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SPONTANEOUS FISSION AND SYNTHESIS OF FAR-TRANSURANIUM ELEMENTS

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- USSR -

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-USSR-

[Following is a translation of an article by G. N. Flerov, Ye. D. Donets and V. A. Druin (affiliations not given), in the Russian language periodical Atomnaya energiya (Atomic Energy), Vol 14, No 1, Moscow, January 1963, pages 18 - 26. (The article was submitted to editors on 30 August 1962).]

The possibility of the spontaneous fission of nuclei was predicted theoretically in 1939 on the basis of a model concept regarding the nucleus as a drop of charged liquid [1]. Just after the publication of this report, in the laboratories of many countries, intensive research got underway on spontaneous fission for the heaviest elements known at that time, namely uranium (U) and thorium (Th). In the Leningrad Physico-Technical Institute of the USSR Academy of Sciences, in Prof. I. V. Kurchatov's laboratory, a highly sensitive method was developed. Within its at K. A. Petrzhak and G. N. Flerov were the first scientists to be able to observe fragments of the spontaneous fission of U^{238} [2].

The experimental detection of the fission of U^{238} from the ground (unexcited) state greatly stimulated the interest in studying the new type of radioactive decay of nuclei. Research was conducted basically along two lines: an explanation of the mechanism of the natural fission, and a search for new spontaneously fissionable nuclei. It was established that many transuranium elements, obtained artificially in reactors or accelators, undergo natural fission.

CERTAIN REGULARITIES IN THE NATURAL FISSION OF NUCLEI

By 1952, extensive experimental material had been accumulated on the periods of natural fission and this permitted Seaborg to systematize the data for the first time [3]. He constructed a graph of the dependence of spontaneous fission periods T_{sf} upon the fissility parameter Z^2/A: in the liquid drop model, this represents the ratio of the Coulomb force of the protons' repulsion to the stabilizi

surface force of the nucleus. This approach was refined and expanded later [4, 5]; it is represented in Figure 1 in contemporary form. We can note three basic features in the behavior of the natural fission periods for the various elements: 1) a general tendency toward a decrease in T with an increase in Z^2/A; 2) a "parabolic" form of curves, in which there fall the values $T_{s.f.}$ of the various isotopes of one element, and 3) an increase in the $T_{s.f.}$ of nuclei with an odd number of neutrons or protons by 10^3 - 10^6 times in comparison with the $T_{s.f.}$ of an even-even nucleus with the given parameter Z^2/A. The first feature agrees qualitatively with the predictions of the hydrodynamic model, whereas it is impossible to explain the other two from the standpoint of this nuclear model. The theory of the natural fission was developed in close conjunction with the overall theory of the nuclear structure and of nuclear reactions. Various model representations of the nuclear structure were also used for an explanation of the features of the behavior of $T_{s.f.}$ as a function of Z^2/A. It is evident that, for a proper understanding of the fission pattern, it is insufficient to consider only the collective properties of the nucleus, but it is also necessary to consider the behavior of individual nucleons in case of the origination of distortion of the nucleus as a whole. As was demonstrated by Nielsson [6], the energy of individual nucleons varies greatly with the increase in nuclear distortion. This could lead to an appreciable variation in the hydrodynamic fission barrier. An analysis of the effective fission barriers with the use of the Nielsson diagrams was conducted by Johansson [7], who showed that with a consideration of the single-particle corrections to the hydrodynamic barrier, one can obtain a more regular behavior of $T_{s.f.}$ as a function of Z^2/A. The scattering of the points becomes much less; they cluster near the straight line (Figure 2).

In spite of the considerable advances of the theory in explanation of natural fission, it (the theory) still is qualitative. Specifically, it is quite difficult to estimate theoretically the lifetimes of the far transuranium elements. Therefore for such estimations, we resort to various semi-empirical formulas and to extrapolations of the experimental dependences in the region of the unknown nuclei. The formulas developed by Svyatetskiy [8] and Dorn [9] are widely used. The precondition for their derivation was the circumstance that the experimental values of the masses of nuclei in their ground state deviate (from the points on the smooth mass surface, computed on the basis of a hydro-

