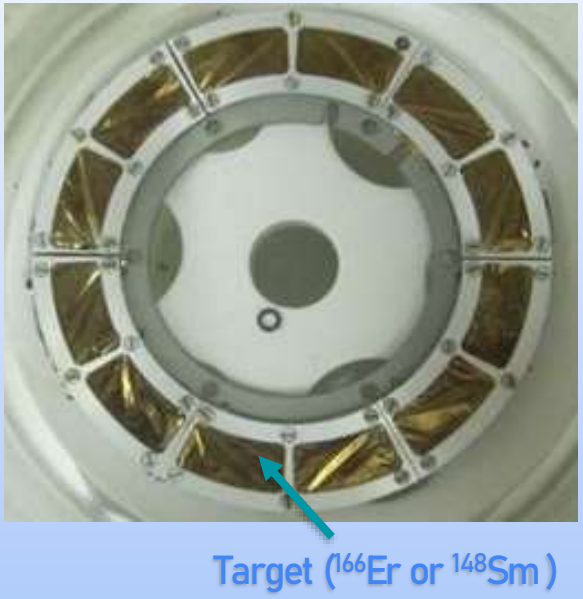
The mass-spectrometer “MASHA” is connected to the U-400M cyclotron of the Flerov Laboratory for Nuclear Reactions (FLNR) JINR, Dubna.

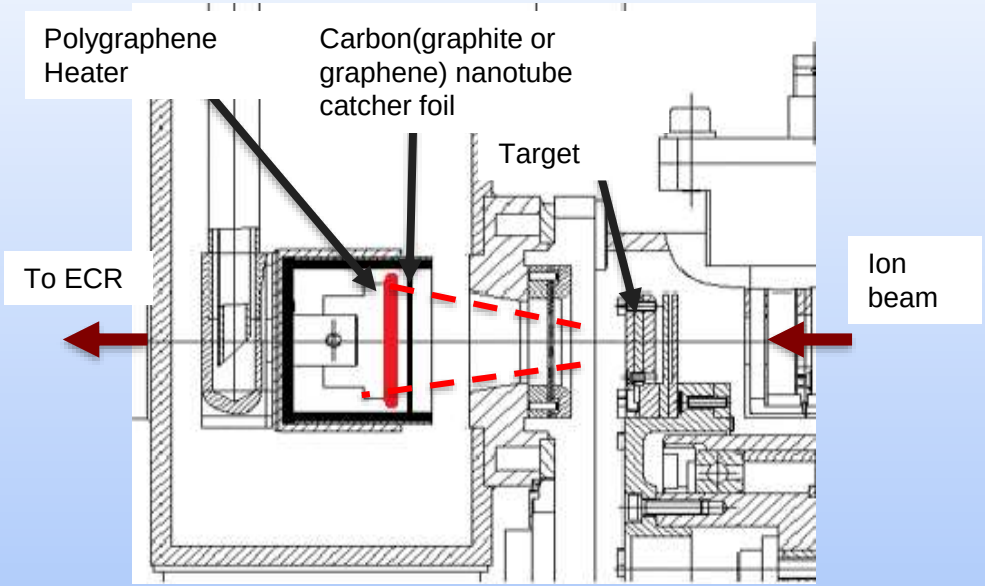
MASHA schematics



- MASHA setup is a combination of ISOL method of nuclear synthesis and separation of radioactive nuclei with the classic magneto-optical mass analysis, allowing identification of the synthesized nuclides in the wide mass range (A = 1 – 450 u).

New arrangement of rotating target and separation system

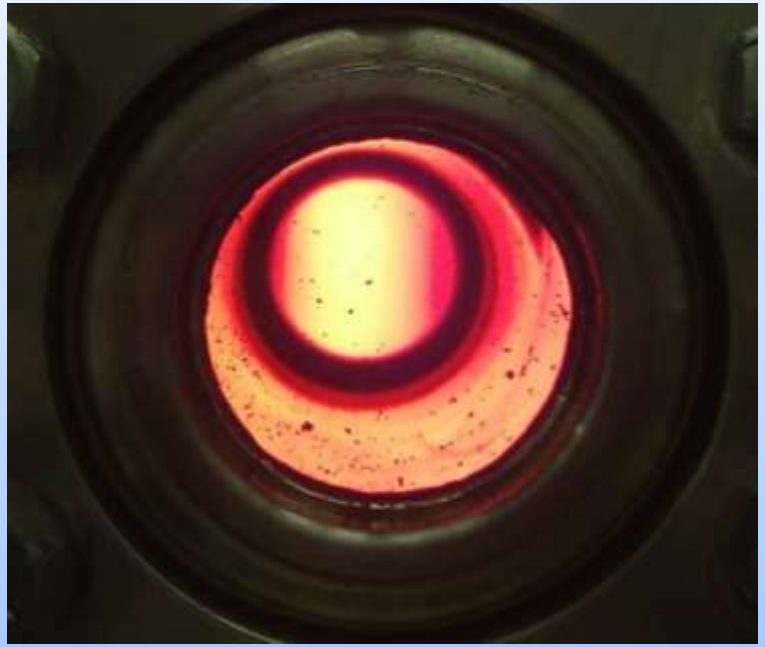




Rotating target wheel

Atoms, synthesized in nuclear reactions and emitted from the target, are stopped in the hot catcher. Due to diffusion, they move towards the hot catcher surface and next to the chamber of the ECR ion source, where are ionized to charge state Q = +1 and accelerated with the aid of the three electrode system.

Hot catcher



Represents the main unit of ISOL system. Heated up to 1500-1800°C.

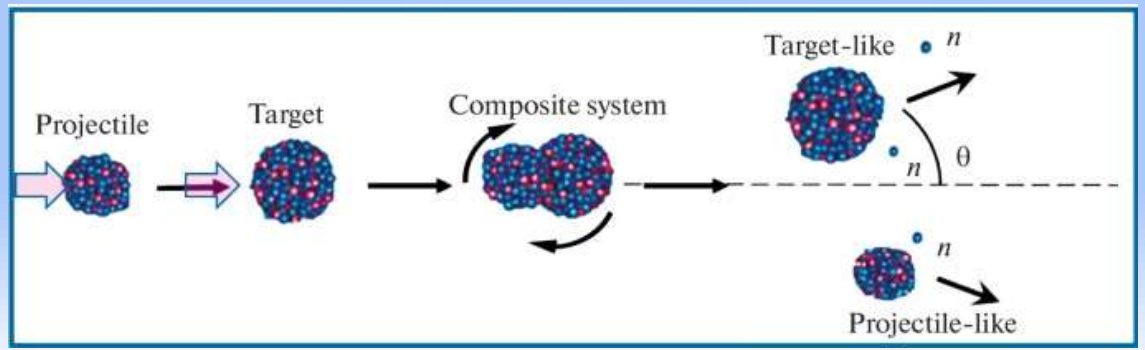
Focal strip detector

Focal plane silicon multi strip detector
Silicon detector well-type:
Front: 3 crystals 64 strips each. Pitch 1.25 mm;
Side: 4 crystals each side 16 strips. Pitch 5 mm;
Latter: 1 crystal like side ones.

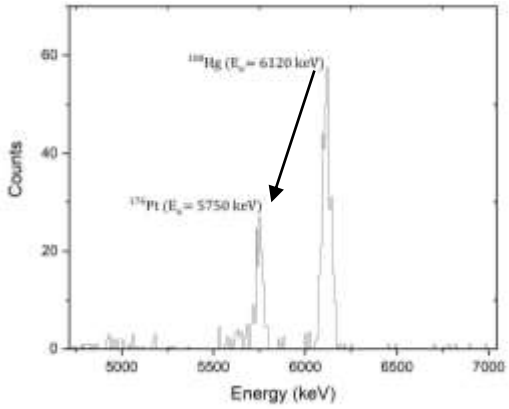
Aim of the project

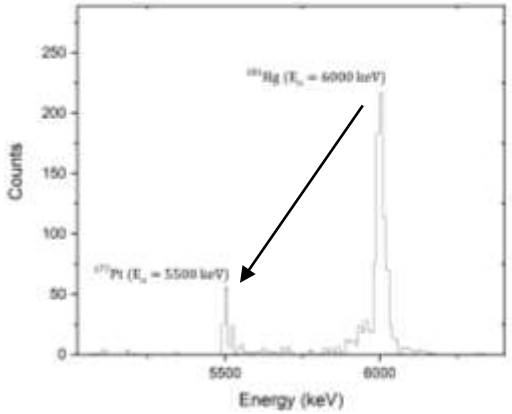
- A systematic study of the fusion evaporation reactions on heavy ion beams.
- To get acquainted with the basics of α-decay analysis using decay chains of investigated nuclei.
- To perform peak analysis and the strip detector calibration.

