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Original Research Article

EESR, 1(2) 2020 [201-207]

Thermal neutron fission of uranium-233 by Monte-Carlo method

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DOI : https://dx.doi.org/10.47204/EESR.1.2.2020.201-207P

ABSTRACT

In order to investigate the thermal fission of U-233, a detailed simulation program has been put together with an operational mode. In the calculations carried out by Monte-Carlo method, the distribution of the secondary mass chain yield obtained through slow neutron fission, independent yield of secondary products as well as their independent yield fractions have been calculated and charge distributions of secondary products and their most probable charge values have been found. The variation of the number of prompt neutrons emitted from the product with the mass number; and similarly energy spectra of the products in the laboratory and in the center of mass systems have been studied. Due to the fact that Adiabatic model has been found to have produced better results in slow neutron fission systems during previous experimental studies, the rate of deformation energy in this study has been calculated by utilizing adiabatic model as well. The distribution of the energy of the gamma rays emitted from the product with the mass of the product itself has been investigated. The width parameter of the secondary product charge distribution of U-233 in thermal neutron fission has also been investigated. The results obtained have been compared with the other thermal fission systems and experimental values available.

KEYWORDS

U-233; Thermal fission; Yield; Monte-Carlo.

INTRODUCTION

Nowadays the energy requirement was obtained by fossile fuels (80%), hydraulic (10 %) and by nuclear (10 %) energies[1,2]. The environmental pollution originating from the coal and insufficient petroleum and natural gas reserves cause to utilization of nuclear energy in last decades[2,3]. Although the capital cost of nuclear energy is high, lower fuel prices cause to economic utilization of nuclear sources. Nowadays, nuclear energy provides 10 % of the electric energy of the World[4]. The power reactors consist of natural uranium and uranium-235 and of reactors enriched with uranium fuel. In the World in the 31 country are 432 active nuclear central with a total power of 340347 MW[4,5]. The fissile elements can be used as nuclear fuel is U-235, U-233 and U-239. The reason of expanded utilization of U-235 in the recent years is the naturel presence of U-235 in the uranium element[6,7]. Nuclear fission proces can be defined by the pumping of the heavily uranium elements by neutrons[8-10]. In the thermal fission of U-233, in order to determine the ratio of deformation energies it was used two models namely adiabatic and statistic[11,12], Fissile elements which can be used as nuclear energy sources are U-235, Pu-239 and U-233[4,12]. Although, there is a lot of studies to find energy concerning the U-235 and Pu-239 limited studies were about thermal fission of U-233[15,16]. There is no experimental and theoretical data's during thermal fission of the nucleus of U-233 to obtain nuclear energy in the literature.

In the frame work of this study, it was aimed to obtain the maximum nuclear energy by thermal neutron fission using adiabatic model in Turkey since in the future it will be used nuclear energy since the other energy sources (coal petroleum electricity) are very limited. The calculation was performed by using Monte-Carlo Method. The goals in this study are to obtain the disturbance of secondary mass chain by calculation of independent yields of secondary products and independent yields ratio and to determine the disturbances of charge of secondary products and the most probable charge values. With the mass numbers of prompt neutron separating by the neutrons and the variation of product mass of mass center energy were investigated by using adiabatic model. In this model the ratio of deformation energies was calculated. The variation of product mass separated by the gamma beams energies and the variation of width of secondary product in the neutron fission of U-233 were determined. Furthermore, the data obtained from the Monte-Carlo Method were correlated with the other thermal fission process values and experimental studies.

THEORETICAL BACKGROUND

There are studies giving the product yields altogether of several fission systems which are measured with different experimental methods and calculating the most appropriate value from these experimental data[13,20]. Meek and Rider have analyzed nearly 13000 product yields which are measured from several energy levels' fissions of Thorium, Uranium and Plutonium[14,16-18]. They have published the experimental data values considering the conditions of the experiment, the error limits and the number of repeats and decay properties of the products. Yamamato and Sugiyama have corrected the primary product yield distributions with instantaneous-neutron numbers in order to obtain the graphics of secondary product mass yields[3,6,8,17]. The values for the slow neutron fission of U-233 founded by Yamamato are given together with Crouch's experimental data in Figure 1.

