E13-2006-19

Yu. S. Tsyganov

A BRIEF REVIEW OF ULTRA-RARE ALPHA DECAY DETECTION TECHNIQUE

Цыганов Ю. С. E13-2006-19
Краткий обзор техники детектирования ультраредких альфа-распадов

Описаны три подхода к измерению редких альфа-распадов в реакциях с тяжелыми ионами. Первый основан на химическом выделении с последующим нанесением активности непосредственно на поверхность детектора, в то время как второй связан с измерением распадов долгоживущих ядер, имплантированных в кремниевый детектор с применением техники электромагнитной сепарации. Третий подход связан с применением детектирования коррелированных пар в режиме реального времени в реакциях с ^{48}Ca с мишенями, такими как ^{242,244}Pu, ^{245,248}Cm, ^{243}Am и ^{249}Cf. Именно благодаря этой методике стало возможным радикальное подавление фона в реакциях полного слияния (3–5n), нацеленных на синтез новых сверхтяжелых элементов с $Z = 113$–118.

Работа выполнена в Лаборатории ядерных реакций им. Г. Н. Флерова ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2006

Tsyganov Yu. S. E13-2006-19
A Brief Review of Ultra-Rare Alpha Decay Detection Technique

Three approaches to the measurement of a rare alpha decaying products produced in heavy-ion induced nuclear reactions are described. One is based on a chemical extraction and following deposition of the nuclides under investigation onto the surface of the detector, whereas the second one is associated with long-lived products implanted into silicon detectors by using the electromagnetic separation technique. The third approach relates with an application of real-time mode detection of correlated energy-time-position recoil-alpha sequences from ^{48}Ca-induced nuclear reactions with actinide targets, like ^{242,244}Pu, ^{245,248}Cm, ^{243}Am, and ^{249}Cf. Namely with this technique it has became possible to provide a radical suppression of backgrounds in the full fusion (3–5n) reactions aimed at the synthesis of superheavy elements with $Z = 113$–118.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2006

INTRODUCTION

One of the fundamental outcomes of the nuclear shell model is the prediction of the existence of the «Island of Stability» in the domain of the superheavy elements (SHE). A considerable increase in nuclear stability was expected for the heaviest neutron-rich nuclei with $N > 170$ in the vicinity of the closed spherical shells, $Z = 114$ (or possibly 120, 122, or 126) and $N = 184$, similar to the effect of the closed shells on the stability of double-magic ^{208}Pb ($Z = 82$ and $N = 126$). Therefore, first recent experiments aimed at the synthesis of the heaviest nuclei involved the complete fusion reactions of long-lived even-Z target nuclei ^{242,244}Pu and ^{248}Cm with ^{48}Ca projectiles leading to the compound nuclei ^{290}114 ($N = 176$), ^{292}114 ($N = 178$) and ^{296}116 ($N = 180$) with the maximum accessible neutron-richness [1, 2]. The isotopes of elements 114 and 116 with $N = 172$–177 produced in these reactions decay primarily through α emission. The decay chains of consecutive α emission are terminated by the spontaneous fission (SF) of descendant even–even or even–odd nuclei with $Z = 112$ or 110. For the neighboring odd-Z elements, especially their odd–odd isotopes, the probability of α decay with respect to spontaneous fission should increase due to the strong hindrance of SF caused by unpaired nucleons. For such nuclei, such as isotopes 113 and 115, one might expect longer consecutive α-decay chains terminated by the SF of relatively high descendant nuclides with $Z \leqslant 105$ [3]. To perform these experiments at FLNR (JINR) the Dubna Gas-Filled Recoil Separator (DGFRS) was used [4]. Namely with this effective facility it has became possible to synthesize 17 isotopes of new chemical elements with atomic numbers 112–118 [5]. Of course, only with high intense beams of ^{48}Ca ions delivered by U400 cyclotron the region of reaction cross section about one picobarn or lower is reachable. From the viewpoint of the detection system design, the main requirement is the real possibility to detect ultrarare decays during long-term experiments, and to discriminate different background events.

