PRODUCTION OF EXOTIC NUCLEI IN URANIUM PHOTOFISSION REACTIONS*

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Yields of reactions resulting in formation of exotic nuclei during uranium photofission are measured. The nuclei are identified and their yields are found by the method based on measurement of γ ray spectra from their radioactive decay. The nuclei for investigation are produced using the microtron bremsstrahlung beam and their γ spectra are measured at the HPGe detector. The optimum conditions for production of exotic nuclei in photonuclear reactions are discussed.

Photonuclear reactions play a special part in investigations of properties of atomic nuclei [1] due to a number of their specific features. First, interaction of γ rays with the nucleus (absorption and emission processes) is entirely electromagnetic, which allows these processes to be described quite correctly. Second, high penetrability and intensity of γ rays provided by modern electron accelerators makes it possible to obtain quite high yields of the nuclides of interest and to investigate nuclei with the extremely low likelihood of being formed. Among these nuclides are the so-called exotic nuclei characterized by excess of nucleons of one sort (protons or neutrons), or by specific features of their nuclear structure (high angular momentum, great deviation of the equilibrium shape from the spherical one), or by an unusual radioactive decay mode (emission of various delayed particles after the β-decay). Investigations of exotic nuclei are of great interest because their nuclear structure manifests some aspects which are difficult to observe in ordinary. Therefore, these

* This work has been supported by RFBR 11-02-92200 and 12-02-00361-a.

investigations appreciably add to our knowledge of the nuclear structure. That is why interest in these nuclei never wanes and amount of research in this field grows every year. One of the most effective ways to produce exotic nuclei is fission of heavy actinide nuclei [2]. It is complicated process in which the shape of the nucleus changes from spherical (or near-spherical) to well-deformed as scission into two fragments occurs. Internal energy in the nucleus is many times redistributed between various degrees of freedom, both collective and single-particle ones. As a result, fission of the nucleus reveals the nuclear properties which are practically never observed in other processes. Therefore, it can be assumed that nuclear fission will be an effective tool for producing a wide range of exotic nuclei and investigating their properties.
The table below presents some exotic nuclei, specific features of their structure, and spectroscopic characteristics that are necessary for their identification and determination of their yields (half-life and energy of the most intense γ line in their radioactive decay) [3].
The exotic nuclei in question were produced and their yields were measured using the bremsstrahlung of the accelerated electron from the MT–25 microtron of the Flerov Laboratory of Nuclear Reactions, JINR [4]. The energy of the accelerated electrons was 25 MeV, and the beam intensity was 20 μA.

Table 1.

Fragment	Nuclear structure feature	T(1/2)	E(γ), KeV	Yields (1/f, %) in reactions	
				238U (γ, f)	235U (n, f)
102Zr	Anomalously large quadrupole deformation	2.9 s	535	1.2x10↑-1	1.5x10↑-1
132Sn	Doubly magic nucleus, Z = 50, N = 82	40 s	992	6.2x10↑-1	~1.3
136Sb	Emitter of delayed neutron pairs	2.5 s	1320	2.2x10↑-2	1.6x10↑-2
140J	Emitter of delayed α particles	1.9 s	377	1.6x10↑-4	1.8x10↑-4
135mCs	High-spin isomer (I = 19/2)	53 min	992	5.5x10↑-6	1.2x10↑-6

The fission fragments that escaped from the targets were slowed down in the aluminum collector 20 μm thick immediately adjacent to the irradiated targets. After irradiation the collectors were transported to a room shielded against the microtron bremsstrahlung, where their γ spectra were measured using the HPGe detector and the γ spectrum processing code [5]. When dealing with short-lived nuclei (half-lives shorter than 2 s), we used a gas flow with aerosols

[6] in which the fission fragments emitted from the irradiated target were slowed down and transported to a room with a low γ radiation background.
From the thus measured γ spectra we determined yields of exotic fragments under study referred to the total number of photofission fragments. The latter was found from the known yield of the La-140 nucleus with the 1596-keV γ line in the U-238 photofission, which was 5% of the total yield of fragments [7]. All these yields are presented in the table, where similar yields from the thermal-neutron fission of the U-235 nucleus are also given for comparison [8]. It is evident from the table that relative yields of most exotic nuclei from uranium photofission are somewhat on a par with yields from thermal-neutron 235U fission. At the same time the use of thick targets and powerful γ-ray sources will allow obtaining much higher yields of nuclei under study. With the above parameters of the electron beam from the FLNR microtron and with the targets of mass up to hundreds of milligrams, yields of the above-mentioned exotic nuclei as high as 10↑8 per second can be obtained. As a result, it will be possible not only to produce and identify these exotic nuclei but also to study their properties, e.g., to measure their masses, nuclear multipole moments, and other parameters. Also, a wide range of so far unstudied exotic nuclei, including those with extremely low yields, e.g., the doubly magic nucleus 78Ni very far off the β-stability valley, can become available for investigations. The data on the yields of exotic nuclei and on their dependence on the nucleon composition of the fissioning nucleus can be used for planning new experiments with photonuclear reactions. They will allow optimizing conditions for production of those fission fragments of heavy nuclei which are of interest for investigation.

The authors are grateful to Yu.Ts. Oganessian, S.N. Dmitriev, and Yu.E. Penionzhkevich for their attention to the work.
The work was supported by the RFBR, projects no. 11-02-92200 and 12-02-00361-a.

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