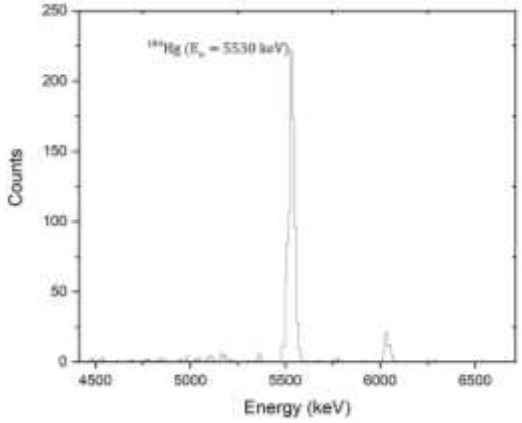
As the production of the superheavy nuclei is a long and complicated process due to its little cross-section, for test experiments the nuclei of Hg and Rn was chosen. Mercury supposed to be a homologue to superheavy element Cn with Z=112 and stands in the same row in Periodic table, thus representing the same physical and chemical properties as known SHEs, but has huge cross-section and greater lifetimes. Radon (inert gas) was chosen as the comparative to adhesive mercury.
Test reactions shown in this work:
Complete fusion:
$^{40}Ar + {}^{148}Sm \rightarrow {}^{188\text{-}xn}Hg+xn;$
$^{40}Ar + {}^{166}Er \rightarrow {}^{206\text{-}xn}Rn+xn;$
Multinucleon transfer:
$^{48}Ca + {}^{242}Pu$ leading to neutron rich Rn isotopes near N=126 shell closure and are of a great interest also.

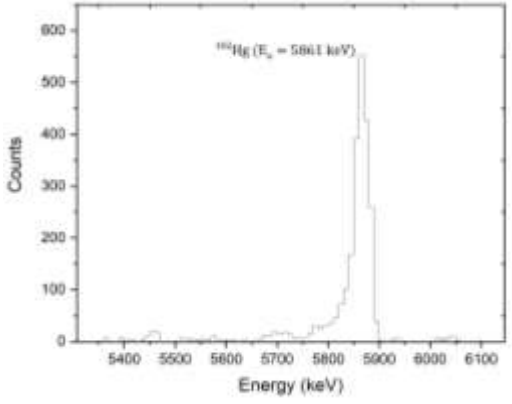


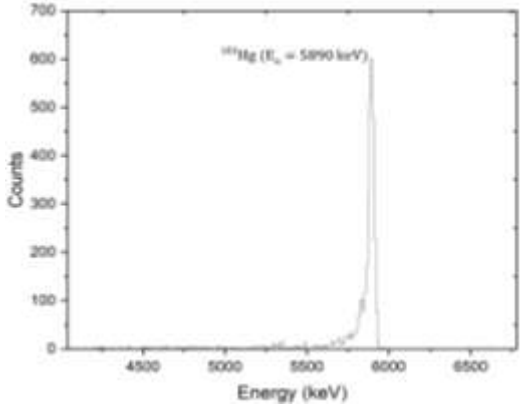
Processed energy spectrums on reaction $^{40}Ar + {}^{148}Sm$ with beam energy of $E_{beam} = 5 - 6\ MeV/n$.

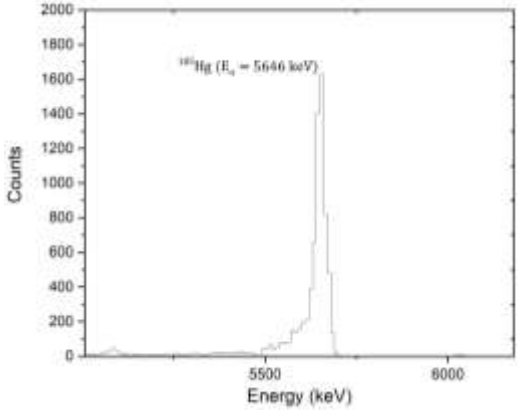


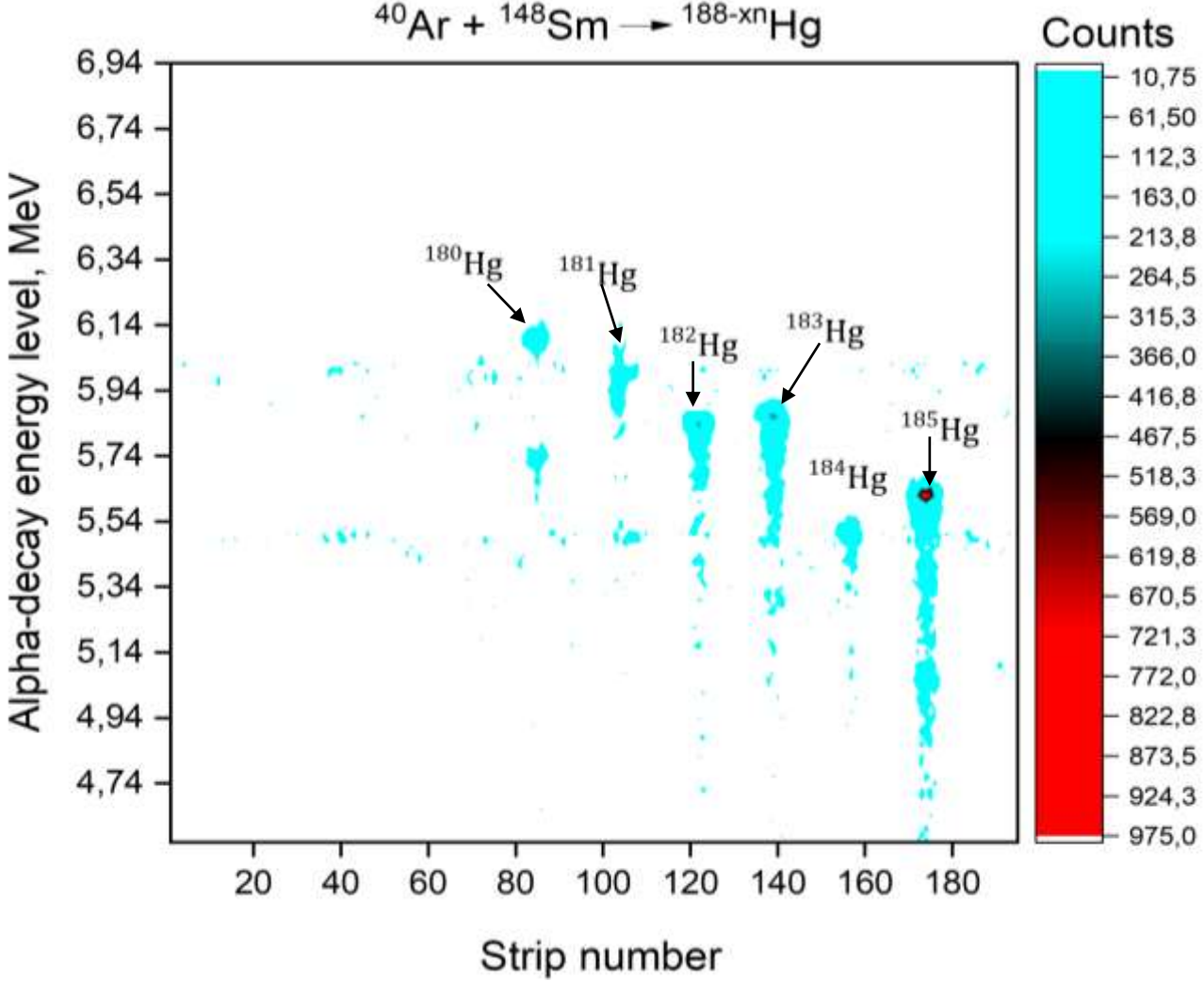




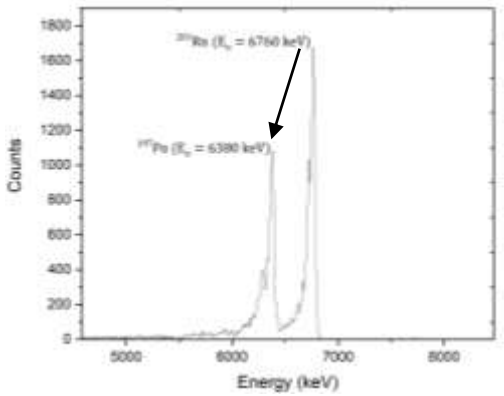


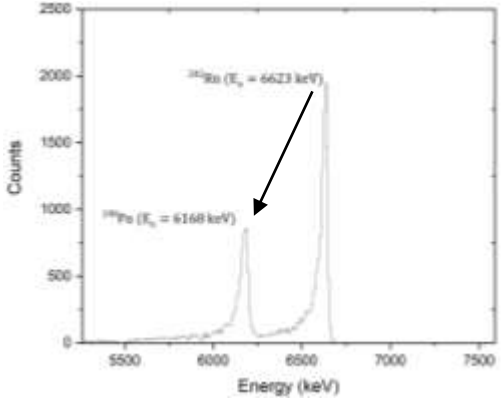


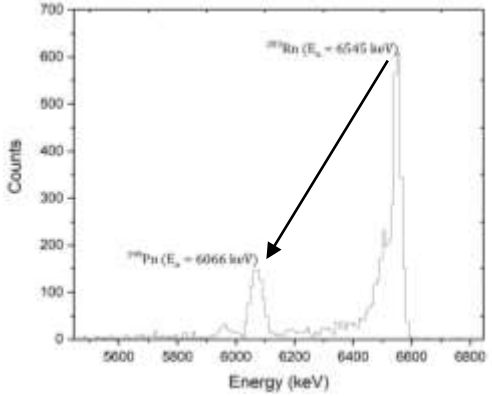


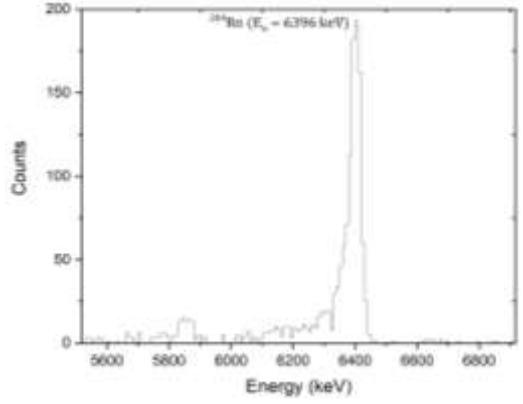

40Ar + 148Sm → 188-xnHg
Counts
10,75
61,50
112,3
163,0
213,8
264,5
315,3
366,0
416,8
467,5
518,3
569,0
619,8
670,5
721,3
772,0
822,8
873,5
924,3
975,0
Alpha-decay energy level, MeV
6,94
6,74
6,54
6,34
6,14
5,94
5,74
5,54
5,34
5,14
4,94
4,74
180Hg
181Hg
182Hg
183Hg
184Hg
185Hg
20
40
60
80
100
120
140
160
180
Strip number

