INVESTIGATION OF NEUTRON-RICH OSMIUM ISOTOPES IN THE REACTION ^{136}XE+^{208}PB AT THE ENERGIES CLOSED TO COULOMB BARRIER*

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At the present time, a great interest is paid to the research of the properties of atomic nuclei (isotopes) located far from the beta stability line. Neutron-rich osmium isotopes of multi-nucleon transfer reactions investigated in this work. The reaction ^{136}Xe+^{208}Pb with energy near Coulomb barrier is used for production osmium isotopes. The CORSAR-V setup was created in framework of our investigations. Method of separation volatile reaction products from non-volatile products was realized from experimental setup. The fist experimental results were obtained at this time.

1. Introductions

One of the main problems of modern nuclear physics is determination of extreme conditions for atomic nuclei existence. In the recent years, great attention has been paid to receiving nuclei, which are located far away from the line of stability, and to studying of properties of these nuclei. Today, only the “north-east” region of nuclide chart with the number of neutrons N≈126 hasn’t been properly studied. In the framework of this project we offer to fill this region in the nuclide chart. We suggest using multi-nucleon transfer and quasi-fission reactions [1].

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Reaction $^{136}Xe+^{208}Pb$ was selected for solving this problem. The main idea of this experiment is to use stabilizing effect of closed neutron shells in both nuclei. Transfer of protons may be preferable from lead to xenon, since the light fragment (formed in this reaction) is a strongly-connected nucleus and, therefore, Q value of reaction is ≈0.

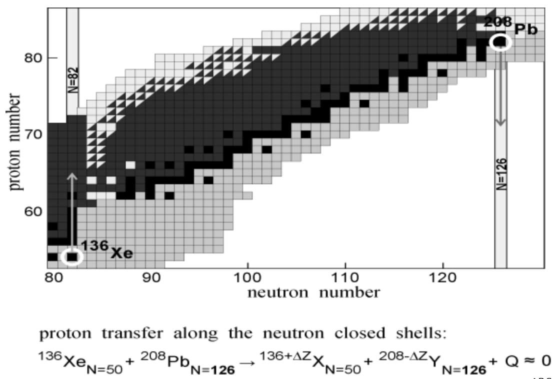


Figure 1. Chart of nuclides demonstrates possibility of proton transfer in reaction $^{136}Xe+^{208}Pb$ with energy near Coulomb barrier (black squares – stable nuclei).[1]

2. Experimental apparatus.

Theoretical prerequisites for carrying out the experiment devoted to investigation of multi-nucleon transfer reactions using the radiochemical method of gas transport are described in this work.

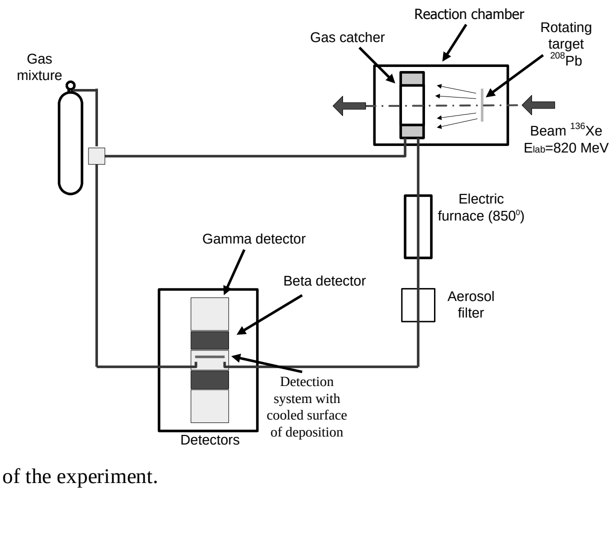


Figure 2. Scheme of the experiment.

Measurements are made with the CORSAR-V setup (correlation setup for the reaction products registration (volatile products)) which was designed for the identification and investigation of the properties of neutron-rich heavy nuclei in the region of nuclei near N = 126.

The setup has a closed gas system of gas recycling. A gas mixture (80%He + 20%O) at the pressure of 1.5 atm is fed to the gas catcher (Fig. 3) which is located in the reaction chamber. A rotating target of ^{208}Pb (450 mkg/cm2) is located in front of the gas catcher (Fig. 4). Gas catcher system is a stainless steel cylinder with hole in center of 36mm of diameter (for initial beam of ^{136}Xe to pass through). The catcher face which is in front of the nearby rotating target has windows covered with Mylar foils 25mm thick. The gas catcher was designed so that the products of the reaction under study going at~35◦(74≤ Z ≤76, N≥125 and kinetic energy 400<E<600 MeV) can pass through the Mylar foil to be taken by the gas mixture flow. Elastic scattered beam of ^{136}Xe (with kinetic energy E > 540 MeV) will not be taken by the gas flow because will have enough energy to arrive to the back wall of the gas catcher container. Reaction products which have kinetic energy E<400 MeV will be stopped in the Mylar foil. Catcher's efficiency for the capture of the studied reaction products and their transport to a cooled surface is roughly 60-70%.

