The virtual character of spontaneous and induced (with the participation of thermal neutrons) ternary fission of nuclei with the emission of prescission nucleons and light nuclei.

S. G. Kadmensky, Ya. O. Otvodenko
E-mail: kadmensky@phys.vsu.ru
Voronezh State University, Voronezh, Russia

1 Introduction

In the theory of elementary particles decays and reactions with the participation of intermediate virtual states of various elementary particles are well known [A.I.Akhiyeser, V.B.Berestetsky, *Quantum electrodynamics* (Fizmatgiz, Moscow, 1959)]. One of these reactions is Compton scattering of photons by free electrons. The amplitude of this scattering is represented by the Feynman diagram (Fig. 1) which contains Green function describing virtual state of intermediate electron e^*, energy and moment of which are not connected by Einstein's relativistic formula. To such decays it can be related the beta-decay of free neutron, which is described by the Feynman diagram with the participation of the intermediate virtual state of the W_- -meson. Similar processes with the participation of virtual states of different intermediate elementary particles are also known in atomic and nuclear physics.

The question arises whether there are nuclear decays and reactions with the appearance of virtual states of intermediate composite nuclei, whose energies lie outside mass surfaces of these decays and reactions. The answer to this question was given in articles [S.G.Kadmensky, Yu.V.Ivankov, Phys. Atom. Nucl. **77**, 1019 (2014); **77**, 1532 (2014); S.G.Kadmensky, A.O.Bulychev, Bull. Russ. Acad. Sci.: Phys. **79**, 872 (2015); **80**, 921 (2016)], where the theory of sequential multiparticle virtual nuclear decays was developed and used to describe the characteristics of $2p$ - decays of neutron-deficient nuclei. Later it will be showed [S.G.Kadmensky, L.V.Titova, D.E.Lyubashevsky, Phys. Atom. Nucl. **83**, 581 (2020)] that the method of description of double β -decays of nuclei developed in works [L.A.Sliv JETP **20**, 1141 (1950), J.Suhonen , O.Civitareze Phys. Rep. 300, 123 (1998)] with using the second-order of perturbation theory for weak interaction Hamiltonian, corresponds to the concept of virtuality of these decays. Finally, in the article [S.G.Kadmensky, L.V.Titova, D.E.Lyubashevsky Bull. Russ. Acad. Sci.: Phys. **83**, 1190 (2022)] it was demonstrated that the ternary and quaternary fission of nuclei with the flight of prescission α-particles is also the virtual process.

The purpose of the present work is the analysis new properties of spontaneous and induced (with the participation of thermal neutrons) nuclear ternary fission with the flight of prescission nucleons and different light nuclei.

2 The spontaneous and induced (with the participation of thermal neutrons) binary fission of nuclei

The binary fission of fissile nucleus (FN) (A, Z) is connected with the scission of FN into light (A_L, Z_L) and heavy (A_H, Z_H) fragments of fission with close values of charges and masses. The process of this fission can be connected on the base the generalized model of nuclei [A.Bohr, B.Mottelson Nuclear Structure (Benjamin, New York, 1974), V.1, 2], which simultaneously takes into account the nucleonic and collective rotational and deformational modes of motion of atomic nuclei, with the evolution of shape of FN, described by the it's collective deformation parameters, from close to spherical through a prolonged spheroid to a dumbbell-like shape with a neck for the prescission configuration (see Fig. 1.).

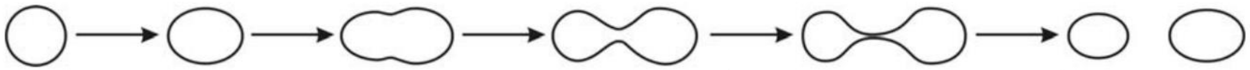


Fig. 1. Sequential stages of atomic nucleus fission

For description of this evolution it can introduced the potential energy $E(\beta_\lambda)$ of deformation with deformation parameters β_λ for ground state of FN by formula:

$$E(\beta_\lambda) = \tilde{E}(\beta_\lambda) + E_{sh}(\beta_\lambda)\,, \qquad (1)$$

where $\tilde{E}(\beta_\lambda)$ is the binding energy calculated in the droplet model of the nucleus [C.F.Weizssacker, Zs. f. Phys. V. **96**, 431 (1935)] and $E_{sh}(\beta_\lambda)$ is the shell correction [V.M.Strutinsky, JETP. V. **37**, 613 (1960), V.M.Strutinsky Nucl. Phys. V.**3**, 614 (1965)] and the deformation potential $V(\beta_\lambda) = E(\beta_\lambda) - E(\beta_{20})$ [V.M.Strutinsky Nucl. Phys. V.**3**, 614 (1965); A.Bohr, B.Mottelson Nuclear Structure (Benjamin, New York, 1975), Vol. 2] is represented in Fig. 2

