View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by edoc

Beta-delayed fission probabilities of transfermium nuclei, involved in the r-process

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2016 J. Phys.: Conf. Ser. 665 012060

(http://iopscience.iop.org/1742-6596/665/1/012060)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 131.152.112.139
This content was downloaded on 20/02/2017 at 10:44

Please note that terms and conditions apply.

You may also be interested in:

Multi-dimensional potential energy surfaces and non-axial octupole correlations in actinide and transfermium nuclei from relativistic mean field models
Bing-Nan Lu, Jie Zhao, En-Guang Zhao et al.

Mass asymmetry in fission, fusion and mass transfer due to the fragmentation in valleys
A Sandulescu and W Greiner

Heavy-ion fusion and the production of elements 103, 105 and 107
M T Magda, A Sandulescu, D G Popescu et al.

Isomer spectroscopy in 254No
R-D Herzberg, P T Greenlees, P A Butler et al.

Synthesis of superheavy elements in heavy-ion fusion reactions
M T Magda, A Pop, D Poenaru et al.

Pushing the Limits: Nuclear Structure of Heavy Elements
P T Greenlees

Charge spectrum of galactic cosmic ray nuclei as measured in meteorite olivines
Andrei B Aleksandrov, Aleksandr V Bagulya, Mikhail S Vladimirov et al.

Nuclear Physics in Astrophysics VI (NPA6) IOP Publishing
Journal of Physics: Conference Series **665** (2016) 012060 doi:10.1088/1742-6596/665/1/012060

Beta-delayed fission probabilities of transfermium nuclei, involved in the r-process

I Panov[1], **Yu Lutostansky**[2], **F-K Thielemann**[3]
[1]Institute for Theoretical and Experimental Physics NRC Kurchatov Institute, Moscow, Russia
[2]NRC Kurchatov Institute, Moscow, Russia
[3]Department of Physics, University of Basel, Basel, Switzerland

E-mail: `igor.panov@itep.ru`

Abstract. For the nucleosynthesis of heavy and superheavy nuclei fission becomes very important when the r-process runs in a very high neutron density environment. In part, fission is responsible for the formation of heavy nuclei due to the inclusion of fission products as new seed nuclei (fission cycling). More than that, beta-delayed fission, along with spontaneous fission, is responsible in the late stages of the r-process for the suppression of superheavy element yields.

For beta-delayed fission probability calculations a model description of the beta-strength-functions is required. Extended theoretical predictions for astro-physical applications were provided long ago, and new predictions also for superheavy nuclei with uptodate nuclear input are needed. For the further extension of data to heavier transactinides the models of strength-functions should be modified, taking into account more complicated level schemes. In our present calculations the strength-function model is based on the quasi-particle approximation of Finite Fermi Systems Theory.

The probabilities of beta-delayed fission and beta-delayed neutron emission are calculated for some transfermium neutron-rich nuclei, and the influence of beta-delayed fission upon superheavy element formation is discussed.

1. Introduction

In physical scenarios with long r-process duration fission plays an important role [1], [2]. Fission, in part beta-delayed fission, effects strongly on formation of heavy and superheavy elements and nuclei-cosmo-chronometers as well. Nuclei of all chemical elements, participating in the nucleosynthesis under very high neutron density environment during multiple neutron captures achieve an equilibrium among the isotopes of each heavy element and following beta-decay of neutron-rich unstable isotope results in formation of new element. During beta-decay of such neutron-rich nuclei, emission of delayed neutron occurs leading to broading path of the r-process. In transuranium region in addition to beta-delayed neutron emission the beta-delayed fission appeared, leading together with neutron-induced fission to termination of the nucleosynthesis of more heavier nuclei during the r-process and (mainly) after neutron freeze-out. All these beta-delayed processes [3, 4] influence on the formation of heavy (and superheavy) elements yields. For a number of transactinide nuclei, participating in the r-process, neutron separation energy is less than 3 MeV, and total beta-decay energy is about 10 MeV or even more. That is why a real competition between beta-delayed neutron emission and beta-delayed fission exists, depending on nuclear structure, fission barrier and neutron separation energy values and leads to big changes of their values. Though the number of extended calculations of beta-delayed processes probabilities are exist up to Z=100 [2-5], the knowledge of these data also important [6] for superheavy region (for nuclei with Z>100), as well as reevaluation of existed data.

