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ON THE SEARCH FOR DENSITY ISOMERS AT INTERACTION OF RELATIVISTIC ^{12}C NUCLEI WITH LEAD

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Introduction

This paper deals with the results of experiments on the search for nuclear isomers with a high excitation energy. First of all, we concerned ourselves with density isomers, though these states can be of different nature. According to the pion condensation theory of Migdal et al.[1], superdense nuclei can exist; they can be both stable and metastable against the transition to the normal phase. Implementation of this or that version depends upon parameters of the model, in particular upon the quantity g' which determines the strength of the short range repulsive spin-isospin interaction between nucleons. It follows from presently known estimations of g' [2,3] and from Ref.[4] that it might be more probable to find metastable density isomers. The excitation energy of an isomer of the mass number A is $E^* = \Delta B \cdot A$ where ΔB is the difference of binding energies per nucleon in the normal and isomeric states. The excitation energy range for isomers like that is $0 \leqslant E^* \leqslant B(A)$ where $B(A)$ is the total binding energy of a nucleus of normal density. This energy will be given off at the tunnel transition through the barrier between the superdense and normal phases causing multiple evaporation of nucleons. The probability of the tunnel transition exponentially depends on parameters of the barrier and on the corresponding mass coefficient. Therefore, as in the case of spontaneous fission, one can expect that life-times of density isomers will vary in a wide range.

In this paper we have tried to detect the density isomers by multiple emission of delayed neutrons when lead is irradiated by a ^{12}C-beam of an energy of 15 and 43 GeV. We used a heavy target (Pb) taking into consideration results of Ref. /4/ for the dependence of the binding energy of superdense nuclei on the mass number. The neutron decay channel was chosen since a high efficiency of neutron detectors allows a high sensitivity for the search. Besides, we have taken into account the conclusion of Ref. /5/ that emission of delayed neutrons at the decay of density isomers is the most characteristic manifestation of π^--condensate.

Note that isomeric states of unusually high excitation energy can have another nature. For example, Wong /6/ investigated stability of the toroidal and "bubble" shape of nuclei. It was shown on the basis of the modified shell model that shape isomers may exist and their excitation energy is several tens of MeV. They are separated from the ground state by the potential barrier. A decay of these isomers must also involve emission of several delayed neutrons.

A search for density isomers by neutron activity has already been described in the literature. For example, Ref. /7/ did it for targets irradiated with 70 GeV protons. The activity was measured under low-background conditions with a high sensitivity technique, but it was done more than a year after the end of the irradiation. In our paper /8/ we measured the neutron radiation of the targets bombarded with relativistic ^4He and ^{12}C nuclei, i.e. under more favourable conditions for production of density isomers. The life-time interval from 1 s to 10^4 s was covered. The upper values obtained for the production probability of three-neutron emitters are within the range from $3 \cdot 10^{-6}$ (for Fe + ^{12}C) to $3 \cdot 10^{-5}$ (for Pb + ^{12}C). In this paper the sensitivity of the search for abnormal nuclei has been considerably increased owing to higher efficiency of the detector and better background conditions.

Experimental Technique

The experiments were carried out at the slow extraction channel of the JINR synchrophasotron. The lead target (diameter 45 mm and thickness 10 mm) was irradiated by the ^{12}C-beam of the energy of 15 and 43 GeV. A detailed description of the facility is given in Ref. /9/; here we will just briefly characterise some units of it. The beam intensity was monitored by measuring the secondary particles emitted from the target. For this purpose a telescope of three scintillation detectors placed at an angle 120° to the beam was used. The telescope was calibrated at a lower intensity by means of another telescope of two scintillators placed directly behind the target, the first scintillator being of the same size as the target. The shape and position of the beam were controlled by the double wire chamber placed in front of the target.

The neutron multiplicity detector was installed on the concrete roof of the channel (120 cm) 4 m off the beam line. There is a hole in the channel roof designed for periodically delivering the target to the inside of the detector. The irradiation time was 100 s in each cycle, the measurement time (the target is in the detector) was also 100 s, the time of target movement was ≈ 2 s. The operation mode of the target moving mechanism was set by a special electronic device connected to photodiods monitoring the position of the target.