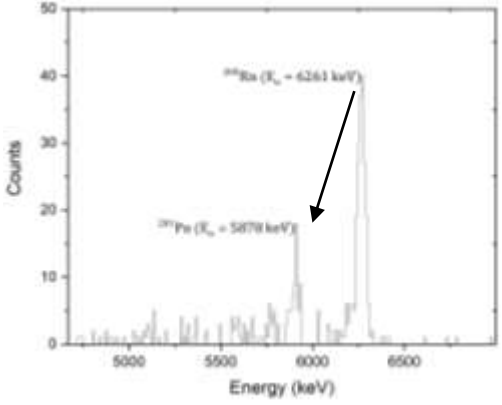
Processed energy spectrums on reaction ^{40}Ar + ^{166}Er with beam energy of E_{beam}= 5 - 6 MeV/n.

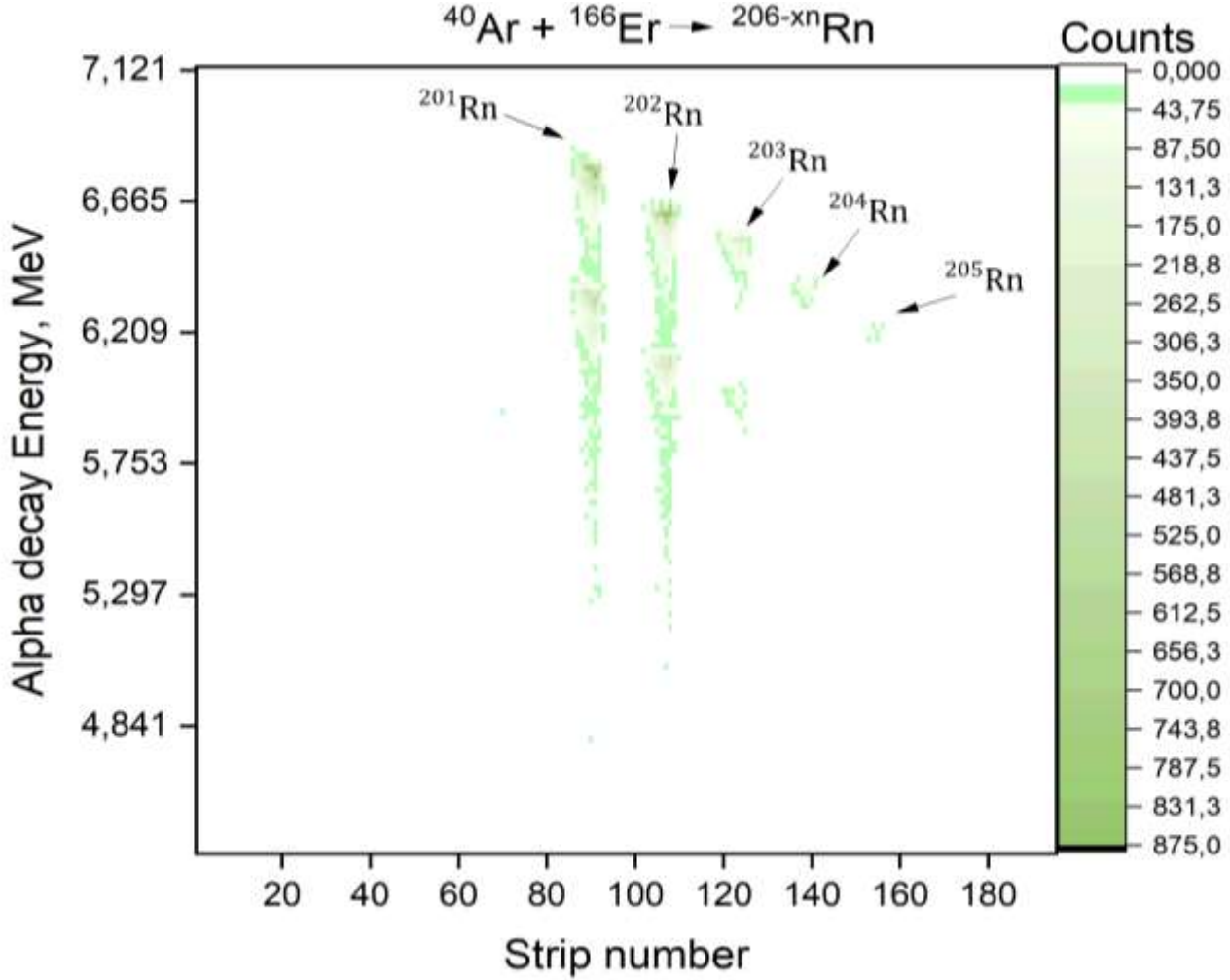




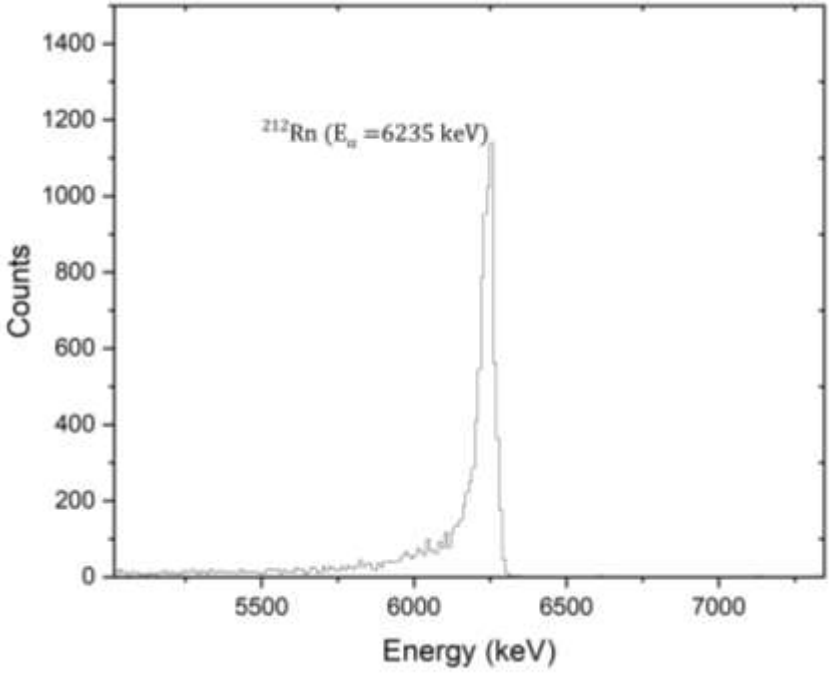


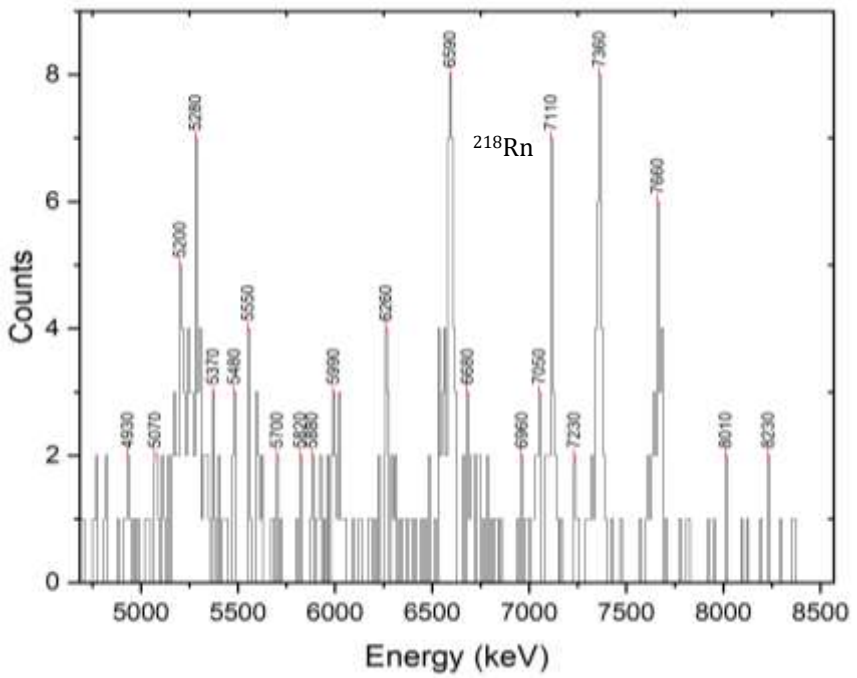


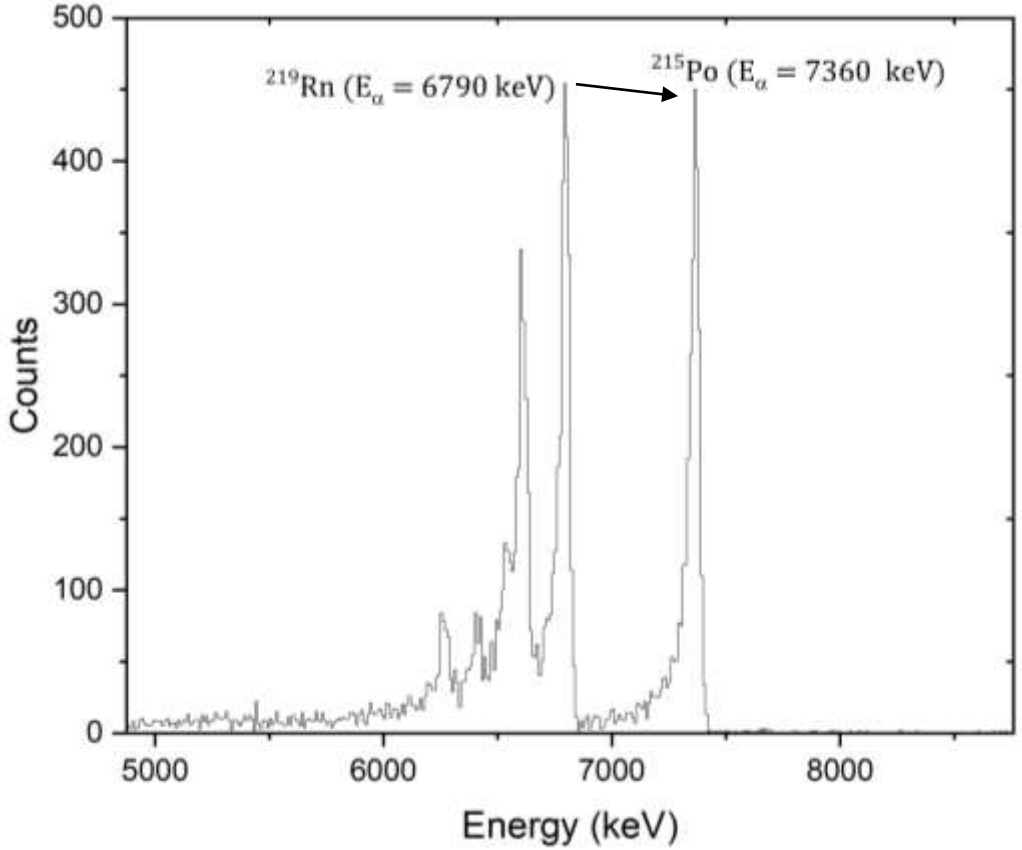



$^{40}Ar + ^{166}Er \rightarrow ^{206-xn}Rn$
Counts
0,000
43,75
87,50
131,3
175,0
218,8
262,5
306,3
350,0
393,8
437,5
481,3
525,0
568,8
612,5
656,3
700,0
743,8
787,5
831,3
875,0
^{201}Rn
^{202}Rn
^{203}Rn
^{204}Rn
^{205}Rn
Alpha decay Energy, MeV
7,121
6,665
6,209
5,753
5,297
4,841
20
40
60
80
100
120
140
160
180
Strip number

Processed energy spectrums on reaction ^{48}Ca + ^{242}Pu with beam energy of $E_{beam} = 5 - 6$ MeV/n.

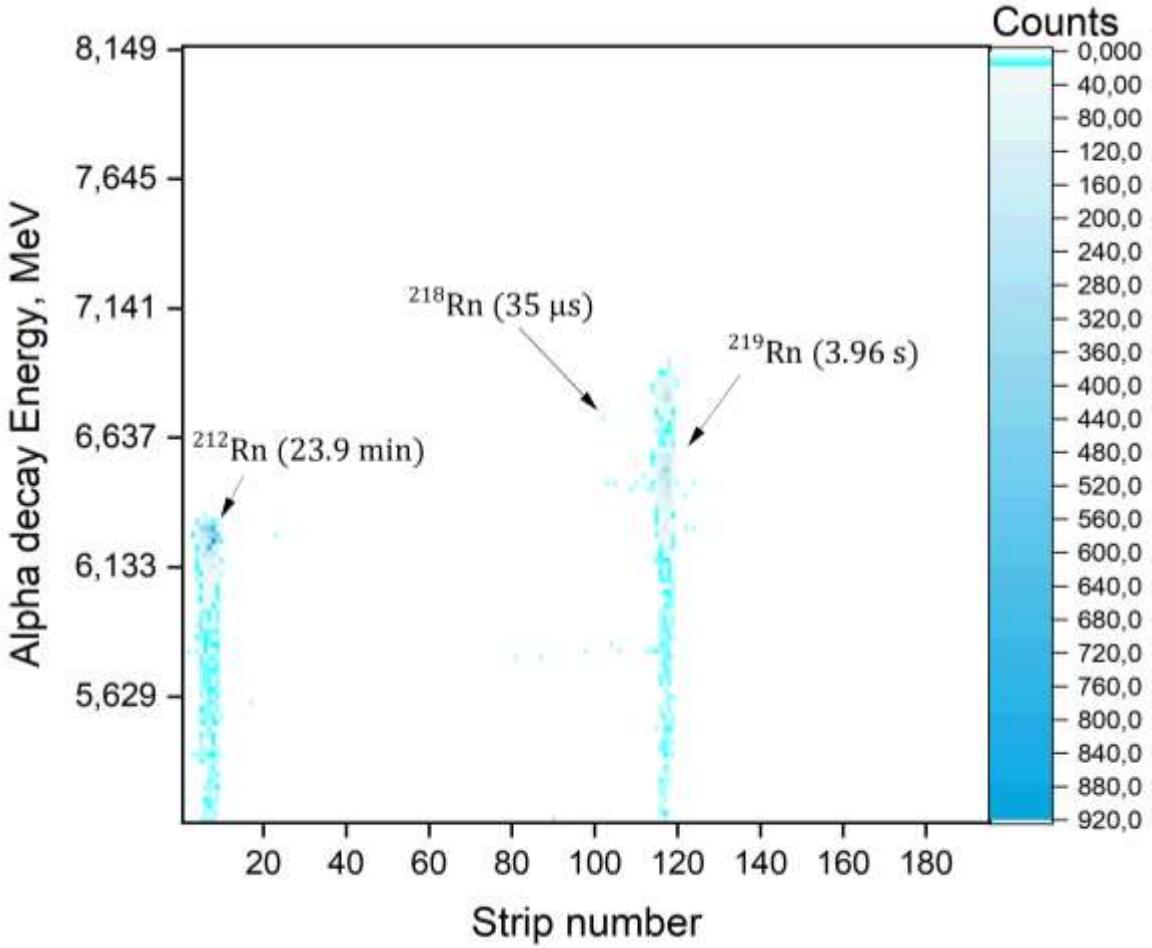






Continue of energy spectrums on reaction ^{48}Ca + ^{242}Pu with beam energy of E_{beam}= 5 - 6 MeV/n.

Production of Radon isotopes in the reaction $^{48}Ca + ^{242}Pu$



Results and discussion

- The results obtained makes availability to identify the energies of the isotopes of Hg, Rn in the reactions with heavy ions.

- The peak analysis and strip detector calibration was performed using mathematical ang graphing tool Origin software. The obtained results corresponds the table data with the errors not more than 2%.

- In the reaction of $^{48}Ca + ^{242}Pu$ leading to the Rn isotopes it was observed that some of the isotopes with A=213, 214, 215, 216 and 217 were not shown at the graph due to the short life time of the nuclei. ^{218}Rn is barely visible (4 - 5 entries) with the $T_{1/2}$ = 35 ms. It is the evident visualization of the separation time for solid ISOL method and its limits. Our colleagues further will tell about how does this limits could be overcome in future experiments.

