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AN ON-LINE SYSTEM OF IONIZATION CHAMBERS FOR THE OBSERVATION OF SHORT-LIVED FISSIONABLE NUCLEI

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Система ионизации камер для наблюдения короткоживущих делящихся ядер на пучке тяжелых ионов

Описывается сконструированная и испытанная система из шести ионизационных камер для наблюдения короткоживущих спонтанно-делящихся ядер непосредственно на пучке тяжелых ионов. Ионизационные камеры располагались вокруг оси пучка. Составные ядра, выбитые из мишени, тормозились в водороде так, чтобы осколки их деления эффективно регистрировались ионизационными камерами. Эффективность регистрации актов спонтанного деления составляла 60%. Пучок ионов модулировался во времени, и осколки регистрировались в промежутках между сгустками ионов. Камера была испытана на пучке ионов аргона при двух модуляциях пучка. Первая модуляция пучка обеспечивала длительность сгустков ионов 2,5 мс, а промежутки между сгустками составляли 4,5 мс. При второй модуляции пучка длительность сгустков составляла 30 мкс, промежутки между сгустками ионов равнялись 30 мкс. При первой модуляции пучка была выполнена ядерная реакция $^{207}Pb(^{40}Ar, 3n)^{244}Fm$. Сечение реакции, полученное нами, равнялось $(4,7 \pm 0,7) \cdot 10^{-33}$ см^2, что хорошо согласуется с ранее выполненными измерениями. При первой модуляции пучка возможно наблюдение спонтанно делящихся ядер с временем жизни от одной десятой миллисекунды до нескольких миллисекунд. При второй модуляции возможно наблюдение спонтанно делящихся ядер с временем жизни более 5 мкс.

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Gaeggeler H. et al.

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An On-Line System of Ionization Chambers for the Observation of Short-Lived Fissionable Nuclei

An on-line system of six ionization chambers designed for observing short-lived spontaneously fissioning isotopes has been developed and tested. In the test experiments using an Ar ion beam spontaneous fission fragments from ^{244}Fm have been detected. It has been shown that the performance rate of the system can amount to 5 μs at a beam intensity of 0.16 μA.

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

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INTRODUCTION

Spontaneous fission is one of the principal of radioactive decay of heavy nuclei, and its probability increases sharply with increasing atomic number (see fig. 1)/1/ . In the region of hypothetic superheavy elements the search and synthesis of which are of great interest, most isotopes are also expected to have short lifetimes with respect to spontaneous fission ($T_{1/2} < 10^{-3}$ s). In particular, this concerns those nuclei which can be synthesized by complete fusion reactions in different target-projectile combinations /2/ .

To synthesize and investigate spontaneously fissioning nuclei one has so far used experimental equipment comprizing mechanical devices to transport nuclear reaction products to the detecting systems. In such equipment, solid track detectors are employed to record spontaneous fission fragments. In this case the quantities measured are the number of spontaneous fission tracks and their time distribution. The shortest half-lives measured using mechanical devices lie in the range of 0.25-0.5 ms for the nuclei $^{250}102$, ^{254}Ku /1/ , and ^{258}Fm /4/.

