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Синтез нейтронодефицитных изотопов ^{242}Fm, $^{250}102$, ^{254}Ku

С помощью реакций $^{233}U(^{22}Ne, 5n)$, $^{204}Pb(^{40}Ar, 2n)$, $^{206}Pb(^{50}Ti, 2n)$ синтезированы новые нейтронодефицитные изотопы $^{250}102$, ^{242}Fm, ^{254}Ku. Основным видом их распада является спонтанное деление. Получены периоды полураспада для $^{250}102$, ^{242}Fm, ^{254}Ku 0,25; 0,8 и 0,5 мс соответственно. Обсуждаются закономерности периодов спонтанного деления изотопов трансфермиевых элементов.

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Synthesis of the New Neutron-Deficient Isotopes $^{250}102$, ^{242}Fm and ^{254}Ku

The new neutron-deficient isotopes $^{250}102$, ^{242}Fm and ^{254}Ku have been synthesiyed by the reactions $^{233}U(^{22}Ne, 5n)$, $^{204}Pb(^{40}Ar, 2n)$ and $^{206}Pb(^{50}Ti, 2n)$ respectively. It is found that spontaneous fission is the main mode of their decay. The spontaneous fission half-lives of these isotopes have been measured to be equal to 0.25, 0.8 and 0.5 msec, respectively. Some regularities in the spontaneous fission half-lives of transfermium isotopes are discussed.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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I. INTRODUCTION

In the synthesis of new isotopes of transfermium elements, the spontaneous fission probability for the heaviest nuclides is of great importance. Since spontaneous fission is one of the main factors that determine the stability of superheavy elements, the solution of this important problem has attracted the attention of a number of investigators. However, in spite of considerable achievements in fission physics during the recent years, much still remains unclear, and additional data are needed for further progress in this direction.

In fact, a number of plausible predictions exist regarding the α-decay properties of the so far unsynthesized isotopes of heavy elements of $Z=104$, 106, etc. Calculations suggest that α-decay of nuclei of atomic numbers up to $Z=126$ is not expected to lead to a dramatic decrease in nuclear lifetime. At the same time, the spontaneous fission predictions are substantially less certain. Moreover, it has recently become evident that even extrapolation into the region adjacent to the boundary of the known nuclei appears unreliable. A long time ago, Ghiorso et al.[1,2] developed the empirical systematics of spontaneous-

fission half-lives (see. fig. 1), which indicates that the spontaneous fission half-lives of the isotopes of elements 100 and 102 depend strongly on nucleon number with a sharp maximum for $N = 152$. The authors of this systematics predicted the same dependence for the isotopes of the heavier elements.

However, the investigation of the properties of element 104 isotopes revealed serious grounds for doubting the validity of this extrapolation. Flerov et al.[3] have first synthesized the kurchatovium isotope ^{260}Ku which undergoes spontaneous fission with a half-life of 0.1 sec. Later, Ghiorso et al.[2,4,5] have investigated the α-decay of odd isotopes with mass numbers 257, 259 and 261. Oganessian et al.[6] have established that ^{259}Ku undergoes spontaneous fission (the partial half-life $T_{1/2}^{SF}$ being equal to 20-30 s) in 15-20% of the cases. Nurmia[7] has reported spontaneous fission half-lives of the isotopes ^{258}Ku ($T_{1/2}^{SF}$ = 10 msec) and ^{261}Ku ($T_{1/2}^{SF} \geq 10$ min).

By comparing these results with the systematics of Ghiorso et al. (fig. 1) one can see that odd Ku isotopes have high spontaneous fission hindrance factors (10^7 - 10^{12}), and the half-life of ^{260}Ku exceeds the value predicted by Ghiorso's systematics by a factor of 10^6 - 10^7. This long half-life of ^{260}Ku has been the subject of discussions between the Berkeley and Dubna laboratories.

To solve the controversy, it was necessary to obtain some data on the spontaneous fission probability for new kurchatovium isotopes, in particular, ^{256}Ku, with $N = 152$. The isotope ^{256}Ku, as well as the odd isotope ^{255}Ku, have recently been synthesized by

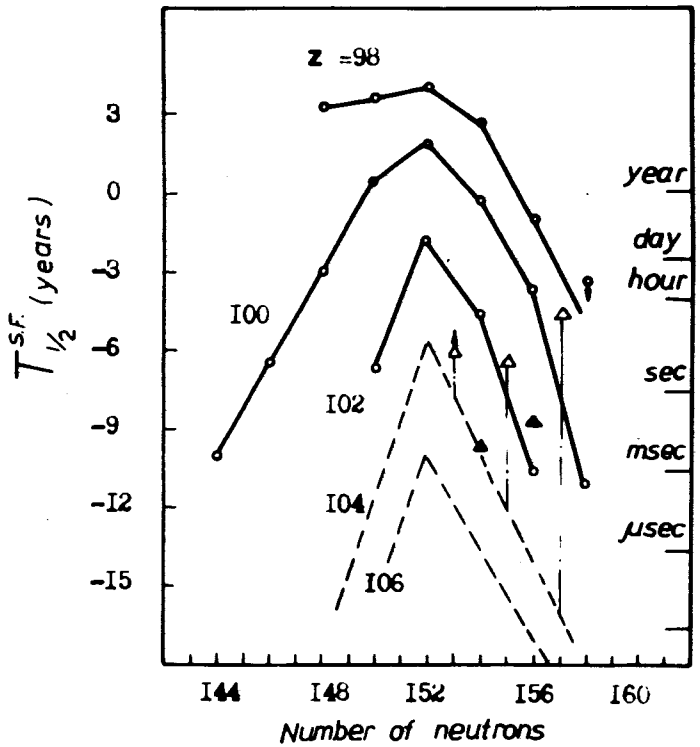

Fig. 1. Systematics of spontaneous fission half-lives for elements with Z=98, 100, 102 and 104. Circles correspond to the experimental values of spontaneous fission half-lives of the even isotopes. The closed and open triangles stand for even and odd isotopes, respectively. The dashed curves show the extrapolation using the data of Ghiorso et al.[1,2,3].