- To be continued…

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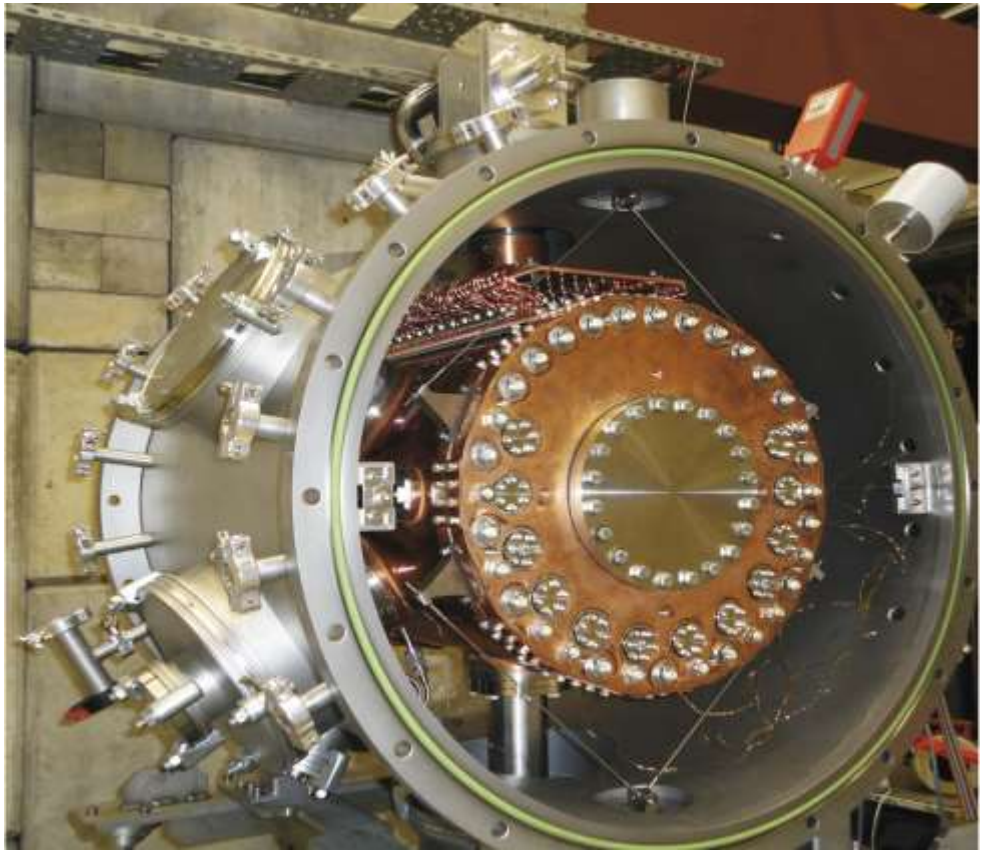
CRYOGENIC GAS CELL AND ITS APPLICATION FOR EVR ANALYSIS

Contents

- Description of cryogenic gas stopping cell
- A motivation to use gas state ISOL methodic in analysis
- Advantages and Disadvantages
- Suggested setup
- Aim and Objectives
- Optimization of the Stopping Efficiency
- Results and Discussion
- Conclusion

Cryogenic gas-filled ion stopper “Gas Catcher”



- Contains 2 independent and thermally insulated vacuum vessels.
- Inner cold chamber have working temperature of 40 K via helium refrigerator Sumitomo RDK-500B.
- Outer chamber is a warm camera (room temperature, 300 K) is an vacuum thermal insulator for a inner one.

Advantages and disadvantages of ISOL method

Main advantages of solid ISOL method:

- Ability to get a secondary beam of high intensity (up to 10^8 pps);
- Small emittance and ΔE of the secondary beam;
- Ability to use in the reactions of multinucleon transfer, when the target material is dissolved inside graphite;
- Compact dimensions.

The disadvantages are:

- Extraction time of the system Hot Catcher + Ion Source is very huge. 1.8 s;
- Small separation efficiency of about 7%;
- The selectivity of physical or chemical properties of a reaction products.

Advantages and disadvantages of Gas Catcher

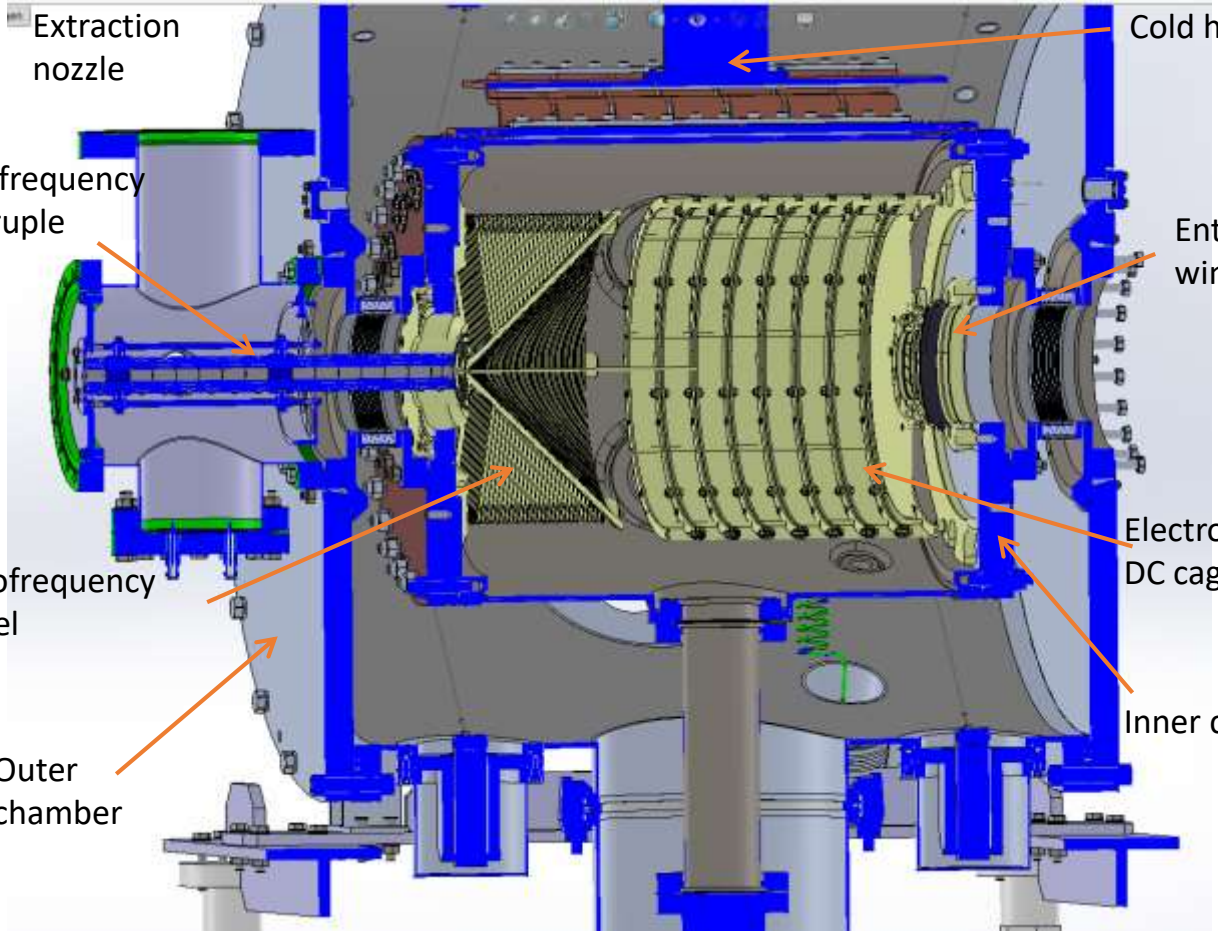
Main advantages of gas catcher:

- High separation efficiency;
- Very low separation time opens the huge variety of new short-living isotopes for the investigation;
- No need in additional ionization.
- Chemically inert environment, does not suffer from any of physical isotopes properties.

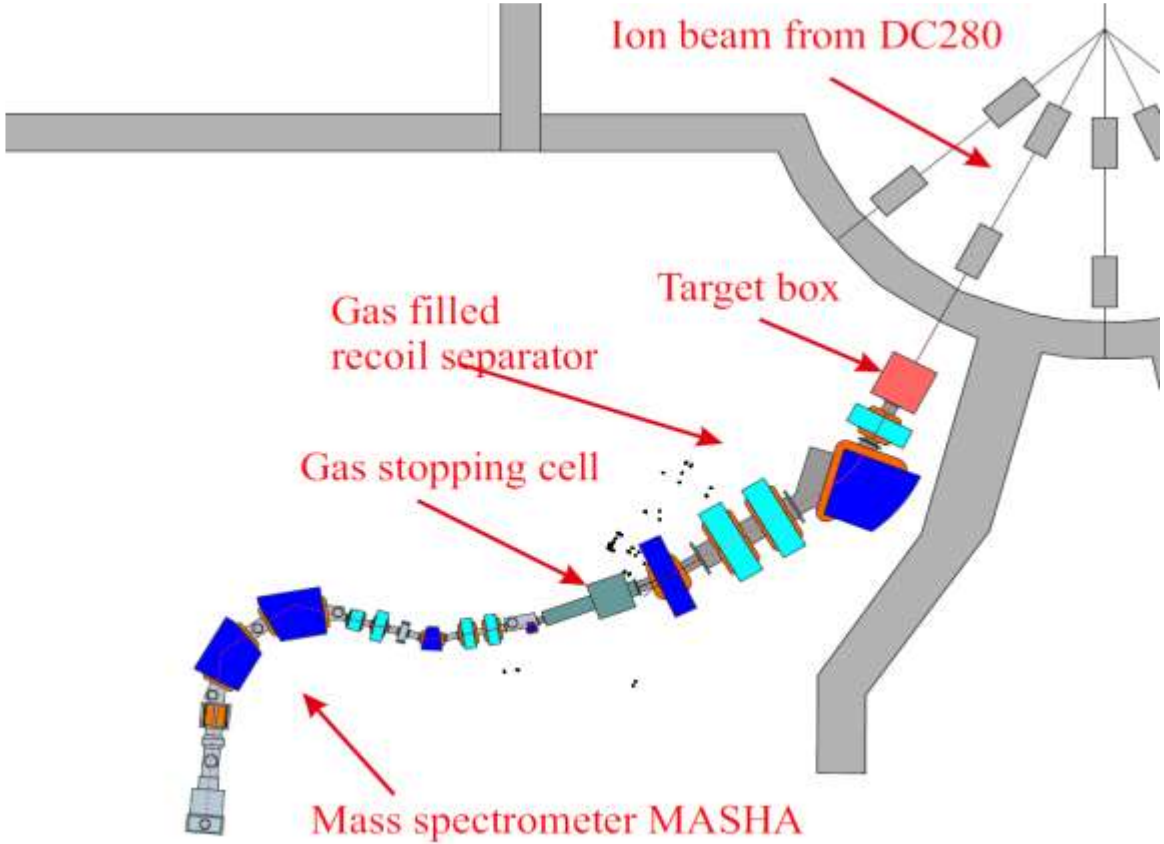
Disadvantages are:

- Strongly limiting by ionization rate density.
- Many parameters, such as buffer gas pressure, the voltage gradient and geometry of Gas Cell have very big influence on extraction time.
- High demands to the vacuum technique and buffer gas purity (less than 10^{-9} mixture).