1. LOW BACKGROUND MEASUREMENTS OF RARE ALPHA DECAY EVENTS

Measurement of alpha decays after chemical extraction of the products under investigation is of great importance in study of long-lived alpha decaying reaction products. These measurements provide supplementary information in addition to fast on-line electromagnetic recoil separators. In [6] extremely low background level 0.02–0.03 d^{-1} (6–7 MeV interval) is achieved by using differential vacuum pumping of a double measurement chamber. Note, that here the internal chamber was made of teflon to minimize alpha-particle backgrounds, as it contains thorium and uranium in amounts less than 10^{-9} g/g. Another step in minimizing the background was the use of surface-barrier detectors manufactured in the Laboratory that had no long-term contact with various metal-containing media. Holders of the detectors were made of plexiglas for the same reason.

Measurements with low alpha-background are required also if one wishes to estimate the contribution of long-lived background after long-term bombardment (for instance, ^{22}Ne + ^{242}Pu $\rightarrow$ Rf*, beam dose $\sim 3.6e + 18$) employing electromagnetic separator technique [7]. In contrast to the method described above, in this case all the nuclei of interest were implanted into an array of six silicon detectors that was placed at the focal plane of the separator. After the bombardment flange with these detectors was detached from the separator and attached to a separate chamber. The top of each detector was covered with 60-μm teflon foil, through which the external gaseous atmosphere could reach the detector. The chamber was filled with nitrogen evaporated from a Dewar flask. The pressure of the nitrogen was slightly higher than the atmospheric, while the output tube of the chamber was placed into a water vessel; this provided a 30–50 mm H_2O surplus pressure. In Fig. 1 the decay curve of 6.1 MeV line is shown.

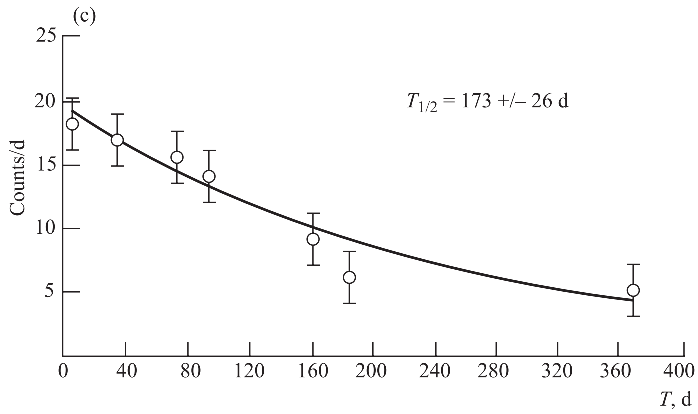

Fig. 1. Decay curve of 6.1 MeV line measured after ^{242}Pu+^{22}Ne $\rightarrow$ Rf* bombardment

2. DETECTION OF GENETICALLY LINKED SEQUENCES

In a long-term experiment aimed at the synthesis of SHE, the observed event is in the best case just a sequence of some signals. Each signal, by itself, cannot be identified even formally in the sense that almost all of them are results of radioactive decays, statistically independent of each other. Therefore, it is very difficult to decide if they originate from the nuclide of interest or just from random background. So, here both the background signals and those genetically linked, are statistically independent and formally undistinguishable. The only way to separate them is given by the difference in time characteristics of their combinations, or, speaking more generally, by the differences of probabilistic characteristics of these combinations. Let us analyze the sequence of a recoil, n alpha particles and spontaneous fission (SF) in the framework of Zlokazov formalism [8]. Let us assume that mth alpha particle is linked with recoil and this chain is used for switching off the beam for a short time (up to minutes). Additional assumption is about the nature of SF background, namely it is assumed that it does not depend on whether the beam is on or off, and mostly originates from the uniform background of previously implanted SF nuclei.

Following the approach of [8], but taking into account four imitator groups (recoil-alpha particles in beam — alpha particles out of beam — SF) one can easily obtain the formula

$$\eta = \frac{C_n^m}{K^{n-m}}. \qquad (1)$$

Her η is the ratio of two probabilities* for data interpretations as a random sequence P_s and P_s^{act}, which correspond to conventional detection mode (no pauses in target irradiation) and real-time (active) detection mode, respectively [9]. Parameter K is the suppression factor for alpha-decay imitator signals, usually of the order of $10^2 - 10^3$, and $C_n^m = \dfrac{n!}{m!(n-m)!}$.