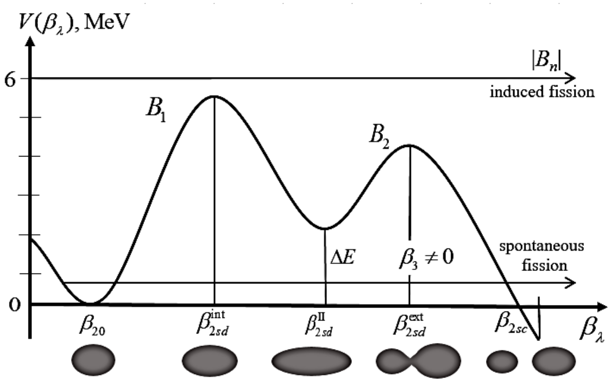


Fig. 2. Deformation potential $V(\beta_\lambda)$ for actinide nuclei.

The binary fission of nuclei is observed experimentally in the forms of spontaneous or induced fission. The spontaneous binary fission occurs if FN is in the ground state and is described by the wave function $\psi_{K0}^{JM}(\beta_\lambda)$ with total spin J and it's projections M, K taking into account the zero collective deformation vibration of this nuclei, at which FN passes into the prescission configuration through overcoming the potential deformation barriers shown in Fig. 2. This FN state with wave function $\psi_{K0}^{JM}(\beta_\lambda)$ corresponds to the transition fission state [A.Bohr, B.Mottelson Nuclear Structure (Benjamin, New York, 1974), V.2] for spontaneous fission. The binary fission is induced if the compound fissile nucleus (CFN) (A,Z) forming, for example, for capture of thermal neutron with a very low kinetic energy $T_n \approx 0.025$ eV by target nucleus (A-1, Z), is in the excited state with the excitation energy $|B_n| \approx 6$ MeV, where B_n is binding energy of captured neutron. For nuclear times $T_0 \approx 10^{-22}$ s this excited state transits into the neutron resonance state of CFN, whose wave function ψ_K^{JM} is represented when using the Wigner random matrix method [E.P.Wigner Ann. Math. V. **62**, 548 (1955); V.**65**, 203 (1958); V.**67**, 325 (1958); S.G.Kadmensky, V.P.Markushev, V.I.Furman Nucl. Phys., V.**35**, 300 (1982); S.G.Kadmensky Nucl. Phys. V.**65**, 1833 (2002)] as:

$$\psi_K^{JM} = \sum_{i \neq 0} b_i \psi_{iK}^{JM} + b_0 \psi_{0K}^{JM}(\beta_\lambda) . \qquad (2)$$

In this formula the wave function ψ_{iK}^{JM} corresponds to the i-quasiparticle excited state of CFN and the wave function $\psi_{0K}^{JM}(\beta_\lambda)$ describes the collective deformation motion of the CFN with energy equal the excitation energy $|B_n|$ and corresponds to the transition fission state of the CFN [A.Bohr, B.Mottelson Nuclear Structure (Benjamin, New York, 1975), Vol. 2]. The squares of coefficients b_i and b_0 in (1) have mean values of $\overline{(b_i)^2} = 1/N$, where N is the total number of quasi-particle states participating in formation of wave function (1). The induced fission of CFN occurs with a noticeable probability if the energy $|B_n|$ exceeds heights of the internal and external fission deformation barriers.

3 The spontaneous and induced (with the participation of thermal neutrons) ternary nuclear fission

The ternary fission of FN (A,Z) as well as it's binary fission begins with the transition to prescission configuration shown in Fig. 1. Then the third light particle p with (A_p,Z_p) named prescission flies out of this configuration with the appearance of the state of intermediate nucleus ($A-A_p$,$Z-Z_p$), which is divided into light (A_{LF},Z_{LF}) and heavy (A_{HF},Z_{HF}) fission fragments. The experimental angular distributions of fragments of ternary fission of NF are close to the angular distributions of fragments of binary fission of NF due to the weak influence of the emitted third particle p on the angular distributions of ternary fission fragments [S.G.Kadmensky, L.V.Titova, P.V.Kostryukov Bull. Ras. Phys. V **82**. 1299, (2015)]. The angular distribution of third particles p