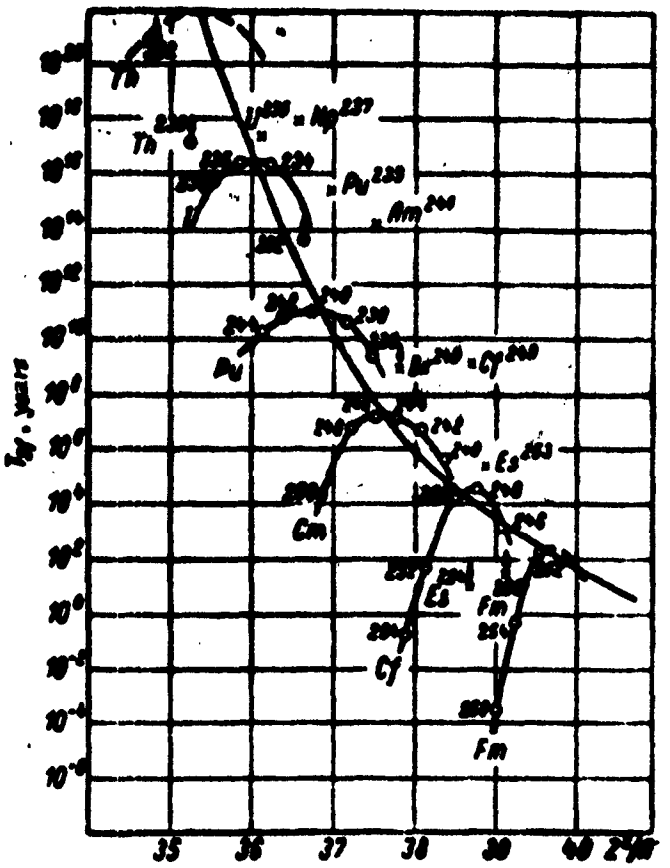

Figure 1. Dependence of periods, T_{sf}, of natural fission upon fissility parameter, Z^2/A.

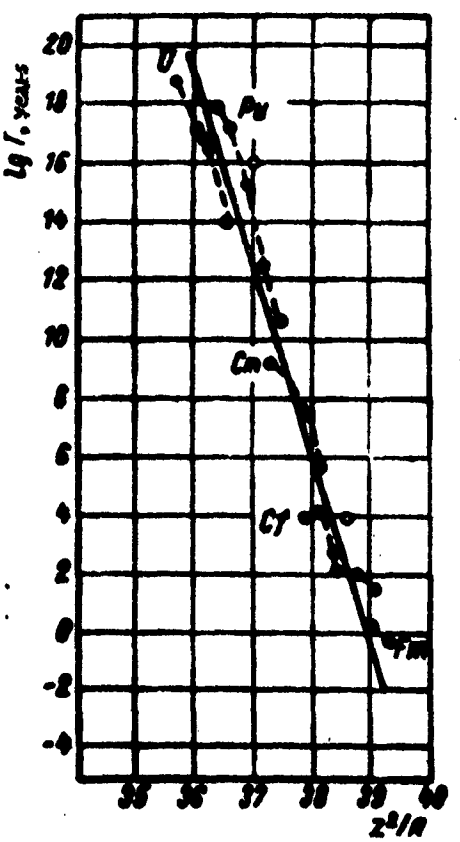

Figure 2. Dependence of experimental values for T_{sf}, taking single-particle corrections into account, upon Z^2/A [7].

dynamic model) by the value $\delta \underline{m}$, while the experimental values for the periods of spontaneous fission deviate by the value δT from the values expected for this model.

Svyatetskiy noted that the values for δT and $\delta \underline{m}$ correlate in a definite way with one another. This now appears natural, since we already know that the hydrodynamic formula for the masses disregards the shell structure of the nuclei, the fluctuations in the pairing energies, the heterogeneity of the angular and radial distributions of the charges etc., and all these energy effects affect the lifetime of the nuclei in relation to natural fission. Introducing the empirical corrections $K\delta \underline{m}$ into the observed periods of natural fission, Svyatetskiy obtained the uniform dependence of $T_{sf} + K\delta m$ upon Z^2/A for the even-even nuclei at $K = 5 - (Z^2/A - 37.5)$.

Dorn modified somewhat the Svyatetskiy formula, having added the term $\sqrt{Z/A}$ in order to get a greater smoothing of the lines. The analytical Svyatetskiy-Dorn expression for the periods of natural fission has the form:

$$\left.\begin{array}{l}\log T_{\text{even-even}}\\ \log T_{\text{odd A}}\\ \log T_{\text{odd-odd}}\end{array}\right\} = \left\{\begin{array}{l}-30.06\\ -23.46\\ -18.56\end{array}\right\} - 7.8\theta + 0.35\theta^2 +$$

$$+0.073\theta^3 + 1389\sqrt{Z/A} - (4 - \theta)\,\delta \underline{m}$$

where $\theta = Z^2/A - 37.5$; T_{sf} is expressed in seconds, while δm is given in mega-electron-volts (Mev). For an estimation of the natural fission periods of unknown nuclei, δm can be found as the deviation of the tabular value of the mass according to Cameron [10] from a point on the smooth mass surface:

$$M = 1000A - 8.3557A + 19.12A^{2/3} - 0.76278\,\frac{Z^2}{A^{1/3}} +$$

$$+25.444\,\frac{(N - Z)^2}{A} + 0.420(N - Z).$$

The results of computing the natural fission periods based on the Svyatetskiy-Dorn formula for certain isotopes of curium, californium, fermium, and also for the elements 102 and 104 are given in Figure 3. For comparison,

