The XXVII International Scientific Conference of Young Scientists and Specialists (AYSS-2023)

Production and spectroscopic investigation of Hg and Rn isotopes produced in complete fusion reaction and multi-nucleon transfer reaction at MASHA facility

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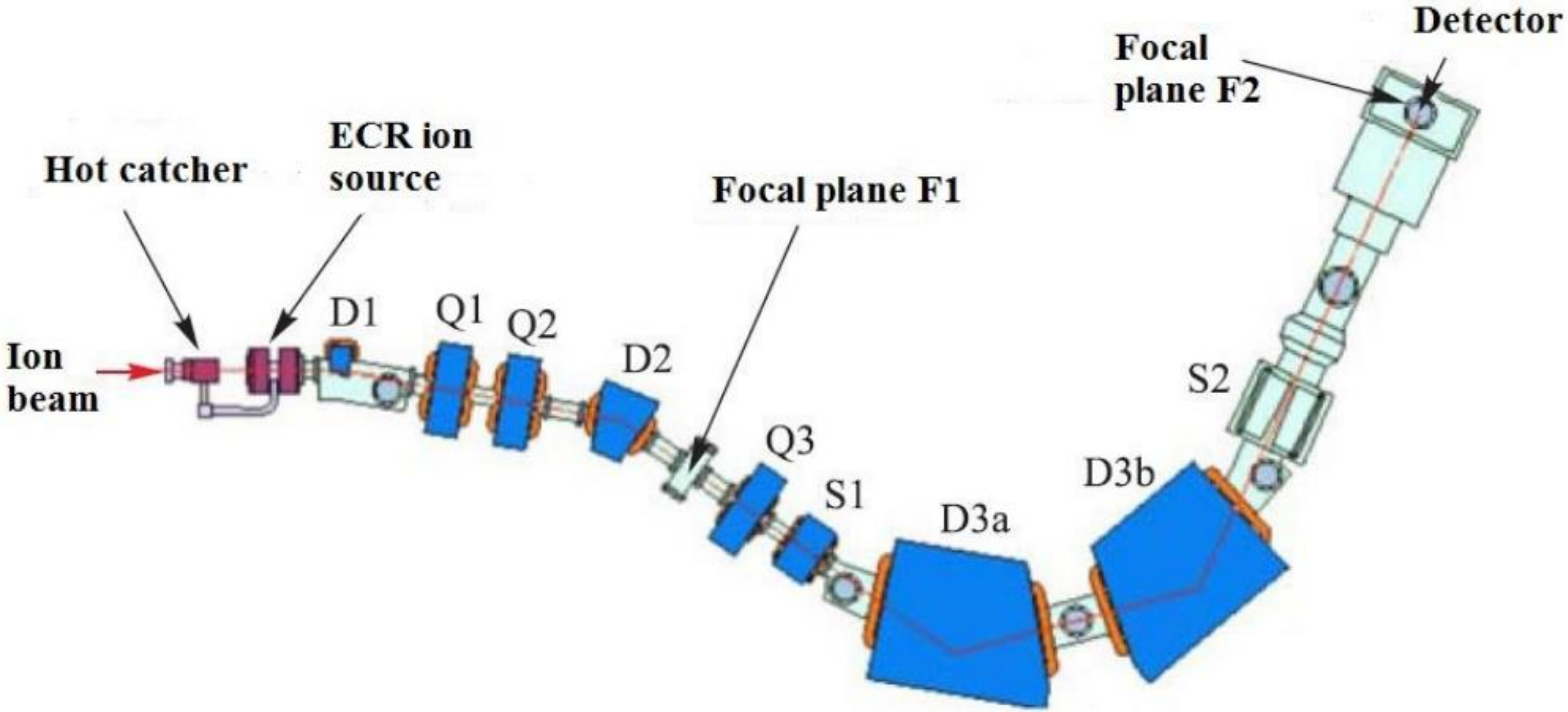
Aim of the work:

- The production and spectroscopic investigation of Mercury and Radon isotopes was performed using complete fusion reactions neutron evaporation residues and multi-nucleon transfer reaction at the mass-separator MASHA.
- The MASHA setup is installed on the beam line of Cyclotron U-400M at Flerov Laboratory of Nuclear Reactions (FLNR) in Joint Institute for Nuclear Research (JINR), Dubna, Russia.
- The isotopes produced in complete fusion reactions $^{148}Sm(^{40}Ar, xn)\ ^{188-x}Hg$, $^{166}Er(^{40}Ar, xn)\ ^{206-x}Rn$ and multi-nucleon transfer reaction $^{48}Ca + ^{242}Pu$ were passed through the magnetooptical system of MASHA setup with charge state Q=+1 and were separated on the basis of their mass to charge ratio.
- For the detection of these isotopes, a position sensitive Si detector was used.
- Further, the experimental data obtained were analyzed and spectroscopic investigations were carried out.
- The goal of the work was to compare the theoretical and experimental values of energy of alpha decay. Theoretical values were obtained using table of nucleoids while experimental values using physical analysis of data.

MASHA Facility



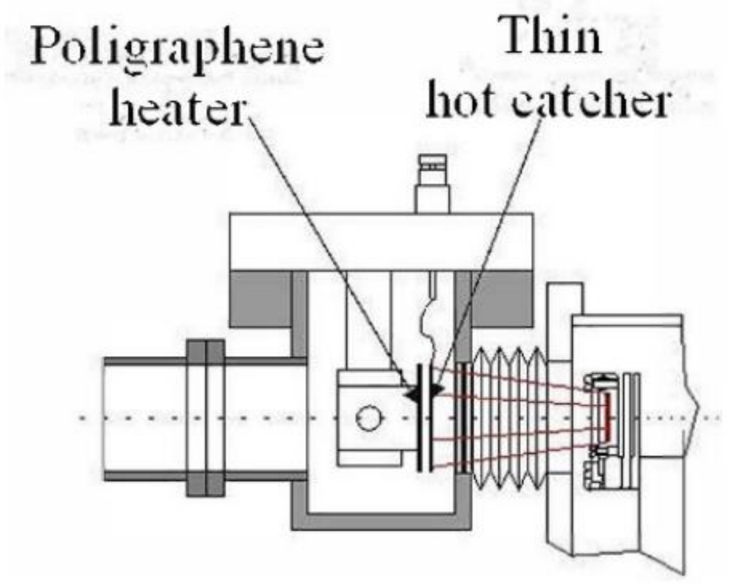
Main Parts:

1. TARGET BOX:

- The target box consists of a rotating disc divided into 6 sectors, which are sputtered with target material(s) as shown in Fig.
- The disc rotates with a frequency of 25Hz [1].
- The high energetic projectile particle ejected from U-400M cyclotron collides with the target material present in rotating disc to induce some kind of nuclear reaction.
- The products of the nuclear reaction are stopped by the hot catcher.

2. HOT CATCHER:

- The hot catcher mainly consists two components, one is poly-graphene heater and the other one is absorber material.
- The latter is usually made up of thin film of graphite or carbon nanotubes heated by the former up to a temperature of 1800 − 2000^{o}C.
- As depicted in figure the absorber is installed in front of the heater at a distance of 2 mm along the beam axis of MASHA [2].
- The products of the nuclear reaction is stopped by the absorber material, vaporized to gaseous form and are passed to the ECR ion source.