in ternary fission has anisotropic character with the maximum in the equatorial direction to the direction of light fission fragment emission [M.Mutterer, J.P.Theobald Dinuclear Decay Modes. Bristol: IOP Publ., Chap. 1. 12. (1996); M.Mutterer,Yu.N.Kopatch, P.Jesinger et al., Nucl. Phys. A. V. 738, 122 (2004); S.Vermote, C.Wagemans, O.Serot Nucl. Phys. A. 837 176 (2010)], that allows to conclude that the emitted *p*-particle is formed in the neck of FN prescission configuration. The experimental energy distribution $W(T_p)$ of prescission third particles *p* with kinetic energy T_p have maximum value at energies $T_{p\max}$, which noticeably exceeds the heat Q_p^A of the *p*-decay of the ground states of nuclei NF (A,Z) with the emission of particles *p* and the formation of ground states of daughter nuclei ($A-A_p$,$Z-Z_p$) and having the form:

$$Q_p^A = E(A,Z) - E(A-A_p, Z-Z_p) - E(A_p, Z_p) \ , \qquad (3)$$

where $E(A,Z)$ is binding energy of NF (1). The indicated fact is serious argument for the justification of the virtual mechanism of the appearance of third prescission particles in ternary nuclear fission.

4 The virtual mechanism of ternary fission of atomic nuclei with the emission of prescission nucleons and light nuclei. Using the results of works on the theory of virtual decays of atomic nuclei [S.G.Kadmensky, Yu.V.Ivankov, Phys. Atom. Nucl. **77**, 1019 (2014); **77**, 1532 (2014); S.G.Kadmensky, A.O.Bulychev, Bull. Russ. Acad. Sci.: Phys. **79**, 872 (2015); **80**, 921 (2016);S.G.Kadmensky, L.V.Titova, D.E.Lyubashevsky, Phys. Atom. Nucl. **83**, 581 (2020)], can obtain a formula for the width of Γ_{pf} the virtual spontaneous ternary nuclear fission NF with the emission of third light particles *p*:

$$\Gamma_{pf}^{A} = \frac{1}{2\pi} \int_0^{Q_f^{A-A_p}} \frac{\Gamma_p^{A}(T_p)\Gamma_f^{(A-A_p)}(Q_f^{A-A_p} - T_p + Q_p^A)}{(Q_p^A - T_p)^2} dT_p \qquad (4)$$

where $\Gamma_p^{A}(T_p)$ is *p*-decay width of the ground state of nucleus NF (A,Z) with the emission of particles *p* and the formation of ground states of daughter nucleus ($A-A_p$,$Z-Z_p$), $\Gamma_f^{(A-A_p)}(Q_f^{A-A_p} - T_p + Q_p^A)$ - full width of binary nuclear fission ($A-A_p$,$Z-Z_p$) the heat of this fission $Q_f^{A-A_p}$:

$$Q_f^{A-A_p} = E(A-A_p, Z-Z_p) - E(A_{LF}, Z_{LF}) - E(A_{HF}, Z_{HF}) \qquad (5)$$

Note that the width of the induced ternary fission of CNF (A,Z) nucleus formed during the capture of a thermal neutron into the ground state of the target nucleus (A-1, Z) is also determined by formula (4), since the CNF excitation energy, equal to $|B_n|$, is conserved in the corresponding prescission configuration of this nucleus and does not participate in the formation energy of the emission p-particle. Now it's possible introduce the yield of p-particles in ternary nuclear fission to the number of binary fission fragments, defined as: $\Gamma_{pf}^{A} / \Gamma_f^A(Q_f^{A-A_p})$:

$$\Gamma_{pf}^{A} = \frac{1}{2\pi} \int_0^{Q_f^{A-A_p}} \frac{\Gamma_p^A(T_p)\Gamma_f^{(A-A_p)}(Q_f^{A-A_p} - T_p + Q_p^A)}{(Q_p^A - T_p)^2 \Gamma_f^A(Q_f^A)} dT_p \tag{6}$$