Axial cut of the CryoCell with electrode system



Possibilities to use on a new SHE factory



Aim of investigation

- The aim of the project was to carry out the simulations of the reaction evaporation residue (EVR) ion beam transmission through the entrance window foil of the cryogenic gas cell (CGA) and stopping of them in a buffer gas of helium.

Objectives

- Used software : hybrid empirical and Monte-Carlo–based SRIM (Stopping Ranges In Materials) software.

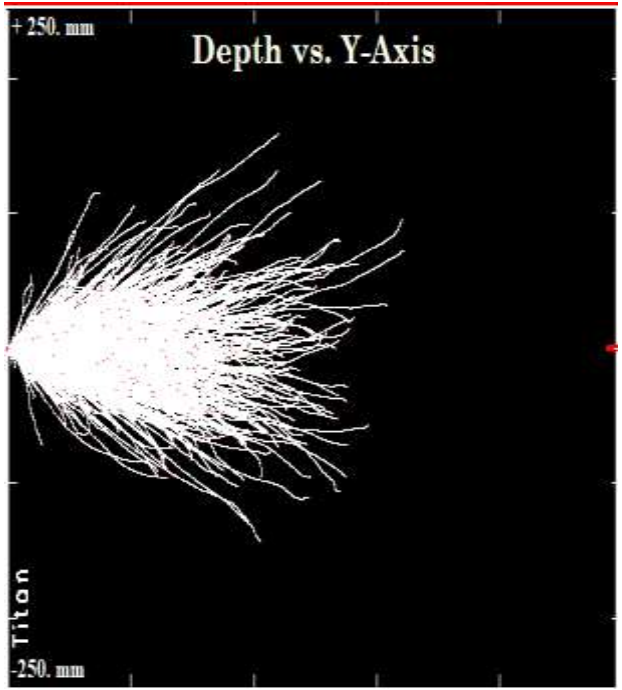
- The choosing of window foil material is also crucial. While cooling down it should have temperature shrinkage parameter close to stainless steel in order to prevent its tearing.

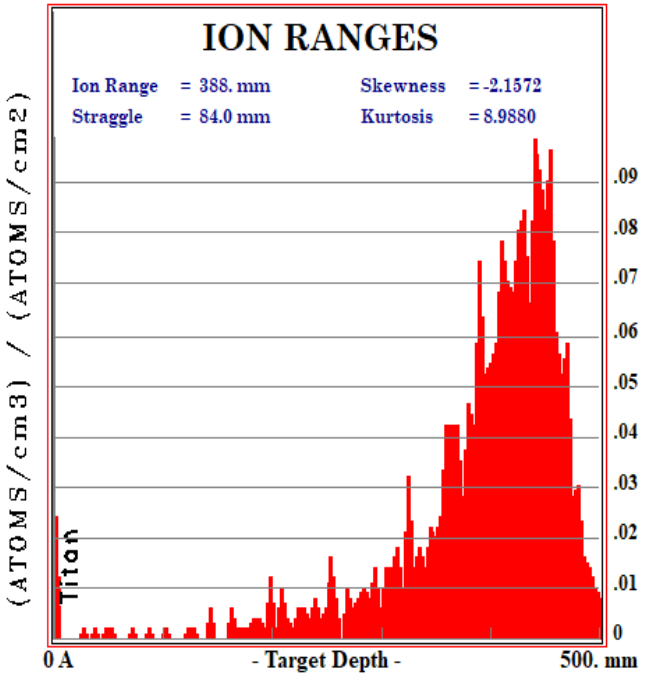
- The EVRs should lose about 90-95% of its energy inside the window before getting inside gas phase.

- Determine the maximum stopping efficiency for ions with different window foil thicknesses and gas pressures.

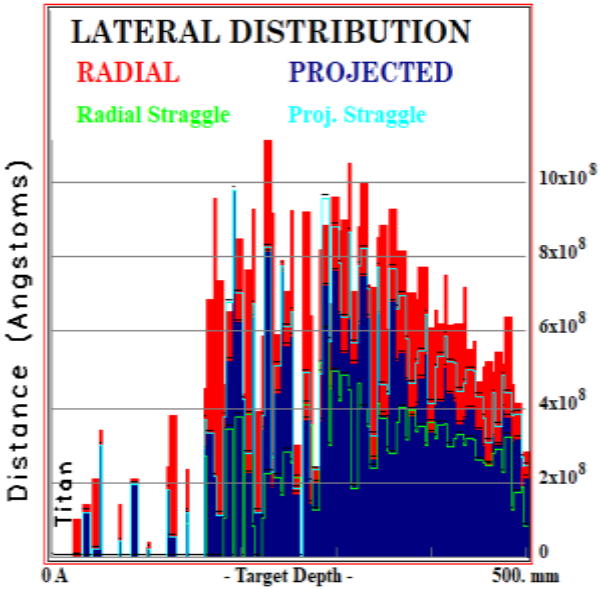
Results and Discussion

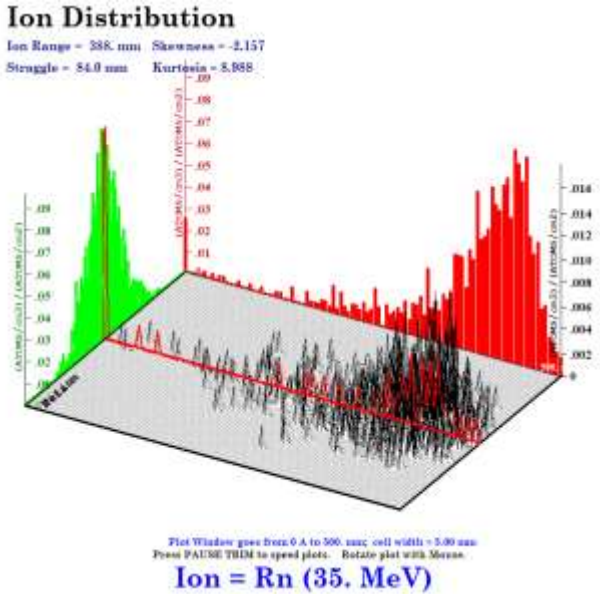
^{205}Rn at 35 MeV and pressure at 30 mbar



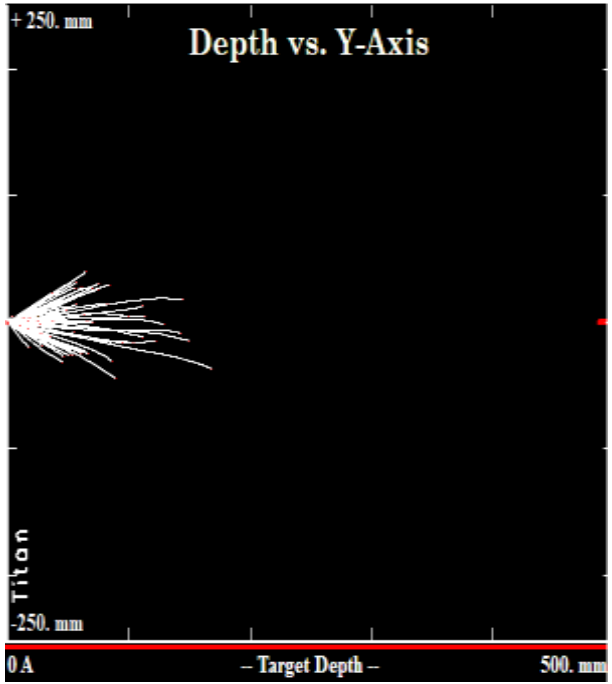


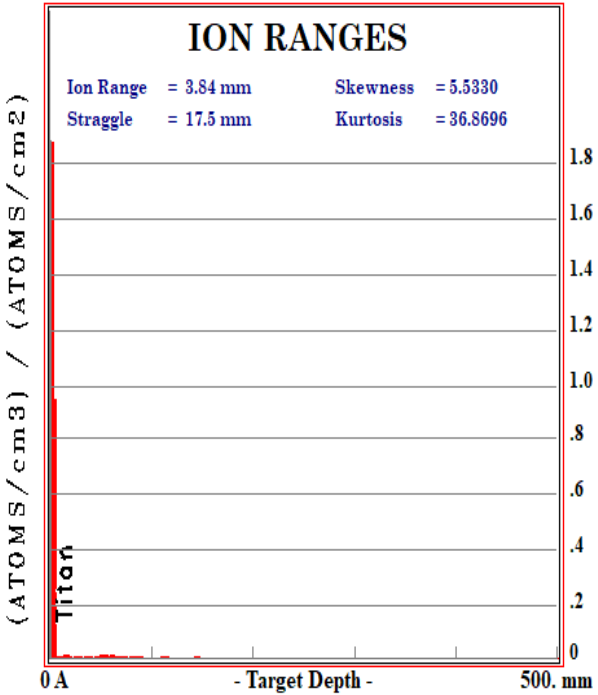
^{205}Rn at 35 MeV and pressure at 30 mbar