3. ECR ION SOURCE:

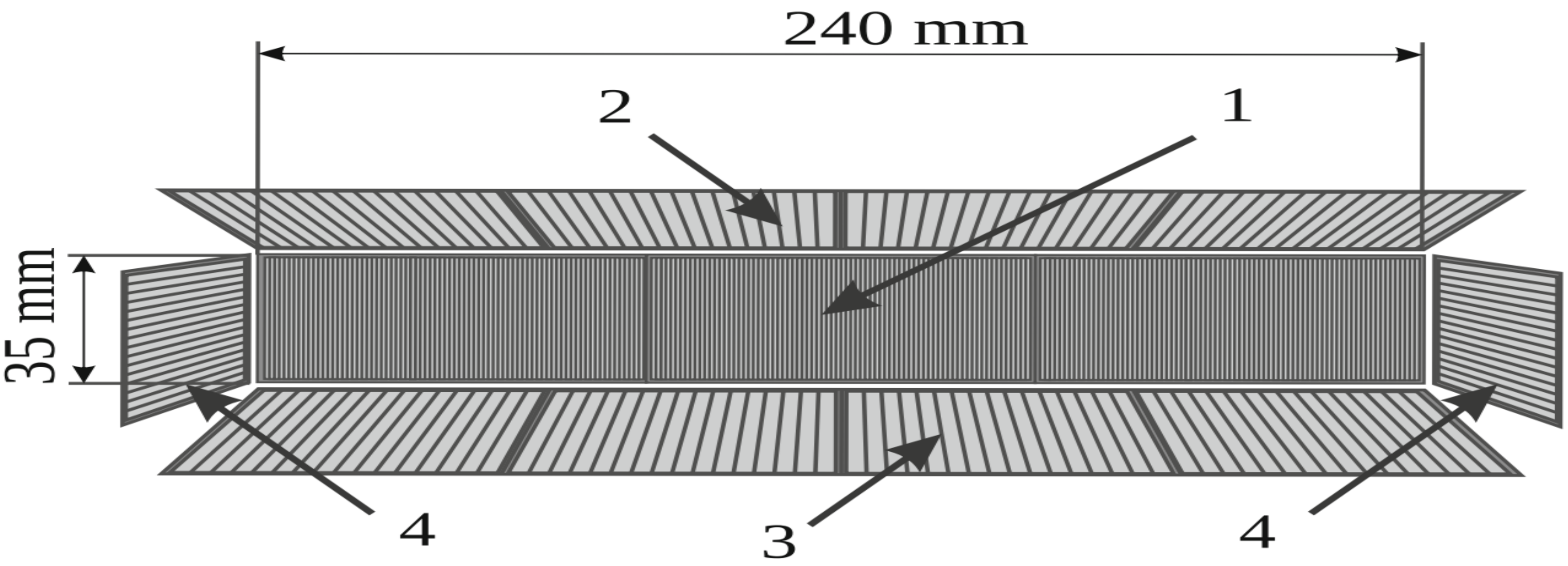
- The ECR (Electron Cyclotron Resonance) ion source with a microwave oscillation frequency of 2.45 GHz [1–4], acts as an ionization chamber of MASHA spectrometer.
- It ionizes the atoms of gaseous isotopic products of nuclear reaction to a charge state Q=+1, and accelerates them to an energy of 38 KeV using three electrode system [1].
- The ionized atoms gets converted to beam and are then separated by magneto-optical system of the MASHA spectrometer.

4. MAGNETO-OPTICAL SYSTEM:

- The magneto-optical system separates the beam of ions on the basis of their mass to charge ratio.
- The magnetic separation of heavy nuclei is performed using four dipole magnets(D1, D2, D3a, D3b), three quadrupole lenses (Q1, Q2, Q3) and two sextupole lenses (S1, S2).
- Once, the heavy nuclei gets separated they are then detected at different strips of position sensitive Si detector.

5. POSITION SENSITIVE Si DETECTOR:

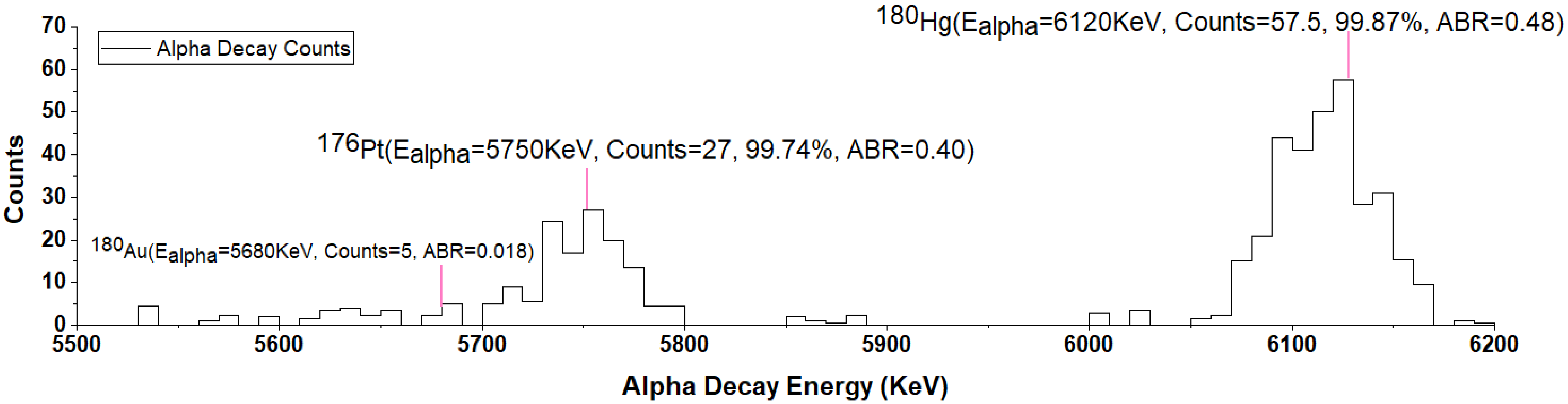
- The position sensitive Si detector is a multiple detector system used to detect the separated heavy nuclei. It is installed at the focal plane (F2) of the MASHA setup.
- The front detector has a dimension of 240x35 mm2 and it consists of 192 strips.
- The upper and lower detector consists of 64 strips each while the left and right lateral detector consists of 16 strips each.
- Each strip has a width of 1.25 mm and each detector has a thickness of 0.3 mm.



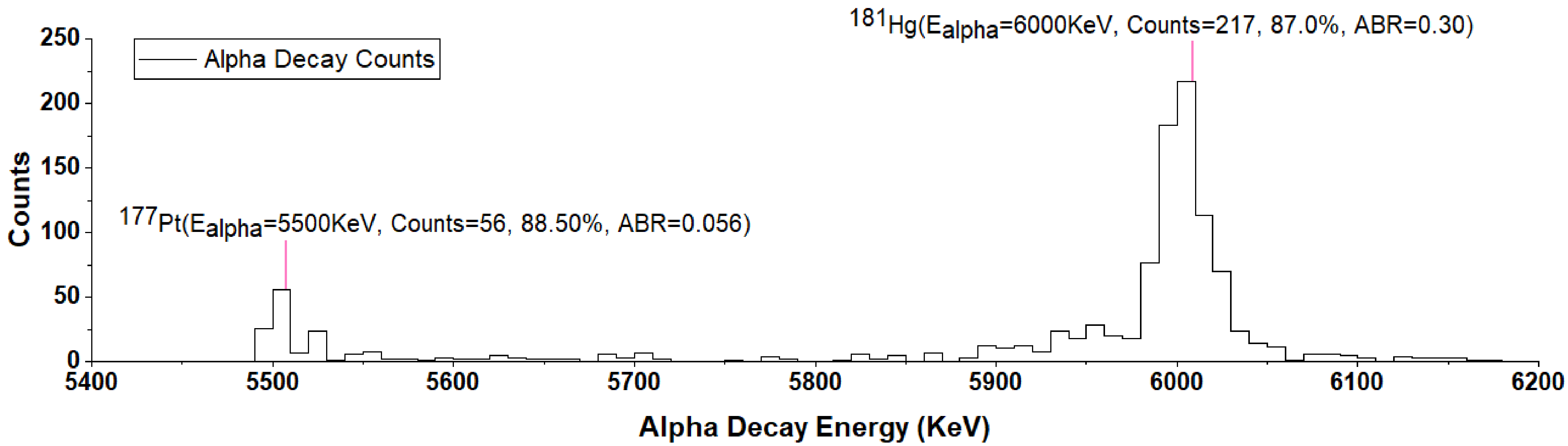
Spectroscopic Investigations Of Mercury Isotopes Using Full-Fusion Reaction $^{148}Sm(^{40}Ar, xn)\ ^{188-x}Hg$

- The complete fusion reaction of $^{148}Sm(^{40}Ar, xn)\ ^{188-x}Hg$ was carried out at MASHA setup.
- The target material sputtered in rotating disc was ^{148}Sm and the products of the nuclear reaction were isotopes of Hg.
- However, only the long-lived isotopes of Hg were detected whose half-life was greater than average separation time (1.8±0.3 s) used by ISOL method for this reaction [1, 3].