Oganessian et al.[8]. The spontaneous fission half-lives were found to be equal to 5 msec and 4 sec, respectively. It became evident that the half-lives of doubly even kurchatovium isotopes do not in fact agree with the predictions of Ghiorso's systematics[1,2], and that they increase smoothly as one goes from ^{256}Ku(N=152)to ^{260}Ku (N=152).

A qualitative interpretation of the substantial change in the regularity for $T_{1/2}^{SF}$ in moving from Z=102 to Z=104 is given in ref.[8]. This interpretation is based on the modern concept of the double-humped fission barrier structure and on the deformation energy calculations for heavy nuclei using the Strutinsky method[9]. An important conclusion that follows from this interpretation is that in a certain region of the Z and N values, in particular, at $Z \geq 104$, the stabilizing effect of the subshell N=152 may disappear. In addition, one can expect that the sharp decrease in the $T_{1/2}^{SF}$ values at $N<152$ and $N>152$, shown in fig. 1, can be replaced by a smoother dependence if one goes rather far from N=152.

The calculations of the fission barrier penetrability, carried out by Randrup et al.[10] Pauli and Ledergerber[11], and Moller and Nix[12,13] generally confirm these conclusions. A more detailed consideration of the problem requires spontaneous fission data for the new isotopes located in the region where the previously known regularities do not hold.

The production of these new isotopes of elements 100, 102 and 104 is just the purpose of the present work. Until recently this problem seemed too complicated to be

solved. The traditional method of sythesizing new elements using C, O and Ne projectiles is associated with the formation of highly excited compound nuclei which are very likely to undergo spontaneous fission during the de-excitation process. Therefore, the cross sections for the reactions which can produce new isotopes of elements 100-104 appear to be vanishingly small.

The new synthesis method[14] based on the use of the complete-fusion reactions of the type Pb+Ar, Pb+Ti, etc., permits the effective production of quite a number of neutron-deficient isotopes which have been inaccessible previously. The advantage of this method is the possibility of producing comparatively slightly excited compound nuclei, whose ground-state transition occurs following the evaporation of as a few as two or three neutrons.

For the production of the new isotopes ^{254}Ku and ^{242}Ku, the reactions ^{206}Pb(^{50}Ti, 2n) and ^{204}Pb(^{40}Ar, 2n) were used. In the experiments aimed at the synthesis of the isotope ^{250}102 use was made of the reaction ^{233}U(^{22}Ne,5n), which is one of the few reactions of this type, by which the production of new neutron-deficient isotopes of transfermium elements is possible.

The analysis of the experimental data has been carried out using the well known method of calculating the excitation functions for reactions involving the evaporation of a certain number of neutrons from the compound nucleus. This method is described in detail in ref.[15]. The calculations for reactions initiated by Ar and Ti ions have been performed using the same set of parameters

as in refs./8,14/. The only distinctive feature of these calculations from the previous ones lies in the fact that the width ratio of neutron emission to fission, Γ_n/Γ_f, has be been calculated with the help of the empirical relation obtained taking into account the latest data/8,14,16/.This relation was deduced under the assumption that for nuclei with $Z \geq 104$ the effect of the subshell $N = 152$ vanishes not only on the spontaneous fission half-lives but on the Γ_n/Γ_f value as well. The systematics of the Γ_n/Γ_f ratio, which includes also the results obtained in the present paper is shown in fig. 2. This figure also shows the curves that approximate the experimental data.

II. DESCRIPTION OF EXPERIMENTS

The experiments have been performed using an external beam from the U-300 Heavy Ion Cyclotron of the Joint Institute for Nuclear Research. The bombardments of targets prepared of ^{233}U and stable isotopes were carried out using different experimental arrangements.

The $^{22}Ne^{4+}$ ion beam with the initial energy of 182 MeV, after being retarded in a stack of aluminium foils, passed through a thin target made of $^{238}U_3O_8$ (1 mg/cm^2 of uranium) deposited onto a 5μm aluminium backing (see fig. 3a). The recoil nuclei escaping from the target struck the edge of a thin rotating disk. The disk was surrounded by mica track detectors for fission fragments. Spontaneous fission events were identified both by two coincident tracks in the opposite micas (50% of the decay events

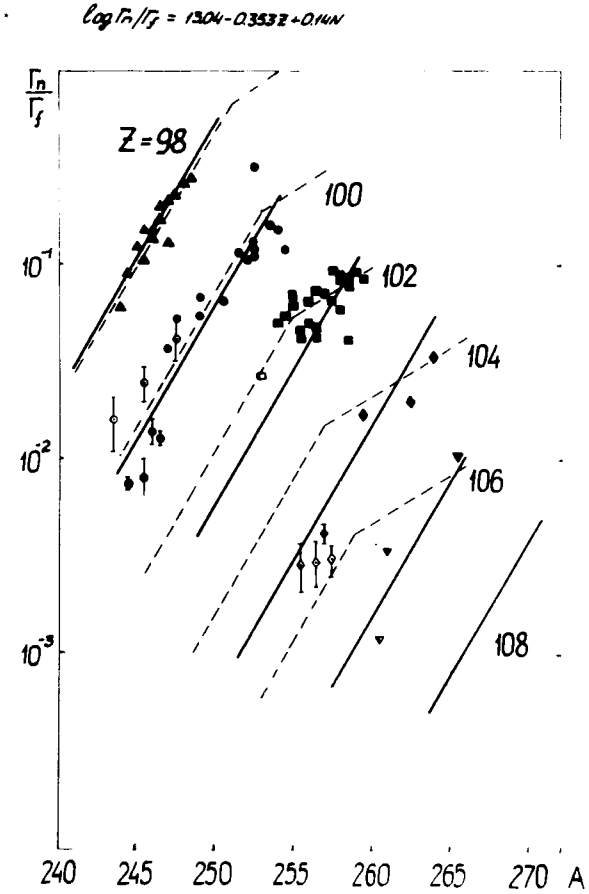

Fig. 2. The Γ_n/Γ_f systematics taking into account the results of investigations of nuclear reactions of the type Pb(Ar, xn) , Pb(Ti, xn) and Pb(Cr, xn).

recorded) and by single tracks. The total detection efficiency for spontaneous fission reaction products was 60%.