From here it is possible to obtain the energy distribution of the emission p-particles:

$$W_{pf}(T) = \frac{1}{2\pi} \frac{\Gamma_p^A(T_p)\Gamma_f^{(A-A_p)}(Q_f^{A-A_p} - T_p + Q_p^A)}{(Q_p^A - T_p)^2 \Gamma_f^A(Q_f^A)} \quad , \tag{7}$$

normalized to the yield of p-particles with respect to the number of binary fission fragments. Taking into account that the energy Q_f^A for actinide nuclei reaches 170 MeV, which is much higher than the energies $T_p - Q_p^A$ and the proximity of the widths $\Gamma_f^{(A-A_p)}(Q_f^{A-A_p})$ and $\Gamma_f^A(Q_f^A)$, formula (7) can be transformed into the form:

$$W_{pf}(T_p) = W_p(T_p) = \frac{1}{2\pi} \frac{\Gamma_p^A(T_p)}{(Q_p^A - T_p)^2} \tag{8}$$

Hence the width value $\Gamma_p^A(T_p)$ is obtained:

$$\Gamma_p^A(T_p) = 2\pi W_p(T_p)(Q_p^A - T_p)^2 \, , \tag{9}$$

which can be used to analyze the mechanism of ternary nuclear fission.

5 Description of the experimental characteristics of spontaneous and induced ternary fission of nuclei with the emission of prescission nucleons and light nuclei

Using the experimental value $W_p(T_p)$ for various particles it is possible to construct a width $\Gamma_p^A(T_p)$ that can be represented as the Gamow formula:

$$\Gamma_p^A\left(T_p\right) = \omega_\alpha \frac{\hbar\sqrt{2T_p}}{2r_{neck}\sqrt{M_p}} P(T) \tag{10}$$

where $P(T_p)$ is the permeability factor of the Coulomb barrier, taken in the above-barrier fission at $T=T_{max}$ equal to one, ω_p is the probability of the formation of a *p*-particle in the parent nucleus, r_{neck} is the radius of the neck of the parent nucleus and *c* is the speed of light.

Further, the experimental characteristics of nuclear fission with the release of α -particles, tritons, protons, deuterons in ternary nuclear fission are described, as well as $\Gamma(T_{max})$, for some nuclei r_{neck} and the probability ω_0 of particle formation in the parent nucleus according to known experimental values radii r_{neck}^{exp} [O.Serot, N.Carjan, C.Wagemans Eur. Phys. J. A. **8**. 187 (2000)]. It is noteworthy that in spontaneous and induced ternary fission such characteristics as the yield $\Gamma_{pf}^{A} / \Gamma_{f}^{A}$, *FWHM* and the value of the maximum kinetic energy *T* coincide (see Tables 1-5).

5.1 Spontaneous and induced ternary nuclear fission with the emission of prescission α -particles.

Table 1 shows the characteristics of ternary fission with alpha-particle emission, where $\Gamma_{\alpha f}^{A} / \Gamma_{f}^{A} = N_{\alpha f}$ is the ratio of the widths of binary and ternary fission, *FWHM* is width at half height, T_{max} is the energy at maximum, Q_α is the decay energy, B_n is the binding energy, $\Gamma(T_{max})$ is width at maximum, r_{neck} is the radius of the neck of FN. Experimental data on $\Gamma_{\alpha f}^{A} / \Gamma_{f}^{A}$, *FWHM*, <T> for compound nuclei $^{244}Cm_{96}$, $^{246}Cm_{96}$, $^{248}Cm_{96}$ can be found in [S.Vermote , C.Wagemans, O.Serot. Nucl. Phys. A **806** 1 (2008)], for nuclei $^{250}Cf_{98}$, $^{252}Cf_{98}$ in[S.Vermote , C.Wagemans, O.Serot. Nucl. Phys. A **837** 176 (2010)], and finally for ^{234}U, ^{236}U in [M.Mutterer, Yu.N.Kopatch, P.Jesinger et al., Nucl. Phys. A. V. **738**, 122 (2004)].

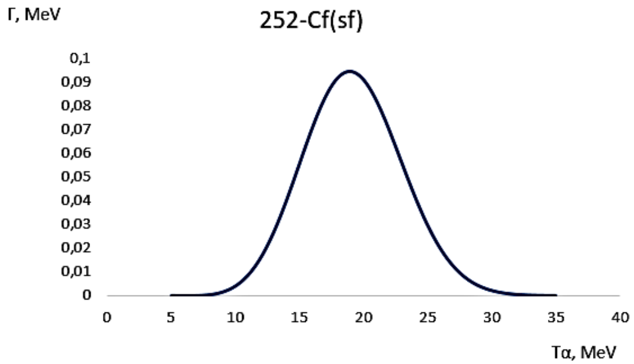
Table 1. Nuclear fission with emission of α-particles