2. Model and calculations

Part of the r-process nuclear stream can escape fission and reach the superheavy region and the surviving of the formed superheavy elements, unstabale against beta-decay, depends in part on beta-delayed fission rates, which strongly depend on the values of beta-delayed fission probabilities $P_{\beta df}$. For beta-delayed fission calculations, except a number of important characteristics, such as nuclear masses and fission barriers, the beta strength-functions are required. The beta-strength function $S_\beta(E)$ defines the probabilities of charge-exchanges processes and beta-delayed processes as well [4,7,8]. The most important of beta-delayed processes for very neutron rich nuclei are: probabilities of one, two and three neutron emission, and for actinide region - beta-delayed fission. For these nuclei values of the probabilities can be high and probably may reach 100% in total.

The main contribution in $S_\beta(E)$ belongs to transitions of Gamov-Teller (GT) type, including Giant GT-resonance, "pigmy"-resonances and other isobaric states (IS). The beta-strength function is usually defined [9] as depending on average energy distribution of matrix elements of excitation states E_i in daughter nucleus:

$$S_\beta = \frac{\overline{d\sum M^2(E_i)}}{dE}\frac{1}{6260}, \qquad (1)$$

and is expressed usually as reduced transition probability B_{GT}: $B_{GT} = D\frac{g_V^2}{g_A^2}\cdot S_\beta$, where $\overline{dM^2(E_i)}$ is the averaged addition of matrix elements of all beta-transitions in range dE.

The beta-strength function S_β has resonant structure which is strongly depends on the model used. In present calculations the matrix elements values M_i^2 as well as energies of their states were got in numerical solution of Finite Fermi Systems Theory (FFST) equations [10] when quasi-classical approach to equations for effective nuclear field of GT-type was applied [7, 8].

In constructing of $S_\beta(E)$-function we took into account the fragmentation of the high-lying IS, and their consequent broadening as it was done in [11]. According to [10] the serial expansion of the width is: $\Gamma(\mathrm{E}) = \alpha E^2 + \beta E^3 + \ldots$. In calculation of $S_\beta(E)$ it suffices to use only the first term of $\Gamma(E)$ serial expansion, which effectively takes into account three-quasiparticle configurations. The value $\alpha \approx \varepsilon_F^{-1}$ and in present calculations α =0.018 MeV^{-1} , obtained from the averaged experimental widths of GTR, was used.

The probabilities of beta-delayed processes were derived according to formulae

$$P_{\beta df}(Z,A) = \int_{S_n+\delta}^{Q_\beta}\sum_i S_\beta^i(E)\cdot f(Q_\beta - E)\cdot\frac{\Gamma_f}{\Gamma_{tot}}dE \Big/ \int_0^{Q_\beta}\sum_i S_\beta^i(E)\cdot f(Q_\beta - E)dE\ . \qquad (2)$$

where f(Z, Q_b - E) is the Fermi function and Γ_f is the fission partial width. When $E - B_f > \delta$ we can let $\Gamma_n \gg \Gamma_f$ and δ is equal ≈50 KeV according to [12].

The comparison of calculated probabilities of beta-delayed fission $P_{\beta df}$, based on different strength-function models, show that $P_{\beta df}$-values approximately in factor 2 lower when the proposed model of $S_\beta(E)$ was used instead of the old one [5]. In present calculations as in previous works for calculations of different rates for the r-process [2, 14], the predictions of masses and fission barriers, based on ETFSI model [13], were used.

For the very neutron rich isotopes of Fermium and heavier elements the fission barriers increase when N approaches 184, that is reflected in strong decrease of $P_{\beta df}$ values for the nuclei with N ≈ 184 (Fig.1).