The average ^{22}Ne ion current was 2.5 x x 10^{12} part/sec.

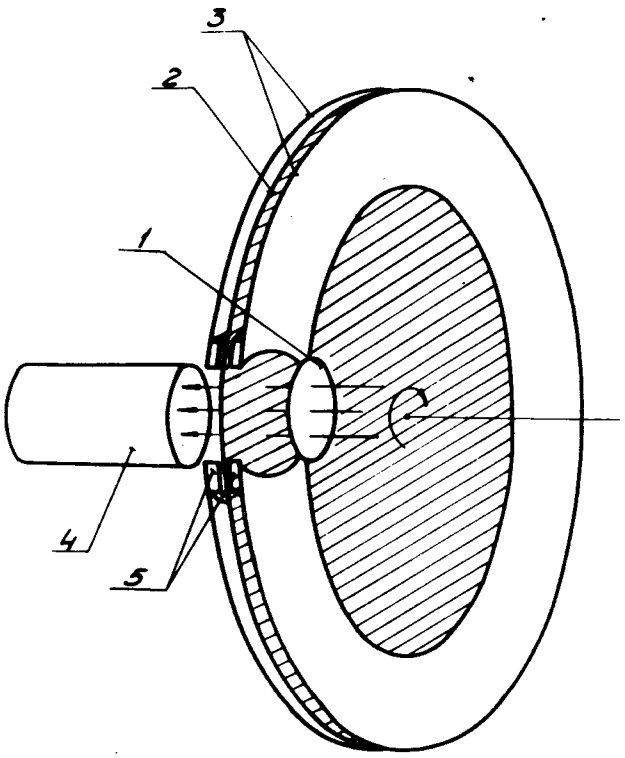

Fig. 3a. The experimental arrangement for the observation of short-lived spontaneous fission products formed in the reaction $^{233}U + ^{22}Ne$: 1 - the ^{233}U target, 2 - an aluminium foil disk ($d = 5\mu m$, $\phi = 16$ cm), 3 - mica detectors for fission fragments, 4 - Faraday cup, 5 - screens preventing the prompt reaction products from striking mica detectors.

The bombardment of the stable targets manufactured of separated lead isotopes was carried out using the experimental arrangement shown in fig. 3b. The $^{40}Ar^{6+}$ and $^{50}Ti^{7+}$ ion beams passed through diaphgrams and

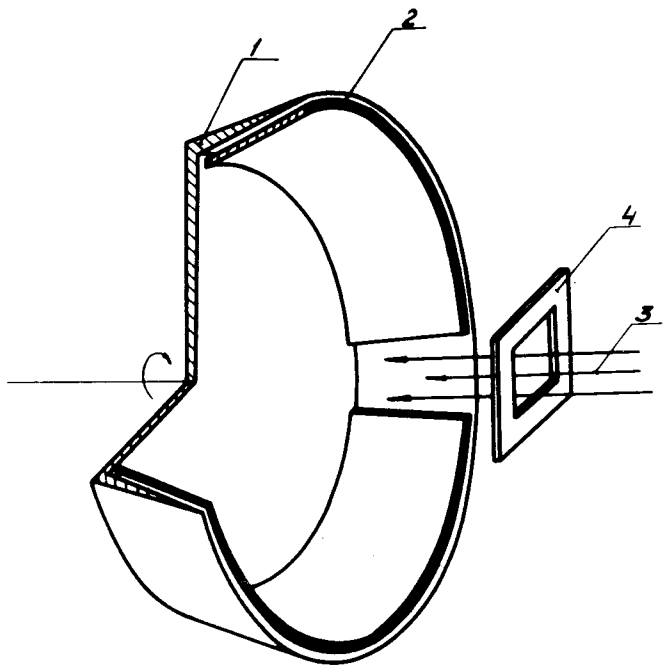

Fig. 3b. The experimental arrangement for the observation of short-lived spontaneous fission products formed in the bombardment of stable isotopes by heavy ions: 1 - the truncated cone onto the inner surface of which the target substance was deposited, 2 - mica detector for fission fragments, 3 - ion beam, 4 - collimator.

struck a rotating target. The target material was deposited onto a backing by vacuum vaporization (see fig. 3b). The layer thickness was equal to 2-5 mg/cm^2 .

The angle between the beam direction and the target surface was equal to 12°. Therefore, from the standpoint of the formation of complete-fusion reaction products the target appeared to be infinitely thick. Recoil nuclei were stopped at a depth of 1.0 - 2.5 mg/cm^2 from the target surface. This permitted the efficient observation of the fragments formed as a result of spontaneous fission of these nuclei. The fission fragments were detected using mica detectors shown in fig. 3b. The detection efficiency for spontaneous fission events was about 50%.

The average Ar^{6+} and Ti^{7+} ion currents were determined using the activation method to be equal to 2 x 10^{12} part/sec and 10^{11} part/sec, respectively.

In both experimental arrangements shown in figs. 3a and 3b, the maximum rotation velocity was 24 000 rev/min permitting detection of reaction products with a half-life of $T_{1/2} \geq 200$ msec.