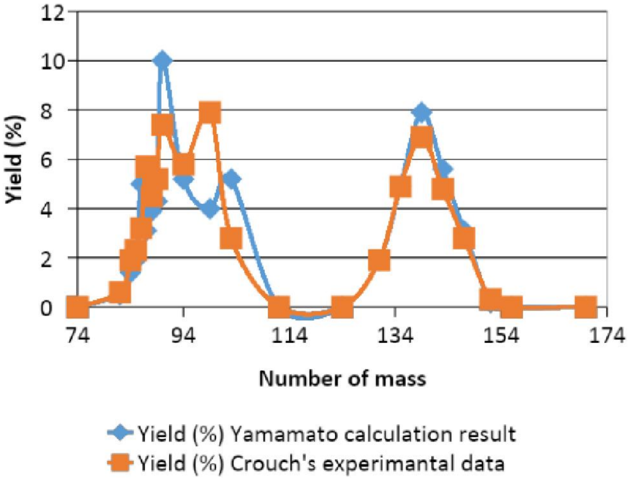

Figure 1: The distribution of mass chain yields in the slow neutron fission of U-233

The experimental results are described in accordance with these models by utilizing the statistical and adiabatic models for the theoretical calculations performed by Sardeta[5]. There is a strong interaction between the collective motion of the core from the statistical model and motions of single particle. The collective motion develops quickly towards the breaking point as reported by Aritomo[12]. Since the nucleons cannot follow this motion as adiabatic, a portion of the energy is transferred to the nucleons as exciting energy. Thus a balance is established between the nucleons' degrees of freedom at the breaking point and the temperatures of the products are equal at break as reported by Naika and Pomp[11,14]. In contrast, in the division process toward the breaking point, the collective motion of the nucleus develops slowly in adiabatic model and the nucleons follow the nucleus's collective motion as adiabatic as reported by Reinhard[20]. Under these circumstances the interaction between the nucleus's single particle motion and its collective motion is weak and the internal temperature of products at break can be considered to be zero. Until now is the fine structure that was formed with double proton nucleus. It is observed that especially possibility of double protons or double neutrons nucleus occurrence is higher as reported by Kawano and Naika[8,12]. Another feature observed in the yield-mass graphics is that a curve belonging to a heavy mass group does not move a lot but there are obvious shifts in the light mass groups. Another common features found in yield graphics is that symmetric mass division possibility is low but as excitation energy goes up this possibility goes up[11,13]. It is very important that number and energy distribution of the prompt nucleus are examined so as to explain the developments during the diversion of the nucleus in fission and due to its importance in practices[5,6]. First experimental study analyzing prompt neutron number product mass and change for the slow neutron fission of the U-233 nucleus was made by Fraser and Milton[8,13,21].

As a result of these experiments in which prompt neutrons were counted as coincidences with fission products it was founded that in a division neutron numbers of heavy and light products were different and total prompt number released product pairs determined change with mass ratio[22]. By many scientist's prompt neutron of each product was found with values of primary and secondary product efficiency through physical measurement. Of these, prompt neutron and yield-mass distribution of U-233 for fission by Terrell can be seen in Figure 2. In the following studies, Walsh and Boldeman analyzed the fine structure of the prompt neutron in fission, compared it with the construction in the product yield distribution and observed that for both distributions this construction was found at same mass[23,24]. Adiabatic and statistical models were used for explaining results of mass related prompt neutron numbers[25]. The most important difference between these two models is the extent of the interaction between collective character of the divided nucleus and one particle actions of the nucleons. In the adiabatic model this interaction is weak and in the statistical model the interaction is strong.

With a new approach to adiabatic model, Terrell, Kawano and Qiao suggested that deformation that divided nucleus included is depended on the features of the product[9,14,23].

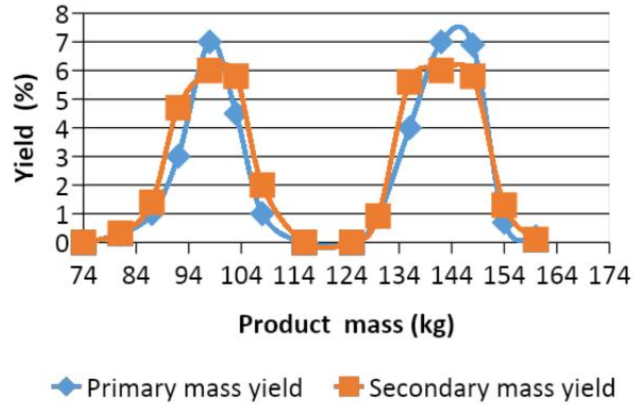

Figure 2: Yield–mass distribution of U^{233}+n fission

Methods used in the calculations

Since neutron division from fission product is a statistical issue, for calculation of prompt neutrons' and gamma lights' average number and energy Monte-Carlo method is used. Monte Carlo method is based on Weissskopff's "nuclear evaporation" model[26].

