Neutron Induced Fission Cross Section Of U-237 And Np-237

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Abstract:

Theoretical results have been based on the current experimental data published in EXFOR library in international Atomic Energy Agency (IAEA) described in detail for the thermal neutron induced fission cross sections with their error in a systematic manner of U-237 and Np-237. These data reviewed and analyzed. An estimate of neutron induced fission spectrum weighted average cross sections are their respective errors of the available data preformed with a Matlab-8.0 by install a recom.m program . The authors aims of this work have been attempt, thorough statistical evaluation of existing a recommended thermal neutron fission cross sections for U-237 and Np-237 in the energy range between their respective thresholds up to 24.9MeV for U-237 and up to 19.9MeV for Np-237. The purpose of this work is to combine the recommended ${}^{237}_{92}U(n,f)$ cross sections with recommended (n,f) cross sections of contamination Np-237 which is the daughter of U-237. The contamination contribution has been added by the in growth factor 25%, 50%, 75%, 100% from the ${}^{237}_{93}Np(n,f)$ reaction. The recommended (n,f) cross section have been averaged for U-237 and U-235 the value obtain for the ratio $\sigma_{ave} Recom\,{}^{237}_{92}U(n,f)/\sigma_{ave} Recom\,{}^{235}_{92}U(n,f)$ is 0.6971 which is agreement with the value 0.62 obtained by McNally et al.. The spin effect term has been discussed in the binding energy calculations. The relative neutron flux for U-237 is in comparable with that for Np-237 neutron fission cross sections.

Key Words: Neutron Fission, Recommended Cross Sections, Contamination, Spin Effect, Neutron Flux.

1.Inroduction

The radionuclide, Uranium-237, can be easily detected by its beta and gamma rays and it also has a convenient half-life,6.75days[1]. Uranium-237 has been discovered first by Japanese investigators (1940)[2], extensive studies have been made on the excitation function of different nuclear reactions for producing this nuclide. On the other hand, this nuclide can be found in the waste of the reactor fuel and fallouts after nuclear explosion so Uranium-237 produced is always accompanied with the target nuclide Uranium-238[3]. The radioactive nuclide Np-237 is with half-life $2.144x10^6$ y is a daughter of the 6.8day U-237 beta decay. where U-236 on absorption of a thermal neutron does not undergo fission but becomes U-237 which quickly beta decay to Np-237. However, the neutron capture cross section of U-236 is low, and this process does not happen quickly in a thermal reactor. spent nuclear fuel typically contains about 0.4% U-236. With a much greater cross section Np-237 may eventually absorb another neutron becoming Np-238 which quickly beta decay to Plutonium-238 Also, Np-237 alpha decay to Pa-233 [4,5].

The object of this work attempts to evaluate thermal neutron fission cross sections of U-237 Np-237 in the energy range from threshold up to 24.9MeV and 19.9MeV respectively. The sets of experimental data collected from EXFOR library have been interpolated, normalized and recalculated in fine steps of intervals. Hence the calculated results given in this work attached to the recommended values which can be viewed in the following consideration:

1- The interpolation for the nearest data for each energy interval as a function of cross sections and their corresponding errors have been done using Matlab-8.0.

2- The sets of experimental cross sections data are collected for different authors and with different energy intervals. The cross sections with their corresponding errors for each value are re-arranged according to the energy interval 0.01 MeV for available different energy range for each author.

3- The normalization for the statistical distribution of cross sections errors to the corresponding cross section values for each author has been done.

4- The interpolated values are calculated to obtain the recommended cross section which is based on the weighted average calculation.

In the present study ${}^{235}_{92}U(n,f)$ cross sections used as standard[6]. A brief description to each individually considered data set or different authors is given below for ${}^{237}_{92}U(n,f)$ and ${}^{237}_{93}Np(n,f)$ cross sections respectively.

2. ${}^{237}_{92}U(n,f)$ and ${}^{237}_{93}Np(n,f)$ Recommended Cross Section

The measured data from EXFOR library for the cross sections of ${}^{237}_{92}U(n,f)$ reaction reported by Mcnally J.W. et al.(1974)[7], Caner M. et al.(1976)[8], and Burk J.T. et al.(2006)[9], have been plotted, interpolated, and recalculated in fine steps of 0.001MeV from 98.7E-3MeV up to

2.49E+1MeV for an incident neutron by using recom.m program, as shown in figure (1).