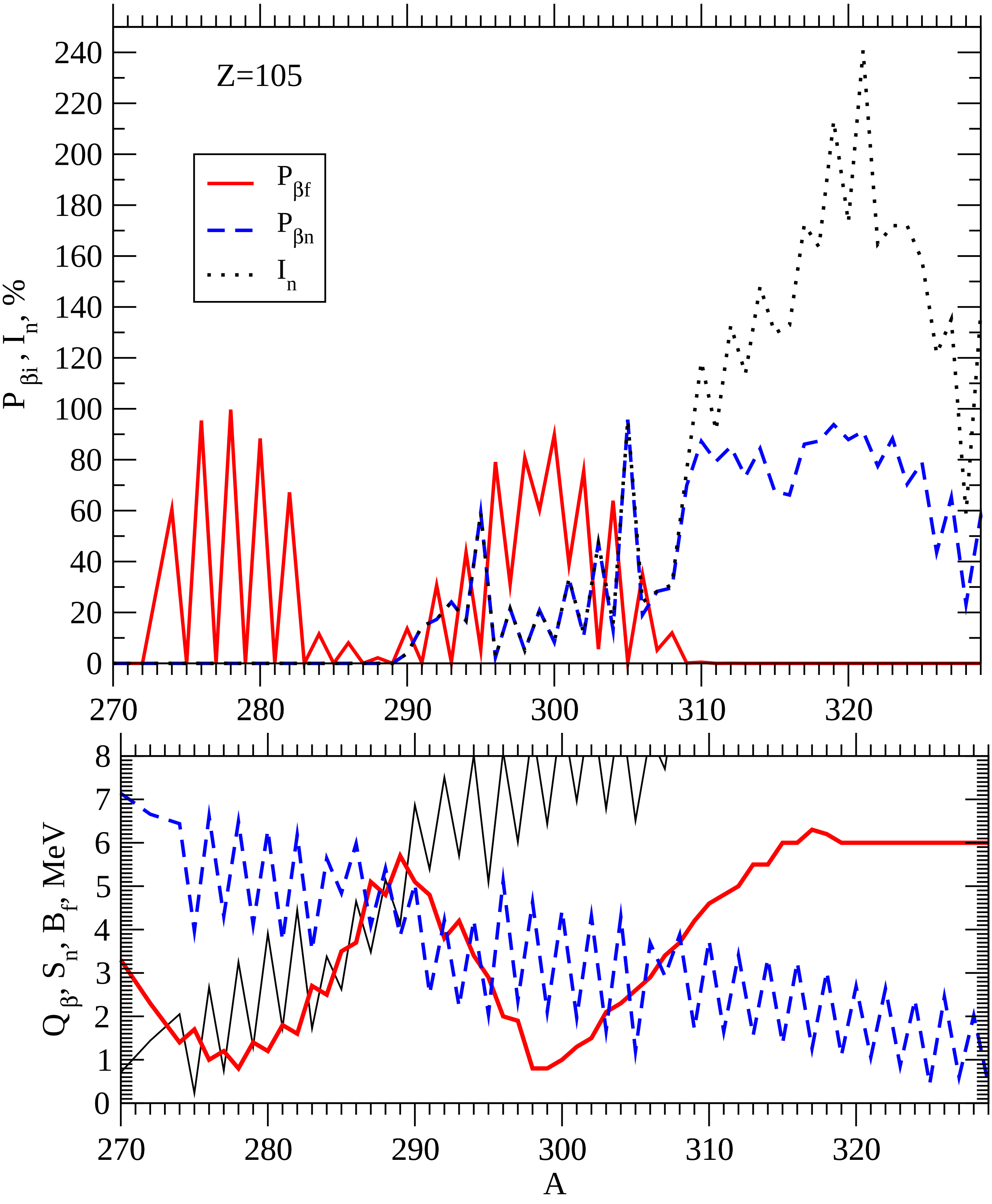

Fig. 1. Upper panel: the neutron beta-delayed emission probabilities $P_{\beta dn}$ (dashed line), beta-delayed fission probabilities $P_{\beta df}$ (line) and number of delayed neutrons per one decay (in percents) I_n (dotted line) for isotopes of Dubnium (Z=105); down panel: total energy of beta-decay Q_β (line), neutron separation energy S_n (dashed line) and fission barriers (bold line) for the same isotopes (in MeV).

At the upper plot of Fig.1 the present calculations of $P_{\beta df}$ for different isotopes of Dubnium are presented, as well as $P_{\beta dn}$-values and number of emitted neutrons during each beta-decay. Strong odd-even effect is explained by the structure of strength function and strong dependence of neutron separation energy on the number of neutrons, which in turn leads to strong variations of the energy window $S_n - B_f$ and changes of "pigmy"-resonances contributions into $P_{\beta df}$ and $P_{\beta dn}$.