Nuclear fission with emission of α-particles																		
Compound nucleus	$\delta = N_\alpha / N_f = \Gamma_\alpha$		*FWHM*, МэВ		<T>, МэВ		Q_α, МэВ	B_n, МэВ		$\Gamma(T_{max})$, МэВ		r_{neck}, фм		r_{neck}^{exp}, ф		ω_0	
	(sf)	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*		*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*
$^{244}Cm_{96}$	$3{,}16\cdot10^{-3}$	$2{,}43\cdot10^{-3}$	9,99	10,32	15,99	16,14	5,90	-	-5,70	0,12	0,10	0,80	0,97	2,5	2,5	0,03	0,03
$^{246}Cm_{96}$	$2{,}49\cdot10^{-3}$	$2{,}15\cdot10^{-3}$	9,73	10,10	16,41	16,35	5,47	-	-5,52	0,11	0,08	0,88	0,97	2,5	2,5	0,03	0
$^{248}Cm_{96}$	$2{,}30\cdot10^{-3}$	$1{,}85\cdot10^{-3}$	10,03	10,37	15,97	16,01	5,16	-	-5,16	0,10	0,08	1,23	1,24	2,5	2,5	0	0,02
$^{250}Cf_{98}$	$2{,}93\cdot10^{-3}$	$2{,}77\cdot10^{-3}$	10,49	10,64	15,95	16,09	6,13	-	-5,60	0,09	0,10	1,06	0,97	2,5	2,5	0,02	0
$^{252}Cf_{98}$	$2{,}56\cdot10^{-3}$	$2{,}41\cdot10^{-3}$	10,22	10,60	15,96	15,89	6,22	-	-5,11	0,09	0,09	1,06	1,14	2,5	2,5	0,02	0,02

Compound nucleus	$\Gamma^{A}_{\alpha f} / \Gamma^{A}_{f}$	*FWHM*, МэВ	<T>, МэВ	Q_{α}, МэВ	B_n, МэВ	$\Gamma(T_{max})$	r_{neck}, фм	r^{exp}_{neck}, фм [1]	ω_0
	(n,f)	*(n,f)*	*(n,f)*		*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*
$^{234}U_{92}$	$2{,}17\cdot10^{-3}$	9,4	15,7	4,90	-5,76	0,08	0,85	2,5	0,02
$^{236}U_{92}$	$1{,}70\cdot10^{-3}$	9,6	15,8	4,57	-5,29	0,081	1,06	2,5	0,02
$^{240}Pu_{94}$	$2{,}22\cdot10^{-3}$	9,0	15,9	5,26	-5,65	0,082	0,90	2,5	0
$^{242}Pu_{94}$	$1{,}86\cdot10^{-3}$	8,3	15,9	5,14	-5,24	0,094	1,05	2,5	0

[1] [O.Serot, N.Carjan, C.Wagemans Eur. Phys. J. A. **8**. 187 (2000)]

The dependences $\Gamma(T)$ and $W(T)$ for the spontaneous and induced fission of the compound nucleus ^{252}Cf with emission α-particle are shown below. The dependences for the other nuclei aren't given, since they are identical with those presented below.



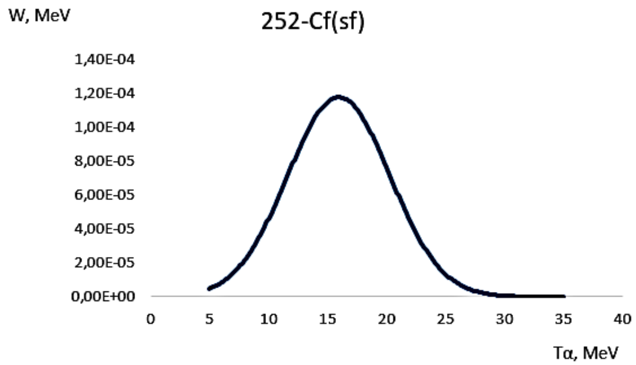


Fig.3. The dependences $\Gamma(T)$ and $W(T)$ for the spontaneous and induced fission of the compound nucleus ^{252}Cf with emission α-particle

5.2 Spontaneous and induced ternary nuclear fission with the emission of prescission ^{1}H.

Experimental data on $\Gamma^{A}_{\alpha f} / \Gamma^{A}_{f}$, *FWHM*, <T> for compound nucleus $^{252}Cf_{98}$ presented in [G.M.Raisbeck, T.D.Thomas Phys. Rev., , V.172, 1272 (1968)], and for $^{236}U_{92}$ in [J.Chwaszczewska Phys. Lett. V. 24B 87 (1967)].