Computer program used in the studies

In this study, in order to detect the product distributions during neutron fission and the prompt-neutron numbers, their energies and the gamma energies a computer mathematical program namely Fortran 4 was used.

RESULT AND DISCUSSION

Primary product mass chain yield and charge values

For the primary fragment mass chain product and charge values of U-233, values found by Meek and Rider were used and product mass and change graphic was drawn and is shown in Figure 3[6,11,16]. The yields increased at U-233 by products 90, 99, 135 and 146, respectively.

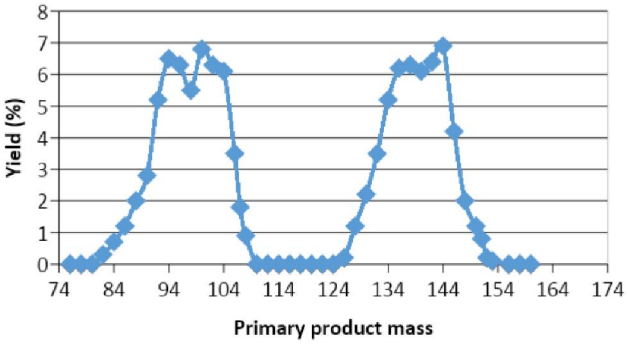

Figure 3: U-233's primary fragment mass chain yield

Yield of fragment product mass chain

In this study the fragment data of product mass chain and the most probable charge of fragment product mass chain (Zp) data were obtained by Meek and Rider, Wolsberg respectively[12,14,16,25]. By using Zp and primary fragment independent yield ratio (PA(Z)) data's via the method namely "became distant from unchanged charge distribution" it was calculated the secondary product charge distribution. Then, it was calculated the wide parameter (c) as 0.79 by using the width parameter (α = 0.56) obtained by Meek and Rider used in low energy fission[3,6,16]. Figure 4 shows the relationship between the secondary product charge and PA(Z) for mass number (A)124 during thermal fission of U-233. According to this Figure it was observed that the maximum secondary product charges was obtained as 49 at a PA(Z) value of 0.65. These data are in accordance with the maximum secondary product charges and PA(Z) values found by Meek and Rider (data not shown)[15-17].

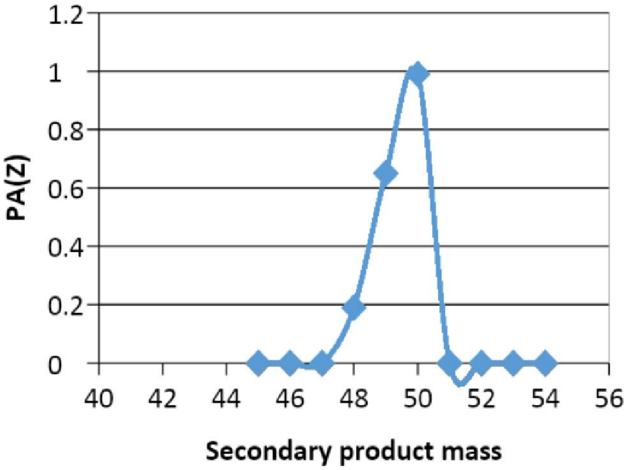

Figure 4: Distribution of independent yield fractions for A=124 chain during U-233's prompt neutron fission

Product yield and charge distribution of U-233 in thermal neutron fission

By multiplying the total yield of mass change (Y), and independent yield ratio PA(Z) it was calculated the ındependent yield of every isobar, the secondary product mass yield of U-233 was obtained. The relationship between mass of secondary product and percent of yield was illustrated in Figure 5 for the fission of U-233. The maximum yields of secondary product mass were 7.99 and 8.8.