The neutron detector consists of a moderator (polyethylene) and 35 proportional counters filled with ^{3}He (4 atm) mixed with 1% of CO_2. The counters are placed in three rows around the central cylindrical hole in the moderator. This hole is 130 mm in diameter and 630 mm in length. Each counter has a preamplifier and amplifier with a differential discriminator. Their outputs are connected with a summator. Detection of several neutrons simultaneously produced in the target results in a group of time correlated pulses statistically dispersed in accordance with the distribution of the neutron life-times in the detector. The summator output was attached to a special eletronic circuit /10/ which selected events corresponding to appearance of 1-7 pulses within 100 μs. Registration was carried out by a multiscaling analyser of the CAMAC standard with eight inputs /11/. It was periodically switched on for 100 s as soon as the target appeared inside the detector. Thus, eight time distributions were measured at the same time: for single-neutron counting rate and for events with detection of $\geqslant 2$, $\geqslant 3$, ..., $\geqslant 7$ neutrons. Besides, a "background" time spectrum was also measured when the target was under the beam. The analyser was blocked during the beam dump; it was also blocked when stray pick-up occurred. In the latter case we used an "antenna": a depressurized counter with the same amplifying device as in operating counters.

The correlation interval was chosen to be 100 μs on the basis of measurements of the distribution of neutron life-times in the detector. The measurements were performed for neutrons from spontaneous fission of ^{238}U and for neutrons produced in the detector by cosmic rays. A multiscalar analyser was used; the first pulse from the correlated group of neutron pulses triggered it for 10^{-3} s . The mean life-time of the neutron in the detector was found to be 65 μs. The interval 100 μs embraces 72% of the total probability of detection of each neutron that follows the starting one.

The neutron detection efficiency $\mathcal{E}_1$ was determined by means of a calibrating Po-Be source and a sample of natural uranium. The mean value of $\mathcal{E}_1$ was found to be 40%.

Our paper /9/ provides detailed calculations of the detector response function that relates the distribution of events over the multiplicity (n) of neutrons to the measured distribution over the multiplicity (m) of pulses in the correlation interval. The efficiency of detection of multiple

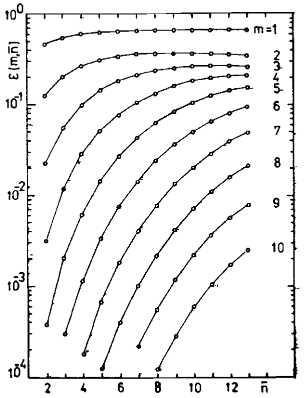

Fig.1. Efficiency for the detection of m neutrons as a function of the mean number of neutrons in the event.

events $\mathcal{E}(m, \bar{n})$ was calculated on the basis of this response function, the Poisson distribution being assumed for the probability of occurrence of the given number of neutrons at the mean equal to $\bar{n}$. It is shown in Fig. 1. To be more exact, the figure shows dependence of the mean number of measured events with the multiplicity m (per initial event) upon the mean number of neutrons $\bar{n}$.

Experimental Results and Discussions

Fig. 2 shows time distributions of events with one, $\geqslant 2$, $\geqslant 3$, $\geqslant 4$ and $\geqslant 5$ neutrons detected. The data were obtained at irradiation of the target with a 15-GeV ^{12}C beam. The total flux of the beam through the target was $1.8 \cdot 10^{11}$ particles, the experiment's duration was about 7 hours. The main contribution to the first spectrum is made by the neutron emitter with $T_{1/2} = (4.12 \pm 0.10)$ s. It is undoubtedly ^{17}N produced owing to the target fragmentation process. The decay of this nucleus involves emission of the delayed neutron with a probability 95%. The constant counting rate at $T > 60$ s is mainly due to background neutrons. In time distributions of events with the multiplicity $m \geq 2$, $\geqslant 3$, $\geqslant 4$, $\geqslant 5$ one also observes a great counting rate in the initial section of the time scale. Here the half-lifes are respectively 2, 3, 4, 5 times less than for ^{17}N. This new "activity" should be attributed to chance coincidences (within 100 μs) of neutrons from ^{17}N. The intensity of chance coincidences becomes negligible at $T > 45$ s, 30 s, 20 s and 16 s for $m \geqslant 2$, $\geqslant 3$, $\geqslant 4$ and $\geqslant 5$ respectively. The number of events behind these time cuts can be explained by the cosmic background specially measured for a long time /9/.