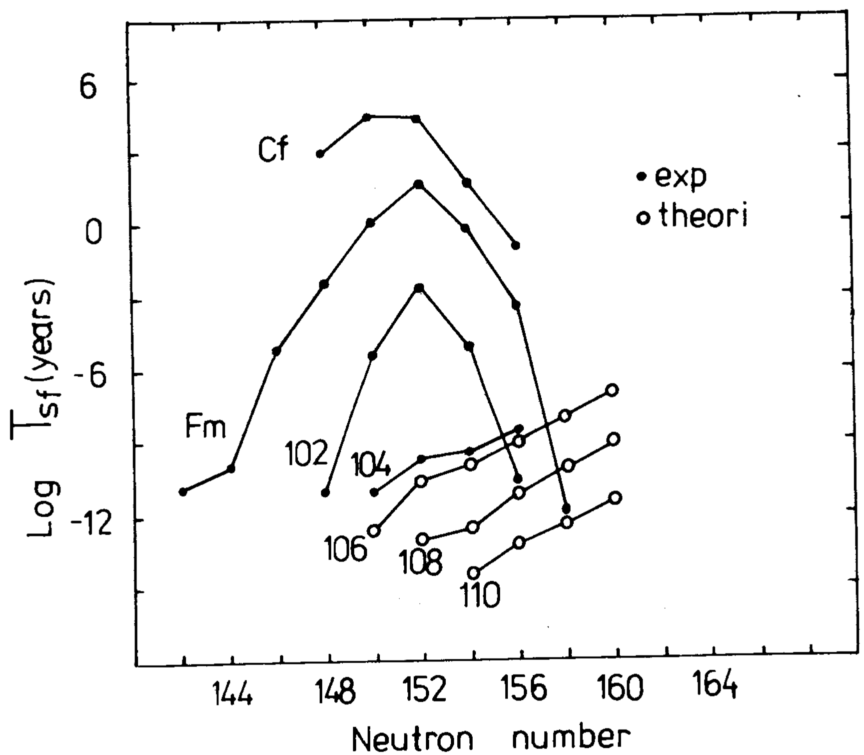

Fig. 1. Systematics of spontaneous fission half-lives for doubly even isotopes of the $Z \geq 100$ elements [1] . (Theoretical predictions for s.f. half-lives for Z = 106, 108 and 110 nuclei are taken from ref. [2]).

An investigation of spontaneously fissioning nuclei having lifetimes considerably shorter than 1 ms requires the development of a new equipment. The present paper deals with a study of a system of ionization chambers operated on-line with a heavy ion beam. In the presence of a time-modulated

ion beam this system is capable of detecting spontaneous fission fragments from reaction products in intervals between successive ion beam bunches. By varying the modulation period one can in principle observe spontaneously fissioning nuclei having half-lives from tens of nanoseconds to several milliseconds.

DESCRIPTION OF THE DEVICE

A schematic view of the device is shown in fig. 2. A heavy ion beam passed through a target (1). The nuclei produced as a result of the complete fusion reaction were knocked out from the target and stopped in the gas available in the central part of the volume restricted by the surface of grids (2,3). The spontaneous fission fragments were recorded using six ionization chambers placed around the beam axis. Balls (4) 8 mm in diameter, fixed on insulators (5), served as collecting electrodes of the ionization chambers. All the collecting electrodes were under a high voltage of about 1000 V.

The grids (2,3) made of 100 μm Nichrome wire formed a truncated cone and separated the volume of the ionization chambers from the space, where the beam passed and recoil nuclei were stopped. The grid transparency was 90%. It was established experimentally that the best operating conditions for the ionization chambers were provided if the grid (2) was grounded, and a negative potential of 1000 V was applied to grid (3). With such potentials on the grids, the

