EXOTIC HIGH NEUTRON MULTIPLICITY MODES IN ^{252}Cf(sf)

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Abstract. The structures presumably linked with collinear multicluster decay (CMD) of ^{252}Cf nucleus become visible in the mass-mass distribution of fission fragments gated by neutrons detected in coincidence. A reliability of the structures observed was estimated using Hough transformation. Analysis shows that CMD mode in question manifests itself as isotropic source of multiplicity ~ 4. Alternative treating is also possible that moving source of multiplicity 9 is decisive for the effect. Another exotic "collimated" neutron source is discussed as well.

INTRODUCTION

Some years ago in the frame of the program of studying of a new type of nuclear transformation called by us as collinear cluster tripartition (CCT) or more precisely collinear multicluster decay (CMD) bearing in mind our recent results obtained in this field [1], the experiment was performed aimed at measuring of neutrons correlated with unusual decay channel [2]. We expected one of the CMD modes to be an isotropic neutron source of high multiplicity. A special designed neutron detector based on ^{3}He counters was used in order to reveal this mode. All in all 140 neutron counters were located as a belt surrounded ^{252}Cf source in orthogonal to the mean fission axis plane (fig.1). Six modules of FOBOS spectrometer in each arm were used for measuring of fission fragments (FF) masses.

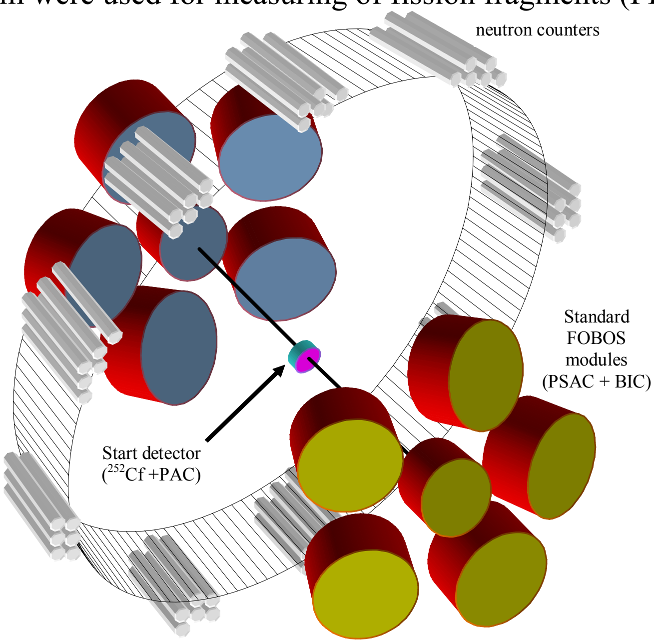


FIGURE 1. Sketch of the experimental setup used for registration of neutrons emitted in the CMD channel in coincidence with fission fragments.

EXPERIMENTAL RESULTS UNDER ANALYSIS

Probability distribution for number of detected neutrons in a time gate started by fission event is shown in fig. 2. The spectrum predicted by the model of the neutron detection channel [2] is shown as well for comparison. As can be referred from the figure the model gives an adequate description of the experimental curve up to number of detected neutrons amounts to five. The yields at higher multiplicities forming a "tail" in the spectrum are underestimated in the model, which accounts only "conventional" neutrons originated likely uniquely from binary fission. Thus some unusual neutron source could give rise to the "tail" observed. We shell try to estimate characteristics of this source below.

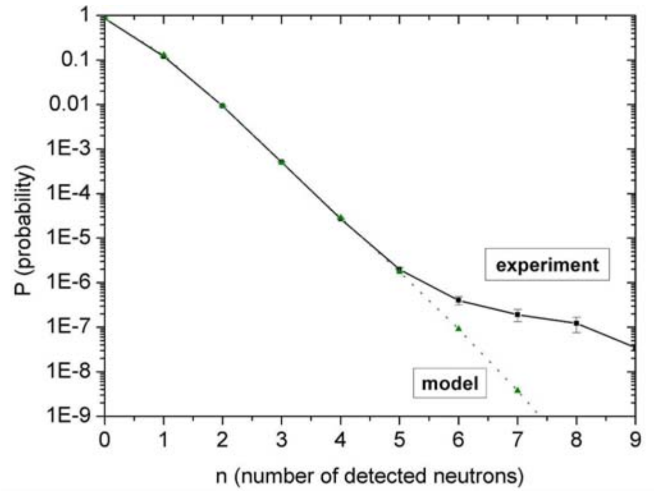


FIGURE 2. Experimental probability of detecting of fixed number of neutrons emitted in a single fission event.