These theoretical data were correlated with the experimental studies of Crouch[9,28]. It was found similar curves and it can be concluded that the theoretical data from our study are in accordance with the experimental results of Crouch (Figure 6)[12,13,28]. This figure illustrates the graph between the mass number and secondary product yield (%) obtained from our theoretical data and from Crouch data[6,28].

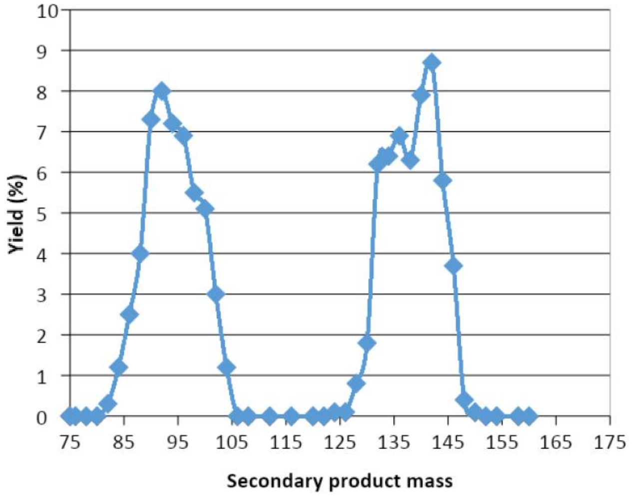

Figure 5: Secondary product t yield change with product mass during U-233's fission.

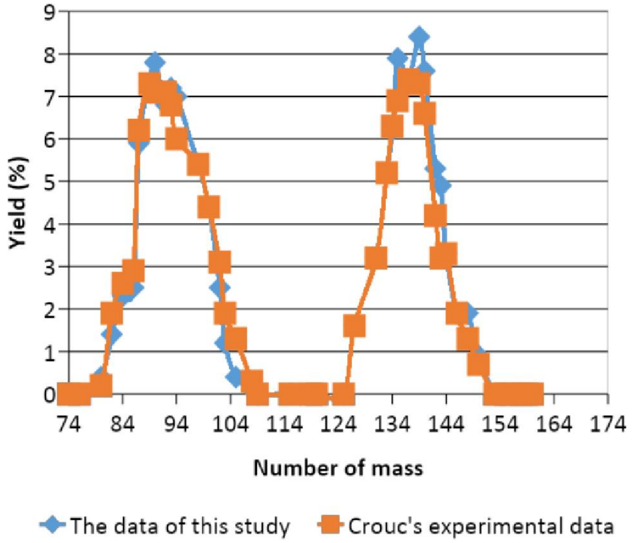

Figure 6: Comparison of secondary product yield distribution according to product mass during U-233's fission.

In Figure 6 it was observed some thin structures in proton numbers. The maximum peaks observed in this figure can be defıned as the poınts of mass value carryıng double number of protons. As a result, it was found that the plot in Figure 6 exhibited a Gaussian distribution.

Figure 7 shows the plot between mass of secondary product and distribution of width parameter in the U-233 fission.

Disturbance of gamma and prompt neutron beams during thermal neutron fission U-233

The variation of prompt neutron numbers (V_A and variation of product mass is illustrated in Figure 8.

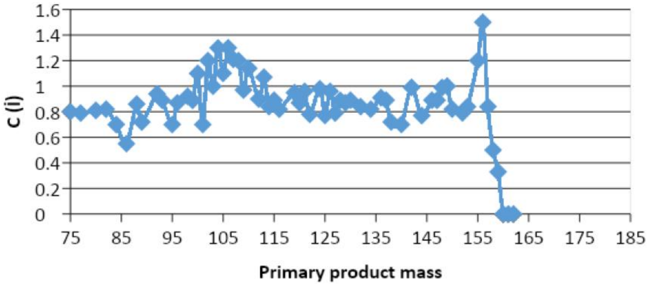

Figure 7: Secondary product charge distribution width parameter distribution in U-233 fission