These measurements with induced neutron for E_n=98.7E-3MeV to 1.83MeV peaked at 1.83MeV and 1688mb measured by Mcnally et al.; for E_n=1.10E-2MeV to 7.00E-1MeV peaked at 0.011MeV and 1137mb measured by Caner et al.; and for E_n =4.93E-1MeV to 2.49E+1 peaked at 24.09MeV and 2080mb measured by Burke et al. Error given by the authors range between 19% and 195% measured relative to (n,f) reaction.

Younes W. and Britt H.C. (2003) [10] extracted the ${}^{237}_{92}U(n,f)$ cross sections. The results are in reasonable agreement with the results of Mcnally. They have combined fission probabilities with calculated neutron absorption cross sections, including corrections for differences in angular momentum between the direct and neutron induced reactions. From this analysis they have extracted equivalent ${}^{237}_{92}U(n,f)$ cross sections.

The measured data from EXFOR library for the cross sections of ${}^{237}_{93}Np(n,f)$ reaction reported by lisowski P.W. et al.(1988)[11], Merla K. et al.(1991)[12], Cennini P. et al.(2004)[13], Basunia M. et al.(2009)[14], and Daikaki M. et al.(2013)[15] have been plotted, interpolated, and recalculated in fine steps of 0.01MeV from 0.5585MeV up 19.9MeV for an incident neutron by using recom.m program, as shown in figure (1). These measurements with induced neutrons for E_n =1.002MeV to 19.82MeV peaked at 8.72MeV and 2301mb measured by Lisowski et al.; for E_n=4.9MeV to 18.5MeV peaked at 18.5MeV and 2310mb measured by Merla et al.; for E_n=0.558MeV to 0.65MeV peaked at 0.653MeV and 928.49mb measured by Cennini et al.; for E_n=10.2MeV to 19.9MeV peaked at 16.5MeV and 2430mb measured by Basunia et al.; and for E_n =4.58MeV to 5.32MeV peaked at 4.58MeV and 1590mb measured by Daikaki et al. Errors given by the authors range between 8.9% and 70% measured relative (n,f)reaction.

3.Np-237 Daughter Contamination

. Generally the recommended data shows arise in the cross section above ${}^{237}_{93}Np(n,f)$ threshold energy. This rise is due to the ingrowth of the ${}^{237}_{93}Np(n,f)$ daughter contamination figure (2)represents the relation between the cross section of ${}^{237}_{92}U(n,f)$ and ${}^{237}_{93}Np(n,f)$ where the contamination of recommended cross section of ${}^{237}_{93}Np(n,f)$ is added. The ingrowth of ${}^{237}_{93}Np$ daughter contamination is from the beta decay of ${}^{237}_{92}U$. Figure (2)shows the calculated result of reducing the contamination and adding an additional

25%, 50%, 75% and 100% contribution from the ${}^{237}_{93}Np(n,f)$ reaction. From these results it can be seen that the contamination correction could make differences in the shape of the cross sections at higher energies than originally shape with 100% contamination. It should be notice that the divergence between cross section of ${}^{237}_{92}U(n,f)$ and ${}^{237}_{93}Np(n,f)$ begins approximately at the threshold energy of ${}^{237}_{93}Np(n,f)$ reaction (E_{thr}=0.4MeV). From this result it can be seen that the discrepancy apparent between the calculated result and the experimental data reported by Youns and Britt [10], Mcnally et al.[7]; Cowen et al.[16]; and Lynn et al.[17], because their result are together in the region from 0.1 to 0.4MeV below the ${}^{237}_{93}Np(n,f)$ threshold energy. Above 5MeV E_n=6.1MeV at 439.7mb the recommended ${}^{237}_{92}U(n,f)$ is diverge toward higher values of cross sections reaching to En=7.1MeV at 943mb with peaked 943mb at E_n=7.1MeV. This divergence between the recommended ${}^{237}_{92}U(n,f)$ and 25% added contamination of recommended cross section of ${}^{237}_{93}Np(n,f)$ reaction. Above 10MeV E_n=13.35MeV at 1084.3mb another divergence is observed for recommended cross section ${}^{237}_{92}U(n,f)$ towards higher values of cross sections reaching to E_n=17.5MeV at 1957mb with a peaked 1957mb at E_n=17.5MeV, but this divergence in this region is with the 50% added contamination of recommended cross section of ${}^{237}_{93}Np(n,f)$ reaction.