Next interesting feature noted in [3] is connected with the FF mass-mass distributions obtained under condition that fixed numbers of neutrons were detected in selected fission event. Corresponding distribution when two or more neutrons were detected is shown in fig. 3. It seems the points below the "thickening" in the upper part of the figure presented a diffused edge of the locus of conventional binary fission form regular structures consisting of lines to be parallel to the coordinate axes (Ma,Mb=const) or tilted to them at 45^0. Evidently the line tilted at 45^0 reference to abscissa corresponds to the condition Ms=Ma+Mb=const. Perpendicular line (-45^0 reference to abscissa axis) if it goes through the points Ma=Mb makes evident sense. Let us imagine that we deal with ternary nuclear system looks like a chain. If the middle partner of the chain exports equal number of nucleons from its body to two adjacent clusters their masses form the line parallel to the Ma=Mb line in the mass-mass plot. One observes such line if a middle cluster is missed for detection. Using additional selection by the fragments velocities i.e. Va≈Vb we revealed a rectangle bounded by known magic numbers (fig. 3a).

Something similar was obtained while n≥3 (where n is a number of detected neutrons) selection rule was applied (fig. 4).

The yields of unusual points (below the locus of binary fission) forming in fact the structures discussed amount to $1.28*10^{-4}$ and $2.5*10^{-5}$ for distributions in fig. 3 and fig. 4 respectively.

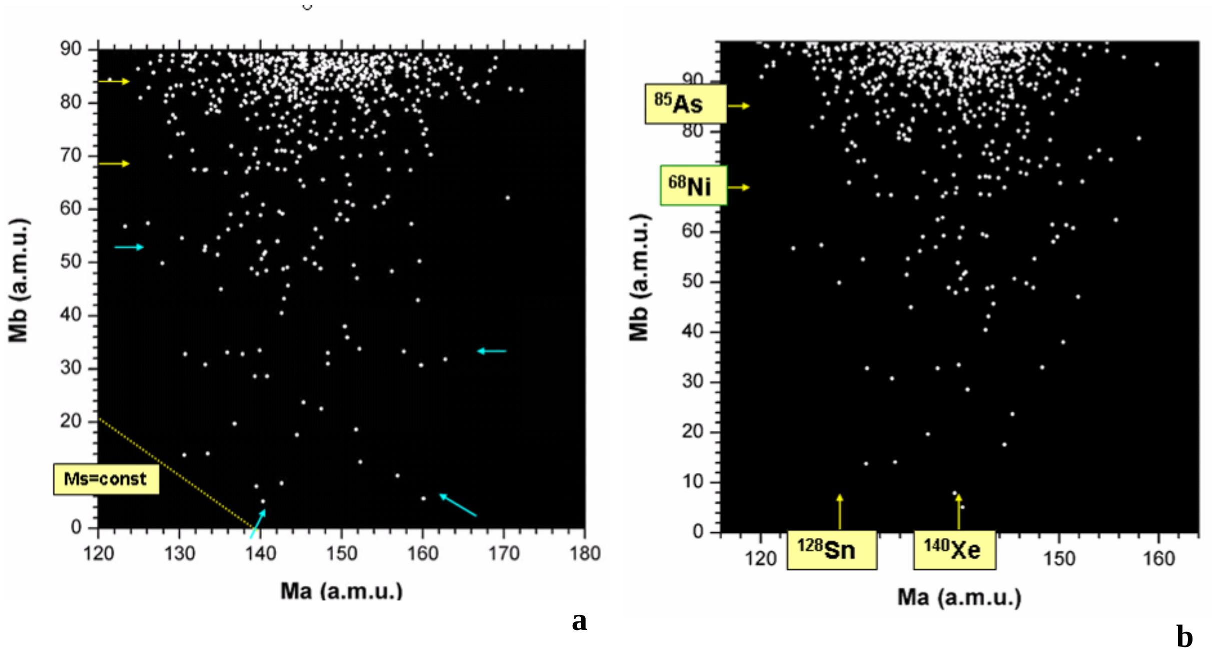


FIGURE 3. Mass-mass distribution of the FF under condition that two or more neutrons were detected in fission event selected (a). The same distribution but only events where Va ≈ Vb are shown (b).