experimental points are marked with an "x", through which broken lines are drawn. It is obvious that for californium isotopes, there is satisfactory agreement with the formula, whereas for fermium the position and the pattern of the broken and solid lines differ appreciably. For the heavy curium isotopes, the formula predicts an abrupt increase in the probability of natural fission, while for the elements 102 and 104 in the range of neutrons' numbers > 152, the rates of the decrease in the natural fission periods are somewhat retarded as compared with californium and fermium. In report [11], analyzing the yield curve of various transuranium elements during the thermonuclear explosion dubbed "Mike", Dorn demonstrated that this formula gives depressed $T_{s.f}$ -values for very heavy isotopes (e. g., Fm^{254} and Fm^{255}). The author concludes that for an explanation of the yield curve, it is necessary to assume that in the region remote from the line of β-stability, natural fission can not occur faster than the β-disintegration, i.e. that the Svyatetskiy-Dorn formula is incorrect for nuclei enriched with neutrons. At present, it does not appear possible to determine exactly the range of the N-value where this formula is valid. If we speak of new, as yet undiscovered elements, directly containing the ones that are studied, evidently the most reliable method of estimating the lifetime of these elements in relation to spontaneous fission will then still be the extrapolation of the empirical dependences $T_{s.f}$ upon Z and A. For this purpose we can use, e.g., the dependence of $T_{s.f}$ upon the number of neutrons N in the nucleus at constant Z (Figure 4) or the dependence of $T_{s.f}$ upon the number of protons, Z, in the nucleus at fixed N (Figure 5). A simple graphic extrapolation yields (for the elements 102 and 104) $T_{s.f}$ -values differing substantially from the computed ones. Specifically, for the isotope 104^{260}, from Figures 4 and 5, we can expect lifetimes of 0.01 - 1 second, whereas the Svyatetskiy-Dorn formula leads to a value, for the period, equalling 1 hour.

Quite significant for a prediction of the properties of new elements is the explanation of the question as to how great is the effect of the subshell with N = 152 upon the fission barrier in the range of high A-values.

At very high A-values, the parameter Z^2/A becomes appreciably less than $(Z^2/A)_{N=152}$. In conformity with the position of the hydrodynamic model, such nuclei should be more stable in respect to fission. Competition on the part of

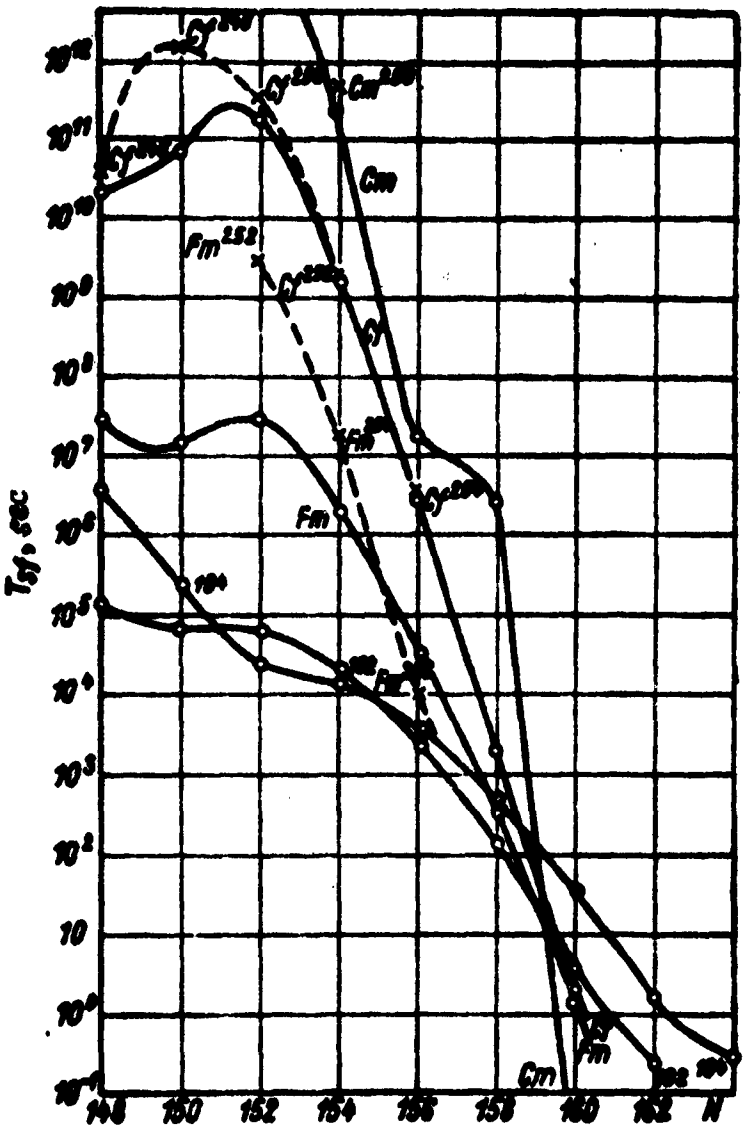

Figure 3. Dependence of T_{sf} -values computed from the Svyatetskiy-Dorn formula upon the number, N, of neutrons in the nucleus:

———O——— = results of calculation; ----X--- = experimental data.