The calculated results for 75% added contamination of ${}^{237}_{93}Np(n,f)$ above 1.0MeV up to 13.35MeV a convergence is observed with the recommended cross section of ${}^{237}_{92}U(n,f)$. All measurement results were reported from an exponentially decaying electromagnetic pules and from the ingrowth of ${}^{237}_{93}Np$ which is the daughter of 6.8day ${}^{237}_{92}U$ decay. The measurement were preformed for steady state irradiation and done over a 30 day period to permit ingrowth of ${}^{237}_{93}Np$ from the beta decay of ${}^{237}_{93}Np$ [10].

4. $\sigma_{ave}Recom{}^{237}_{92}U(n,f)/\sigma_{ave}Recom{}^{235}_{92}U(n,f)$

The recommended ${}^{235}_{92}U(n,f)$ cross section has been calculated, otherwise to calculate the $\sigma_{ave}Recom{}^{237}_{92}U(n,f)/\sigma_{ave}Recom{}^{235}_{92}U(n,f)$ ratio. Figure (3)shows the measured data from EXFOR library for the cross sections of ${}^{235}_{92}U(n,f)$reaction reported by Iwasaki T. et al. (1988) [18], Johnson R.G. et al. (1988)[19], Carlson A.D. et al.(1991)[20], Merla K.et al.(1991)[21], Nolte R. et al.(2007)[22],and Hughes R.O. et al.(2012) [23],have been plotted, interpolated, and recalculated in fine steps of

0.001MeV from 10.47E-3MeV up to 1.99E+2MeV for an incident neutron by using recom.m program, as shown in figure (3).

Then by comparing the assembly data by averaging the cross section for ${}^{237}_{92}U(n,f)$ and doing the same with the cross section of ${}^{235}_{92}U(n,f)$. The calculated results for this ratio is ${}^{237}_{92}U(n,f)/{}^{235}_{92}U(n,f)$ =0.6971. this ratio had been measured by Mcnally et al. and the value obtained for this ratio was 0.62 which is in reasonable agreement with the present calculation.

5. Spin Effect

In calculation of the binding energy the spin effect term is given by[24]:

$$\text{spin effect} = \pm a_5/A^{3/4} \quad ......(1)$$

Where a_5 is constant equal to 34MeV and sign is
+ve for even-even nuclei
-ve for odd-odd nuclei
And Zero for even-odd and odd-even nuclei.

The critical energy for fission (CEF) is given by [25]:

$$\text{CEF} \propto A^{\frac{2}{3}}\left(5.2 - \frac{0.117Z^2}{A}\right) \quad .....(2)$$

$$\text{The deformation energy} = \beta^2\left(5.2A^{\frac{2}{3}} - \frac{0.117Z^2}{A^{\frac{1}{3}}}\right) \quad ......(3)$$

Where β is the deformation parameter.

The first time in the parentheses is the change in the surface tension and the second term is the change in the electrostatic repulsion energy. When the deformation energy is zero or negative, the spherical nucleus will be deformed, and then undergo fission spontaneously. Therefore, the condition for spontaneous fission is as follows:

$$\frac{0.117Z^2}{A^{\frac{1}{3}}} > 5.2A^{\frac{2}{3}}$$

i.e.

$$\frac{Z^2}{A^{\frac{1}{3}}} > 44.5$$

Approximatly the maximum atomic number for stability against fission is about 105 with expected mass number exceeding 250. For even–even nucleus type, the nucleus is exceptional stable, and when they are both odd, the nucleus is particularly unstable. This may be attributed to the stability effect of the pairing of nucleon spins[25]. Therefore, the plus sign applies for U-238(Z=92, N=146) while the minus sign is for Np-238(Z=93, N=145). For even-odd or odd-even nuclei, i.e. U-237(Z=92,N=145) and Np-237(Z=93, N=144) the spin is zero respectively. The compound nucleus formation for U-237 and Np-237 is given by:

$${}^{237}_{92}U + n \rightarrow [{}^{238}_{92}U]^*$$

even-odd even-even

$${}^{237}_{93}Np + n \rightarrow [{}^{238}_{93}Np]^*$$

odd-even odd-odd

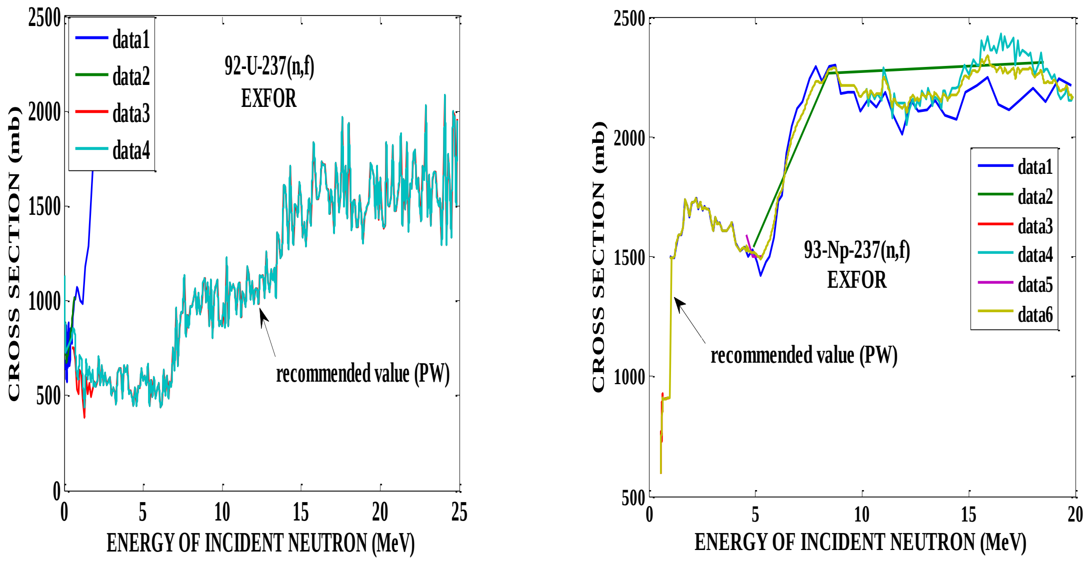
To determine the excitation energy of the compound nucleus in the case of U-237 as a target nucleus. The total binding energy of this nucleus has been calculated. The corresponding quantity is determined for the compound nucleus formed by adding a neutron, that is, U-238. The difference between these two binding energies represents the excitation energy of the compound nucleus U-238 when a thermal neutron is taken up by a Uranium-237 which is calculated to be B.E.(U-238)- B.E.(U-237)= 6.1535MeV. The calculated deformation energy of U-237 is=1.8195MeV. Since the experiments show that the minimum neutron energy is about 1.1MeV[25]. The discrepancy between calculated and experimental energies is due to the inexact nature of the calculation. The calculation of binding energies show, with no doubt, the cause of the discrepancy. It is due to entirely to the effect of the spin effect term. Since the compound nucleus U-238 is even-even, this term makes a positive contribution of about 60MeV to the binding energy, while it is zero in U-237 which is even-odd nucleus. In the case of Np-237, the situation is the same. The compound Np-238 is odd-odd nucleus and the spin effect is -60 MeV with a negative sign, but the target Np-237 is odd-even nucleus and the spin is zero. This effect is responsible for addition of 0.0MeV in the excitation energies of the compound nuclei formed by U-237 and Np-237. In general for even-odd nucleus U-237 the compound nucleus formed by absorption of thermal neutron will be even-even U-238. With relatively large amount of excitation energy of the compound nucleus. Providing Z^2/A for a target is sufficiently high. Hence, such a neutron will be able to induce fission. This consideration will be similar to that for odd-odd Np-238 nucleus. Therefore, for fission to be possible it would necessary employ neutron of high energy. Upon repeating the calculations for Np-237 and the corresponding compound nucleus, the excitation energy of the compound nucleus Np-238 is calculated to be B.E.(Np-238)- B.E.(Np-237)= 5.4875MeV. The calculation deformation energy of Np-237 is 1.6561MeV. Therefor the incident neutron would need to have at least MeV. Since the experimental show that the minimum neutron energy is about 1.1MeV[25]. The discrepancy between the calculated and experimental energies is due to the inexact nature of the calculations. The calculation of binding energies show, with no doubt, the cause of the discrepancy. It is due to entirely to the effect of the spin effect term. Since the compound nucleus Np-238 is odd-odd, this term makes a positive contribution of about 60MeV to the binding energy, while it is zero in U-237 which is even-odd nucleus.