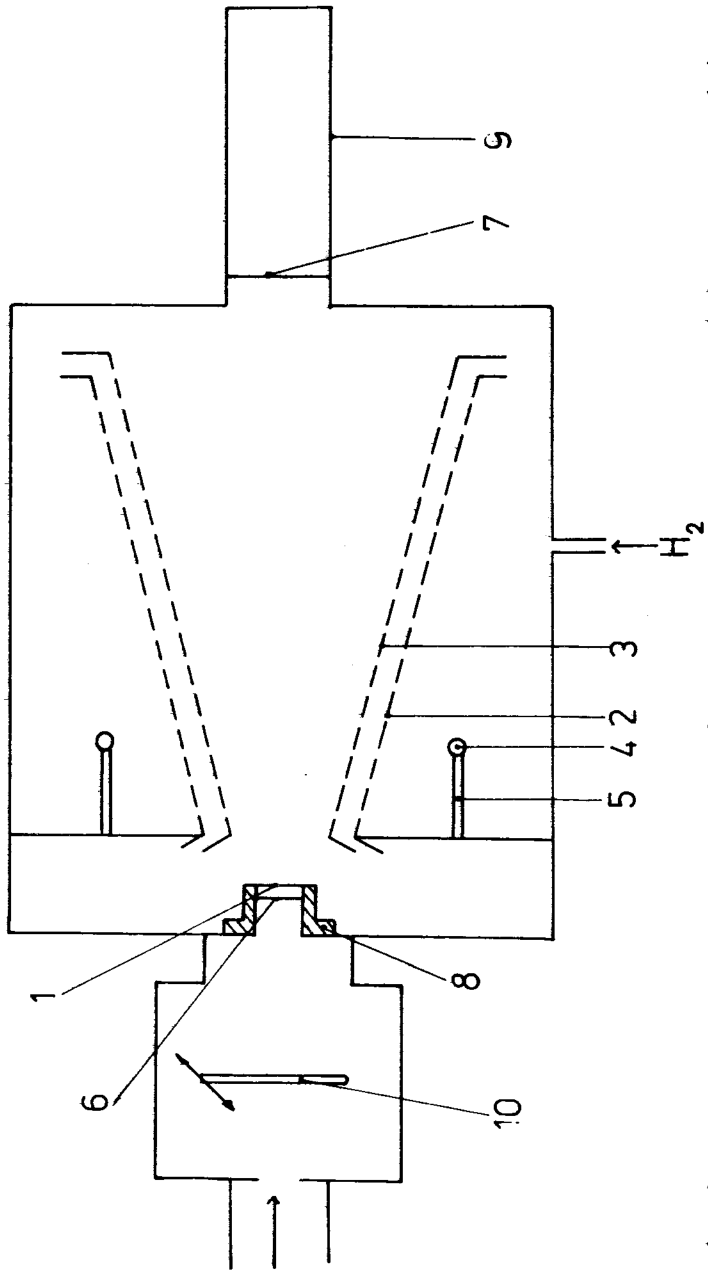

Fig.2. A scheme of the experimental arrangement: (1) target, (2) and (3) grids, (4) collecting electrode, (5) insulator, (6) and (7) vacuum foils, (8) support, (9) Faraday cup, (10) movable rod.

plasma occurring in the gas had a small effect on the performance of the ionization chambers.

The system of ionization chambers was embedded into an aluminium cylinder with an inner diameter of 300 mm and length of 400 mm, filled with hydrogen and separated from the rest of the device parts by vacuum foils (6,7). The entrance vacuum foil (6) and target (1) were fastened in a water-cooled copper support (8). The support transparency with respect to the ion beam was 68%. The hydrogen pressure was chosen in such a way as the compound nuclei emitted from the target might be stopped in the central part of the volume restricted by the grids. The recoil range was determined from the data listed in the tables[5].

A Faraday cup (9) was used to check the beam intensity. The integral particle flux was determined from the yield of the products of the complete fusion reaction on a cadmium target. For this purpose, a cadmium foil was fixed on a movable rod (10) crossing the beam from time to time.

The electronic circuit was designed to separate signals due to spontaneous fission fragments, and determine the time interval between the arrival of these signals and the subsequent bunch. A simplified diagram of the electronics is shown in fig. 3. After amplification and shaping, signals from the six ionization chambers arrived at the inputs of six 512-channel amplitude digital converters (ADC). If the amplitude of any signal corresponded to the signal of the fission fragment, the ADC triggered the time digital converter (TDC). The stop signal