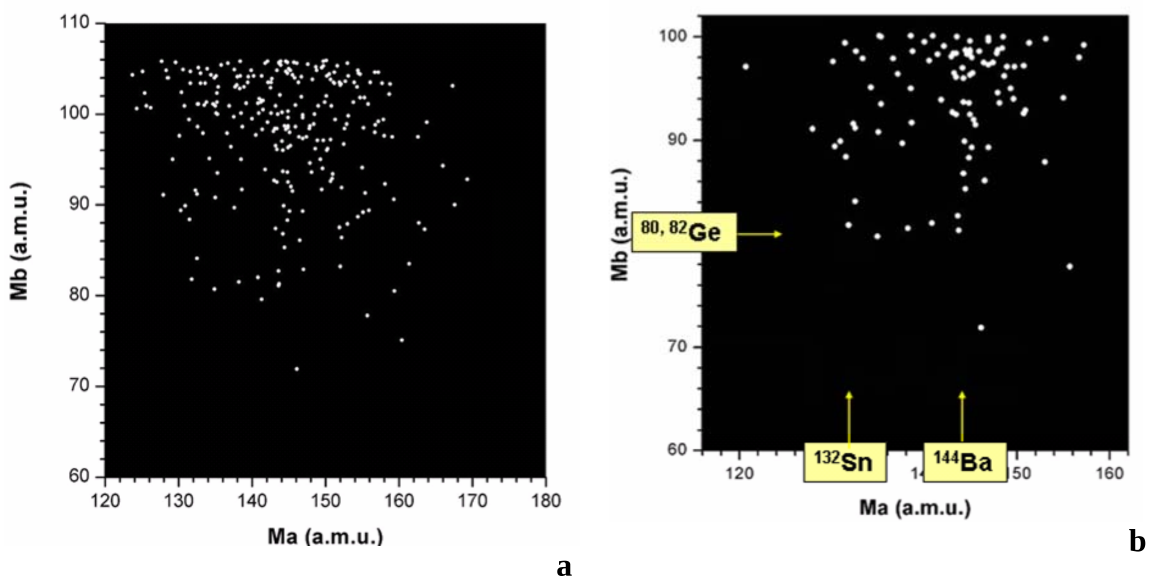


FIGURE 4. Mass-mass distribution of the FF under condition that three or more neutrons ($n \geq 3$) were detected in fission event selected (a). The same distribution but only events where Va ≈ Vb are shown (b).

It should be stressed that the structures seen in figs. 3, 4 manifest themselves clearly only in one spectrometer arm namely in this looking to the baking of the Cf source. Similar effect we have already noted as the "bump" structure in the FF mass-mass distributions originated both from ^{252}Cf (sf) and ^{235}U(n_{th}, f) [4, 5] (fig. 5). Events selection sensitive to the nuclear charge of the fragments let us to suppress substantially a background under the bump (fig. 5b). Internal structure of the bump consists of tilted ridges Ma+Mb=const and these to be parallel to the coordinate axes (i.e. Ma=const, Mb=const) are vividly seen in this case. Just the latter straight lines prove to constitute the rectangles in figs. 3b, 4b.