Caption to left of figure T , seconds

the shell effect leads to a decrease in T_{sf}, however the role of this effect should be considerably less, remote from N = 152, and then we can expect a rise in the right branches of the curves in Figure 4. It is difficult to predict the beginning of such a rise. Johansson [7], analyzing the behavior of the

neutron levels all the way to N = 160, concludes that the heavy isotopes of californium and fermium will live longer than follows from the graphic extrapolations. For instance, the extrapolational value of $T_{s.f.}$ for Fm^{258} constitutes several minutes, while according to Johansson estimation, it should equal an hour. For Cf^{256}, in the same way there was obtained a $T_{s.f.}$ -value of between a year and a month.

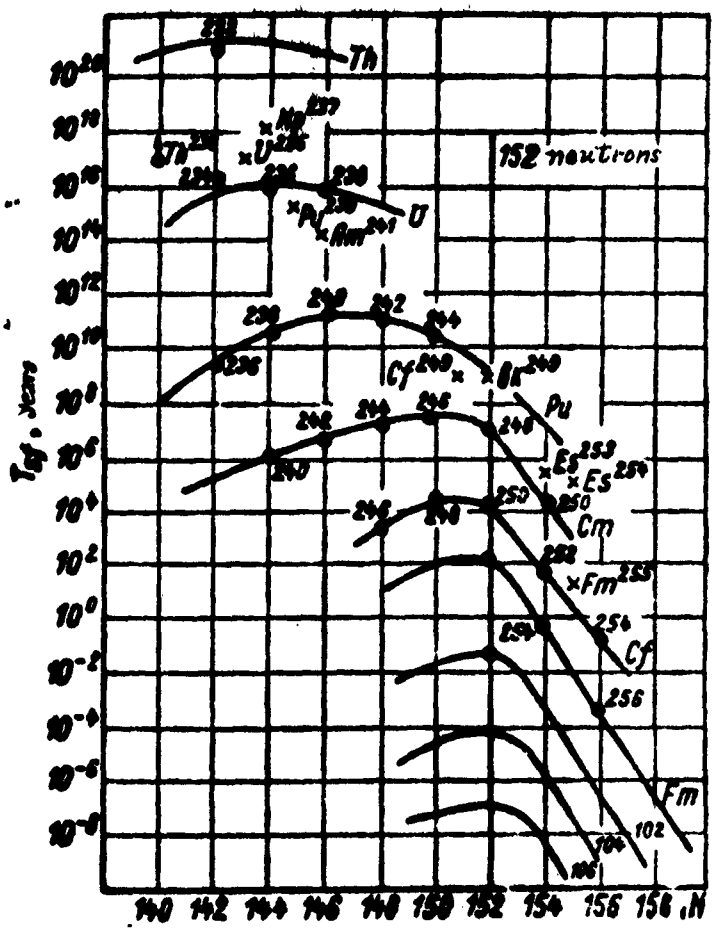

Figure 4. Variation in $T_{s.f.}$ in dependence on number, N, of neutrons in nucleus. Captions with figure: to left: $T_{s.f.}$, years. Within figure, upper right: 152 neutrons

Only by experiment can all these problems be solved. However, in the course of an experimental determination of the spontaneous fission periods of certain relatively heavy isotopes of Fm and Cf, certain major difficulties

arise in connection with the problem of their synthesis.

To estimate the various possible variants of obtaining such isotopes, we shall examine first of all the modern state of the problem of deriving and studying the properties of new transuranium elements, and we shall also try to point out certain approaches that will permit us to delve more deeply into this field.