III. EXPERIMENTAL RESULTS AND DISCUSSION

III.1. Synthesis of the Isotope $^{250}102$

A thin ^{233}U target was bombarded by ^{22}Ne ions with an energy of 120 MeV, corresponding to the calculated maximum of the excitation function for the reaction $^{233}U(^{22}Ne, 5n)$. The decay curve for the spontaneous fission activity observed ($T_{1/2} = 0.25 \pm 0.05$ msec) is shown in fig. 4. The production cross section for the activity is $\sigma \cong 1.5 \times 10^{-33}$ cm^2. The rest of the experimental data are listed in table 1. In our opinion, the 0.25msec spontaneous fission activity can be attri-

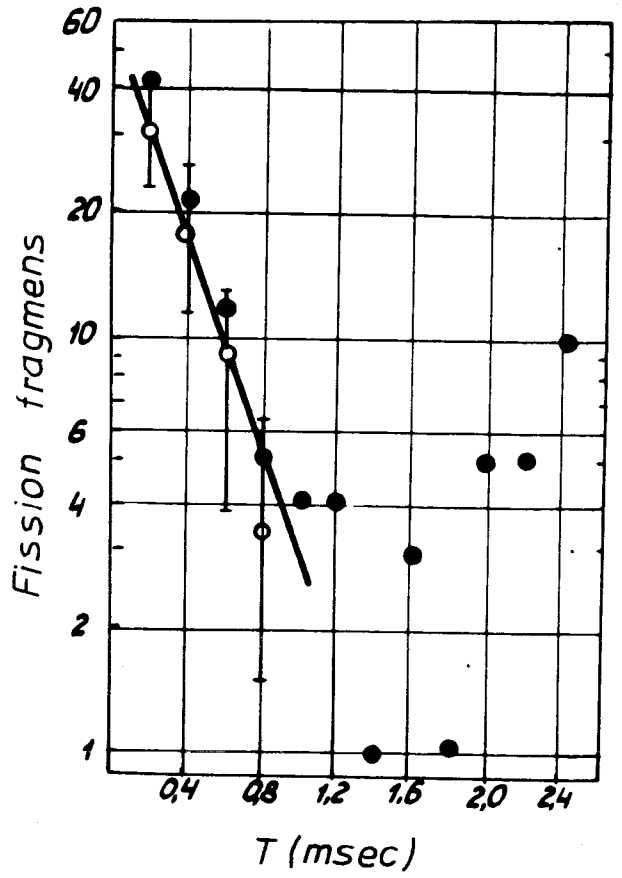

Fig. 4. The decay of the spontaneous fission activity observed in the bombardment of ^{233}U by ^{22}Ne ions. An increase in the number of tracks in the interval 2.0-2.4 mseec is due to the incidence of a small fraction of prompt fission fragments from the target onto the mica detectors. In the half-life determination this background was subtracted (open circles).

TABLE 1

Nuclear reaction	Ion energy (MeV)	Compound nucleus excitation energy (MeV)	Time interval for observation of activity decay (msec)	Integral ion flux	Number of s.f.events detected	Half-life (msec)
$^{233}U + ^{22}Ne$	120±1.5	43.8-52.3	0.1-2.5	4×10^{16}	60	0.25±0.05
$^{206}Pb + ^{40}Ar$	225	28-65	0.2-5.0	1.9×10^{16}	78	4
$^{204}Pb + ^{40}Ar$	"	27-64	0.1-2.5	5.3×10^{16}	208	
$^{204}Pb + ^{40}Ar$	"	"	0.2-5.0	2.5×10^{16}	88	0.8±0.2
$^{206}Pb + ^{40}Ar$	203-225*	43.5-65.5	"	2.4×10^{16}	12	0.8
$^{206}Pb + ^{40}Ar$	"	"	"	"	24	4
$^{206}Pb + ^{50}Ti$	245	15.7-28.7	0.1-2.5	2.4×10^{15}	15	
$^{206}Pb + ^{50}Ti$	"	"	0.3-7.5	1.7×10^{15}	13	0.5±0.2
$^{208}Pb + ^{48}Ti$	255	21.8-45.7	0.3-7.5	1.5×10^{15}	1	-

* The energy interval has been determined taking into account the stopping power of ^{40}Ar ions in the inclined lead target. The stopping power was found using the tables of Northcliffe and Schilling[30]

buted to the isotope $^{250}102$. In fact, the reaction $^{233}U(^{22}Ne, 5n)^{250}102$ is predominant among other reactions of the $(^{22}Ne, xn)$ type at the chosen ^{22}Ne energy (120 MeV). Calculations suggest that under the given experimental conditions the reaction $^{233}U(^{22}Ne, 4n)$ may have a comparable cross section. However, the isotope $^{251}102$ formed in this reaction is a known one; it undergoes α-decay with $T_{1/2}$ = 0-8 sec (refs.[17,18]). The other known isotopes of element 102, mendelevium or fermium, which could in principle be produced in this experiment have half-lives also strongly different from 0.25 msec and undergo mainly α-decay. The calculated cross section section for the reaction $^{233}U(^{22}Ne, 6n)^{249}102$ is at least a factor of 20 smaller than that for the 5n reaction. Therefore, the isotopes of elements 102 with mass 249 and less cannot account for this activity.

It is not excluded that in the bombardment of the ^{233}U target by neon ions spontaneously fissioning isomers can be formed as a result of multinucleon transfer reactions. However, among the known spontaneous fission isomers there are none with half-lives close to 0-25 msec. The closest half-lives characterize ^{238m}Am ($T_{1/2}$ = 35 sec), ^{240m}Am ($T_{1/2}$ = 0.9 msec) and ^{246m}Am ($T_{1/2}$ = = 73 sec). The cross sections for the ground state production of these isotopes can be calculated on the basis of the data available on multinucleon transfer reactions[19-21]. By taking the maximum known isomeric ratio equal to 10^{-3} (ref.[22]) we obtain the cross sections for the isomers indicated to be a factor of 10^2 - 10^4 smaller than the value

obtained for the 0.25 msec activity. This result agrees with the data for the production of ^{238m}Pu (ref. [23]) and ^{240m}Am (ref. [24]) by bombarding ^{232}Th and ^{238}U targets with different ions.

