The combined study of cluster decay of a particular nuclide and fusion of its decay products can serve a tool of investigation of the mechanism of both processes [1]. The deep subbarrier fusion provides independent information on the shape of the barrier of the compound nucleus which can be compared with cluster emission data. We present in this paper the first study of the extremely deep subbarrier fusion of the products of the cluster decay for a nucleus with the well-known partial half-life ($^{230}$U $\rightarrow$ $^{22}$Ne + $^{208}$Pb). The experiment on fission cross section measurements was performed at JYFL. In this experiment, we used the array of solid-state track detectors (mica) installed into the target reaction chamber. Such system allowed us to perform the detection of fission fragments approximately in 4$\pi$-geometry. The sensitivity of the cross sections measurements was achieved at a submicrobarn level. It was also possible to measure the angular distribution of fission fragments and to make a conclusion on their anisotropy. This could help to estimate possible presence of quasi-fission events (resulted in the nonequilibrated fission process without compound nucleus formation). Mica detectors used in our experiment were processed to be insensitive to the light charged particles (up to $^{40}$Ar ions). The fission cross-sections were measured at fifteen $^{22}$Ne beam energies between 90 and 145 MeV. At present time a little more than seventy five percents of the total irradiated area of the detectors is scanned, and in this sense the data are preliminary. The obtained excitation function is presented in Fig.1. It is well reproduced by the potential barrier-passing model PBPM of the HIVAP code [3].

The coupled channel effects were taken into account with the fluctuating fusion barrier (expressed as a percentage of the radius parameter $r_0$) [4]. The PBPM is incorporated with the standard statistical model allowing calculation of the compound nucleus fission and evaporation residues cross sections. Data for evaporation residues obtained earlier [5] are also shown in Fig. 1. As we have seen, their contribution to the fusion cross-section is negligible in the whole energy range. So the fission cross-sections can be considered as the fusion ones.

In our calculations we used the nuclear potential in the exponential form:

$$V_N = V_0 \cdot r_0 \cdot (A_p \cdot A_t)^{1/3}/(A_p^{1/3} + A_t^{1/3}) \cdot \exp\{[r_0 \cdot (A_p^{1/3} + A_t^{1/3}) - R]/d\}.$$ 

The best fit to the data was obtained with the potential parameter values $V_0 = 75$ MeV/fm and $d = 0.75$ fm. They are close to the ones obtained for the neighbor projectiles.

The barrier fluctuating parameter was $\sigma (r_0) / r_0 = 3.5\%$. It is larger than the corresponding value (2.3%) obtained for $^{16}$O + $^{208}$Pb fusion [6] and implies stronger influence of the coupling to the other channels.

The exponential potential extracted from the data analysis is shown in Fig. 2 and compared with different theoretical potentials for the $^{230}$U $\rightarrow$ $^{22}$Ne + $^{208}$Pb system. As we have seen, our potential is very similar to the Cristensen-Winter one [7], which successfully reproduces cluster decay probabilities in the frame of the “alpha – like – decay” model [8].

Besides, the exponential potential can be excellently approximated by Woods-Saxon form factor with the parameters typical for elastic scattering: $V_0=140$ MeV, $r_0 = 1.25$ fm, $a = 0.65$ fm.

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**STUDY OF EXTREMELY DEEP SUBBARRIER $^{22}$Ne+$^{208}$Pb FUSION-FISSION AND EVIDENCE FOR ALPHA-DECAY-LIKE MECHANISM OF $^{230}$U CLUSTER RADIOACTIVITY**

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Fig. 1. $^{22}$Ne + $^{208}$Pb cross-sections: fission data obtained in this experiment (circles) and data for evaporation residues from [5] (triangles). The curves present the fits with the HIVAP code (see text).

Note, that the diffuseness parameter “a” is of quite normal value contrary to some studies claiming that fusion cross-section can be reproduced only with use of abnormally large diffusion. This result is important for understanding the mechanism of fusion. On the other hand, our empirical potential strongly differs from those predicted by the "fission-like" models of cluster radioactivity. Two such potentials [9, 10] are also shown in Fig. 2. So the study of $^{22}$Ne + $^{208}$Pb extremely deep sub-barrier fusion unambiguously leads to the "alpha-like-decay" scenario of cluster decay of $^{230}$U.

According to our approach of combined study of cluster decays and the fusion, the final test of the empirical potential is checking its ability to reproduce the experimental partial half-life of $^{230}$U → $^{22}$Ne + $^{208}$Pb decay. It is $\log T_{1/2} = 19.6 \pm 0.2$ (s) [II]. Taking the penetrability of our exponential barrier, a typical value of the frequency of assaults:

$$\nu = 2 \times 10^{21} \text{ s}^{-1}$$

and theoretical value of the spectroscopic factor $S = 1.1 \times 10^{-16}$. [12] we obtain $\log T_{1/2} = 19.0 \pm 0.5$ (s) (the error is an estimate of the uncertainties of the above-mentioned values). On the other hand the use of the empirical barrier in the framework of "fission-like" model will result in many orders of magnitude smaller half-life.

To conclude, the $^{22}$Ne + $^{208}$Pb fission excitation function was measured for the first time. Use of the solid state track detectors allowed us to reach the cross-section values by 4-5 orders of magnitude lower than in traditional fission experiments. The shape of the barrier extracted from the data belongs to the family of cluster, or "alpha-decay-like" potentials, and can be approximated by the Woods-Saxon form with the diffuseness parameter similar to that obtained in scattering experiments.

The empirical potential is consistent with the $^{230}$U cluster emission probability. So the evidence was obtained that the cluster decay $^{230}$U → $^{22}$Ne + $^{208}$Pb proceeds like alpha-decay, i.e."sudden" formation of a cluster at the surface of the parent nucleus is followed by its passage through the potential barrier. Together with the results of the analysis of scattering and fusion of lighter
nuclei [I] one may conclude that the “alpha-decay-like” mechanism of cluster radioactivity is valid for emission of the fragments with the masses up to $A = 22$.

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