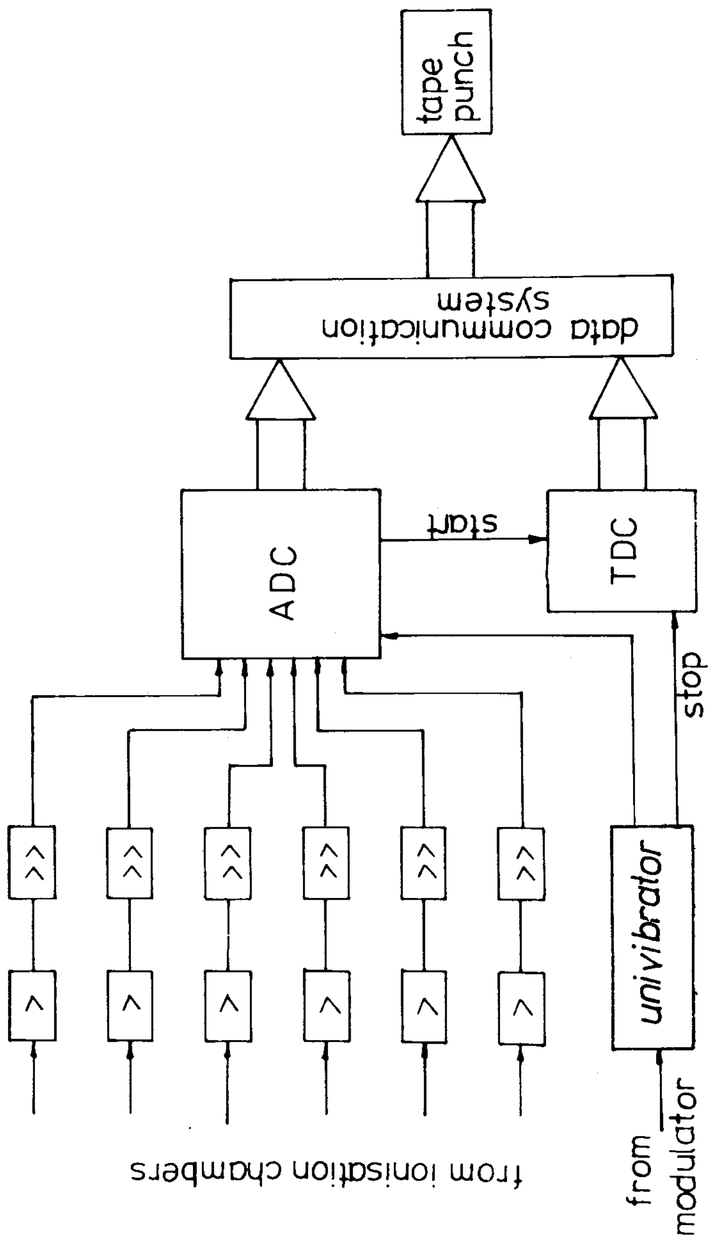

Fig. 3. A diagram of the electronic circuit.

was shaped at the front edge of the bunching pulse. The information about the signal amplitude, the numbers of the ionization chambers sending a start signal and a stop signal were recorded on punch paper tape. Preamplifiers were situated in the vicinity of the ionization chambers in the experimental hall of the cyclotron. The amplifiers gain was variable between 100 and 300. The pulse width was 3 μs. The ADC's could perform in the mode of an independent analysis of signals in each channel and in coincidence between signals of two channels. For the time when the bunch of ions was passing through the system of ionization chambers, the circuit was gated. The gate pulse arrived from a univibrator triggered by the front edge of the pulse arriving from the beam-modulating device.The width of the gate pulse was usually the sum of the width of the ion bunch and the dead time of the amplifying-shaping system. The dead time was conditioned by the passage of the ion bunch through the system and depended on the beam intensity.

RESULTS AND DISCUSSION

To investigate the operation of the ionization chambers and determine its efficiency, calibration measurements on the detection of neutron-induced fission of uranium have been carried out. For this purpose a hollow aluminium cylinder whose surface was coated with a 1 mg/cm^2 layer of ^{238}U was placed in the central part of the volume, where recoils were expected to stop. A neutron source with a total neutron flux of 10^8 n/s was placed inside the cylinder. It was established that the amplitude of signals due to spontaneous fission fragments exceeded by a factor of 10-20 those due to alpha-particles, and the efficiency of the ionization chambers for the detection of fission fragments was 60%.

To determine the probability of recording coincident pulses due to pairs of fission fragments, the system was calibrated using a thin uranium source. A 40 μg/cm ^{235}U layer was deposited onto a 0.5 μm polycarbonate film. The measurements showed that 35% of the total number of the events recorded by the six ionization chambers were coincident ones.

The nuclear reaction $^{207}Pb(^{40}Ar,3n)^{244}Fm$ was used to investigate the performance of the ionization chambers in a heavy ion beam from the U-300 cyclotron of the JINR Laboratory of Nuclear Reactions. The target was prepared by electrodeposition of a 1.4 mg/cm^2 lead layer onto a nickel foil 0.85 mg/cm^2 thick. Under such conditions the argon ion energy in the target was 194-202 MeV, which corresponded to the maximum of the excitation function of the reaction mentioned above.

The detection of the fragments of spontaneous fission of ^{244}Fm was performed under the conditions of the beam modulation provided by the ion source of the U-300 cyclotron. The duration of the ion bunch was 2.5 ms, intervals between the bunches being 4.5 ms. Compound nuclei were stopped in the central part of the volume at a hydrogen pressure of 200 mmHg. At the argon ion current of 0.16 μA the dead time of the amplifying-shaping channels was 100 μs.