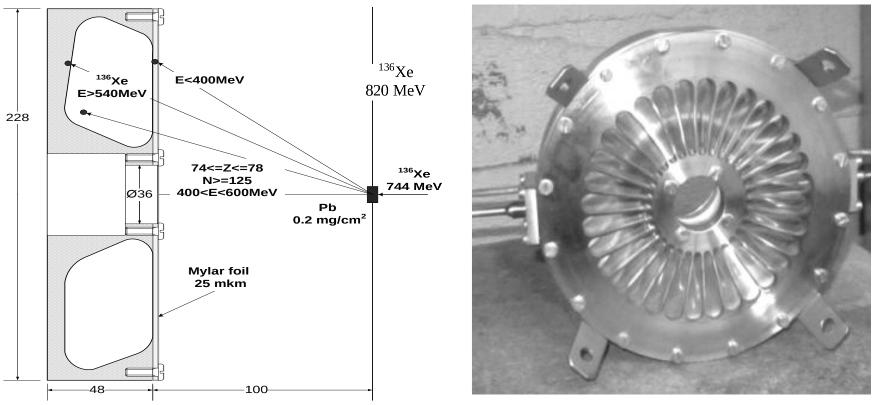


Figure 3. Gas catcher.

The products of the reaction ^{136}Xe (820MeV) + ^{208}Pb are gathered inside the gas mixture of the gas catcher and are transported through electric furnace which

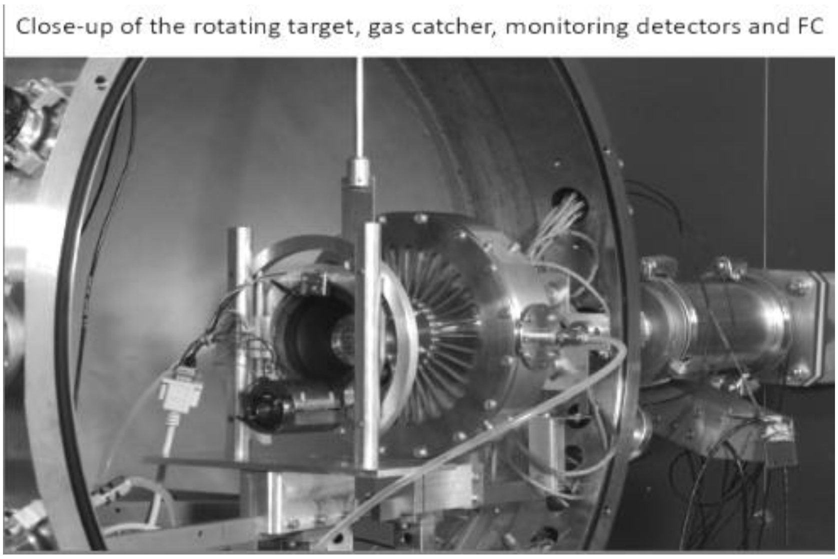


Figure 4. Reaction chamber with rotating target and gas catcher of the recoils inside.

provides oxidation of Os isotopes. Quartz filter was installed for longer oxidation of reaction products in the output tube of furnace. Then gas mixture with OsO_4 flows through heated Teflon tubes to the detection system and is deposited to copper surfaces kept at the temperature of -200°C. Special cap foils with nano-structures were used. These foils allow increasing the surface area of deposition of the reaction products by equivalently of a factor 1000. Two gamma ray detectors were used with an angle of 135 degrees between them to reduce the effect of Compton scattering on gamma rays registration. A nitrogen trap was installed in the gas system to clean the system of water vapors. β-radiation is measured by semiconductor detectors. The registration of β rays is triggered by germanium detectors which measured γ rays. After purification, the gas mixture returns back to the gas catcher.