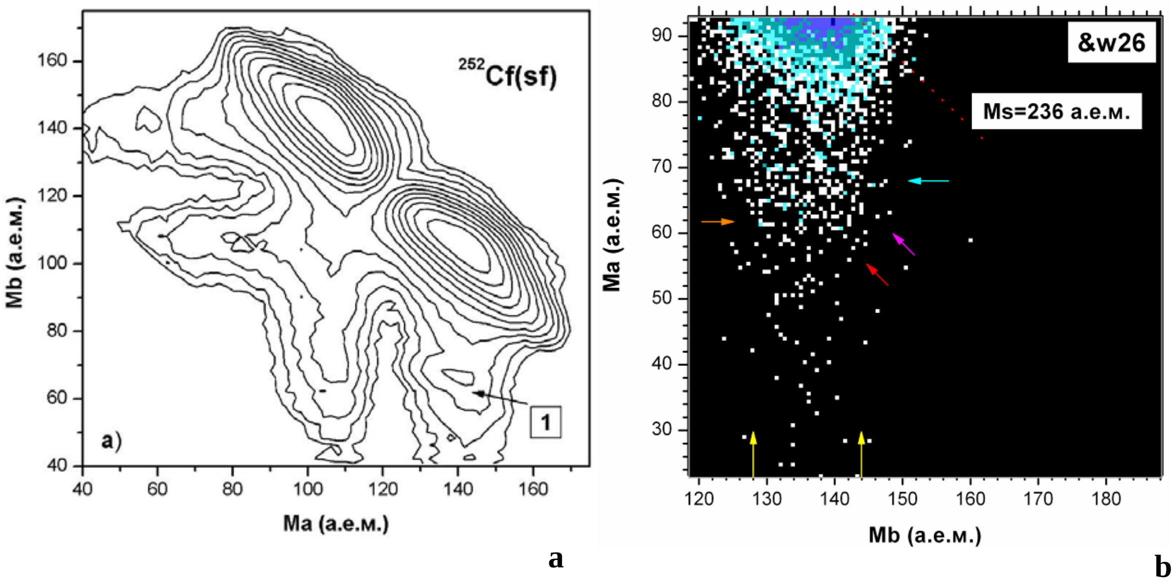


FIGURE 5. "Bump"-structure in the FF mass-mass distribution originated from ^{252}Cf (sf) (a) (bump is marked by the arrow) and ^{235}U(n_{th}, f) (b). In the latter figure arrows point at the internal structures in the bump namely ridges Ma+Mb=const (tilted at 45^0 reference abscissa axis) and Ma, Mb=const.

RELIABILITY OF THE STRUCTURES REVEALED

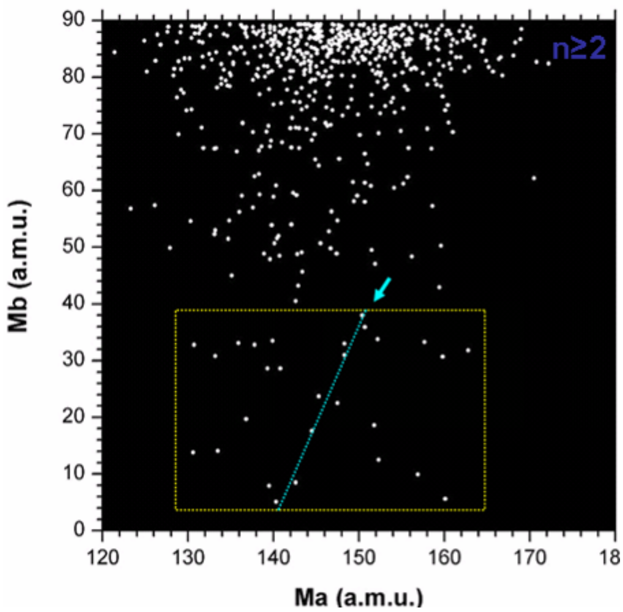


FIGURE 6. Region (rectangle) and image (the line marked by the arrow) chosen for testing a reliability of the structures under analysis. See text for details.

A natural question arises whether the structures at hand really make sense i.e. they are not random sequence of points. In order to answer the question a following simulation was performed. A formal algorithm (Hough transformation [4]) was used for recognition of a line. For instance, inside the rectangle shown in the fig. 6 only one line (marked by the arrow) united nine points was find. Let us estimate a probability of random realization of the line of such length and tilted to the abscissa axis at arbitrary angle. We generated a sequence of random matrices bounded by the rectangle included precisely the same number of points as this in the initial distribution. Each matrix was processed with the Hough algorithm in order to search for the line mentioned above. Among one hundred matrices analyzed only two of them provided positive answer. In other words, a probability of random realization of the line under discussion is about 2%. Absolutely clear that more complicated structure such as rectangle (fig. 3, 4) is much less probable as randomly assembled image.

CMD AS A NEUTRON SOURCE

Let us estimate real neutron multiplicity corresponding to the multibody decays under discussion basing on the model of the neutron registration channel worked out [2]. The modes manifested themselves via decay events where more then two neutrons were detected. An increased number of neutrons (just to remind- corresponding total mean value is substantially less of a unit, see fig.1) could be due to some different reasons. Firstly, it could be binary fission. In this case the structures originate simply from a random grouping of experimental points originated from scattered fragments. As was shown above it is extremely unlikely. Secondly, the structures associate with at least ternary fission. Let us suppose that neutrons are emitted from accelerated fragments moving with the velocities typical for conventional binary fission. Corresponding spectra for some fixed numbers of emitted neutrons are presented in fig. 7. Using the slope of the experimental curve as a criterion one can try to choose the best among the model spectra. The curve looked for corresponds to multiplicity 9.