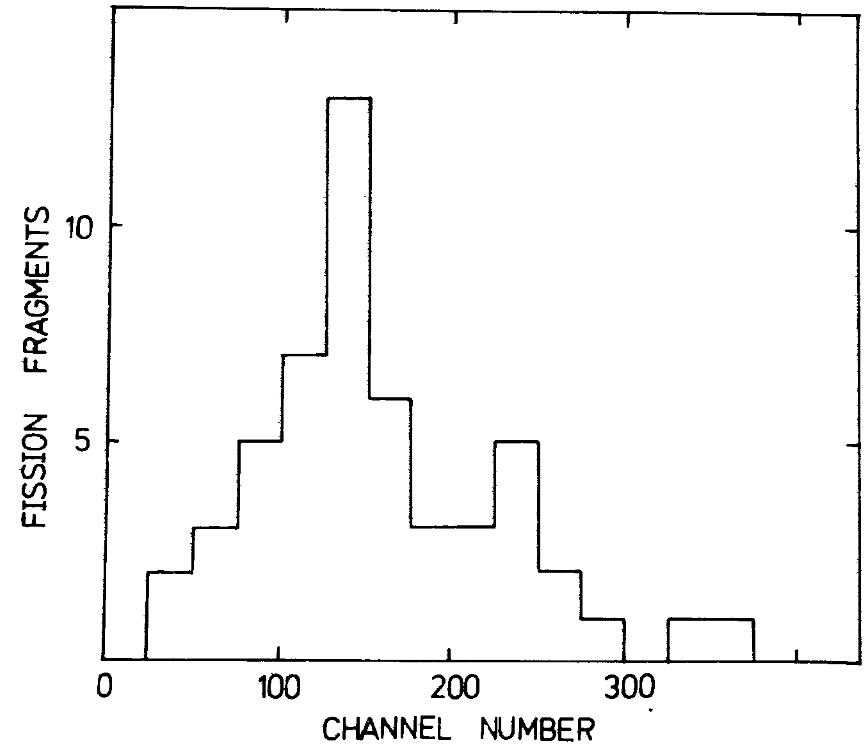

Fig. 4. The pulse-height spectrum of pulses due to spontaneous fission fragments from ^{244}Fm .

Figure 4 shows the pulse-height spectrum of fission fragments from ^{244}Fm , produced during a 30-hour exposure at a total argon ion flux of 2×10^{16} part. The maximum of the spectrum corresponds to an energy release of 60-70 MeV. Only one coincident event has been recorded, which constitutes 1.9% of the total number of the fission fragments detected. The possible reason for such a low efficiency of detecting coincident pulses due to pairs of fission fragments is that because of drifting compound nuclei settle on the charged grid (10) (see fig. 2). In this case only one fission fragment can be observed. The estimation of the drift velocity of these nuclei involved considerable difficulties due to an uncertainty in the magnitude of the electric field in the presence of plasma.

On the basis of this experiment, the cross section for the reaction $^{207}Pb(^{40}Ar,3n)^{244}Fm$ was calculated to be equal to $(4.7 \pm 0.7) \times$ $\times 10^{-33}$ cm^2, this value being in agreement with other data[6].

Thus the experiment carried out permitted the conclusion that the system of ionization chambers performs satisfactorily in a heavy ion beam under the conditions of the beam modulation provided by the ion source of the U-300 cyclotron, and makes it possible to detect spontaneously fissioning nuclei with lifetimes from one tenth of a millisecond to several milliseconds.

The recording of nuclei with shorter half-lives can be provided by using appropriate modulation of the ion beam. We have carried out some preliminary experiments on an argon ion beam with the purpose of investigating the operation of the system at a faster rate of the beam modulation. In these experiments, a mechanical chopper was used made in the form of a rotating disk with apertures. The diameter of the disk was 285 mm and the rate of rotation was 24000 rev/min. Such a chopper divided the beam into bunches with a duration of 30 μs. each and 30 μs intervals. The dead time of the system was 4 μs at a beam intensity of

0.1 μA. This experiment has made it possible to conclude that under the conditions indicated one can detect spontaneously fissioning nuclei with half-lives exceeding 5 μs.

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