3. Experimental results and data analyses.

This work is devoted to investigation of neutron-rich osmium isotopes. The main method of experiment is a separation of volatile from non-volatile products of reaction. This is provided by oxidation of products of reaction (only osmium oxides are volatile products) and separation by quarts filter. Accordingly, only the chains of decay of osmium isotopes can be registered. (Fig. 5)

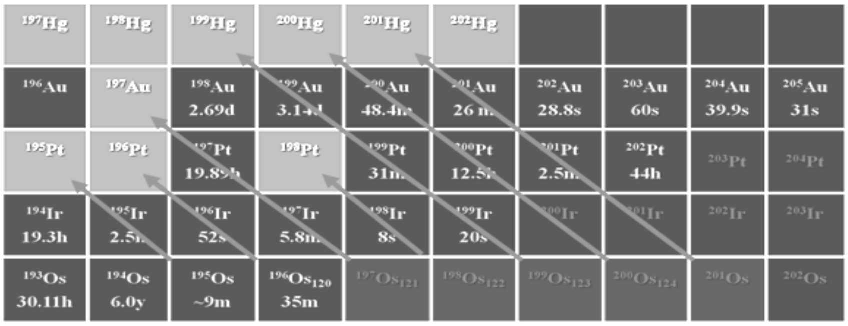


Figure 5. Chart of nuclide map is studied.

Theoretical estimations and calculations for cross section of products of reaction $^{136}Xe+^{208}Pb$ were carried out at FLNR JINR by V.I. Zagrebaev and W.Greiner [2, 3, 4].

Fig.6 (right panel) shows cross-sections of generating of initial heavy neutron-rich elements and their survival probability in reaction $^{136}Xe+^{208}Pb$ at energy E_{cm}=450MeV, which is near to Coulomb barrier (Bass – barrier for this combination is ≈434MeV). The lower panel shows cross-sections of generating nuclei, which are located near the closed neutron shell (N=126).

Therefore, calculations demonstrate that generating of unknown neutron-rich heavy nuclei is quite possible in multi-nucleon transfer reactions at low energies of ions (near Coulomb barrier).

Large number of new nuclides may be generated in the region Z=74-80, as we can see in Fig.6 (left panel) [2].

Experiment was performed on the reaction $^{136}Xe+^{208}Pb$ at the energy 820MeV at the JYFL accelerator K-130 during July 2012. This work is within collaboration between the FLNR, the Accelerator Laboratory of the University of Jyväskylä and the Department of Physics of the University of Naples (Italy).

It should be noted that during the experiment we are used two systems of data acquisition. The first system is a system of CAMAC standard with Kmax software. And the second system is a system of cPCI standard with LyrTech software. The first system of data acquisition has a resolution of about 40 keV for beta- and 4 keV for gamma-detectors. System does not have a timestamp an event. And it allows you to make quickly rough calculations for optimization of experimental conditions. The second system of data acquisition has a much