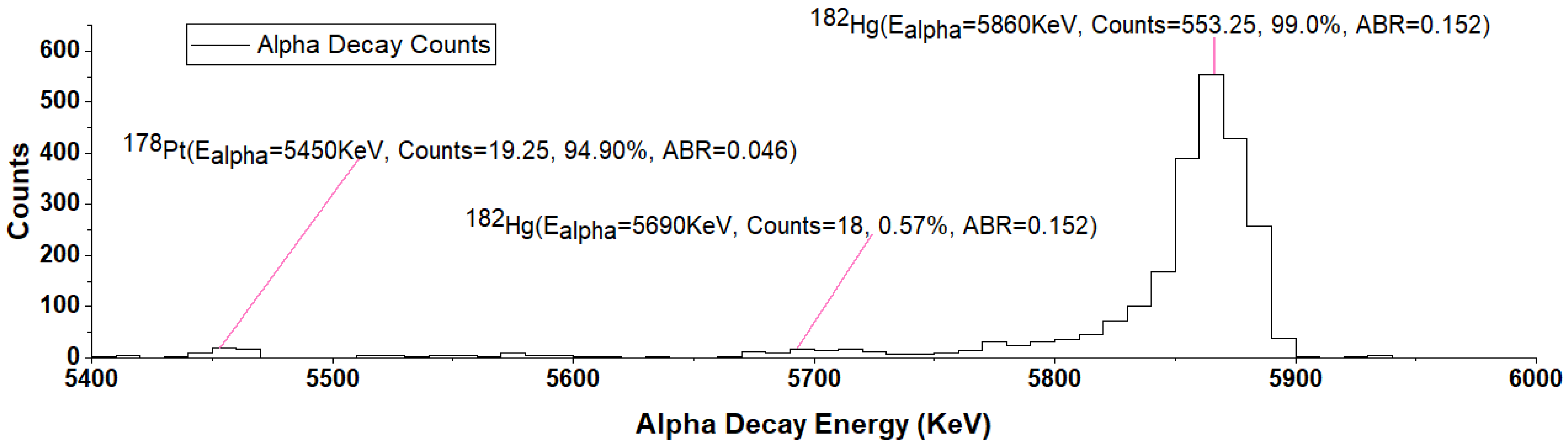
PRODUCTION OF ^{180}Hg:



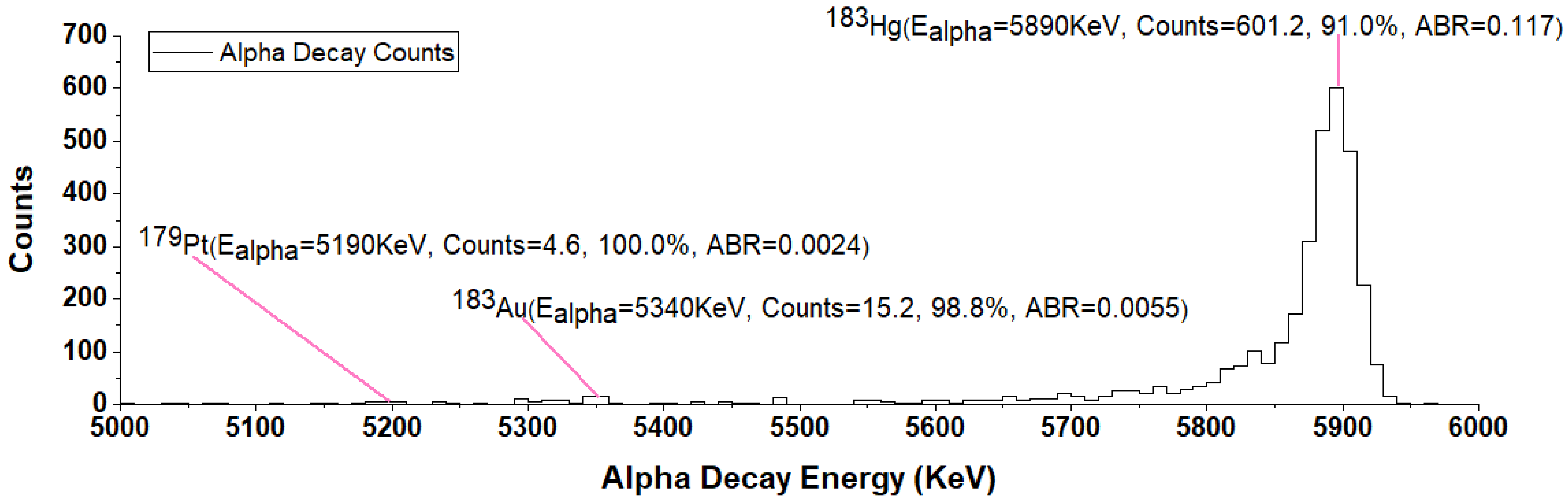
PRODUCTION OF ^{181}Hg:



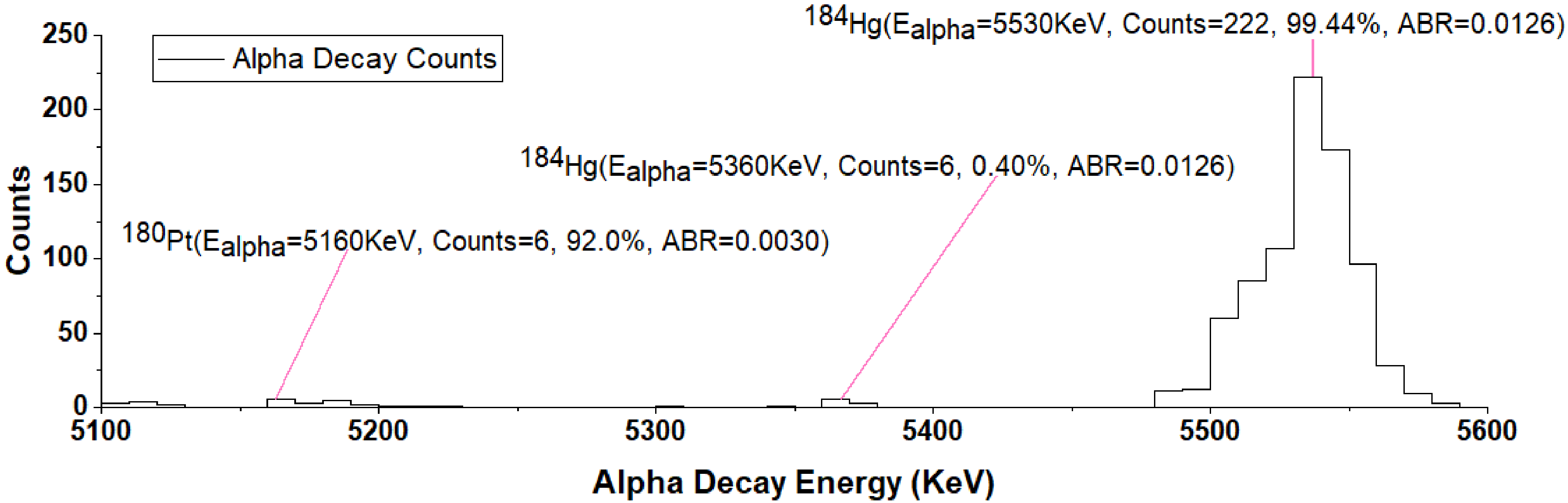
PRODUCTION OF ^{182}Hg:



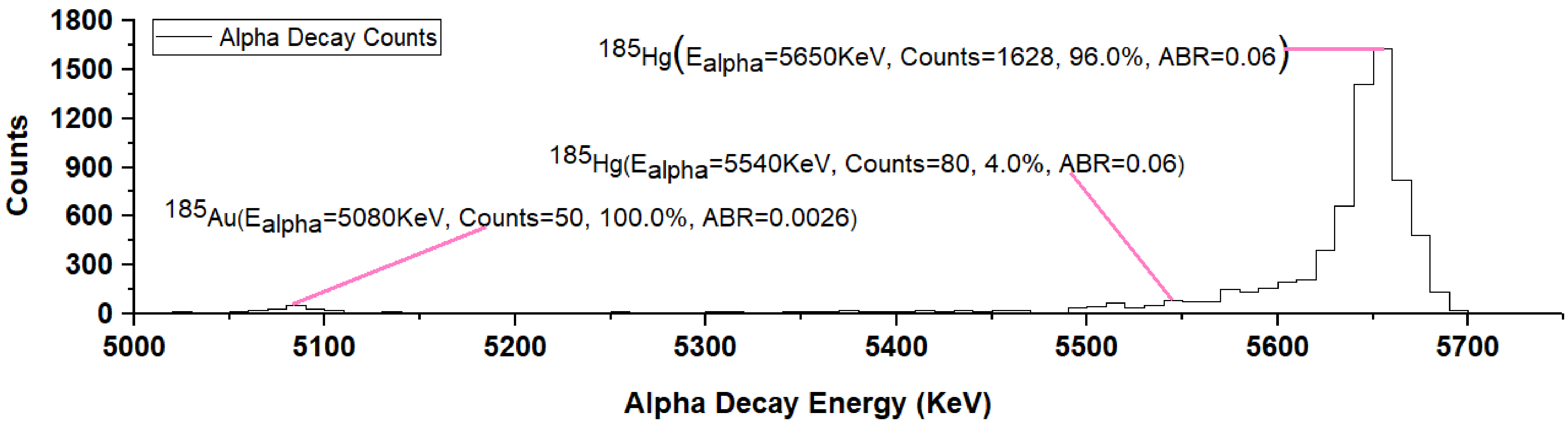
PRODUCTION OF ^{183}Hg:



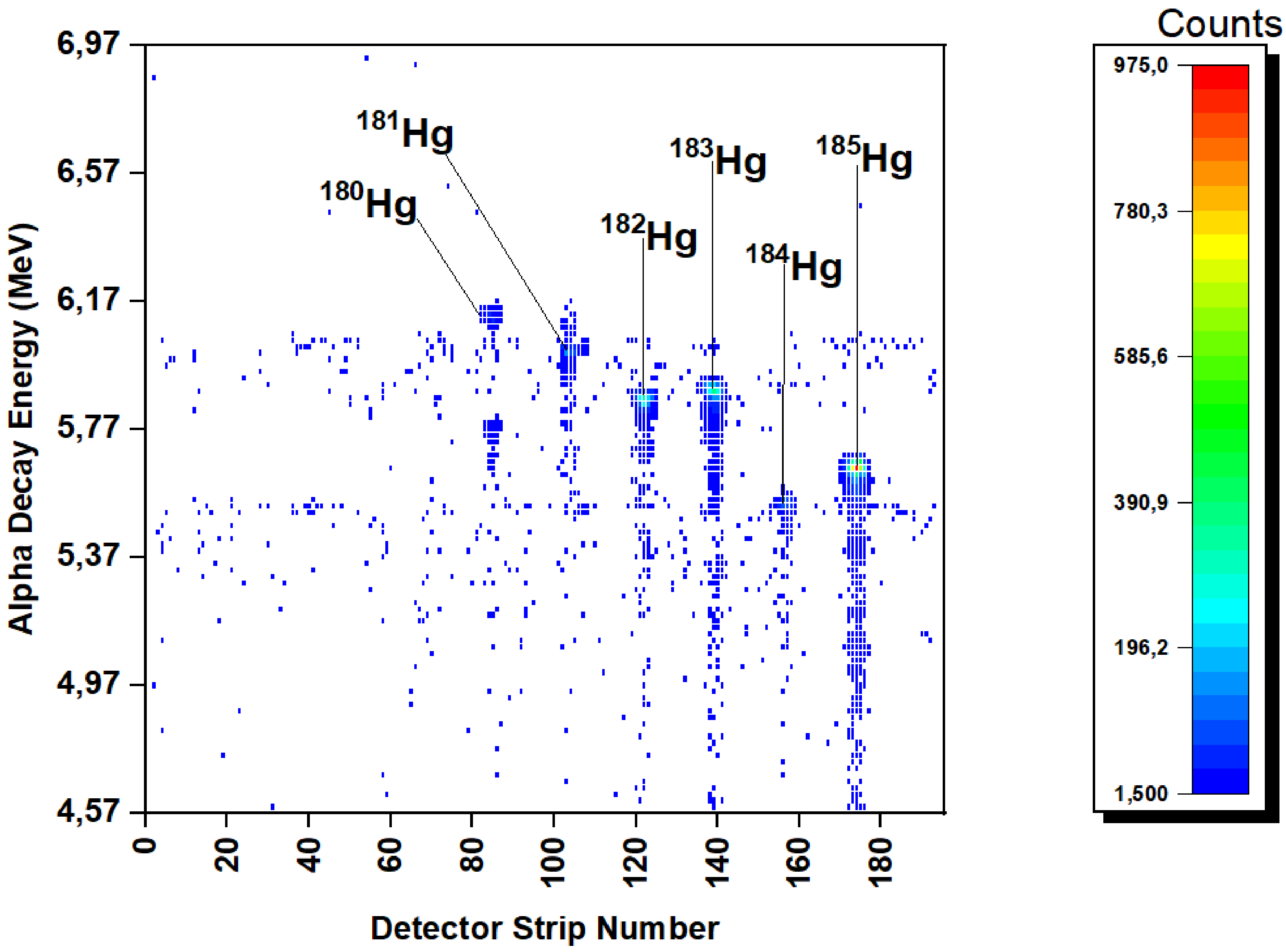
PRODUCTION OF ^{184}Hg:



PRODUCTION OF ^{185}Hg:



HEATMAP OF Hg ISOTOPES:



- The experimental values of Ealpha is compared with its theoretical values obtained from table of nuclides in Table 1.
- It is observed that the % change in their values is even less than 0.3%.
- So, we conclude that the spectroscopic investigation performed for Hg isotopes in reaction $^{148}Sm(^{40}Ar, xn)\ ^{188-x}Hg$ is almost accurate.

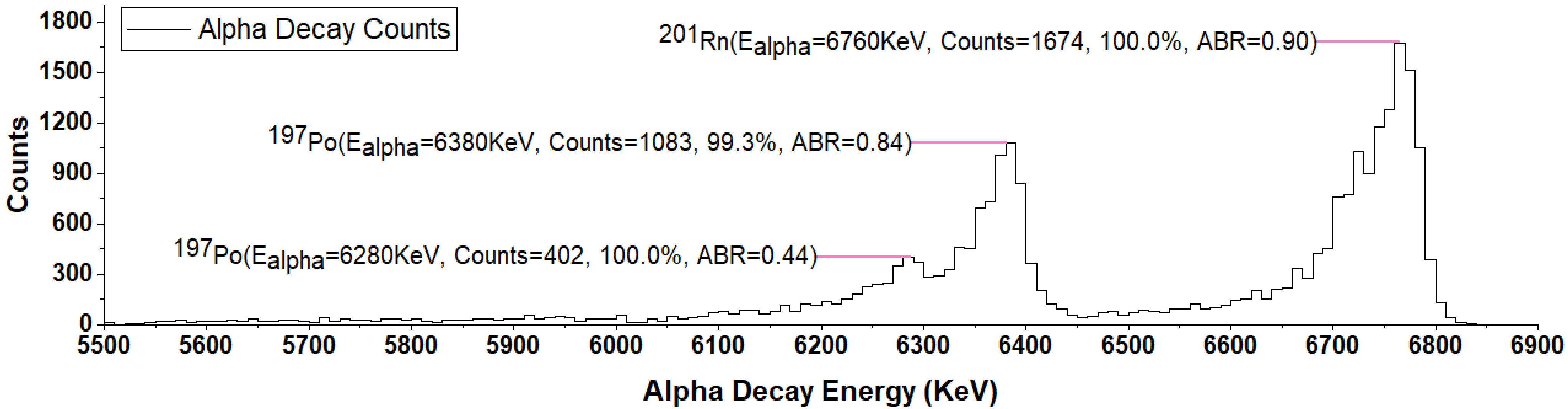
Table 1: Comparison between theoretical and experimental values of E_{alpha}(in KeV) of Hg isotopes produced in reaction $^{148}Sm(^{40}Ar, xn)^{188-x}Hg$.