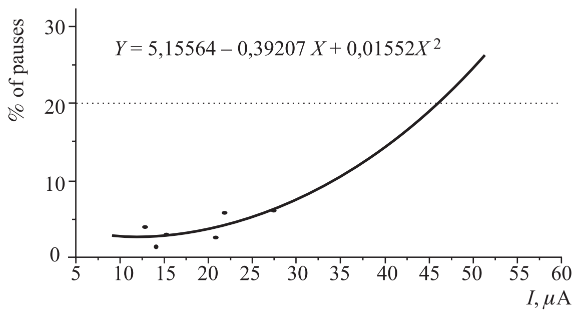

Fig. 2. The dependence of the typical total experimental efficiency loss value against incoming intensity of ^{48}Ca ions. 20 % loss level is shown by the dotted line. Second order (see Ref. [10]) polynomial fit is shown by the solid line. Polynomial second order fit is chosen as to be corresponding to «pessimistic» estimate of the upper level of the beam intensity

---

$^*\eta = \dfrac{P_s^{\text{act}}}{P_s}$.

Note, that the above detection technique, after a certain recoil-alpha sequence is detected the system makes a pause in target irradiation, means minor losses in the total experimental efficiency, of an order of a few percent. In Fig. 2 the value of losses is shown vs. the projectile intensity from cyclotron. This dependence corresponds to 12-strip 4×12-cm^2 PIPS detector used in actual experiments. Position window was taken to be about 1.2 mm, alpha-particle energy interval — 9.9–12.0 MeV and recoil-alpha correlation time — 1 s. Again, the above values are «realistic», corresponding to the experimental ones [2, 4]. Second order polynomial extrapolation gives us a reasonable limit of applicability of the real-time concept. Appropriate values of the recoil registered energies are shown in Fig. 3, a against calculated incoming ones as well as typical distribution according to the strip number measured for ^{252}No recoils (Fig. 3, b).

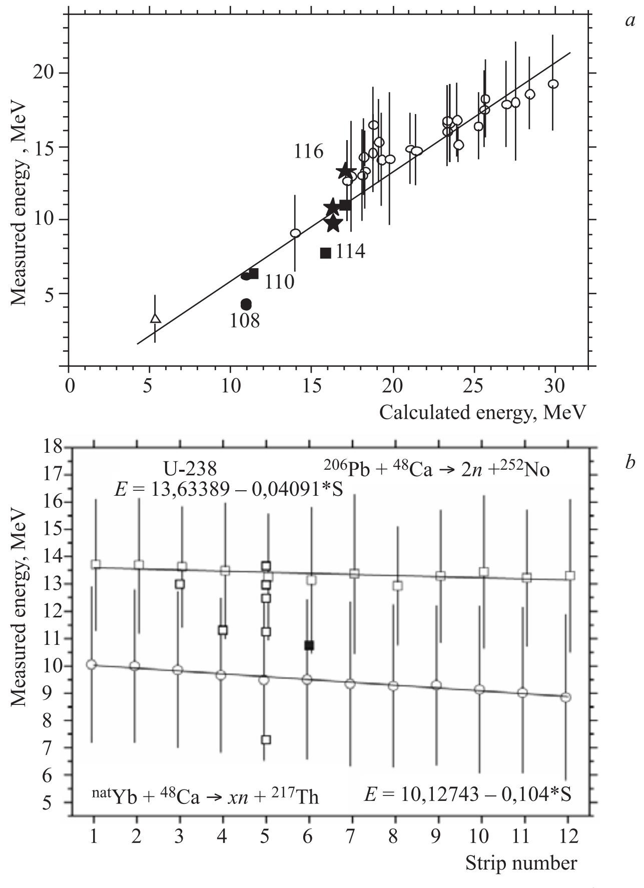

Fig. 3. a) Measured recoli energies are plotted against calculated ones. b) Measured recoil energies against strip number of the DGFRS PIPS detector for two reactions

To demonstrate application of the technique in the Fig. 4 alpha-decay spectrum of SHE is presented.