3. Conclusions

Calculations of beta-strength function $S_\beta(E)$ for neutron-rich nuclei is complicated task because high-energy charge-exchange excitations in continuum should be taken into account. This task is under consideration and can be solved with arbitrary good accuracy in the framework of approach, based on FFST. In this work the previously developed approach [15] for calculation of beta-delayed processes based on quasi-classical approximation for beta-decay field [6] was used. For the consistency with previously produced nuclear data, beta-strength-functions and probabilities of delayed processes were derived with the same nuclear mass and fission barrier predictions [13] as previously calculated neutron-induced rates [14], used in astrophysical nucleosynthesis modelling.

Preliminary calculations of $P_{\beta df}$, presented in this report, pointed out the less role of delayed fission, and results in that data produced during last decades [2, 3] were overestimated, that is confirm the old predictions of beta-decay fission probabilities made on the basis of simple physical evaluations [16].

The extended calculations of $P_{\beta df}$ and $P_{\beta dn}$, made simultaneously on the basis of the same approach can change the character of the r-process passage in the transactinide region, and may be interesting for experiments of synthesis of superheavy elements [17]. These results are needed either for different modelling of astrophysical nucleosynthsis of heavy and superheavy nuclei and neutron impulse nucleosynthsis at experimental istallations as well [18, 19]. The derived results can be improved after further development of strength function model and utilization of nuclear deformations as well.

This work was supported by SNF grant IZ73Z0_152485 SCOPES, Russian Foundation for Basic Research Grants RFBR 13-02-12106_ofi-m, 14-22-03040_ofi-m

4. References

[1] I. V. Panov, F.-K. Thielemann. // Nuclear Physics A, 718, 647 (2003).
[2] I. V. Panov, E. Kolbe, B. Pfeier, et al. // Nucl. Phys. A. 747, 633 (2005).
[3] F.-K. Thielemann, J. Metzinger, H. V. Klapdor-Kleingrothaus. // Zt. Phys. A309, 301 (1983).
[4] Yu. S. Lyutostansky. // Bull. Acad. Sci. USSR, Phys. Ser. 50, 834 (1986).
[5] P. Moller, J. R. Nix, K.-L. Kratz. // ADNDT 66, 131 (1997).
[6] I. Petermann, K. Langanke, G. Martinez-Pinedo, et al. // Eur. Phys. J. A 48, 122 (2012).
[7] Yu.V. Gaponov and Yu. S. Lutostansky // Phys. At. Nucl. 73, 1360 (2010).
[8] Yu. S. Lutostansky // Physics of Atomic Nuclei, 74, 1176 (2011).
[9] P. G. Hansen. // Adv. Nucl. Phys. 45, 159 (1975).
[10] A. B. Migdal. Theory of Finite Fermi Systems. Wiley, New York, 1967.
[11] Yu. S. Lutostansky and N. B. Shulgina. // Phys. Rev. Lett. 67, 430 (1991).
[12] Yu. S. Lyutostansky, I. V. Panov, V. K. Sirotkin. // Phys. Lett. 161, 9 (1985).
[13] A. Mamdouh, J. M. Pearson, M. Rayet, et al. // Nucl. Phys.A 337, 679 (2001).
[14] I. V. Panov et al. // Astronomy and Astrophysics, 513, id.A61 (2010).
[15] V. G. Aleksankin, Yu. S. Lyutostansky, I. V. Panov // Yad. Fiz. 34, 1451 (1981).
[16] I. V. Panov, Yu. S. Lyutostansky, V. I. Ljashuk. // Bull. Acad. Sci. Ussr, Phys. ser. (USA) 54, 2137 (1990).
[17] Yu. Ts. Oganessian. //J. Phys. G, 34, R165 (2007).
[18] Yu. S. Lutostanskii, V. I. Lyashuk, I. V. Panov. // Bull. Russ. Acad. Sci. Phys. 75. 533 (2011).
[19] I. V. Panov, I. Yu. Korneev, G. Martinez-Pinedo, F.-K. Thielemann. // Astronomy Letters. 39 150 (2013).