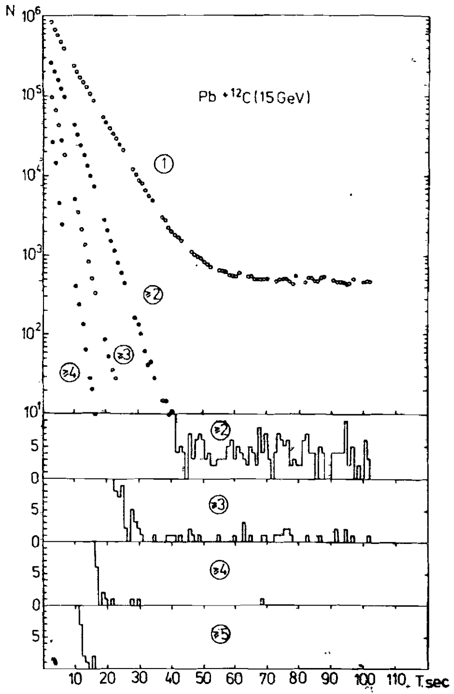

Fig.2. Time distributions of events with detection of one, $\geqslant 2$, $\geqslant 3$, $\geqslant 4$ and $\geqslant 5$ neutrons.

Similar time distributions were also obtained at irradiation of the Pb target by 43 GeV ^{12}C nuclei (the total flux of ^{12}C was $2.7 \cdot 10^{10}$) /12/. In this case the data were supplemented with measurements carried out for 15 hours immediately after switching off the beam (the target was inside the detector).

Thus, we have not found abnormal neutron activity. To determine upper limits of cross sections for reactions leading to production of neutron-active isomers, the values of efficiency for detection of events of multiple emission of neutrons were used (Fig. 1). Besides, a factor was introduced to take into account the dependence of the detection efficiency upon the half-life.

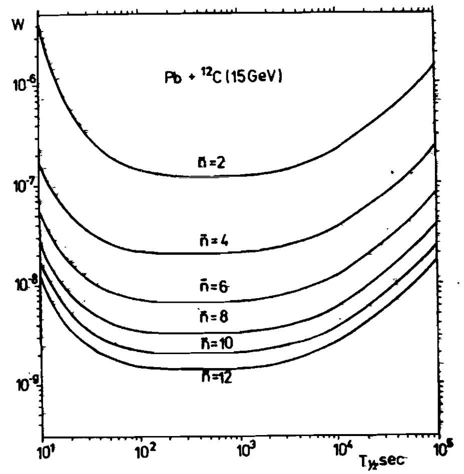

Fig. 3. Upper limits of isomer production probabilities as a function of the supposed half-life for different values of the mean number of neutron emitted (the energy of the ^{12}C beam is 15 GeV).

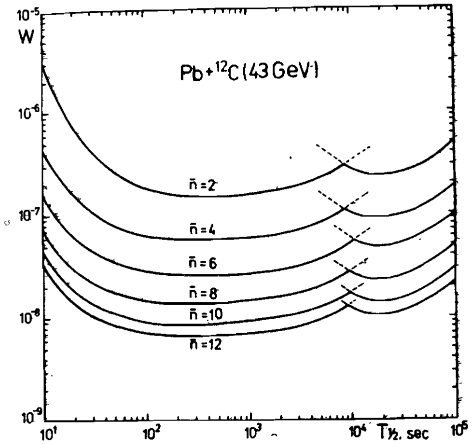

Fig. 4. The same as in Fig. 3, but the ^{12}C beam energy is 43 GeV.