Table 2. Nuclear fission with emission of ^{1}H

Nuclear fission with emission of ^{1}H															
Compound nucleus	$\Gamma^{A}_{pf} / \Gamma^{A}_{f}$		*FWHM*, МэВ		<T>, МэВ		Q_p, МэВ	B_n, МэВ		$\Gamma(T_{max})$, МэВ		фмЕ[1]		ω_0	
	(sf)	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*		*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*
$^{252}Cf_{98}$	$4.6 \cdot 10^{-5}$	-	6,8	-	7,8	-	6,48	-	-5,11	$2{,}2 \cdot 10^{-4}$	-	2,5	-	$8 \cdot 10^{-4}$	-
$^{236}U_{92}$	-	$4.0 \cdot 10^{-5}$	-	6,9	-	8,6	6,71	-	-5,29	-	$2{,}4 \cdot 10^{-4}$	-	2,5	-	$8 \cdot 10^{-4}$

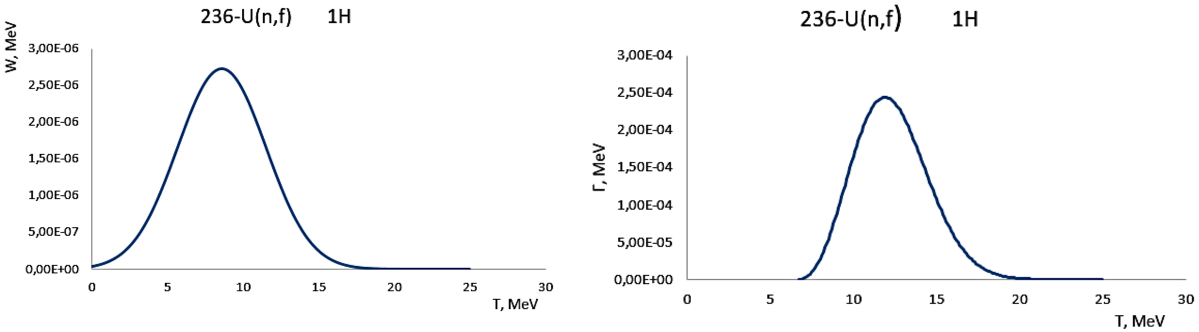


Fig. 4. The dependences $\Gamma(T)$ and $W(T)$ for the spontaneous and induced fission of the compound nucleus ^{236}U with emission ^{1}H

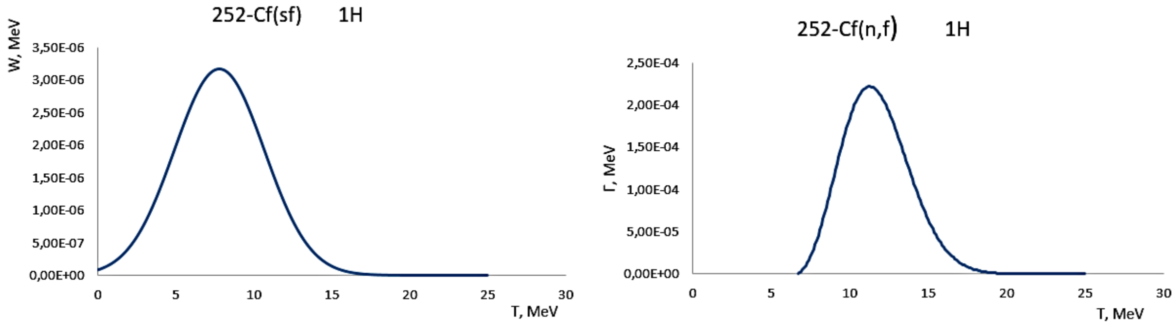


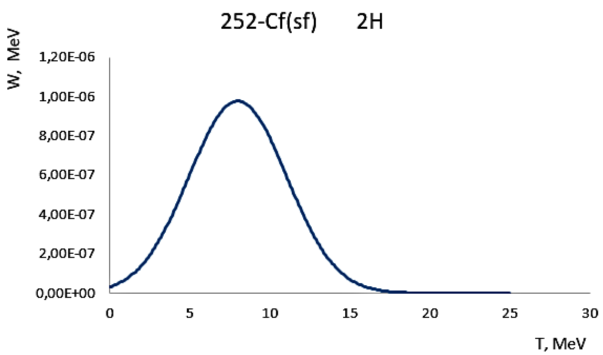
Fig.5. The dependences $\Gamma(T)$ and $W(T)$ for the spontaneous and induced fission of the compound nucleus ^{252}Cf with emission ^{1}H

5.3 Spontaneous and induced ternary nuclear fission with the emission of prescission ^{2}H.

Experimental data on $\Gamma^A_{\alpha f} / \Gamma^A_f$, *FWHM*, <T> for compound nucleus $^{252}Cf_{98}$ presented in [G.M.Raisbeck, T.D.Thomas Phys. Rev., , V.172, 1272 (1968)], and for nucleus $^{236}U_{92}$ in [J.Chwaszczewska Phys. Lett. V. 24B 87 (1967)].