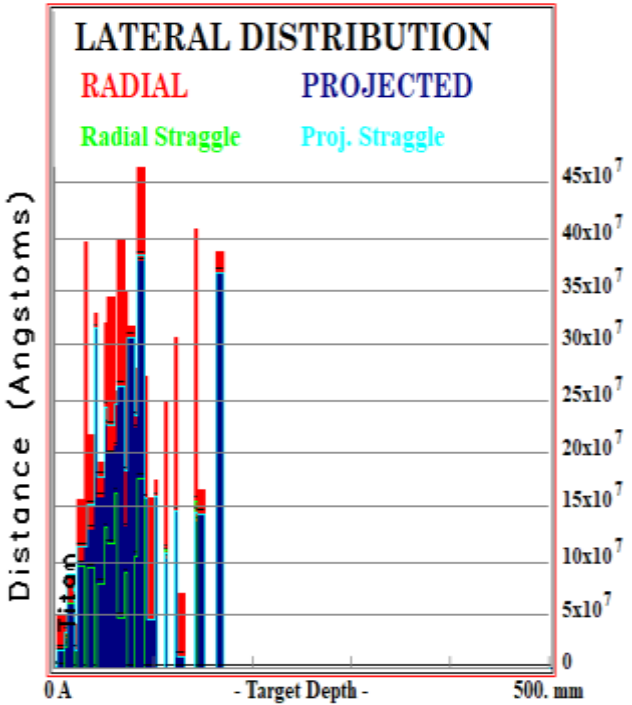


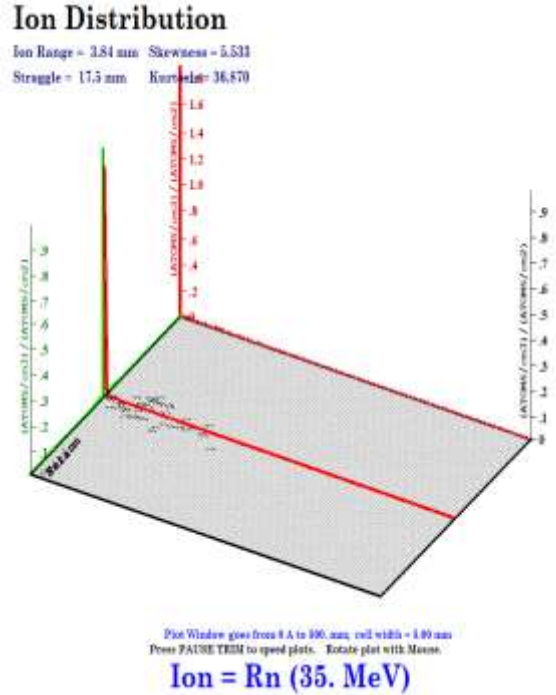
^{205}Rn at 35 MeV and pressure at 100 mbar



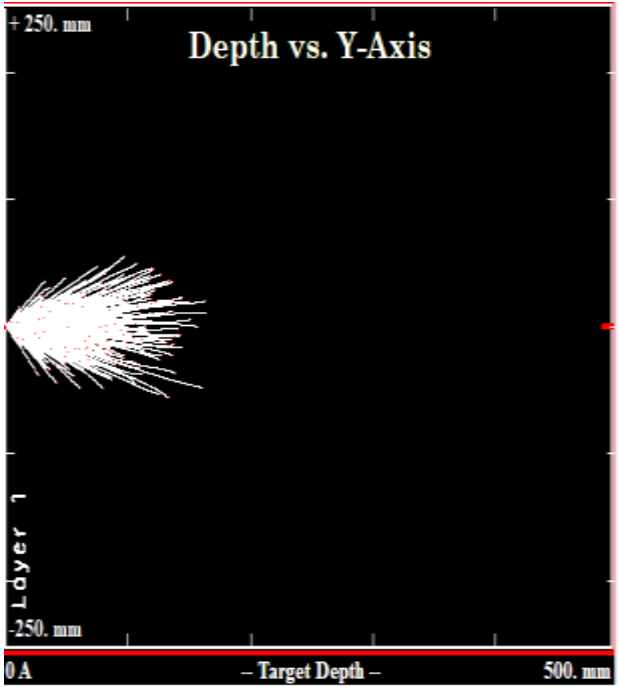


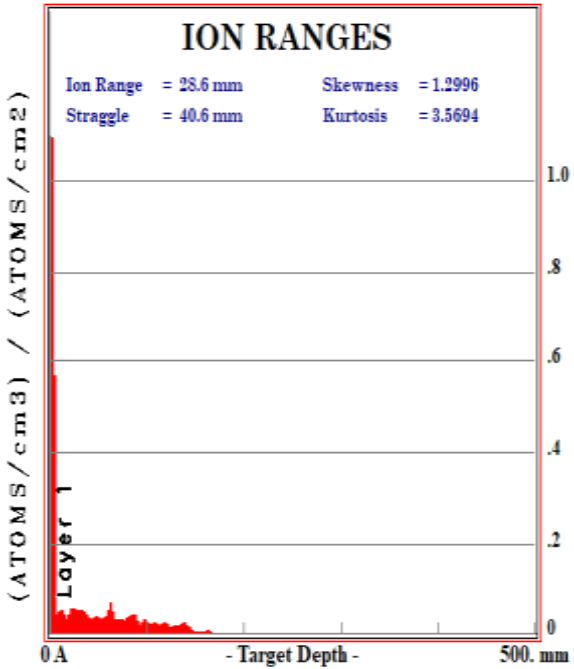
^{205}Rn at 35 MeV and pressure at 100 mbar





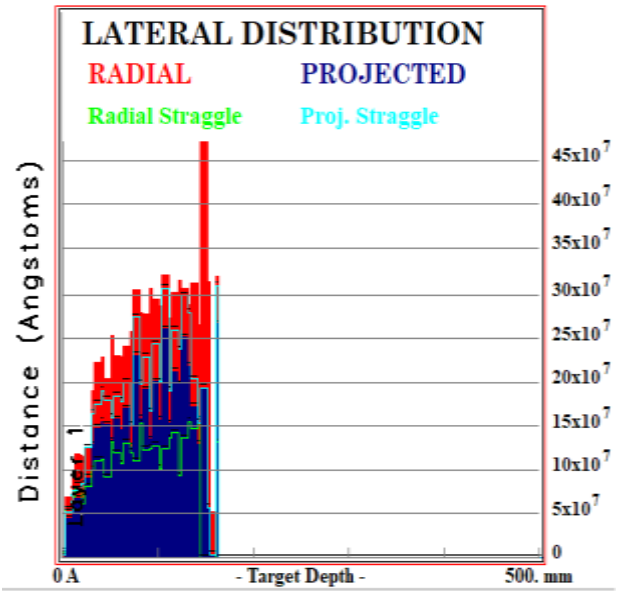
^{205}Rn at 40 MeV and pressure at 70 mbar