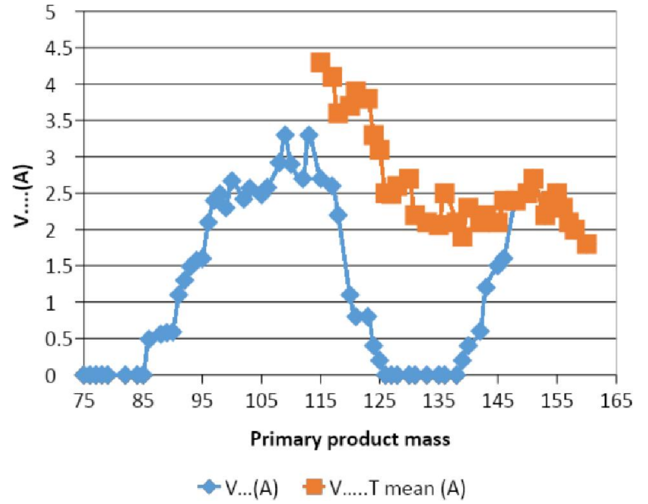

Figure 8: Variation of the number of prompt neutrons in the fission of U-233 with product mass.

Prompt neutron numbers change with product mass in U-233 fission

In this study it was found that the theoretical prompt neutron disturbances calculated by adiabatic model are in good accordance with the experimental results found by Terrel as shown in Figure 9[9,12,23].

In the study of Terrel the light and heavy mass groups in prompt neutron disturbance exhibited similarities with our prompt neutron disturbances[6,12,23]. The mass of products which are at the lowest neutron disturbances are placed in the region which are the masses and containing double numbers nucleon. This showed that the neutron disturbance is related with the layer structure of products.

Statistical and evaporation models for the neutron emission energy spectrum in the center-of-mass system from fission fragments

The kinetic energies ($€_1$) of neutron in the mass centers for each fission were calculated by Monte-Carlo Method. The kinetic energies in the laboratory system ($€_1$) was calculated by the accepters of the neutrons were distributed izotropically. In Figure 10 the variation of product mass versus the kinetic energy in the mass center of prompt neutron was shown. The maximum kinetic energy peaks (2000-2300 MeV) are between 94 and 116 for product masses. The secondary kinetic energy peaks in the same Figure reached up to 1600 MeV for product masses varying between 149 and 160.

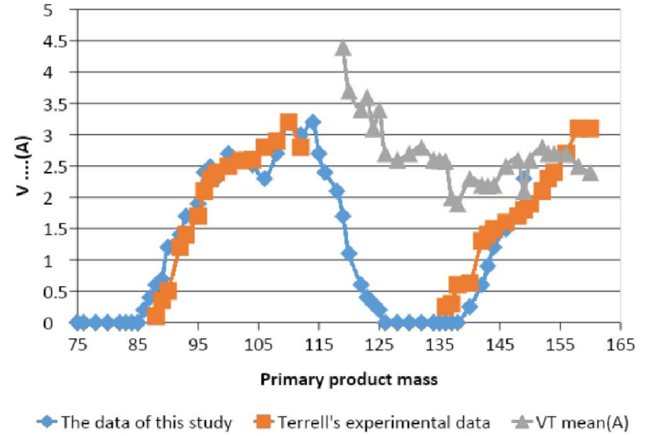

Figure 9: Comparison of prompt neutrons change with output mass in U-233 fission

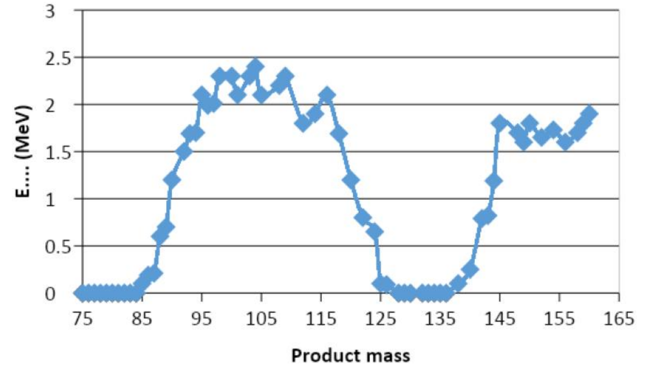

Figure 10: Energy distribution of prompt neutrons mass center in U-233 fission

Figure 11 shows the variation between the heavy product mass of mean total gamma beam energy separated from the fission products and the product mass of mean gamma energy during the fission of U-233 with thermal neutron. In the study Wals and Boldeman declared that double energy is very important and the numbers of prompt neutron are very related with the product charge[12,13,24]. As illustrated in Figure 11 similar to the study of Wals and Boldeman and and Madland increases in gamma energy for products with double proton was observed[10,15,24]. As a result, according to the data obtaining of this study, the double energy is very important in energy distribution during U-233 fission with prompt neutron.