Table 3. Nuclear fission with emission of ^{2}H

Nuclear fission with emission of ^{2}H															
Compound nucleus	$\Gamma^A_{pf} / \Gamma^A_f$		*FWHM*, MэВ		<T>, MэВ		Q_p, MэВ	B_n, MэВ		$\Gamma(T_{max})$, MэВ		фмЕ[1]		ω_0	
	(sf)	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*		*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*
$^{252}Cf_{98}$	$1.5\cdot10^{-5}$	-	7,2	-	8,00	-	-9,27	-	-5,11	$7,3\cdot10^{-5}$	-	2,5	-	$3\cdot10^{-4}$	-
$^{236}U_{92}$	-	$1.2\cdot10^{-5}$	-	7,0	-	7,9	-10,05	-	-5,29	-	$8,11\cdot10^{-5}$	-	2,5	-	$3\cdot10^{-4}$



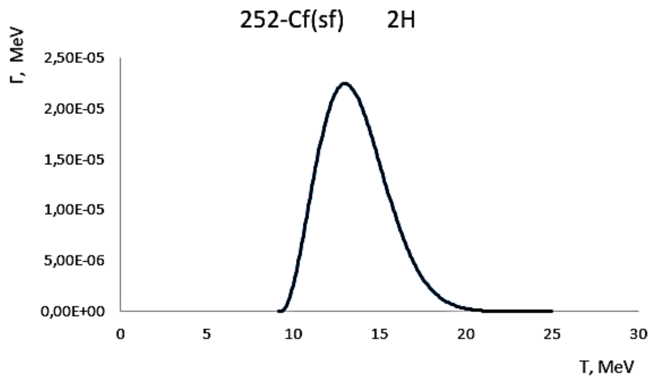


Fig.6. The dependences $\Gamma(T)$ and $W(T)$ for the spontaneous and induced fission of the compound nucleus ^{252}Cf with emission ^{2}H

5.4 Spontaneous and induced ternary nuclear fission with the emission of prescission ^{3}H.

Experimental data on $\Gamma^A_{\alpha f} / \Gamma^A_f$, *FWHM*, <T> for compound nucleus $^{244}Cm_{96}$, $^{246}Cm_{96}$, $^{248}Cm_{96}$ presented in [S.Vermote , C.Wagemans, O.Serot. Nucl. Phys. A **806** 1 (2008)], for nucleus $^{250}Cf_{98}$, $^{252}Cf_{98}$ in[S.Vermote , C.Wagemans, O.Serot. Nucl. Phys. A **837** 176 (2010)], for $^{236}U_{92}$ in [M.Mutterer, Yu.N.Kopatch, P.Jesinger et al., Nucl. Phys. A. V. **738**, 122 (2004)].

Table 4. Nuclear fission with emission of ^{3}H

Nuclear fission with emission of ^{3}H																	
Compound nucleus	$\Gamma^{A}_{pf} / \Gamma^{A}_{f}$		*FWHM*, МэВ		<T>, МэВ		Q_p, МэВ	B_n, МэВ		$\Gamma(T_{max})$, МэВ		r фм		фм[1]		ω_0	
	(sf)	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*		*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*
Cm_{96}	$1,98\cdot10^{-4}$	$1,96\cdot10^{-4}$	7,89	8,13			-11,10	-	-5,70	0	0					$3,13\cdot10^{-2}$	$2,57\cdot10^{-2}$
$^{246}Cm_{96}$	$1,72\cdot10^{-4}$	$1,85\cdot10^{-4}$	7,77	7,76			-12,32	-	-5,52	0	0	0				$2,84\cdot10^{-2}$	$2,37\cdot10^{-2}$
$^{248}Cm_{96}$	$1,79\cdot10^{-4}$	$1,84\cdot10^{-4}$	7,47	7,52			-9,97	-	-5,16	0	0	3,14				$2,55\cdot10^{-2}$	$2,01\cdot10^{-2}$
$^{250}Cf_{98}$	$2,08\cdot10^{-4}$	$2,13\cdot10^{-4}$	8,58	8,52			-9,78	-	-5,60	0	0					$2,36\cdot10^{-2}$	$2,57\cdot10^{-2}$
$^{252}Cf_{98}$	$1,89\cdot10^{-4}$	$2,20\cdot10^{-4}$	8,26	8,39			-9,27	-	-5,11	0	0	3				$2,37\cdot10^{-2}$	$2,19\cdot10^{-2}$