As follows from the systematics of the spontaneous fission half-lives for isomers [25], the assumption that the so far unknown isomers with $T_{1/2} \cong 0.25$ msec still exist should be regarded as an unlikely one.

Thus, the 0.25 msec spontaneous fission activity is most likely to be attributed to the isotope $^{250}102$. The half-life of this isotope for α-particle emission can be estimated to be $T_{1/2} \geq 0.03$ sec (refs. [26-28]). Consequently, spontaneous fission is its principal mode of decay.

III.2. Synthesis of the Isotope ^{242}Fm

A lead target enriched in ^{204}Pb (51% ^{204}Pb, 21.5% ^{206}Pb, 10.9% ^{207}Pb, 16.6% ^{208}Pb) was bombarded by 225 MeV ^{40}Ar ions. The experiment was carried out using the experimental set-up shown in fig. 3b.

The time distributions of the fission fragments tracks observed for two different velocities of target rotation are shown in fig. 5. One can see that, along with the known isotopes ^{244}Fm and ^{246}Fm, which have had to be formed on the admixture lead isotopes with mass numbers 206-208 (ref. [14]), a spontaneous fission activity with a short half-life is also observable. The yields of ^{244}Fm and ^{246}Fm can be determined from the data of ref. [14]. However, in order to eliminate systematic errors due to the use of different experimental arrangements in this

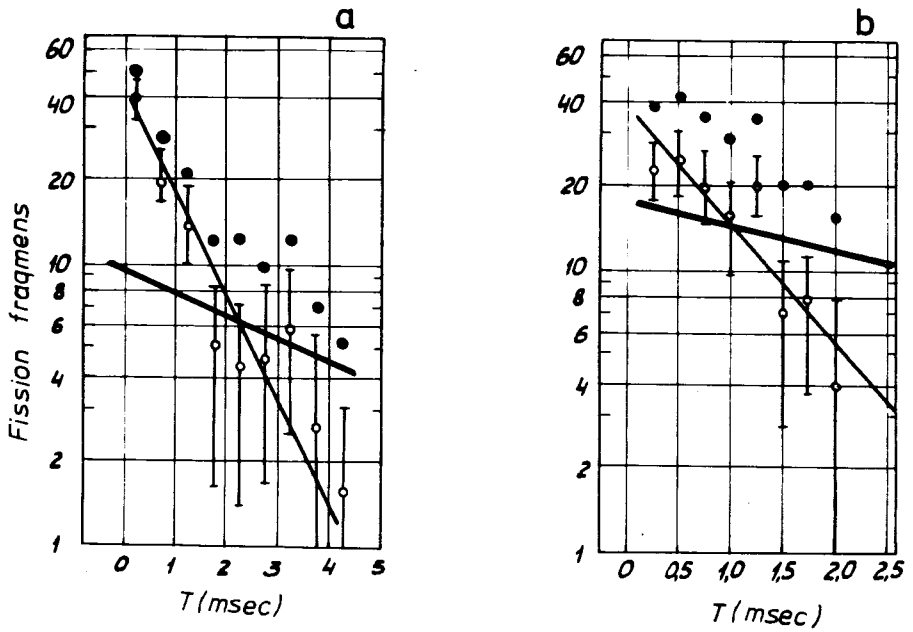

Fig. 5. The decay of the spontaneous fission activity obserbed in the bombardment of ^{204}Pb by ^{40}Ar ions. The target rotation velocities are 24 000 rev/min (a) and 12 000 rev/min (b). The solid line corresponds to the contribution from spontaneous fission of ^{244}Fm and ^{246}Fm, which are formed at the expense of reactions occuring on the heavier lead isotopes available in the target material.

work and in ref. [14], a separate bombardment of a ^{206}Pb (90.4%) target by 225 MeV ^{40}Ar ions has been performed. The results of this bombardment are presented in table 1 (the second line). In this experiment, only the

4 msec spontaneous fission activity attributed to ^{244}Pb has been observed. The short-lived activity whose decay is seen in fig. 5 has not been observed. On the basis of the curves shown in fig. 5 it is possible to estimate the half-life of this activity to be equal to 0.8 ± 0.2 sec. The rest of the experimental data obtained in the bombardment of ^{204}Pb by ^{40}Ar ions are given in table 1 (the third and fourth lines).

When identifying the 0.8 msec activity one can exclude the light californium isotopes $^{239,238}Cf$ since reactions involving α-particle emission under these experimental conditions have yields[8] that are more than two orders of magnitude larger than the yield of this activity. Thus, two possible reactions are left to consider, i.e., $^{204}Pb(^{40}Ar, 2n)^{242}Fm$ and $^{204}Pb(^{40}Ar, 3n)^{241}Fm$. For this purpose we have carried out an experiment in which the production of this emitter was observed in the bombardment of a thin ^{206}Pb target by ^{40}Ar ions with the initial energy of 225 MeV.