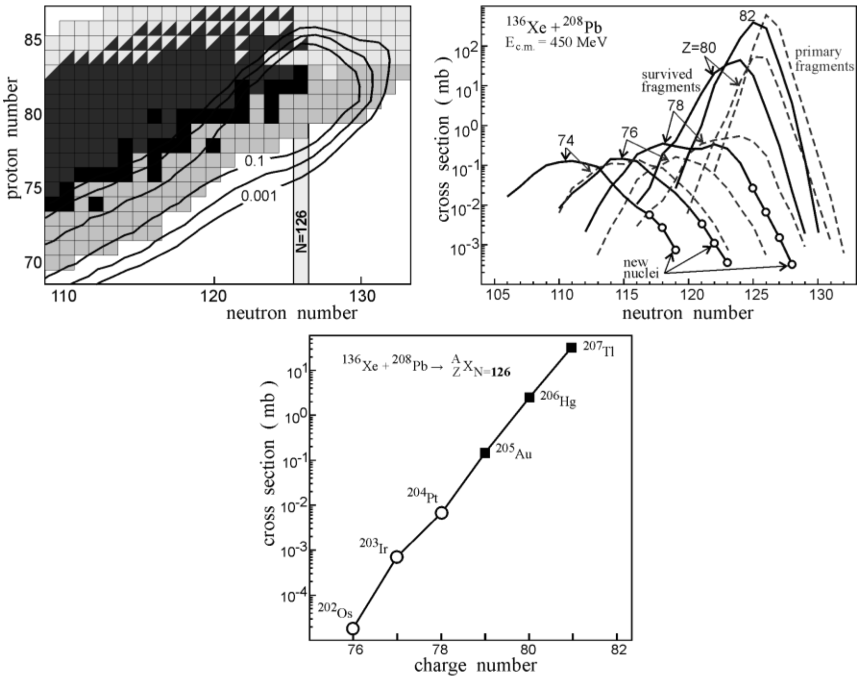


Figure 6. (The Left panel) - full section of formation of heavy fragments $d^2\sigma/dZdN$ (mb, numbers on a planimetric line) in reaction $^{136}Xe+^{208}Pb$ at energy Ecm=450MeV.
(The Right panel) - section of formation of heavy neutron-rich nuclei in reaction Xe+Pb at energy Ecm=450 MeV, blue lines - correspond to the survived nuclei; open points - unknown isotopes.
(The bottom panel) - exit of the nuclei near closed neutron shall N=126 in reaction $^{136}Xe+^{208}Pb$ at energy Ecm=450MeV; (open points) - unknown isotopes.[2]

higher resolution than the first system; it is 25 keV for beta- and 1.5-2 keV for gamma-detectors.

(a)

(b)

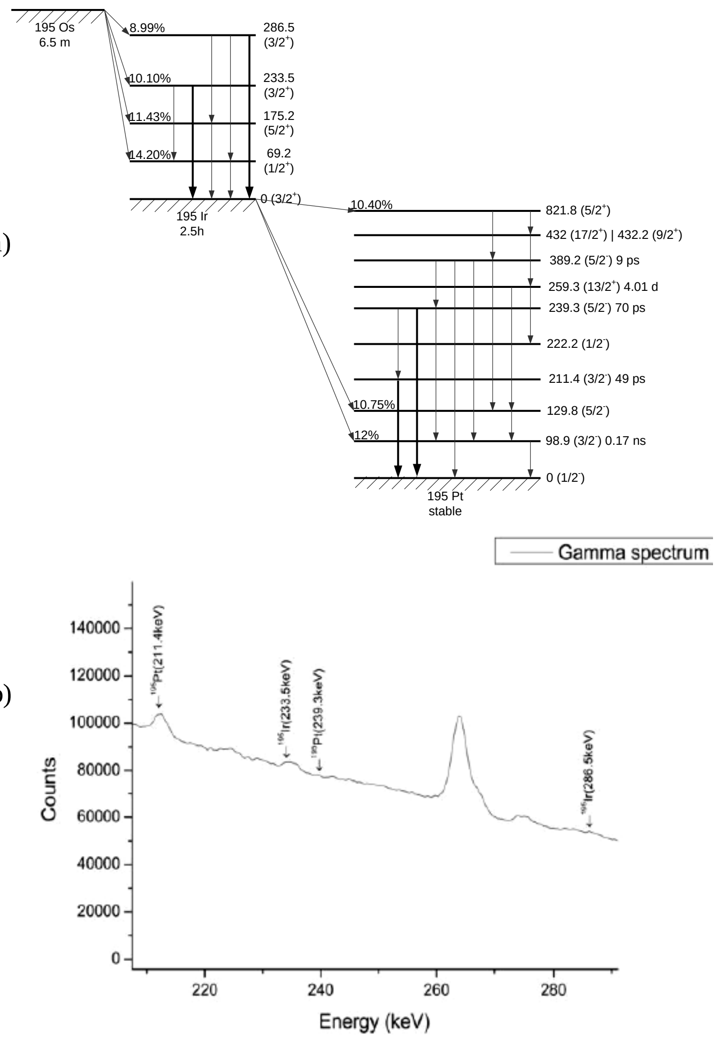


Figure 7. Scheme of decay of ^{195}Os (left panel) and gamma-spectrum for ^{195}Os (right panel).

This system has a timestamp for each registered event. It is allows to estimate the lifetime of isotopes and accurately determine the time of decay of the isotopes. Thereby, estimates results can be obtained from the data which were collected by the first system of data acquisition, and accurate results can be obtained from data of another system.

As a result of the preliminary processing of the experimental data (these data were collected by CAMAC system) on the prompt beta-gamma coincidences, the identification of the decay chains of ^{195}Os and ^{196}Os was made. These isotopes have a large cross section (Fig. 6). In particular, two daughters of the above osmium isotopes, namely Ir and Pt, were identified. Identified level transitions are marked in red.