Compound nucleus	$\Gamma^{A}_{\alpha f} / \Gamma^{A}_{f}$	*FWHM*, МэВ	<T>, МэВ	Q_α, МэВ	B_n, МэВ	$\Gamma(T_{max})$, МэВ	r фм	фм[1]	ω_0
	(n,f)	*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*	*(n,f)*
2	$2,4\cdot10^{-5}$	6,7	7,7	-10,5	-5,29			2,5	$2,10\cdot10^{-2}$

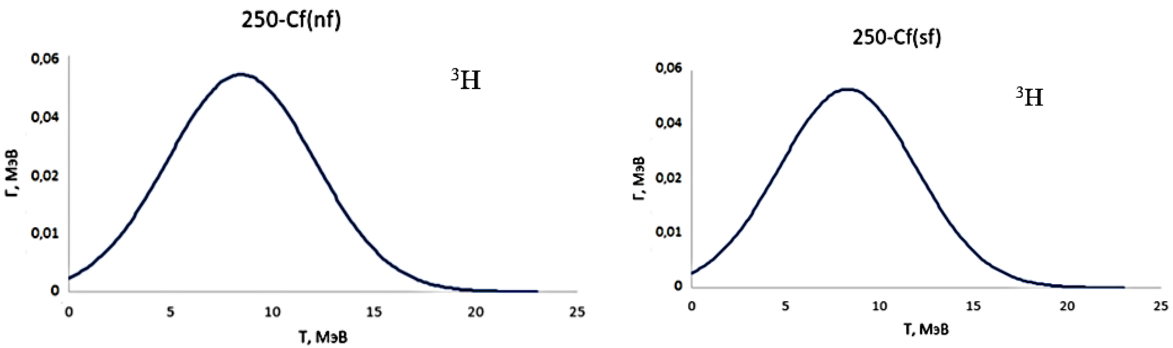


Fig.7. The dependence $\Gamma(T)$ for the spontaneous and induced fission of the compound nucleus ^{250}Cf with emission ^{3}H

5.5 Spontaneous and induced ternary nuclear fission with the emission of prescission ^{6}He.

Table 5. Nuclear fission with emission of ^{6}He

Nuclear fission with emission of ^{6}He															
Compound nucleus	$\Gamma^{A}_{pf} / \Gamma^{A}_{f}$		*FWHM*, МэВ		<T>, МэВ		Q_p, МэВ	B_n, МэВ		$\Gamma(T_{max})$, МэВ		фмЕ[1]		ω_0	
	(sf)	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*		*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*	*(sf)*	*(n,f)*
$^{250}Cf_{98}$	$8,03\cdot10^{-5}$	$6,99\cdot10^{-5}$	10,49	10,35	10,64	10,99	-5,91	-	-5,60	0,05	0,06	2,5	2,5	$2\cdot10^{-3}$	$2\cdot10^{-3}$
$^{252}Cf_{98}$	$7,68\cdot10^{-5}$	$7,58\cdot10^{-5}$	8,95	9,98	11,22	10,84	-4,18	-	-5,11	0,08	0,07	2,5	2,5	$2\cdot10^{-3}$	$2\cdot10^{-3}$

6 Conclusion

New class of nuclear reactions and decays, named virtual, was generalized to nuclear fission with the appearance of third prescission ^{1}H, ^{2}H, ^{3}H. Based on the concepts of the quantum theory of fission and the proposed virtual mechanism of ternary fission, taking into account that the *p*-particle is emitted from the neck of the fissile nucleus in its configuration preceding the scission of this nucleus into fission fragments, the widths of ternary fission, the energy distributions of *p*-particles, and the probabilities ω_0 of formation different third particles in nuclear fission.

It should be noted that in the present work, for the first time, the concept of virtuality is applied to processes associated with emission with ^{1}H, ^{2}H, ^{3}H during spontaneous and induced fission of nuclei of the actinide group.

Thank you for your attention!