Figure 6 shows the calculated excitation functions for the reactions $^{206}Pb(^{40}Ar, xn)$ with x = 2-5. In order to reduce the background due to spontaneous fission of ^{244}Fm produced by reaction involving the emission of two neutrons, the thickness of the ^{206}Pb layer was chosen to be 0.6 mg/cm^2. As a result, the ^{40}Ar ion energy in the target layer was in the range of 203 to 225 MeV. Under these conditions the 0.8 msec activity has been observed. The results of this experiment are presented in table 1 (the fifth and sixth lines). As is seen from fig. 6, the reaction $^{206}Pb(^{40}Ar, 4n)^{241}Fm$ has a too small

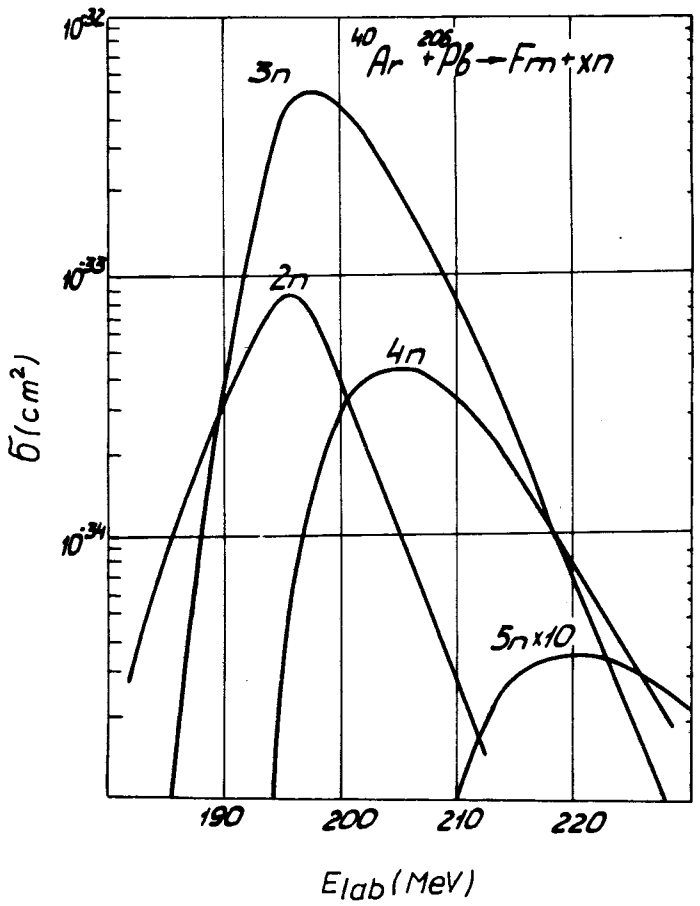

Fig. 6. Calculated excitation functions for the reactions $^{206}Pb(^{40}Ar, xn)$.

cross section to be observed. Consequently, the 0.8 msec emitter could be produced only by the reactions $^{206}Pb(^{40}Ar, 4n)^{242}Fm$ or $^{206}Pb(^{40}Ar, 3n)^{243}Fm$.

A comparison of the ^{204}Pb and ^{206}Pb target yields permits the assignment of the 0.8msec activity to the isotope ^{242}Fm. The estimate of its α-decay probability (see table 2) shows that it decays mainly by spontaneous fission.

III.3. The Production of the Isotope ^{254}Ku

The results of the bombardment of the ^{206}Pb target with ^{50}Ti ions are presented in the seventh and eighth lines of table 1. The decay curves of the spontaneous fission activity observed in these experiments are shown in fig. 7, its half-life being equal to 0.5 ± 0.2 msec. It is natural to assume this activity to be attributable to one of Ku isotopes with mass number 254 or 253. The half-life of the isotope ^{255}Ku ($T_{1/2} \cong 4$ sec) (ref. [8]), which might be produced in the reaction $^{206}Pb(^{50}Ti; 1n)$, substantially differs from 0.5 msec. Under these experimental conditions, the reaction $^{206}Pb(^{50}Ti, 4n)^{252}Ku$ was energetically forbidden. For the same reason, the isotope $^{249}102$ and other lighter isotopes of elements 102 and 100 are excluded.

The excitation functions calculated for the reactions $^{206}Pb(^{50}Ti, xn)$ given in fig. 8 show that the emitter observed can preferentially be identified as the isotope ^{254}Ku. In fact, the maximum ^{50}Ti ion energy equal to 245 MeV turns out to be located much to the left of the excitation function maximum for the reac tion $^{206}Pb(^{50}Ti, 3n)^{253}Ku$. This assumption agrees with the results obtained in the bombardment of the ^{208}Pb (97.8%) target by ^{48}Ti ions. The minimum excitation

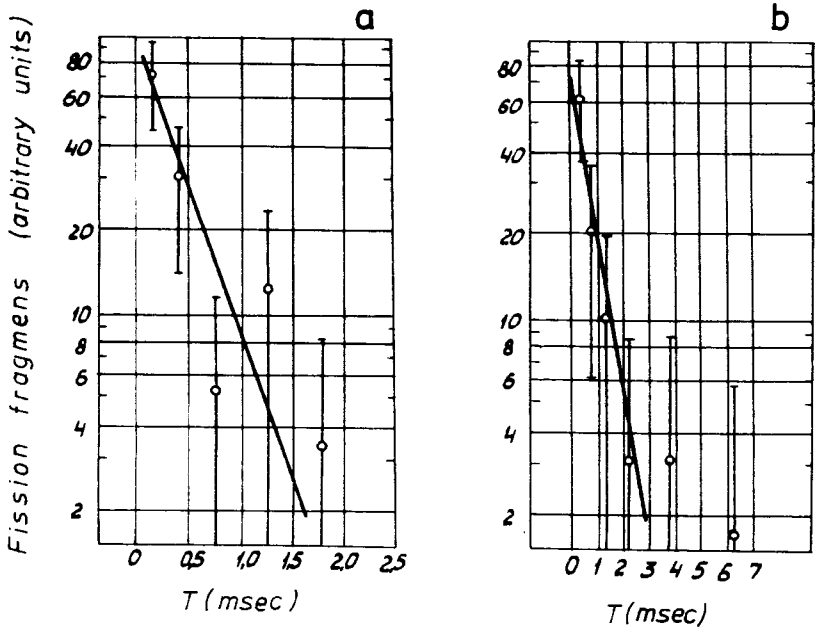

Fig. 7. The decay of the spontaneous fission activity observed in the bombardment of ^{206}Pb by ^{50}Ti ions. The target rotation velocities are 24 000 rev/min (a) and 8 000 rev/min (b).