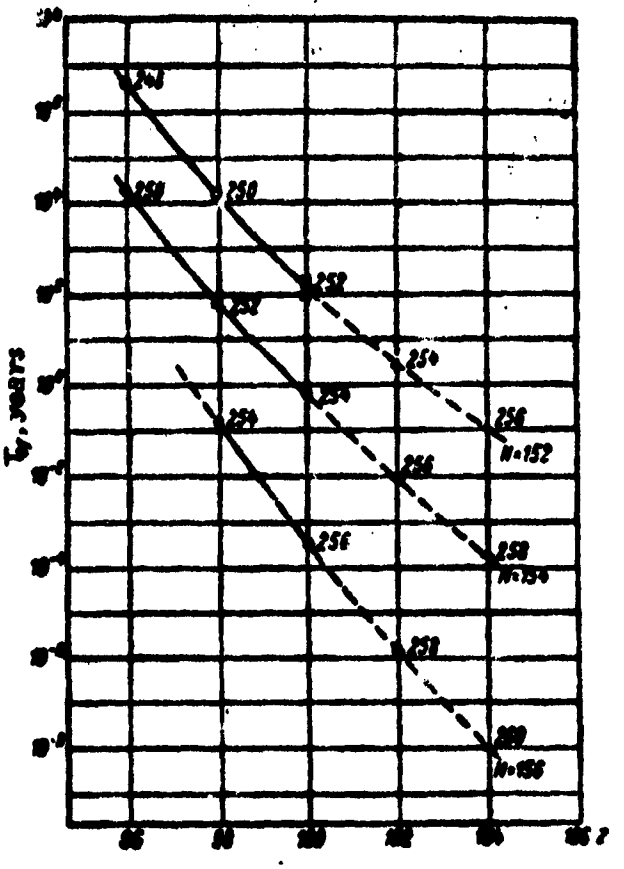

Figure 5. Variation of T_{sf} as a function of the number, Z, of protons in a nucleus.

SYNTHESIS OF TRANSURANIUM ELEMENTS WITH THE AID OF MULTIPLY CHARGED IONS

The beginning of the work in this direction in the USSR is closely linked with the name of I. V. Kurchatov. The first reactor, the first cyclotron of multiply-charged ions, and then a large accelerator of heavy ions in Dubna were developed with the direct participation, supervision, or the enthusiastic support of Igor Vasil'yevich. The mounting of a 300-centimeter cyclotron in the Centralized Institute of Nuclear Research, which permits one to obtain intensive

beams of ions in a wide range of Z and A, opened further extensive possibilities for conducting experiments on the synthesis of new elements. In many countries in recent years, various accelerators of multiply-charged ions have been built and put into operation.

Up to the present, with the aid of heavy ions, there have been synthesized all the earlier known transuranium elements, and also the new elements 102 and 103 (Lawrencium) [12 - 15].

The successful use of this method permits us to consider it the most promising for the synthesis of the new elements. However, the difficulties encountered in this connection are nevertheless so considerable that they compel us to analyze and to test all probable methods of expanding the possibilities of the approach.

Based on the synthesis of the heavy element B_Z^A from the target $A_{Z_1}^{A_1}$ and the accelerated ion $I_{Z_2}^{A_2}$, there is a nuclear reaction of the type:

$$A_{Z_1}^{A_1}(I_{Z_2}^{A_2}, \underline{xn})B_Z^A.$$

The heavy ion, accelerated to an energy slightly greater than the energy of the Coulomb barrier, having penetrated into the target-nucleus with a section close to a geometric one, adds all of its kinetic energy to the compound nucleus. Since the nucleons in the compound nucleus are bound more weakly than in the target-nucleus and in the nucleus of the heavy ion, a part of this energy is expended in unpacking, and the balance (usually 30 - 60 Mev) is expended in the excitation of the compound nucleus. The nucleus can be freed of this energy by the evaporation of several nucleons (usually three - five). However, since we are discussing heavy nuclei, i.e. those with a low fission barrier, the basic fo of disintegration of the compound nucleus is fission, which as a rule predominates at all stages of the nucleons' evaporation. This leads to the situation that the cross sections of the yield of far transuranium elements prove to be several orders of magnitude lower than the geometric ones and usually amount to 10^{-29} - 10^{-33} cm^2.

Sometimes for the synthesis of a heavy element, we use a reaction of the type:

$$A_{Z_1}^{A_1}(I_{Z_2}^{A_2}, He_2^4\underline{xn})\ B_{Z-2}^{A-4}\ ,$$

which differs from the reaction considered above in that, during the capture of a heavy ion, there is emitted an α-particle, and in other respects the process transpires analogously. Since here also there is a stage of evaporation, the cross sections of formation of the B^{A-4}_{Z-2} isotopes are also several orders of magnitude smaller than the geometric ones.

At present, at disposal of the experimenters, there are fairly intensive beams of ions $B^{10,11}$, $C^{12,13}$, $N^{14,15}$, $O^{16,18}$, $Ne^{20,22}$, and adequate amounts of materials for the targets from U^{238} to Cf^{252}. For a long time, the question remained unclarified regarding the selection of Z_1 of the target and Z_2 of the particle for the synthesis of an element with the given $Z = Z_1 + Z_2$. The assumption was expressed that an increase in Z_2 by unity and the corresponding decrease in Z_1 should lead to a decrease of the cross section of yield of an element with the number Z by 10 times. However, an analysis of studies conducted previously [16, 17] and of the new data derived in report [18], shows that these estimations were too pessimistic. The transition from a synthesis of Fm^{256} in the reaction $Pu^{241}(C^{13}, 4n)Fm^{250}$ to the synthesis of Fm^{250} in the reaction $Th^{232}(Ne^{22}, 4n)Fm^{250}$ leads to a decrease in the cross section by twenty times in all, and not by four orders, as had been postulated.