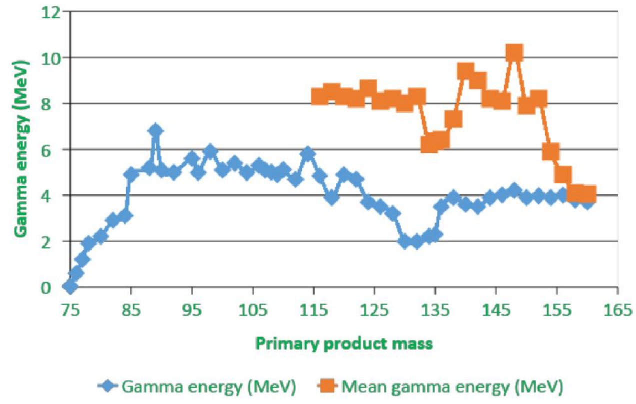

Figure 11: γ- rays energies, released in U-233 fission, change with product mass.

CONCLUSION

The results of this study showed that general aspects for prompt neutron fission show parallelism with aspects of the studies made with Monte-Carlo calculation method. This shows that adiabatic distribution among fragments of excited energy during slow neutron fission division is also valid for U-233 fission. However, in the following studies calculations with statistical model will be made and will be analyzed comparatively.

REFERENCES

[1] A.S.Vorobyev, O.A.Shcherbakov, Yu.S.Pleva, A.M.Gagarski, G.V.Val’ski, G.A.Petrov, V.I.Petrova, T.A.Zavarukhina; Petersburg. Measurements of angular and energy distributions of prompt neutrons from thermal neutron-induced fission. Nuclear Physics Institute, 188350 **(2009)**.

[2] J.N.Wilsona, M.Leboisa, P.Halipréa, S.Oberstedtb, A.Oberstedtc; Scientific Workshop on Nuclear Fission dynamics and the Emission of Prompt Neutrons and Gamma Rays, THEORY-3 Prompt emission in fission induced with fast neutrons, **(2015)**.

[3] O.A.Shcherbakov, Yu.S.Pleva, A.M.Gagarski, G.V.Val’ski, G.A.Petrov, I.Petrova, T.A.Zavarukhina, A.S.Vorobyev; Measurements of angular and energy distributions of prompt neutrons from thermal neutron-induced fission, **(2009)**.

[4] R.Vogta, J.Randrup; Event-by-event modeling of prompt neutrons and photons from neutron-induced and spontaneous fission with FREYA. Physics Procedia, **47**, 82-87 **(2013)**.

[5] L.Bergea, O.Litaizea, O.Serota, C.De Saint Jeana, P.Archiera, Y.Peneliaua; Study on prompt fission neutron spectra and associated covariances for 235U(nth,f) and 239Pu(nth,f). Physics Procedia, **64**, 55-61 **(2015)**.

[6] A.Sardeta, T.Graniera, B.Laurenta, A.Oberstedta; Experimental studies of prompt fission neutron energy spectra. Physics Procedia, **47**, 144-149 **(2013)**.

[7] I.Ruskova, Yu.N.Kopatchb, Ts.Panteleevb, V.R.Skoy, V.N.Shvetsovb, E.Dermendjieva, N.Janevaa, L.B.Pikelnerb, Yu.V.Grigoriev, Zh.V.Mezentsevab, I.Ivanov; Prompt gamma emission in resonance neutron induced fission of 239-Pu. Physics Procedia, **31**, 35-42 **(2012)**.

[8] A.Beiser; Concept of Modern Physics, McGraw Hill Book Company New York, USA, **(1973)**.

[9] T.Kawano, P.Talou, I.Stetcu, M.B.Chadwick; Statistical and evaporation models for the neutron emission energy spectrum in the center-of-mass system from fission fragments. Nuclear Physics A, **913**, 51-70 **(2013)**.

[10] D.G.Madland; Total prompt energy release in the neutron-induced fission of 235U, 238U, and 239Pu. Nuclear Physics A, **772**, 113-137 **(2006)**.