The results are shown in Fig. 3 and 4. The upper limits of the cross section are given in units of the total inelastic cross section for the interaction ^{12}C + Pb ($W = \sigma / \sigma_{in}$) in the function of an assumed half-life for different mean multiplicities of neutrons. The value $3 \cdot 10^{-24}$ cm^2 /13/ was used for σ_{in}. The quantity W gives the upper limit for the production probability of abnormal nuclei in an interaction act. For $\bar{n} = 2$ the data with the pulse multiplicity $m \geqslant 2$ were used, for larger $\bar{n}$ the minimum cross sections are obtained with the data on events with $m \geqslant 4$. The confidence level of estimations in Fig. 3 and 4 is 90%, they were obtained with the calculation technique from Ref. /14/.

To estimate the excitation energy corresponding to emission of the given number of neutrons, we made use of Ref. /15/ where the mean multiplicities of evaporated neutrons had been calculated for nuclei with different A and Z at excitation energies up to 1000 MeV. When relativistic particles interact with nuclei, any isotope lighter than the target can be a final product. The maxima of yields in isotopic distributions of spallation products are in the region of neutron-deficient nuclei. On the other hand, the most stable nuclei with the π -condensate are also neutron-deficient/1,16/. Taking all this into consideration, we have made a table showing for example excitation energies of ^{180}Os and ^{109}In corresponding to emission of different number of neutrons. These nuclei are possible interaction products for which $Z = Z_A + 3$ and $Z = Z_A + 2$ respectively, where Z_A is the value of Z corresponding to β -stability at the given mass number A.

Table 1. Excitation energies (in MeV) corresponding to emission of the given mean number of neutrons $\bar{n}$.

$\bar{n}$	2	4	6	8	10	12
E* (A = 180)	30	60	90	140	200	270
E* (A = 109)	40	90	175	300	500	

Emission of neutrons from isomers of high excitation energy is not the only decay channel: emission of charged particles is also possible. Moreover, emission of protons is more probable for the neutron-deficient nuclei with $Z < 50$. The search for abnormal isomers by multiple emission of delayed protons in the reaction Pb+ ^{16}O (16 GeV) was carried out in Ref. /17/. This paper embraced a wider range of life-times (from 10^{-7} to 10^{5} s). Comparison of our data with Ref. /17/ shows that our limits of isomer production probabilities in the overlapping intervals of the life-times and excitation energies are approximately two orders of magnitude lower. This is the result of using a high-efficiency neutron detector.

Briefly, the result of the work is as follows: upper limits of the probability of production of isomers decaying through multiple emission of delayed neutrons (W) have been determined. It has been done for interaction of a ^{12}C beam at energies 15 and 43 GeV with the lead target. In the first case the values of W are in the interval from $1.4\cdot10^{-9}$ (for $\bar{n}$ = 12) to $4\cdot10^{-6}$ (for $\bar{n}$ = 2) for the half-life range 10-10^{5} s. In the other case the sensitivity of the search is a little worse.

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Авдеев С.П. и др. E7-87-580

О поиске изомеров плотности при взаимодействии релятивистских ядер ^{12}C со свинцом

Мишень из Pb облучалась ядрами ^{12}C с энергией 15 и 43 ГэВ. Периодически мишень доставлялась в полость нейтронного детектора множественности, который позволял измерять временные спектры для событий кратной эмиссии задержанных нейтронов. Аномальные нейтронные излучатели не обнаружены. Оценки верхних границ для вероятности их образования сделаны для интервала периодов полураспада от 10 до 10^5 с и различных средних множественностей нейтронов $\bar{n}$. Полученные величины лежат в пределах от $1{,}4\cdot 10^{-9}$ (для $\bar{n} = 12$) до $4\cdot 10^{-6}$ (для $\bar{n} = 2$).

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1987

Avdeyev S.P. et al. E7-87-580

On the Search for Density Isomers at Interaction of Relativistic ^{12}C Nuclei with Lead

A Pb target was bombarded with ^{12}C nuclei of an energy of 15 and 43 GeV. The target was periodically transported to the inside of the neutron multiplicity detector which allowed measuring time distributions for events of multiple emission of delayed neutrons. Abnormal neutron emitters have not been found. Upper limits of probabilities of their production were estimated for the half-life range $10-10^5$ s and for different mean multiplicities of neutrons $\bar{n}$. The values obtained are within the interval from $1.4\cdot 10^{-9}$ (for $\bar{n} = 12$) to $4\cdot 10^{-6}$ (for $\bar{n} = 2$).

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1987