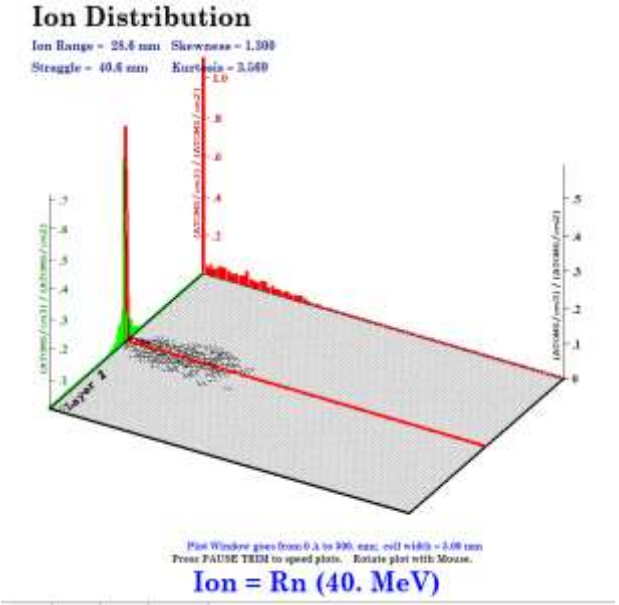




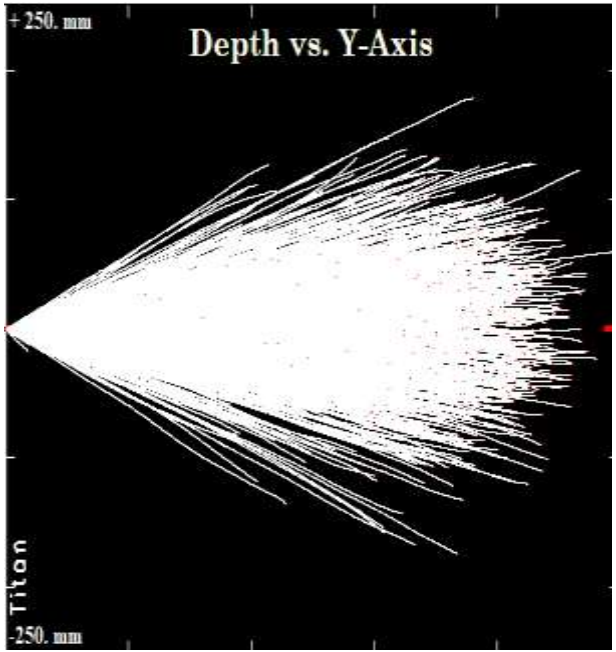
Results and Discussion

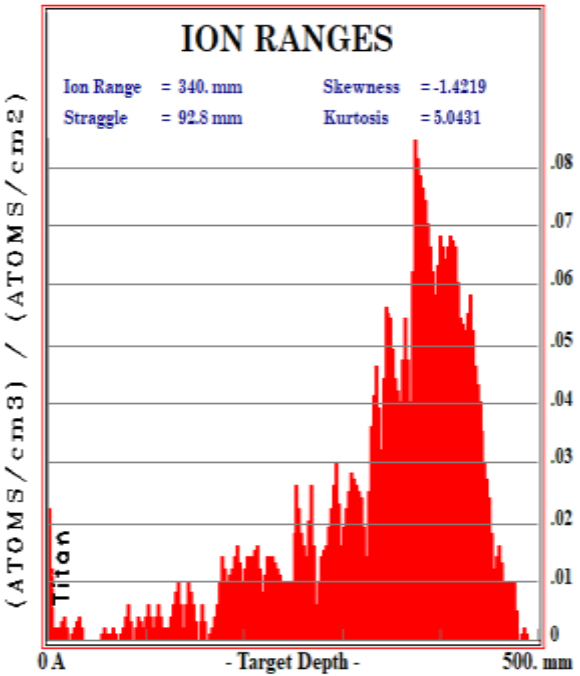
^{205}Rn at 40 MeV and pressure at 70 mbar



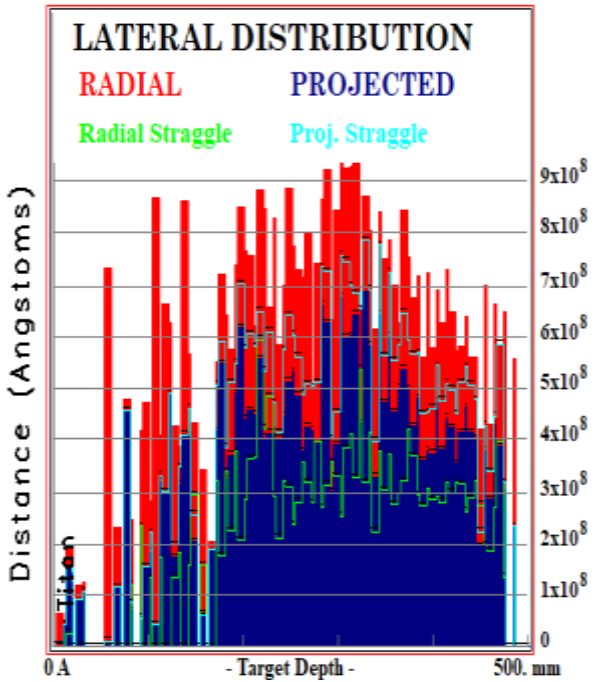


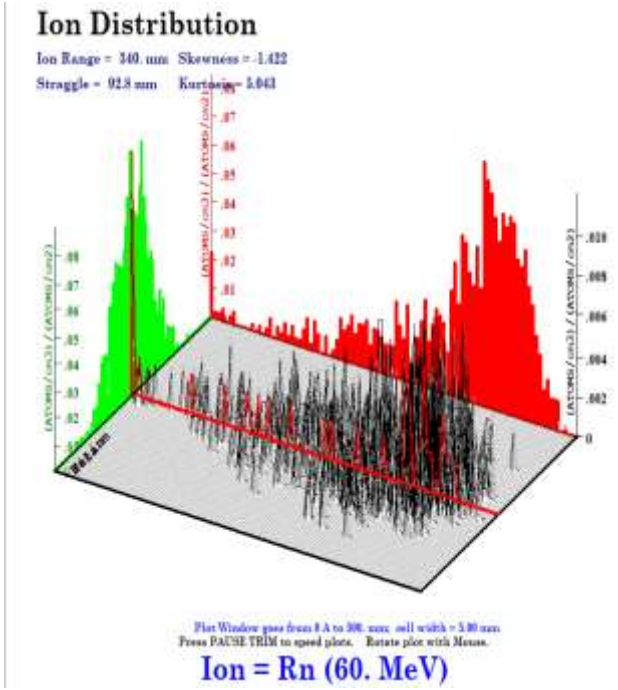
^{205}Rn at 60 MeV and pressure at 70 mbar



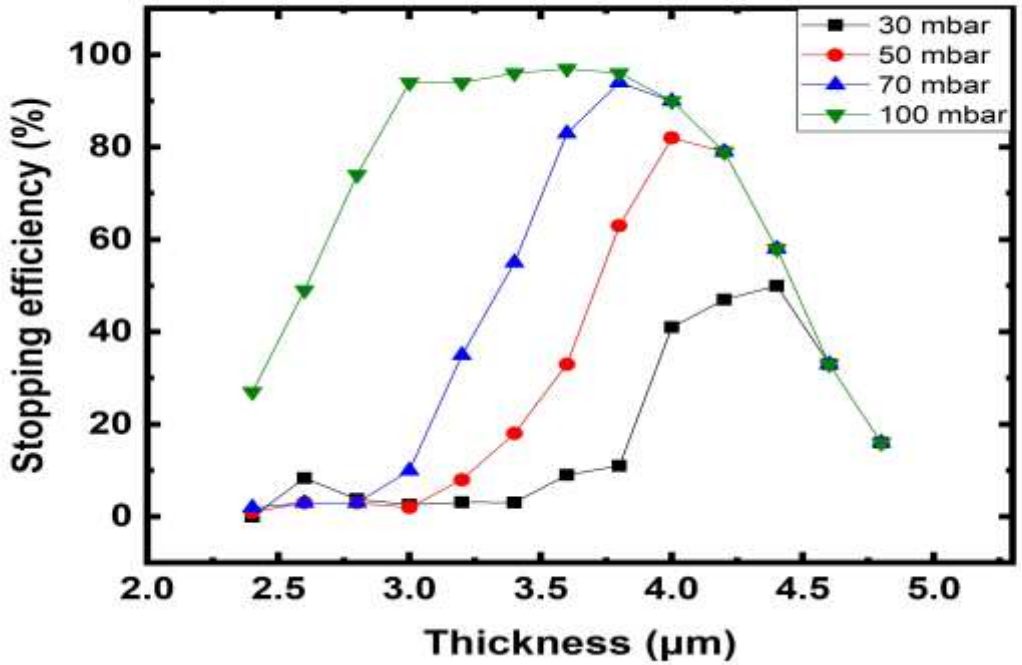


^{205}Rn at 60 MeV and pressure at 70 mbar





Stopping efficiency to foil thickness distribution for radon isotopes



Discussion: Stopping efficiency distribution for radon isotopes

- Simulations were carried out for the ^{205}Rn isotope using the SRIM software at room temperature and gas pressures of 30 mbar, 50 mbar, 70 mbar, and 100 mbar of helium buffer gas. Thickness of the titanium foil was varying from 2.4 μm to 4.8 μm and in this the simulations have done by taking the difference of 0.2 μm.

- It was observed that the increasing of foil thickness leads to more effective stopping efficiency up to 4.2 μm then it fell with the increasing of radial distribution and straggling. Thus, there is no need in foil thickness increasing.

- It has been observed that on increasing the pressure stopping efficiency is also increases and it is almost same when the thickness of the titanium foil reaches 4.2 μm.

Conclusion

- For investigation and studying new variety of isotopes Gas Stopping Cell is very valuable part in ISOL method and will be applied to the mass separator.

- Simulations for the ^{205}Rn isotope were carried out and it was found that the stopping efficiency depend on the foil thickness and the gas pressure, which was shown in presentation.

- Material of the window was chosen titanium because of its thermal expansion coefficient is close to the stainless steel AISI 304 ($\alpha = 8.3\times10^{-6}\ ^{\circ}C^{-1}$) and have not a huge Z number (22). Technologically it is not complicated to get thin titanium foil up to 1 μm.

- The maximum stopping efficiency determined for the thickness of the foil about 4.2-4.5 μm and reached over 90% for 100 mbar helium buffer gas.

- The obtained data could be applied for more efficient parameter choosing such as material, foil thickness and the pressure inside the vessel and could be recalculated for the cryogenic temperatures.

Thank you for your attention and patience!