energy of the compound nucleus ^{256}Ku produced as a result of fusion of ^{208}Pb and ^{48}Ti appears to be 6 MeV higher than that of the system $^{206}Pb + ^{50}Ti$. This should lead to a sharp decrease in the cross section for the reaction $^{206}Pb(^{50}Ti, 2n)$. The calculated factor of this decrease is equal to 30. At the same time, if the 0.5 msec activity were produced in reaction with three neutrons evapo-

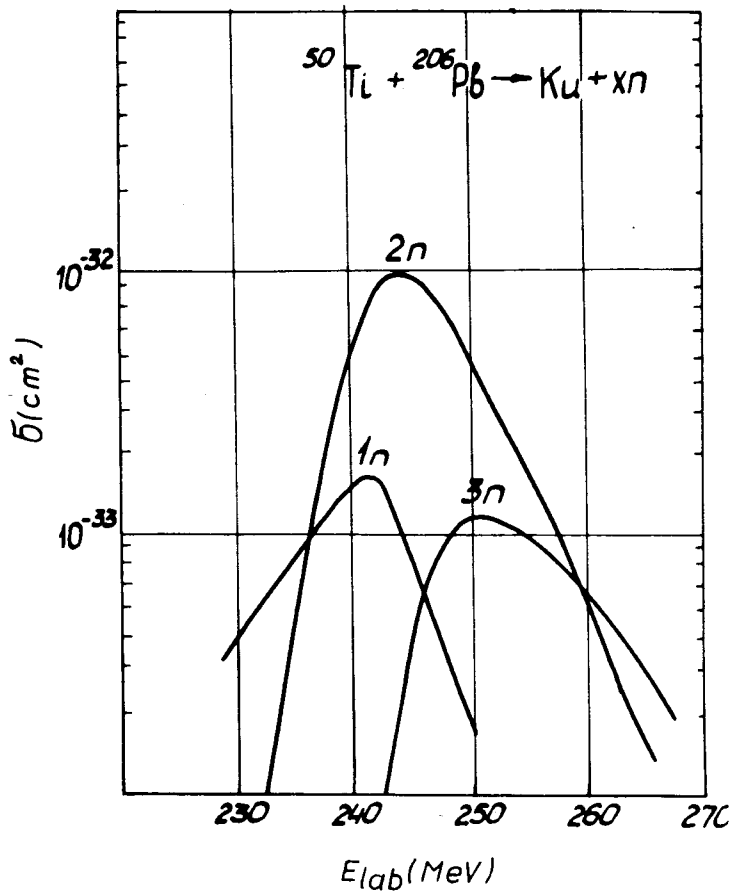

Fig. 8. The calculated excitation functions for the reactions $^{206}Pb(^{50}Ti, xn)$.

rated, its yield had to remain constant since some decrease in the cross section in the maximum would be compensated by the increasing maximum energy of ^{48}Ti ions with respect to ^{50}Ti.

TABLE 2

Reaction	$\sigma_{exp.}$ (nbarn)	$\sigma_{calc.}$ (nbarn)	$T^{SF}_{1/2}$ (msec)	$T^{\alpha}_{1/2}$ (sec)
$^{233}U(^{22}Ne,5n)^{250}102$	1.5	1.5	0.25±0.05	0.03–1
$^{204}Pb(^{40}Ar,2n)^{242}Fm$	1.6	2.7		
$^{206}Pb(^{40}Ar,4n)^{242}Fm$	0.2	0.4	0.8±0.2	0.02–0.25
$^{206}Pb(^{40}Ar,2n)^{244}Fm$	3.6	0.8	4	0.15–1
$^{206}Pb(^{50}Ti,2n)^{254}Ku$	7	10		
$^{208}Pb(^{48}Ti,2n)^{254}Ku$	1	0.3	0.5±0.2	0.004–0.6

In the reaction $^{208}Pb + ^{48}Ti$ (see the last line of table 1) no spontaneous fission activity has practically been observed, since the yield was approximatly ten times lower than that in the reaction $^{206}Pb + ^{50}Ti$.

One can see from table 2 that spontaneous fission is the main mode of decay for ^{254}Ku*.

The results pertaining to the properties of new isotopes and to the regularities of their formation by nuclear reactions are summarized in table 2. The first column presents all the reactions whose products were observed in our experiments. The experimental and calculated cross sections for the reactions are listed respectively in the second and third columns of the table. For the $^{233}U(^{22}Ne, 5n)$ reaction, the maximum cross section has been obtained directly in the experiment. In other cases, the cross sections calculated from the measured yields of the activities produced in the corresponding reactions on thick targets are presented. Possible errors in the absolute cross sections correspond to a factor of two deviation from the true magnitudes. Relative errors are substantially smaller and determined mainly by statistics.

The satisfactory agreement between the experimental and calculated values of cross sections, obtained in the present paper and in refs. /8,14/ permit the conclusion that the mechanism of complete fusion followed

* Spontaneous fission of ^{253}Ku with $T_{1/2} \approx$ ≈1.5 sec has been observed in other experiments performed by Yu.Ts.Oganessian, N.A.Danilov, A.G.Demin, M.P.Ivanov, A.S.Iljinov, A.A.Pleve and S.P.Tretyakova.

by neutron evaporated from a compound nucleus reflects some important aspects of the interaction process in the case of the collision of lead nuclei with heavy projectiles such as Ar or Ti.

The experimentally measured spontaneous fission half-lives of the isotopes produced are listed in the fourth column of table 2. The fifth column presents the estimated half-lives for α-particle emission. The upper limit of these estimates is obtained using the semiempirical mass formula of Kolesnikov /26/, while the lower limit follows from the nuclear mass tables of Viola et al./28/.