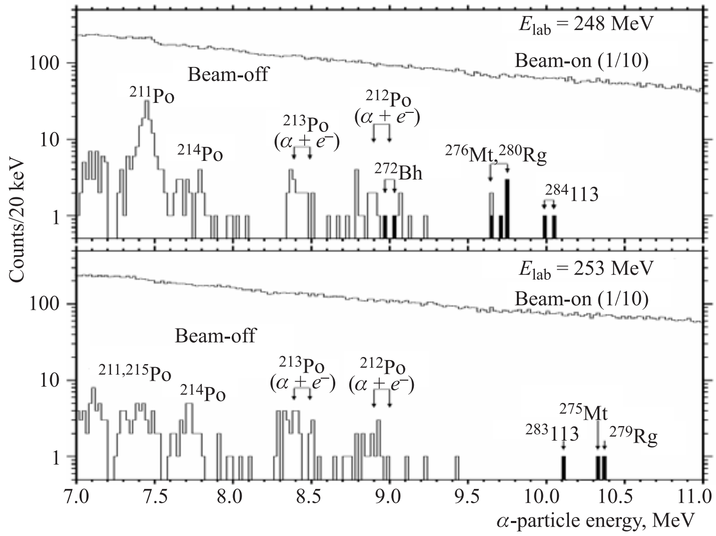

Fig. 4. Spectra of rare alpha decay events measured in ^{243}Am + ^{48}Ca $\rightarrow$ 115 + 3, 4 n experiment [2] at two beam energies (248, 253 MeV). The solid line shows background level — events which imitate alpha decays. Background suppression factor from 9 to 11 MeV region is estimated as $\sim 10^5$

This spectrum demonstrates clearly a possibility of the GFRS detection system to extract single decays from a large array of data obtained from heavy-ion induced nuclear reaction.

SUMMARY

Different on-line and off-line low-background detection techniques together with high intensity accelerators play dominant role in studying of SHE. Namely with these approaches 17 new heavy isotopes were discovered recently. Experiments, aimed at the investigation of chemical properties of SHE (and/or their daughter products) are, in fact, a nice supplement to the physical ones and provide additional base for nuclide identification. It is planned to use real-time detection mode for radical suppression of the backgrounds in the nearest future, with some modifications, using a more general scheme. This would increase the efficiency for multi-chain event detection in a real-time mode compared with the using the recoil-(first) alpha time-energy-position correlation. The scheme is shown in Fig. 5, a, b and Fig. 6 for recoil-α-α-α-α-SF decay (a – common flow-chart of