Thus, in principle there is already a possibility of a synthesis of all the elements up to 108 inclusive. However, in exploiting this possibility, difficulties arise that are linked, not with the synthesis per se, but with the investigation of the properties of the newly derived elements and new isotopes.

As a rule, the reactions of the evaporation of neutrons lead to the formation of light isotopes of new elements with a short lifetime in respect to α-decay. This excludes the use of the chemical methods of identification. In connection with this, the entire research process becomes considerably complicated, and the reliability of its results often decreases.

At the basis of the physical method of the identification of the new α-active element with a short lifetime, there lies the recording of the

α-activity with an energy assumed according to systematics. Simultaneously, there is required the exclusion of all possible causes of background. It was experimentally established that in reactions with heavy ions, in admixtures of lead, bismuth and other elements, in the targets there can originate α-active nuclei in the range Ac-Po, for which the decay properties are close to the properties expected for the new elements [13, 19].

Moreover, in recent papers [13, 19] devoted to an analysis of the products of nuclear reactions Th + Ne, it was demonstrated that similar background activities are formed owing to the reactions of deep splitting-off. An additional source of background can be the unknown light isotopes of Cf, Fm and others.

The subsequent advance to a synthesis of the heavier elements by the method of recording the α-activities will be ever more difficult, and the results will be ever less reliable. This is associated with the fact that in the transition to the heavier particles, the number of background activities increases, while the cross sections of formation of new elements decrease. At present, the researchers have proceeded all the way to a synthesis of the element 104. This is a region where spontaneous fission can become predominant in comparison with other forms of disintegration.

It would have seemed much simpler to record the fact of the formation of a new element according to its natural fission than according to the α-decay or the electron capture, owing to the high sensitivity of the method, associated with the absence of background. The residual nuclei of the reactions, occurring in admixtures in the target, can not undergo spontaneous fission. For the identification of a new element, it would have been sufficient to use the combined investigation of the excitation functions for the formation of a spontaneously fissionable product (this furnishes a knowledge of the atomic weight A) and of the yields of the given nucleus in the cross irradiations of various targets by particles with various values for A_1 and Z_1 (for the establishment of the atomic number of the product being studied). However, the actuality proved more complex than was expected.

In the report [22], it was shown that in the interaction of heavy ions

(Ne^{22}, O^{16}, B^{11} and others) with uranium nuclei, there is formed a spontaneously fissionable isotope with an anomalously short half-life (about 0.015 sec.) An investigation of the functions of the excitation of this isotope's formation in various reactions led the authors to the conclusion that its synthesis occurs owing to the transfer of a part of the nucleons of the bombarding nucleus to the target-nucleus and that its atomic number is $\leqslant 97$. The maximum cross section of the reaction $U^{238} + Ne^{22}$ amounts to about $2 \cdot 10^{-32}$ cm^2. However, the cross section of the reaction $U^{238} + B^{11}$ in experiments using neon is several times greater than the indicated value. The authors express the hypothesis that the observed effect is linked with the natural fission from an isomeric state. In reality, in the exposure of U^{238} to B^{11} ions, there are formed the known isotopes of elements with $Z \leqslant 97$. All of them have lifetimes of ground state considerably longer than 0.015 sec., wherein the periods of the natural fission of these isotopes amount to $T_{sf} \geqslant 10^7$ years. It follows from this that the natural fission of the nuclei being derived is facilitated by more than 10^{16} times.

As yet, there are no direct proofs that this isomer is an isolated case or whether this phenomenon is widespread in nature, and in the reactions isomers can originate with a varying duration of life. The extensive study of these nuclei permits us to get new additional data on the mechanism of a "conventional" spontaneous fission.

Thus the problem of the synthesis and identification of the trans-Fermian elements according to natural fission from the ground (unexcited) state proves to be connected with the obtainment of heavier isotopes, which would provide the possibility of conducting not only physical but also chemical studies of the new elements and would increase considerably the reliability of the identification.

After these preliminary remarks, we now proceed to a consideration of certain possible reactions, which in principle permit us to synthesize the nuclei with the number of neutrons, considerably exceeding the "magic" number N = 152, which can not yield a reaction with the evaporation of neutrons even in the use of the heaviest targets. For example, in case of the irradiation of targets of Cm^{248} by C^{13} ions, one can never get isotopes of the element 103 heavier than 259. As is shown by systematics, these isotopes should have brief lifetimes.