The systematics of spontaneous fission half-lives is given in fig. 9. This includes the data obtained in the present paper, the data on the isotopes $^{255,256}Ku$ (ref. /8/) and the data for the isotope $^{259}106$, first synthesized at Dubna /16/.

One can see from fig. 9 that the half-life of the isotope $^{250}102$ is three orders of magnitude shorter than that of its even neighbour $^{252}102$. Consequently, the known regularity associated with the stabilizing role of the subshell N = 152 is still in effect here.

The value of the ^{254}Ku half-life confirms the conclusion about the smooth dependence of the spontaneous fission probability for Ku isotopes on neutron number /8/. It is noteworthy that the half-life of ^{242}Fm is only a factor of 4 shorter than the half-life of the neighbouring even isotope and is approximately a factor of 1000 longer than the value following from the systematics presented in fig. 1. Thus, the sharp

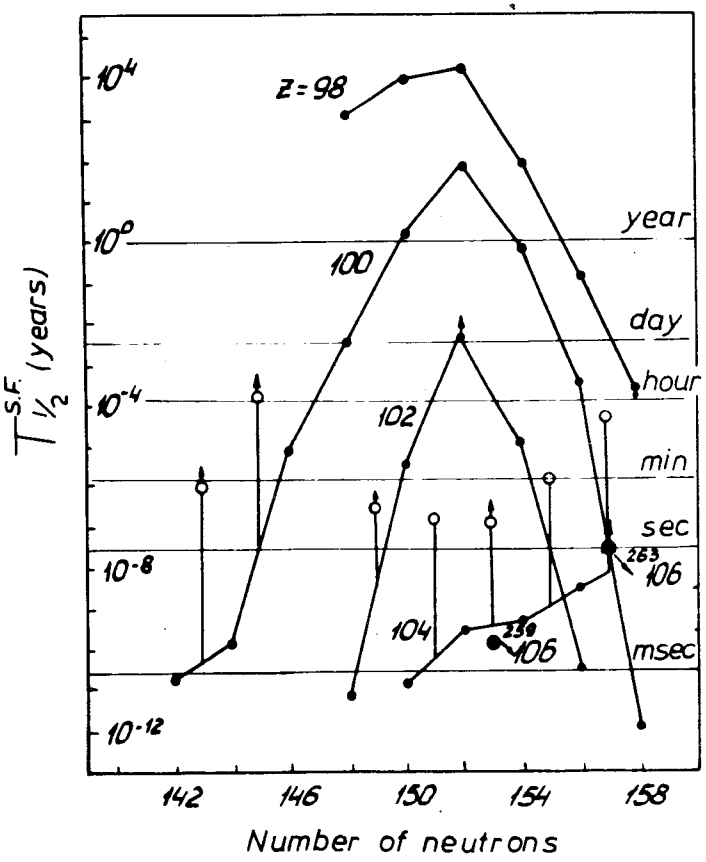

Fig. 9. Systematics of spontaneous fission half-lives taking into account the new data on the isotopes ^{242}Fm, ^{250}102, ^{254}Ku, ^{255}Ku, ^{256}Ku and ^{259}102. The limiting $T_{1/2}$ values for the odd isotopes ^{243}Fm, ^{245}Fm and ^{251}102, obtained on the basis of the results of the present paper and ref.[14], and the limiting $T_{1/2}$ value for the isotope ^{263}106, which follows from the data of Ghiorso et al.[29], are also given.

decrease of the $T^{SF}_{1/2}$ values for fermium isotopes with $N < 152$ ceases with $N = 144$ to give a comparatively smooth dependence which is characteristic of kurchatovium isotopes. These results do not seem surprising within the framework of the double-humped fission barrier structure. Apparently, the fact that the smooth variation of half-lives begins to manifest itself as a result of a factor of 10^{12} decrease in the absolute $T^{SF}_{1/2}$ value in going from ^{252}Fm to both ^{256}Ku and ^{244}Fm deserves attention. One had to expect such a coincidence under the assumption that in both cases the same factor, i.e. the effect of the second barrier, which delays spontaneous fission of isotopes with $N = 152$ is eliminated. In the absence of this delay the half-life $T^{SF}_{1/2}$ is determined only by the first barrier penetrability. The $T^{SF}_{1/2}$ values for the corresponding fermium and kurchatovium isotopes are seen to be of the order of a millisecond.

From the calculations using the Strutinsky method[9] it follows that the height and shape of the first fission barrier in the nuclear region under investigation is slightly dependent on nucleon number. Therefore, one can assume that the rate of a decrease in the spontaneous fission half-lives as one moves to elements with atomic numbers 106-108 should slow down. This assumption is in agreement with experimental results on element 106.

Some lower limits on the $T_{1/2}$ values for the odd isotopes ^{243}Fm ($T_{1/2} \geq 50$ sec), ^{245}Fm ($T_{1/2} \geq 4 \times 10$ sec) and ^{251}102 ($T_{1/2} \geq 10$ sec) estimated on the basis of the data of the present paper and of ref.[14] are given in

fig. 9. This figure also shows the $T_{1/2}^{SF}$ limit for the isotope of element 106 with mass number 263, which can be estimated from the paper by the Berkeley group[29]. On the basis of the systematics shown in fig. 9 we obtain the hindrance factors equal to $\geq 2\times10^4$ for ^{243}Fm and ^{245}Fm, $> 3\times10^3$ for ^{251}102, $\approx 10^3$ for ^{255}Ku, ^{257}Ku and ^{259}Ku and $\approx 10^4$ for ^{261}Ku. For isotopes of element 106 with mass numbers 259 and 263, the hindrance factors seem to lie within 10^3 - 10^4. Thus there is no need in assuming abnormal hindrance factors for kurchatovium odd isotopes, as it followed from the systematics of Ghiorso et al., shown in fig. 1. It should be noted that on the basis of this systematics one had to conclude the hindrance factor for the isotope $^{263}106$ to be $\geq 10^{14}$.

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