$^{195}Os \rightarrow ^{195}Ir$
Gamma radiation of excited isotope of ^{195}Ir:
286.5→0
233.5→0
$^{195}Ir \rightarrow ^{195}Pt$
Gamma radiation of excited isotope of ^{195}Pt:
821.8→389.2→239.3→0
821.8→389.2→239.3→211.4→0

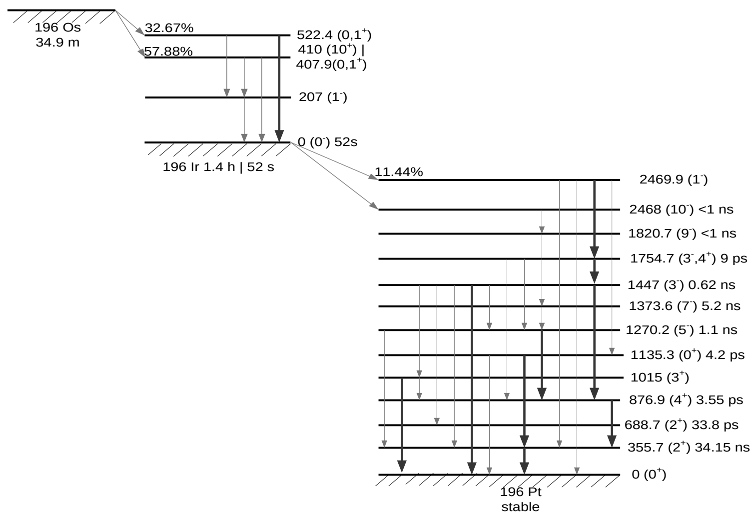
Fig. 7 shows a scheme of decay of ^{195}Os and gamma spectrum which was made by beta-gamma coincidence method.

Gamma-peaks that associated with decay of ^{195}Os were shown on Fig. 7 (b).

Also, gamma-peaks that associated with decay of ^{196}Os were found. It is shown on Fig. 8.

$^{196}Os \rightarrow ^{196}Ir$
Gamma radiation of excited isotope of ^{196}Ir:
522.4→0
$^{196}Ir \rightarrow ^{196}Pt$
Gamma radiation of excited isotope of ^{196}Pt:
2469.9→1754.7→1447→876.9→355.7→0
2469.9→1754.7→1447→0
2469.9→1754.7→1447→1270.2→876.9→355.7→0
2469.9→1754.7→1447→1015→0
2469.9→1135.3→355.7→0

(a)



(b)

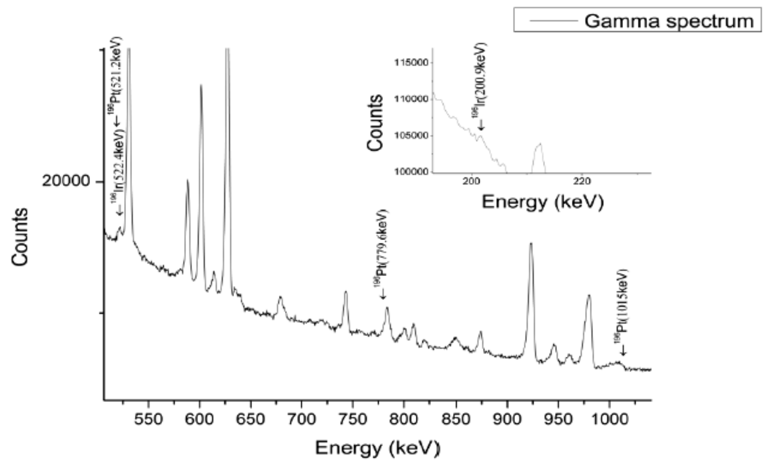


Figure 8. Scheme of decay of ^{196}Os (a) and gamma-spectrum for ^{196}Os (b).

Two chains of decay of ^{195}Os and ^{196}Os were identified on first step of processing of data. It is show that this method is suitable for obtain and investigation of neutron-rich isotopes of osmium.

The analysis for the search of beta delayed – gamma coincidences involving long lived isotopes is in progress. The approaches used for the study of nuclei in the region N =126 can be applied for the synthesis of superheavy elements in low-energy transfer reactions.

4. Conclusion

It can be seen from the above that the experimental setup has a number of technical features. The possibility of separating volatile reaction products from non-volatile products was realized from experimental setup. The cryogenic system of deposition of volatile reaction products was created. Possibility of obtaining and studying the volatile products of osmium has been seen as technical features of experimental setup.

The first data were obtained in Jyväskylä (Finland) on cyclotron K-130 in the reaction $^{136}Xe+^{208}Pb$ with energy at 820MeV.

Preliminary processing of data was made after experiment.

Even preliminary results show that low-energy multi-nucleon transfer reactions give real possibility of receiving heavy and extra-heavy neutron-rich nuclei located near closed neutron shell N=126.

5. ACKNOWLEDGMENTS

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