Nucleus	Theo. E_{alpha}	Exp. E_{alpha}	Δ%
^{180}Hg	6119	6120	0.016
^{181}Hg	6006	6000	0.099
^{182}Hg	5867	5860	0.119
^{183}Hg	5904	5890	0.230
^{184}Hg	5535	5530	0.090
^{185}Hg	5653	5650	0.053

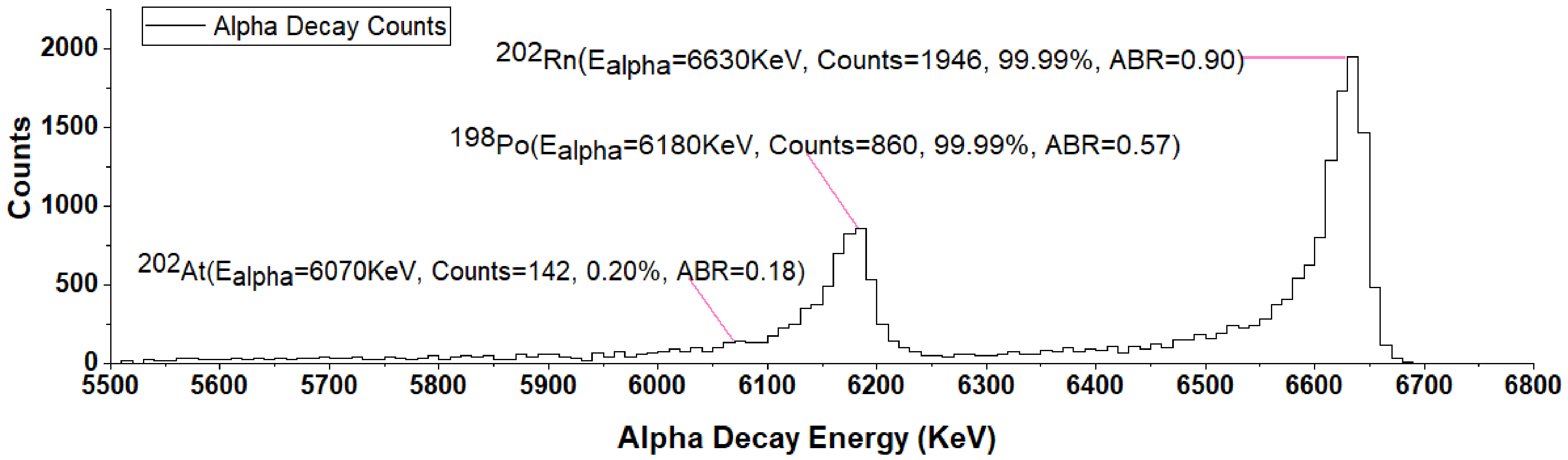
Spectroscopic Investigations Of Radon Isotopes Using Full-Fusion Reaction $^{166}Er(^{40}Ar, xn)\ ^{206-x}Rn$

- A complete fusion reaction was performed between high energetic projectile particle (40Ar) ejected from the window of U-400M cyclotron with an energy ˜198 MeV and the target material 166Er present in the form of rotating disc in the target box of MASHA facility.
- The products of the nuclear reaction were isotopes of Rn which were detected at focal plane (F2) of the position sensitive Si detector.
- Further, using the experimental data obtained from the detector and control system of MASHA, their α-decay energy spectrum and energy-position graphs were plotted.

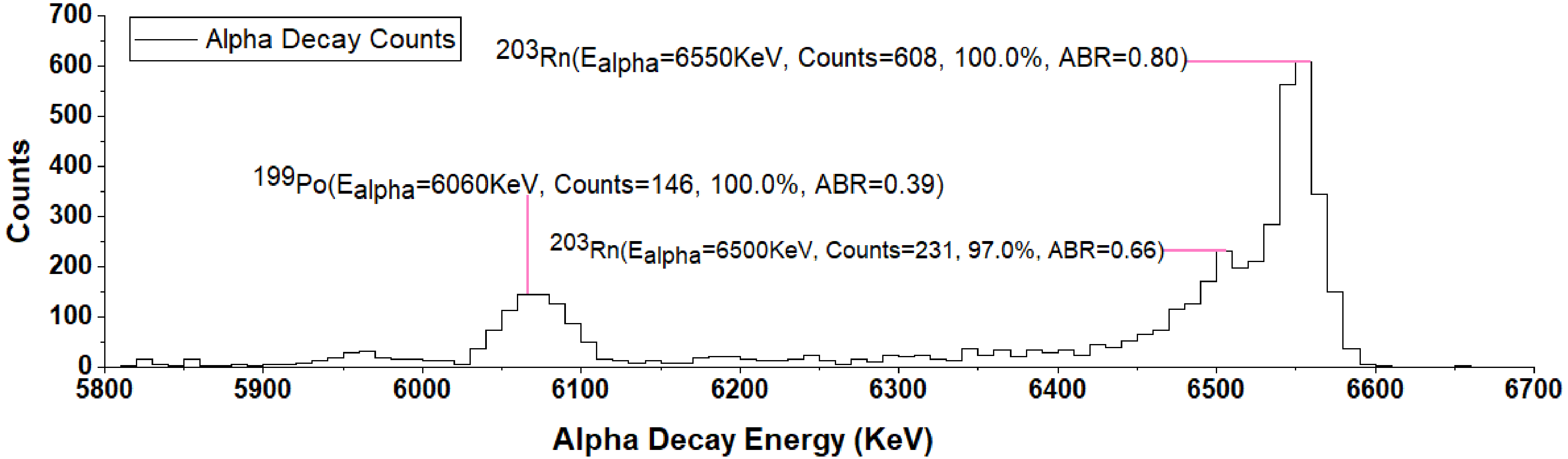
PRODUCTION OF ^{201}Rn:



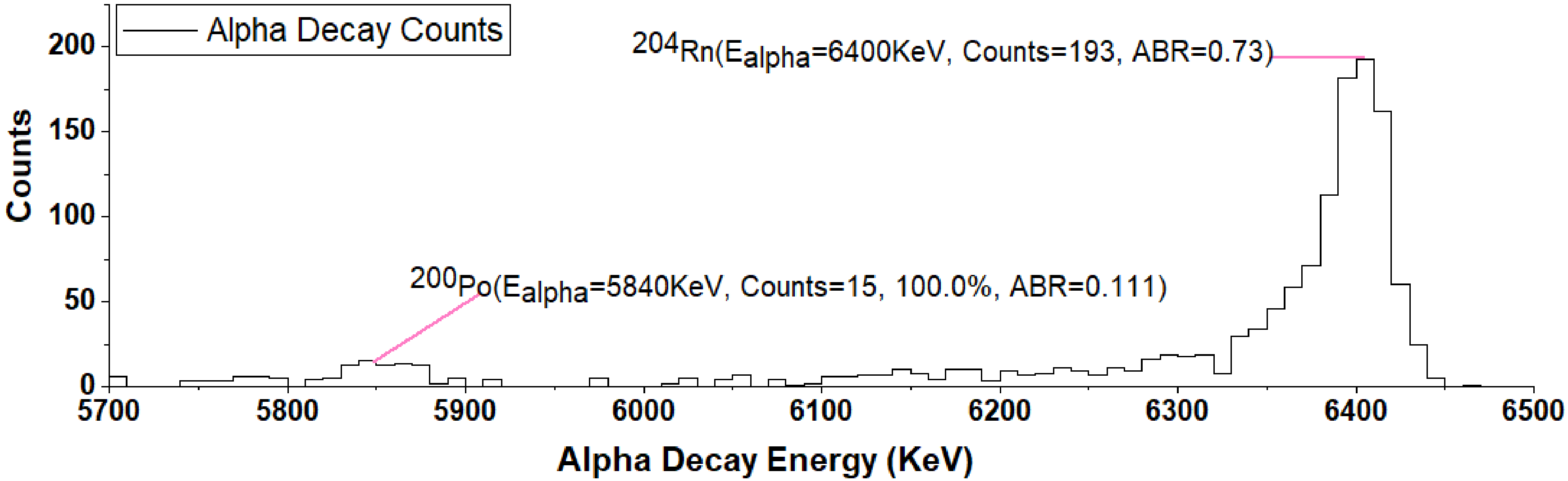
PRODUCTION OF ^{202}Rn:



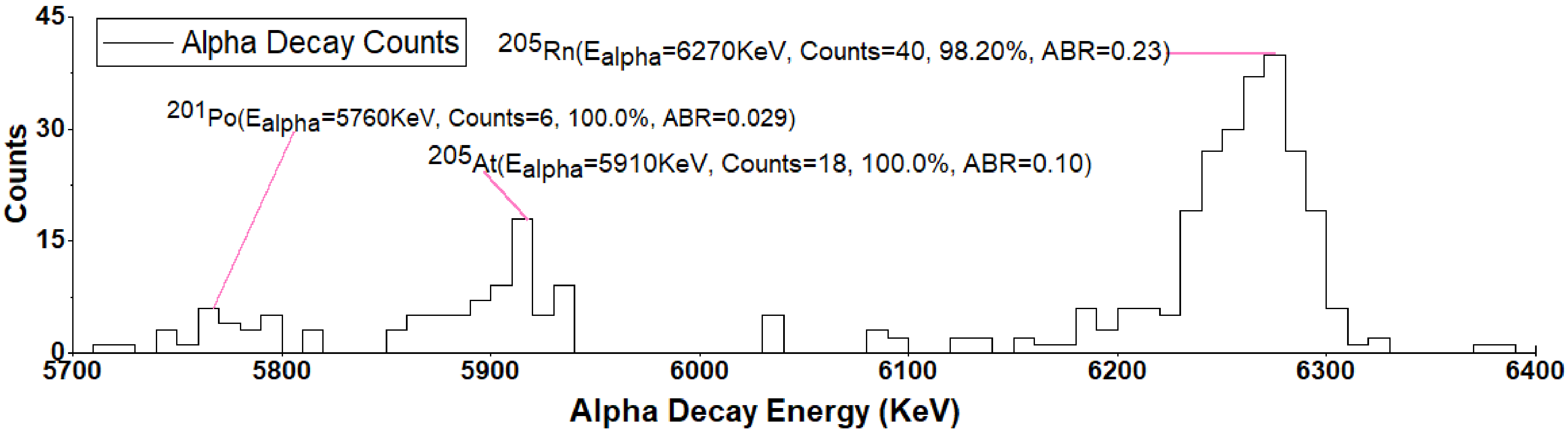
PRODUCTION OF ^{203}Rn:



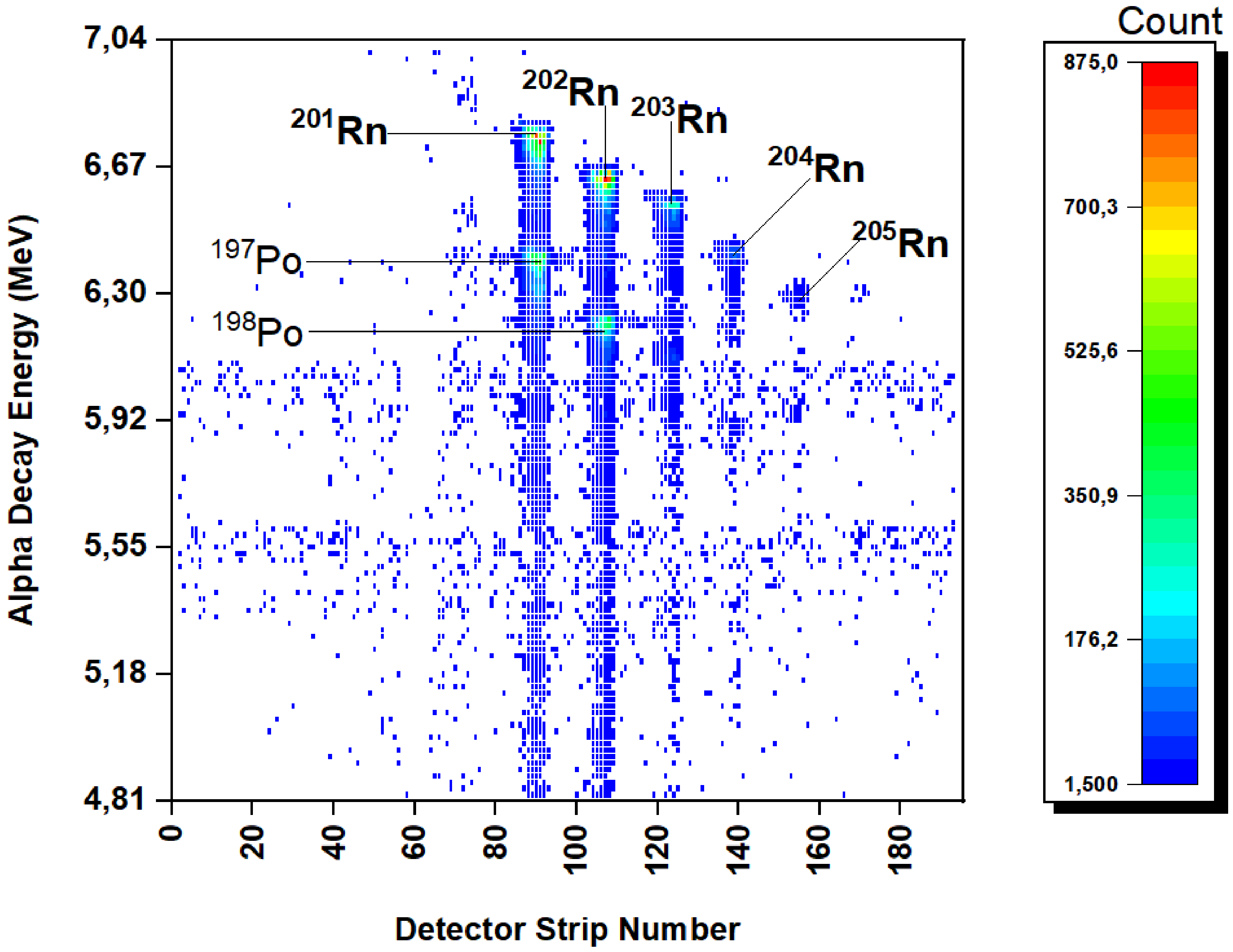
PRODUCTION OF ^{204}Rn:



PRODUCTION OF ^{205}Rn:



HEATMAP OF Rn ISOTOPES ($^{166}Er(^{40}Ar, xn)\ ^{206-x}Rn$):



- The comparison between theoretical and experimental values of Ealpha for Rn isotopes produced in complete fusion reaction ^{166}Er(^{40}Ar, xn) $^{206-x}$Rn is shown in Table 2.
- It is noticed here that the % change between these values is less than 0.3%, so our analysis on this subject is nearly accurate.