6. Neutron Flux

Figure (4) shows the calculated relative neutron flux of ${}^{237}_{92}U(n,f)$ and ${}^{237}_{93}Np(n,f)$ reactions. The flux φ=nv where n is the neutron density which represent the number of neutron/cm^3 of the beam, and v is the velocity of incident neutron in cm/sec. assuming the number of induced neutron is 1E+6, 2E+6, 3E+6 per cm^3 then the flux could be calculated as a function of the energy of incident neutron. The behavior of flux for Np-237 and U-237 neutron fission cross section, shown in figure (4), increase with increasing energy and there are much higher when the neutrons density increase with very good agreement.

7. Conclusions

In this work the contamination of Np-237 (n,f) cross sections is observed in our calculation with different percentage and it is comparable with Younes W. and Britt H.C.(2003)[10]. Also the average ratio of (n,f) cross sections of U-237 relative to U-235 fission cross sections our results show an agreement with Mcnally et al.. It is obviously that the effect of spin orbit have a contribution in our calculations. The neutron flux of U-237 fission reaction and Np-237 fission reaction is depending on the velocity of incident neutron and the neutron density.



Figure(1):Left side:The recommended cross section of the $^{237}_{92}U(n,f)$reaction as calculated by the present work compared with EXFOR library. Right side: The recommended cross section of the $^{237}_{93}Np(n,f)$ reaction as calculated by the present work compared with EXFOR library.

For left side:

Data1:[7]Mcnally J.W. et al.(1974). **Data2:[8] Caner M. et al.(1976).**

Data3:[9] Burke J.T. et al.(2006). **Data4:Present work (PW).**

For right side:

Data1:[11] Lisowski P.W. et al.(1988). **Data2:[12] Merla K. et al.(1991).**

Data3:[13] Cennini P. et al.(2004). **Data4:[14] Basunia M.S. et**

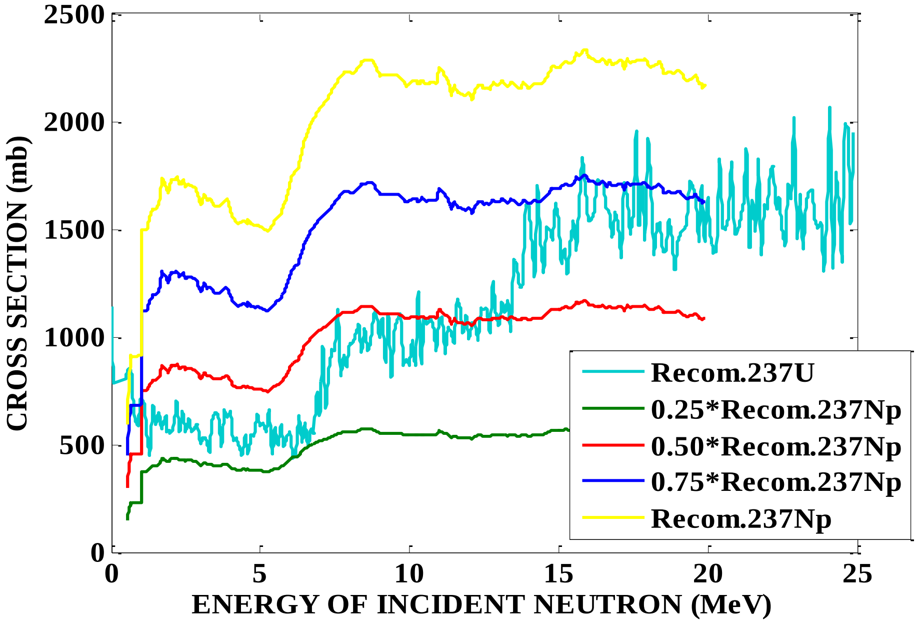
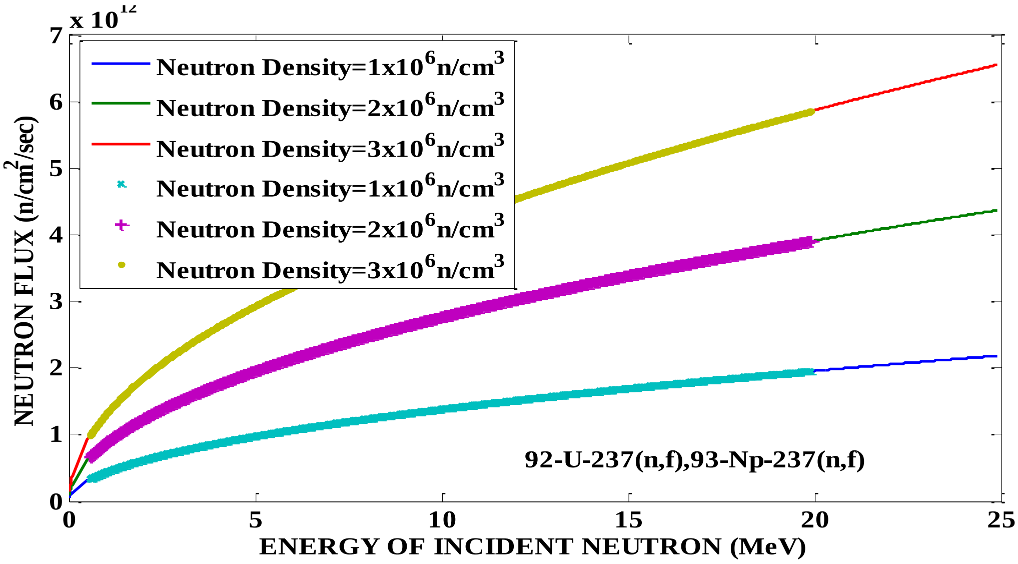