[11] J.N.Wilson, M.Lebois, P.Halipré, S.Oberstedt, A.Oberstedt; Prompt emission in fission induced with fast neutrons. Phys.Procedia, **64**, 107-113 **(2015)**.

[12] H.Naika, V.K.Mulikb, P.M.Prajapatic, B.S.Shivasankard, S.V.Suryanarayanae, K.C.Jagadeesanf; Mass distribution in the quasi-mono-energeti cneutron-induced fission of 238U. Nuclear Physics A, **913**, 185-205 **(2013)**.

[13] Yoshihiro Aritomo, Satoshi Chiba, Katsuhisa Nishio; Independent fission yields studied based on Langevin equation. Progress in Nuclear Energy, **85**, 568-572 **(2015)**.

[14] Yahua Qiao, Ming Zhang, Yi Yang, Shilong Liu, Jizong Wu, Bo Wang; Determination of 235-U isotopic abundance by fission-yield difference method. Nuclear Instruments and Methods in Physics Research A, **739**, 44-47 **(2014)**.

[15] S.Pomp, A.Al-Adili, E.Alhassan, C.Gustavsson, P.Helgesson, C.Hellesen, A.J.Koning, M.Lantz, M.Osterlund, D.Rochman, V.Simutkin, H.Sjostrand,

A.Solders; Experiments and theoretical data for studying the impact of fission yield uncertainties on the nuclear fuel cycle with TALYS/GEF and the total Monte Carlo method. Nuclear Data Sheets, **123**, 220-224 **(2015)**.

[16] A.Al-Adilia, F.J.Hambscha, S.Pompb, S.Oberstedt; Corrections of prompt-neutron emission in fission-fragment experiments. Physics Procedia, **47**, 131-136 **(2013)**.

[17] M.E.Meek, B.F.Rider; Compilation of Fission Product Yields Vallectios Nuclear Center, NEDO-12154-1, **(1974)**.

[18] A.Al-Adilia, F.-J.Hambscha, S.Pompb, S.Oberstedta; Corrections of prompt-neutron emission in fission-fragment experiments. Physics Procedia, **47**, 131-136 **(2013)**.

[19] T.Yamamoto, K.Sugiyama; Report NETU-20 April, Tokohu University Sendai, Japan, **(1977)**.

[20] P.G.Reinhard, K.Goeke; Dissipative adiabatic mean field theory for large amplitude collective motion, **(1986)**.

[21] J.S.Fraser, J.C.D.Milton; Physics Review, 93-818, **(1954)**.

[22] V.A.Rubchenya, W.H.Trzaska, D.N.Vakhtin, J.Äystö, P.Dendooven, S.Hankonen, A.Jokinen, Z.Radivojevich, J.C.Wang, I.D.Alkhazov, A.V.Evsenin, S.V.Khlebnikov, A.V.Kuznetsov, V.G.Lyapin, O.I.Osetrov, G.P.Tiourin, A.A.Aleksandrov, Yu.E.Penionzhkevich; Neutron and fragment yields in proton-induced fission of ^{238}U at intermediate energies. Nuclear Instruments and Methods in Physics, **463(3)**, 653-662 **(2001)**.

[23] J.Terrell; Neutron Yields From Individual Fission Fragments, Los AlamoScientific laboratory university of California, Los Alamos, New Mexico, Physics Review, 127-189 **(1962)**.

[24] R.L.Walsh, J.W.Boldeman; Nuclear Physics, A.276-189 **(1977)**.

[25] A.Chatillon, G.Bélier, T.Granier, B.Laurent, B.Morillon, J.Taieb, R.C.Haight, M.Devlin, R.O.Nelson, S.Noda, J.M.O'Donnell; Measurement of prompt neutron spectra from the ^{239}Pu(n,f) fission reaction for incident neutron energies from 1 to 200 MeV. Phys.Rev.C, **89**, 014611.

[26] Yasunobu Nagaya, Go Chiba, Takamasa Mori, Dwi Irwanto, Ken Nakajima; Comparison of Monte Carlo calculation methods for effective delayed neutron fraction. Annals of Nuclear Energy, **37**, **10**, 1308-1315 **(2010)**.

[27] K.Wolfsberg; LA-5553, UC-34c, **(1974)**.

[28] E.A.C.Crouch; Paper IAEA/SM-170/94, Symposium on Applications of Nuclear Data, Paris, **(1973)**.