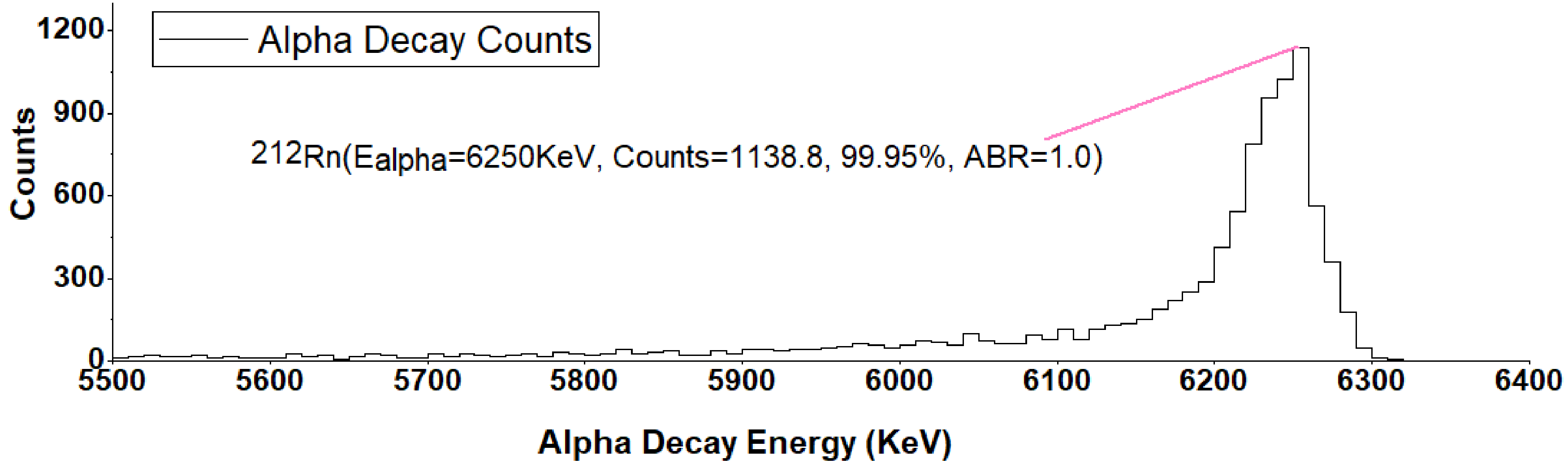
Table 2: Comparison between theoretical and experimental values of E_{alpha}(in KeV) of Rn isotopes produced in reaction $^{166}Er(^{40}Ar, xn)^{206-x}Rn$.

Nucleus	Theo. E_{alpha}	Exp. E_{alpha}	$\Delta\%$
^{201}Rn	6773	6760	0.192
^{202}Rn	6639.5	6630	0.143
$^{203}Rn(ABR = 0.80)$	6549	6550	0.015
$^{203}Rn(ABR = 0.66)$	6499.3	6500	0.011
^{204}Rn	6418.9	6400	0.294
^{205}Rn	6262	6270	0.128

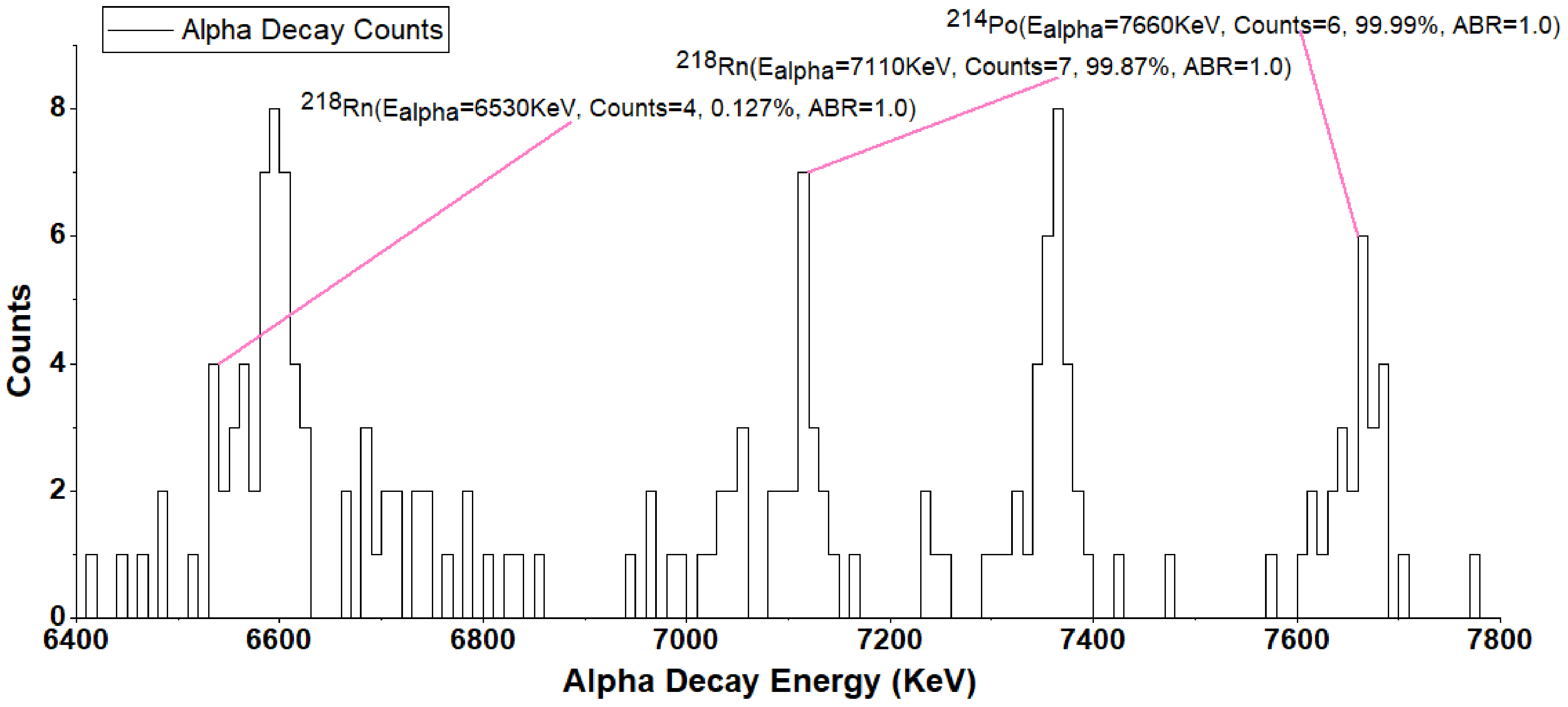
Spectroscopic Investigations Of Radon Isotopes Using MNTR $^{48}Ca + ^{242}Pu$

- Unlike complete fusion reactions discussed above, a MNTR can have any possible product nucleus.
- However, in the reaction of $^{48}Ca + ^{242}Pu$ under some fixed conditions, new neutron-rich Rn isotopes were produced near the neutron N=126 shell closure configuration, using MNTR.
- The isotopes produced were identified first, later their spectroscopic investigations were carried out.
- However, it was observed that only those Rn isotopes reached the detector and were identified which lived at least 35 ms while others decayed in their path.

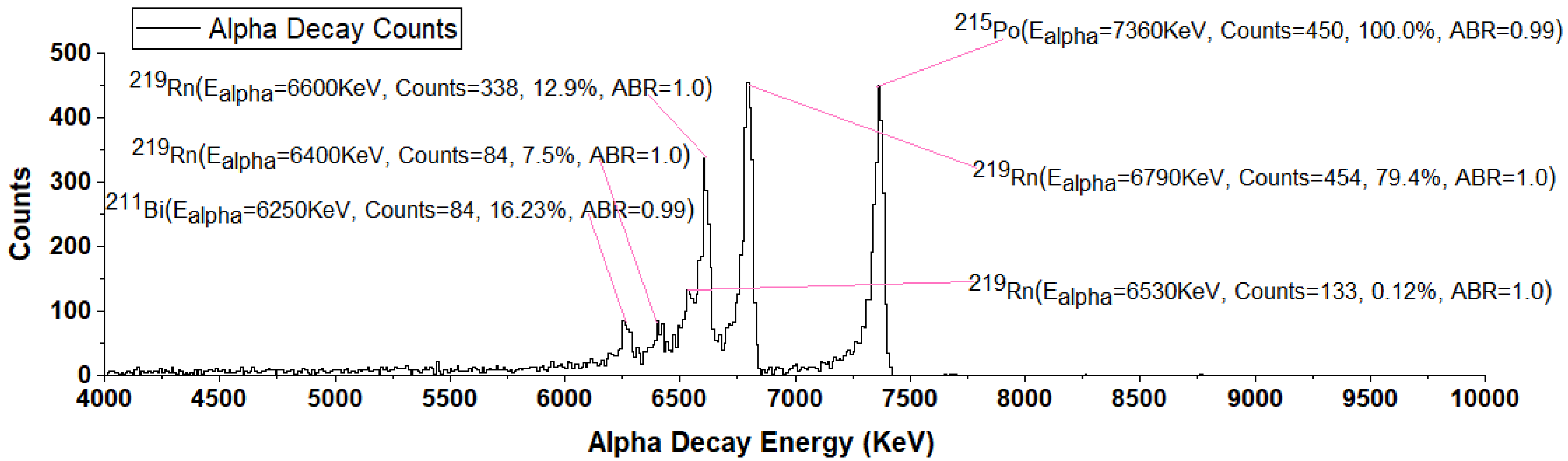
PRODUCTION OF ^{212}Rn:



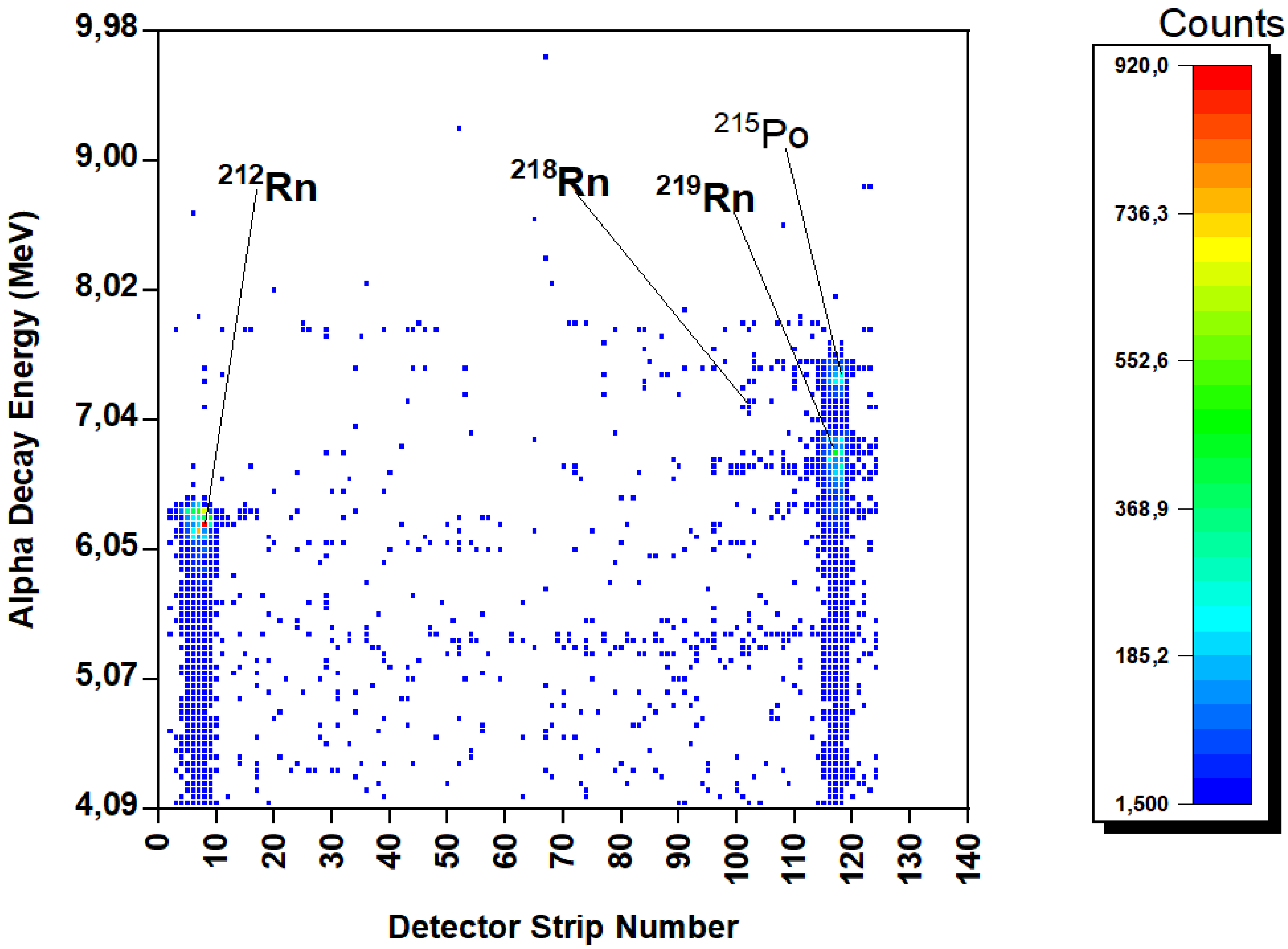
PRODUCTION OF ^{218}Rn:



PRODUCTION OF ^{219}Rn:



HEATMAP OF Rn ISOTOPES ($^{48}Ca + ^{242}Pu$):



- The theoretical and experimental values of Ealpha for Rn isotopes produced via MNTR $^{48}Ca + ^{242}Pu$ is summarized in Table 3.
- < 0.3% change in these values is observed for ^{212}Rn and ^{218}Rn isotopes, while for ^{219}Rn, the % change is < 0.5%. So, our analysis on this reaction is almost accurate.

Table 3: Comparison between theoretical and experimental values of E_{alpha}(in KeV) of Rn isotopes produced in reaction $^{48}Ca + ^{242}Pu$.

Nucleus	Theo. E_{alpha}	Exp. E_{alpha}	$\Delta\%$
^{212}Rn	6264	6250	0.223
^{218}Rn	7129.2	7110	0.269
^{219}Rn	6819.1	6790	0.427

Conclusion:

- In all three test reactions, it is observed that the theoretical energy of alpha decay almost matches with the experimental values of alpha decay with less than .3% change.
- Hence, the spectroscopic investigations of real data are correct.

References

[1] V. Y. Vedeneev, A. Rodin, L. Krupa, A. Belozerov, E. Chernysheva, S. Dmitriev, A. Gulyaev, A. Gulyaeva, D. Kamas, J. Kliman, et al., The current status of the masha setup, Hyperfine Interactions 238 (1) (2017) 1–14.
[2] M. Mamatova, A. Seitkali, E. Kudaibergenova, A. Rodin, L. Krupa, E. Chernysheva, V. Vedeneev, A. Novoselov, A. Podshibyakin, V. Salamatin, et al., Study of production stability of radon and mercury isotopes in complete fusion reactions at the mass-separator masha by “solid hot catcher” technique, in: AIP Conference Proceedings, Vol. 2163, AIP Publishing LLC, 2019, p. 070002.
[3] A. Rodin, A. Belozerov, E. Chernysheva, S. Dmitriev, A. Gulyaev, A. Gulyaeva, M. Itkis, J. Kliman, N. Kondratiev, L. Krupa, et al., Separation efficiency of the masha facility for short-lived mercury isotopes, Hyperfine Interactions 227 (1) (2014) 209–221.
[4] A. Rodin, A. Belozerov, D. Vanin, V. Y. Vedeneyev, A. Gulyaev, A. Gulyaeva, S. Dmitriev, M. Itkis, J. Kliman, N. 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) (2014) 386–393.
[5] A. Rodin, E. Chernysheva, S. Dmitriev, A. Gulyaev, D. Kamas, J. Kliman, L. Krupa, A. Novoselov, Y. T. Oganessian, A. Op´ıchal, et al., Features of the solid-state isol method for fusion evaporation reactions induced by heavy ions, in: Exotic Nuclei: Proceedings of the International Symposium on Exotic Nuclei, World Scientific, 2020, pp. 437–443.

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