Figure (4) shows the calculated relative neutron flux of $^{237}_{92}U(n,f)$ and $^{237}_{93}Np(n,f)$ reactions.



Figure(5): shows the calculated relative neutron flux of $^{237}_{92}U(n,f)$ and $^{237}_{93}Np(n,f)$ reactions.

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المقطع العرضي للانشطار المستحث بالنيوترون ل U-237 وNp-237

مستخلص البحث:

استندت النتائج النظرية إلى البيانات التجريبية الحالية المنشورة في مكتبة EXFOR في الوكالة الدولية للطاقة الذرية (IAEA) الموصوفة بالتفصيل للمقاطع العرضية للانشطار الحراري الناجم عن النيوترونات مع خطأها بطريقة منهجية من U-237 و Np-237. تمت مراجعة هذه البيانات وتحليلها. تقدير المقاطع العرضية المرجحة لطيف الانشطار الناجم عن النيوترونات هو أخطاء كل منها للبيانات المتاحة التي تم تشكيلها مسبقا باستخدام Matlab-8.0 عن طريق تثبيت برنامج recom.m. كان هدف المؤلفين من هذا العمل هو محاولة إجراء تقييم إحصائي شامل للمقاطع العرضية للانشطار النيوتروني الحراري الموصى بها ل U-237 و Np-237 في نطاق الطاقة بين حد العتبة لكل منهما حتى MeV24.9 ل U-237 وحتى MeV19.9 ل Np-237. الغرض من هذا العمل هو الجمع بين المقاطع العرضية الموصى بها مع المقاطع العرضية الموصى $^{237}_{92}U(n,f)$ بها (n,f) للتلوث Np-237 وهي ابنة U-237. تمت إضافة مساهمة التلوث بعامل النمو 25٪ ، 50٪ ، 75٪ ، 100٪ من التفاعل $^{237}_{93}Np(n,f)$. تم حساب متوسط المقطع العرضي (n,f)الموصى به U-237 و U-235 القيمة التي تم الحصول عليها للنسبة

$\sigma_{ave} Recom\, ^{237}_{92}U(n,f)/\sigma_{ave} Recom\, ^{235}_{92}U(n,f)$ هو 0.6971 وهو اتفاق مع القيمة 0.62 التي حصل عليها McNally et al.. تمت مناقشة مصطلح تأثير الدوران في حسابات طاقة الربط. التدفق النيوتروني النسبي ل U-237 يمكن مقارنته بتدفق المقاطع العرضية للانشطار النيوتروني Np-237.

ملاحظة: البحث مستل من رسالة الماجستير للباحث الثاني.