Reaction of Incomplete Fusion in a Heavy Particle. If we use Ar_{18}^{40} or Ca_{20}^{48} as a bombarding particle, it is to be hoped that in the reaction of the marginal interaction with the target-nucleus, there occurs the capture of a considerable part of the bombarding particle, wherein the nucleus is in a near-ground state.

As an example, we consider the reactions of the synthesis of certain heavy isotopes of Fm during the interaction of Ar^{40} with uranium:

$$U^{238} + Ar^{40} \longrightarrow Fm^{256} + Ne^{22};$$

$$U^{238} + Ar^{40} \longrightarrow Fm^{258} + Ne^{20};$$

$$U^{238} + Ar^{40} \longrightarrow Fm^{260} + Ne^{18}.$$

Our hopes for the success of such reactions are based on the following. First, these reactions are threshold ones, wherein their thresholds lie above the Coulomb barrier. This is conditioned by the fact that there occurs the capture of oxygen nuclei from the bound state in Ar^{40} into the bound state in fermium. Hence, there is a certain range of energies of the bombarding particles at which considerable excitations of the fermium nuclei will be energetically impossible, and this signifies that there will occur neither an evaporation or fission of nucleons. Secondly, we have data regarding the fact that in the reactions with the multiply-charged ions, there occurs a considerable yield of such products which in particular can be formed by way of the above-indicated mechanism (for instance, $U^{238} + N^{14} \longrightarrow Cm^{242-244}$). Thirdly, we know reliably [21] that with a large cross section, reactions proceed in which there occurs the capture from the target-nucleus of a large number of the nucleons of the impinging particle. If we increase the mass and charge of this particle, accelerating, let us say, argon or heavier elements, it can then be expected that the reverse reaction will occur: the capture reaction of a large number of nucleons from the impinging particle into the target-nucleus.

For the verification of this method, most feasible is the first of the noted reactions, in which we derive the spontaneously fissionable isotope of Fm^{256} with T_{sf} =2.7 hours, which should assure high sensitivity.

Radiation Capture of a Heavy Ion. Another possibility of approaching the region of β-stability can be the reactions of the radiation capture of a heavy ion. In these reactions, the emission of one high-energy γ-quantum should lower the energy of excitation of the compound nucleus to a level beneath the fission threshold. Such reactions should yield a product with mass numbers larger by four units than those usually obtained in reactions with the evaporation of nucleons. It is clear that the process of emission of one high-energy γ-quantum from a heavy compound nucleus is poor competition for the processes of the fission and evaporation of nucleons. Nevertheless, the fact that in this process, there is but one degree of emission of the gamma quantum $\left(\frac{\Gamma_\gamma}{\Gamma_f + \Gamma_n + \Gamma_p + \ldots}\right)$ in comparison with the usually four stages of the evaporation of neutrons $\left(\frac{\Gamma_n}{\Gamma_n + \Gamma_f}\right)$ provides a certain hope that the effective cross section of this process will not prove to be very small.

Unfortunately, at present there are very few reports [23,24] devoted to reactions of the radiation capture of a heavy ion (moreover, all the studies are conducted for light targets). In this case, the section equals about 10^{-30} cm^2. There is no possibility to obtain in any way from this result a cross section corresponding to the region of heavy transuranium elements.

In our opinion, here it is simplest to establish experimentally the reacti cross section of radiation capture of O^{18} by a U^{238} nucleus with the formation of Fm^{256},

$$U^{238}(O^{18}, \gamma)Fm^{256}.$$

With the use of 100 microamps of current of O^{18} ions, the sensitivity of this method permits us to observe the reactions occurring with a cross section of 10^{-35} cm^2. The effect at such a cross section is about 10 fissions per hour.

Reactions of Evaporation of Nucleons at Use of Products of Nuclear Reactions as Bombarding Particles. Let us dwell in more detail on the data obtained in the report [21].

During the exposure of Th^{232} to Ne^{22} ions, the authors of this paper revealed a large yield of isotopes of Ac^{224}, Ac^{225}, Ac^{226} and Th^{227}. As the sole mechanism which could explain their obtainment, there is the breaking-away of several nucleons from the target-nucleus. At the same time, the authors obtain-

ed data indicating that the nucleons being torn away are in all liklihood transferred to the bombarding particle. Thus, in the exposure of Th^{232} to Ne^{22} ions, there is a beam of secondary particles, among which there will be very heavy isotopes of neon, sodium and magnesium.

Let us estimate the possible intensity of a beam of secondary particles. Proceeding from the report data, we can expect that the cross section of the formation of these particles can equal about 10^{-27} cm^2. With a current of the Ne^{22} ions' beam equalling 100 microamps, and with a Th^{232} target with a thickness of 10 mg/cm^2, we will have about 10^6 particles/sec. Not dwelling on the problem of the high-energy distribution of the secondary particles, we note that such a beam is quite adequate for investigating the reactions proceeding with a cross section $\geqslant 10^{-28}$ cm^2, if the reaction products assure the recording of several fission events in one hour.