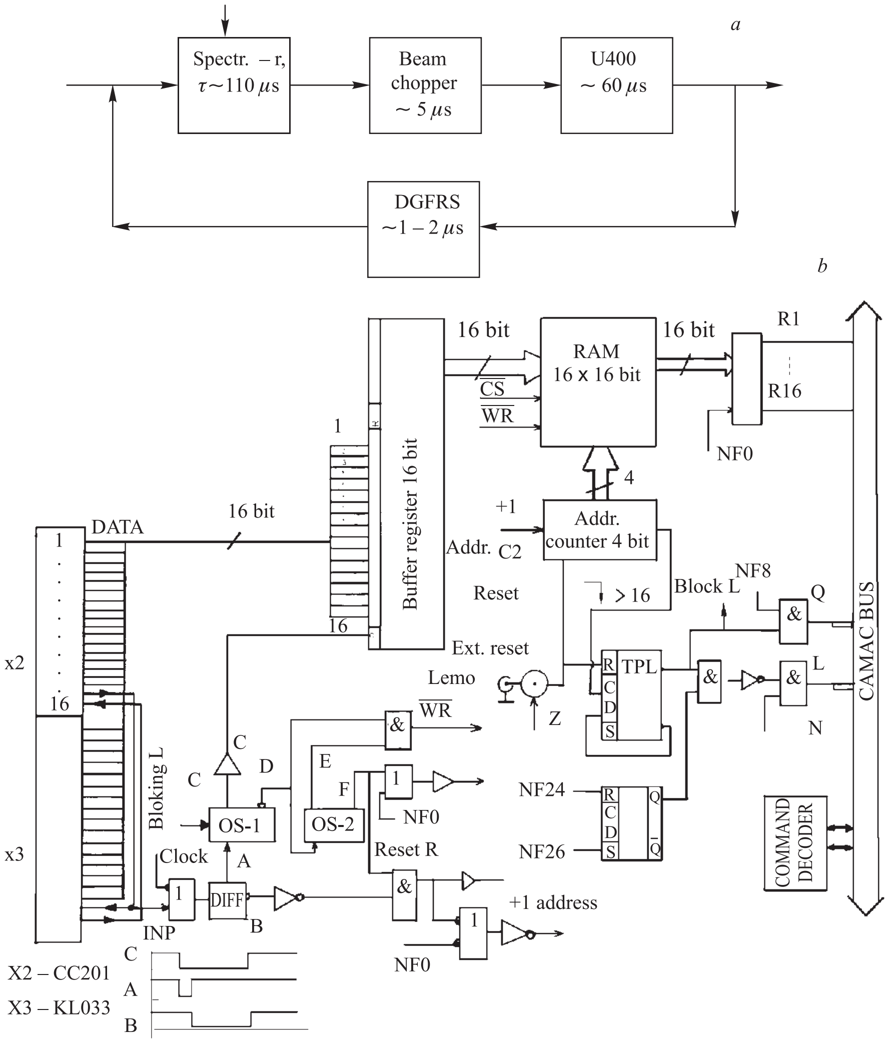

Fig. 5. *a*) The flowchart of the process. Delay times are shown in microseconds. The upper arrow shows a reasonable disturbance factor related with the GFRS spectrometer operation stability. *b*) Scheme of the electronics 16×16 bit CAMAC module operating together with the appropriate code branch, which provides search for recoil-alpha correlated sequences candidate and provides, to some extent, a parallelism in operating with the main from CC202 controller to KL033 buffer memory data writing process

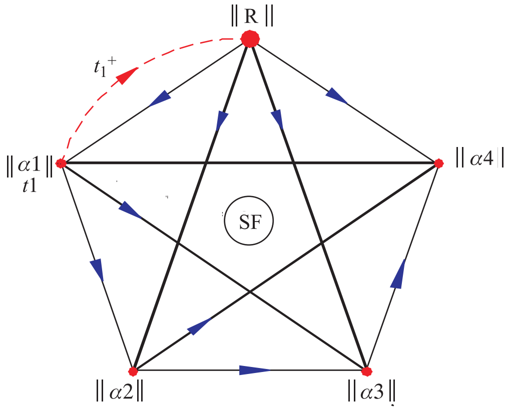

Fig. 6. Scheme of the more complete real-time algorithm to increase the efficiency of detection. Here R — recoil's matrix, α_i — alpha particle matrix (Ref. [9, 10]). Loop t_1^+ denotes writing, in the case of «unsuccess», of elapsed time for first alpha matrix to the recoil matrix cell

the executing process). Here, each link can generate beam pause or replace recoil matrix element by the elapsed time of detected alpha particle. Links with SF event are also shown in Fig. 4, but they are not used to generate pauses. It is reasonable to apply this algorithm especially if the efficiency of recoil detection is far from 100%, for instance, in the highly asymmetric projectile-target combinations (with projectiles like O to Mg.). Additionally, this algorithm can have some advantages in the case if the first alpha particle is detected only by the backward detector and creates no position signal in the focal plane one. As concerning the heavy-ion beam intensity limiting the technique application, the limiting value will definitely be increased, with the upgrade of both the separator and the detection system that is aimed at the decrease of the total background rate.

REFERENCES

1. *Oganessian Yu. Ts. et al.* // Phys. Rev. C. 2000. V. 62. P. 041604.
2. *Oganessian Yu. Ts. et al.* // Phys. Rev. C. 2005. V. 72. P. 034611.
3. *Oganessian Yu. Ts. et al.* // Phys. Rev. C. 2004. V. 69. P. 021601.
4. *Subotic K. et al.* // Nucl. Instr. Meth. Phys. Res. A. 2002. V. 481. P. 71–80.
5. *Dmitriev S. N. et al.* // Mendeleev Comm. 2005. No. 1. P. 1–4.
6. *Kharitonov Yu. P. et al.* // Pribory&Tekhnika Experim. 1987. P. 36–39 (in Russian).

7. *Tsyganov Yu. S., Tomin V. I.* // Appl. Radiat. Isotop. 1998. V. 49, Nos. 1–2. P. 113–115.

8. *Zlokazov V. B.* // Eur. Phys. J. A. 2000. V. 8. P. 81–86.

9. *Tsyganov Yu. S. et al.* // Nucl. Instrum. Meth. Phys. Res. A. 2003. V. 513. P. 413–416; 2004. V. 525. P. 213–215; 2005. V. 558. P. 329–332.

10. *Tsyganov Yu. S.* JINR Communication, P7-2005-117. Dubna, 2005; J. Phys. G. Nucl. Part. Phys. 1999. V. 25. P. 937.

Received on February 13, 2006.

Корректор *Т. Е. Попеко*

Подписано в печать 15.05.2006.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,68. Уч.-изд. л. 0,96. Тираж 305 экз. Заказ № 55332.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@pds.jinr.ru
www.jinr.ru/publish/