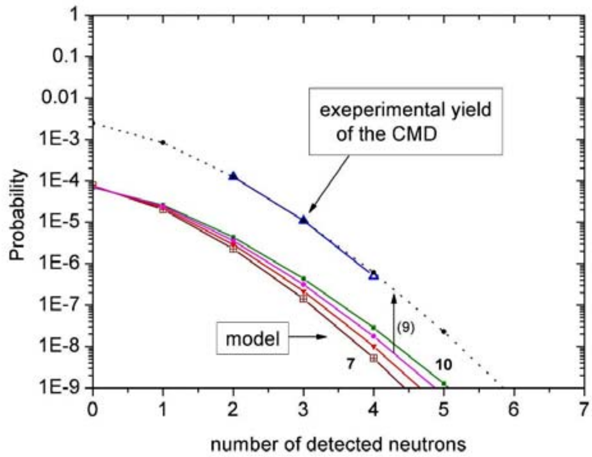


FIGURE 7. Comparison of the neutron yields associated with CMD and model spectra for neutrons emitted from the accelerated fission fragments. Model neutron multiplicities are varied in the range 7÷10neutrons.

Let come to hypothesis that an isotropic neutron source is linked with the structures in question. The results of modeling of such situation are compared with the experimental data in fig. 8. The best agreement is observed for the curve corresponding to four neutrons emitted. Summing up the yields over all this curve one can obtain a total yield of the CMD mode stands behind, namely, $Y{\sim}10^{-3}$/ binary fission being in line with this ($\sim 2{*}10^{-3}$) obtained earlier for the bump in the mass-mass distribution (fig. 5a).

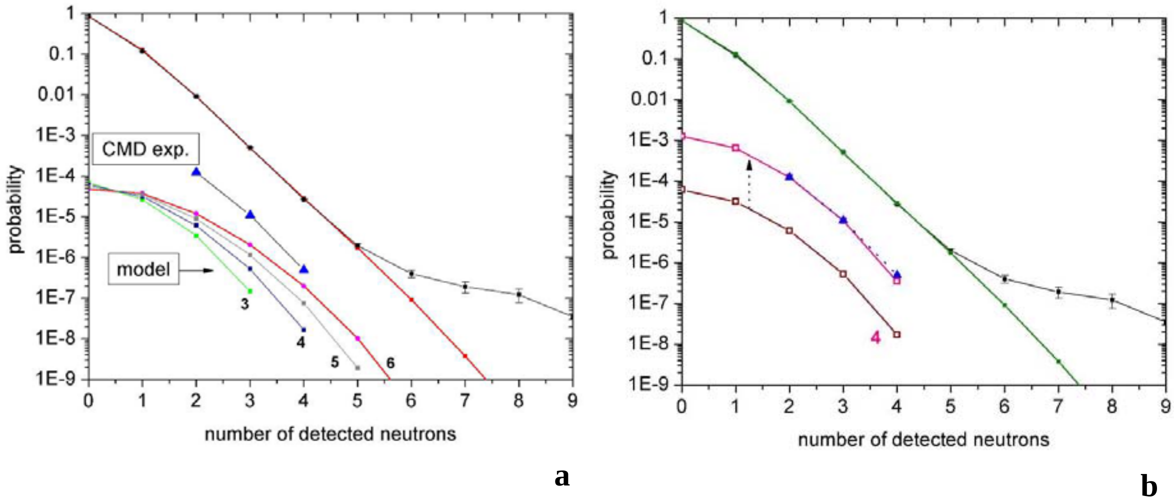


FIGURE 8. Comparison of the CMD mode yields with modeling of the isotropic neutron sources of different multiplicities (marked near curves) (a). Each curve is normalized arbitrary to the total yield 10^{-4}. The model curves provided best agreement with the experiment (b).

Due to the "graphical quality" (clearness) of the structures in fig.3, 4 it is believed a background in the effect region to be less than 20% or in other words we suppose that at the worst only each fifth point in the effect region relates to the background. In its turn the background amounts to scattered fragments of conventional binary fission. Thus according to the assumptions put forward the curve which describes the background should be congruent to the global experimental spectrum P(n) evidently linked with binary fission but shifted to the point 0.2 $P_{eff}(2)$ (the yield of the effect for the abscissa n=2). It is precisely the recipe used to draw the curve marked by the label "background" in fig. 8.