The value of the cross section 10^{-28} cm^2 is not too high even for the region of far transuranium elements, since the fissility of the compound nucleus in this case should be lowered greatly owing to its increased mass, and the process of neutrons' evaporation can compete successfully with the fission. In any case, the verification of this possibility is not associated with major difficulties and can be accomplished successfully during the exposure of a thick target of Th^{232} to Ne^{22} ions, having sufficient energy. Therein, the thorium will serve as a transformer of the beam, and as a target, on which there will occur reactions of $Th^{232}(Ne^{28}, 4n)Fm^{256}$ and $Th^{232}(Na^{28}, 4n)\ Md^{256} \xrightarrow{\text{el. capt.}} Fm^{256}$.

If successful, the methods examined above for the synthesis of far transuranium elements (enriched by neutrons) would, in our view, considerably expand the potentiality of the method of multiply-charged ions in this direction.

We now need to note only certain particular cases of obtaining individual heavy nuclei, and to analyze briefly the reactions of the protons' evaporation from the compound nuclei, since such reactions also lead to the formation of heavy isotopes of the transuranium elements.

From the viewpoint of the systematics of naturally fissionable nuclei, the synthesis of Cf^{256} and Fm^{258} is of great interest, since the results (of estimating the lifetime of these isotopes) conducted by various methods, are too contradictory.

The Cf^{256} isotope in amounts sufficient for its investigations can be synthesized in a reaction of the type $Cf^{254}(O^{18}, O^{16})Cf^{256}$, even if the researcher has at his disposal but 10^{10} nuclei of Cf^{254}.

In the reactions with multiply-charged ions (e.g., $Cm^{248}(B^{11},4n)$ Md^{255} el. capt. Fm^{255} for which $T_{1/2}$ = 21.5 hrs., about 10^9 Fm^{255} nuclei can collect, and, if the capture reaction of three neutrons in any particle proceeds with the cross section of about 10^{-26} cm^2, we can synthesize an amount of Fm^{258} sufficient for the investigation (several disintegrations per hour).

Another possibility of getting relatively heavy isotopes is constituted by the reactions with the evaporation of charged particles. For instance, such can be represented by the reaction $Pu^{242}(Ne^{22}, p\,3\,n)103^{260}$. There are adequate bases for expecting that the isotope 103^{260} will be unstable in relation to electron capture. As the result of electron capture, there forms the isotope 102^{260}, which should be a spontaneously fissionable isotope.

The nuclear reaction (Ne^{22}, p3n) was used successfully for the synthesis 101 of the element Md^{256} at irradiation of U^{238} [25,26]. An analogous reaction of the evaporation of a proton and of two neutrons can lead to the formation of even heavier isotopes. Specifically, in the reaction $Pu^{242}(Ne^{22}, p2n)103^{261}$, we can hope to derive a relatively long-lived isotope of the element 103.

The probability of reaction with the emission of a proton and of only one neutron is very slight. This is explained by the low value of the cross section of the formation of the compound nucleus at low energies of the bombarding particle. Experiment shows that the reaction cross section of U^{238} (Ne^{20}, pn) Md^{256} does not exceed 10^{-36} cm^2. This circumstance fixes the limit of the possibilities of reactions with the evaporation of charged particles in the process of synthesizing the heavy isotopes.

CONCLUSION

The further investigation of the features of natural (spontaneous) fission is linked to a great extent with progress into the fiels of as yet undiscovered elements and the synthesis of the heavy isotopes of Cf, Fm, and the element 102.

Moreover, the investigation of an interesting phenomenon, nemely the fission of isomers of transuranium elements and of nuclear reactions, in which they form, will also provide much new information on the mechanism of nuclei fission

from the ground state.

The conclusions from recently conducted studies, in which a relationship is established between the probability of spontaneous fission and the arrangement of the energy levels of the nucleons in the nucleus [7, 27, 28], permit us to hope for the obtainment of additional data on the structure of the nuclei in a study of the periods of their spontaneous fission.

On the other hand, a study of the regularities in the variation of the periods of spontaneous fission in a wide range of the Z- and A-values will provide the opportunity of answering the question as to how great the role of natural fission is for those isotopes of the trans-fermian elements, the derivation of which is the concern of the immediate future.

The problem of the synthesis of a new element is very complex. For its solution, the development of many special diverse methods is required, wherein the choice of any given method depends greatly on the type of disintegration and the lifetime of the element being studies. The more we know about natural fission, the more precisely we can estimate the T_{sf} -value of the new element, and the greater are the chances for successfully solving the synthesis problem.

Thus the problem of the further study of the regularities of natural fission and the question of the synthesis of new elements are inseparably linked, so that the progress in one field inherently determines the progress in the other

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