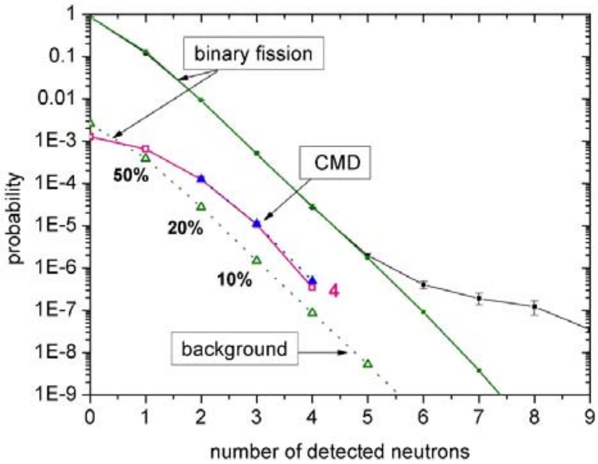
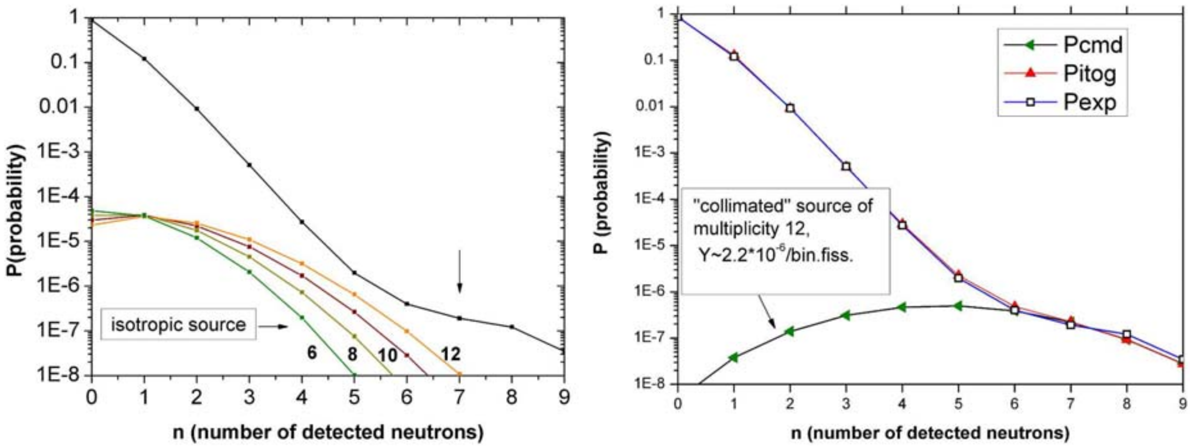


FIGURE 9. Estimation of the background in the region of CMD manifestation.

Having the curve obtained in such a manner we can estimate a contribution of the background in all the range of the detected neutrons. As can be referred from the figure one half of the events when one neutron was detected are due to the background, for three detected neutrons corresponding portion does not exceed 10%. These numbers give an idea why the structures linked with CMD become visible only at increased number of the detected neutrons (n≥2, 3).

EXOTIC NEUTRON SOURCE?



a **b**

FIGURE 10. Fitting of the "tail" (marked by vertical arrow) in the experimental P(n) spectrum. Even isotropic neutron sources of high multiplicity show spectra being too far from the "tail" by the slope (a). "Collimated" neutron source of multiplicity twelve provides the best description of the "tail" (b).

In order to estimate at least roughly parameters of the neutron source delivers the "tail" in the experimental P(n) spectrum (fig. 10) we try as it was done above to fined suitable candidate among isotropic sources of different multiplicities but failed. Really, the spectrum even for multiplicity twelve has absolutely different slope (fig. 10a). The problem is solved if one supposes neutron registration efficiency to be 40% and multiplicity twelve (fig. 10b). It is rather astonishing result bearing in mind that total geometrical efficiency of neutron detectors (neutron belt) is only 19% (but from 4π). In other words the source in question should be collimated in the plane perpendicular to the fission axis. It could be "hot spot" between two fragments right after scission. We are going to verify this exciting conclusion in forthcoming experiment.

ACKNOWLEDGMENTS

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REFERENCES

1. Yu. Pyatkov et al., 6th International Conference on Dynamical Aspects of Nuclear Fission "DANF2006", Smolenice Castle, Slovak Republic, 2-6 October 2006. Conference proceedings, World Scientific Publishing Co. Pte. Ltd., 2008, p. 248-258.
2. D.V. Kamanin et al., Physics of Atomic Nuclei, 66 (2003) 1655.
3. Yu.V. Pyatkov et al., Physics of Atomic Nuclei, 66 (2003) 1631.
4. Yu.V. Pyatkov et al., Romanian Reports in Physics, 59, No. 2, (2007) 569-581.
5. D.V. Kamanin et al., Preprint JINR P15-2007-182, Dubna 2007 (rus).
6. http://homepages.inf.ed.ac.uk/amos/hough.html