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STUDY OF DISINTEGRATION OF MATERIALS IN THE RADIATION FIELD OF THICK LEAD TARGET

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A disintegration of materials was studied by measuring nuclear fragment emission from thick layers of different materials inside and outside thick lead targets irradiated with a beam of protons. A registration of secondary nuclei leaving the layers was performed with lavsan solid-state nuclear track detectors. The results obtained for aluminium, copper, cadmium and lead layers in radiation fields of thick lead targets are discussed. The measurements were carried out with several-GeV proton beam at JINR's Synchrophasotron.

Разрушение материалов изучалось посредством измерения эмиссии ядерных фрагментов из толстых слоев различных материалов внутри и снаружи толстых свинцовых мишеней, облучавшихся пучком протонов. Регистрация вторичных ядер, выходящих из слоев, выполнялась с помощью лавсановых твердотельных трековых детекторов. Обсуждаются результаты, полученные для слоев из алюминия, меди, кадмия и свинца в радиационных полях толстых свинцовых мишеней. Измерения были выполнены на пучке протонов синхрофазотрона ОИЯИ с энергией несколько ГэВ.

INTRODUCTION

Interactions of intermediate-energy protons and other secondary energetic particles with lead nuclei inside thick target cause a fast growth of hadron shower and its enrichment with neutrons. Already in several centimeters away from the axis of the target the hadron field to a large degree consists of neutrons, and thick lead targets represent neutron sources with a small fraction of charged hadrons [1, 2].

A study of disintegration of materials in a radiation field of the extended lead target Ø 20×60 cm irradiated with the proton beam of JINR's Synchrophasotron was carried out as part of the program on (1) application of the method of solid-state nuclear track detectors SSNTD in research on heavy nuclei fission in a neutron field of the lead target and (2) development of the method of neutron threshold detectors for measurement of spatial-energy characteristics of neutron fields at accelerators [1, 3, 4].

In our experiments two lead targets with a diameter of 20 cm and lengths of 20 and 60 cm were used. During an irradiation, the proton beam hit the center of the target along its axis. Lead has an average length of nuclear interaction $\lambda_I \approx 17$ cm for protons, which is close to the dimension of the target Ø 20 × 20 cm. The length of the extended target is about $3.5\lambda_I$; therefore, it is practically the target of full absorption of the beam. Here we discuss results on disintegration of some materials (Al, Cu, Cd and Pb) placed inside the extended lead target, on surfaces of both the targets and in surrounding space.

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1. EXPERIMENT

During irradiations a flux of protons on a target was determined with the help of monitor reaction $^{27}\mathrm{Al}(p,X)^{24}\mathrm{Na}$. The 3-mm aluminum disk of the monitor was placed at a position of ~ 40 cm in front of the target. The cross section of the reaction is 10.0 mb for several-GeV protons with uncertainty of 5% [5, 6]. The flux of protons in different experiments was from 10^{10} up to 10^{14}. The beam profile was ~ 15 mm (FWHM) in horizontal and vertical directions.

The extended target consisted of many lead disks with a diameter of 20 cm and a thickness of 2.5 cm. Some of the disks had 2.5-mm grooves along the diameter of the disks for installation of the T–D–T assemblies (with two layers of material and lavsan detector between them) inside the target. Here we used only the assemblies with Al and Pb layers. In each assembly SSNTD registered the total number of tracks produced by nuclei fragments emitted from surfaces of the layers surrounding the SSNTD.

The measurements of nuclear fragment emission from Al, Cu, Cd and Pb layers were performed for both the targets on target surfaces and at different angles to the beam at a distance of 1 m from the center of the target.

The experimental method of the nuclear fragment registration with 6-μm lavsan film detectors was described in [1, 3, 7].

2. RESULTS OF MEASUREMENTS

Most measurements were carried out with the assemblies Pb–D–Pb for study of target nuclei disintegration and distribution of energetic neutron flux inside and outside the extended lead target. The results of the measurements with 3.65-GeV protons and the assemblies placed inside the target Ø 20×60 cm are shown in Fig. 1. In the figure the curves correspond to different levels of counting rate. Also, indications of the detectors obtained in the measurements are shown. Along the target axis, the number of tracks decreases according to an exponential law of proton beam absorption in lead. At a distance from the target axis, a basic role in disintegration of lead nuclei belongs to high-energy neutrons, mostly in fission reactions at an effective threshold of lead nucleus fission of ~ 90 MeV. Thus, the measured values reflect a distribution of energetic hadrons inside the target.

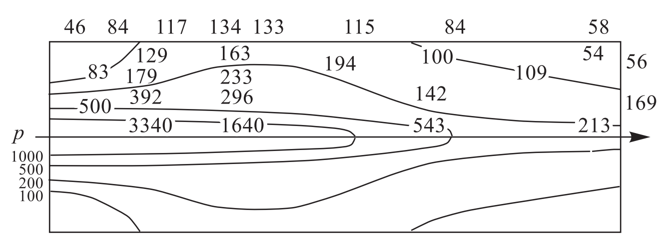

Fig. 1. Distribution of counts of nuclear fragments registered in the assemblies Pb–D–Pb inside the extended lead target irradiated with 3.65-GeV protons. The values correspond to the number of counts per 1 cm^2 and proton flux of 10^{11}. Curves correspond to levels 100, 200, 500 and 1000 counts/cm^2

A distribution of count numbers for the Pb–D–Pb assemblies located on the lateral surface of the target along the axis is shown in Fig. 2. The distribution has a wide maximum at a distance from front surface $Z \sim 20$ cm.

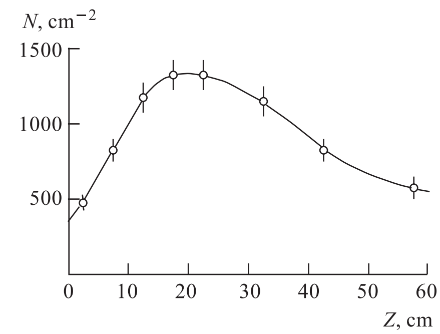

Fig. 2. Distribution of counts of nuclear fragments registered in the Pb–D–Pb assemblies on the lateral surface of the extended lead target (along the axis) irradiated with 3.65-GeV protons with total flux of 10^{12}: points — experimental data; curve — result of fitting

At a proton energy of 3.65 GeV the high-energy neutrons are effectively emitted from the whole lateral surface of the target. The ratio of counts in a maximum and edges at $Z = 0$ and 60 cm is ~ 2.6.

For the assemblies with aluminum layers placed inside the extended target, two different distributions of counts are shown in Fig. 3: (*a*) for $Z = 20$ and 50 cm as a function of distance R from the axis of the target and (*b*) for $R = 3$ and 7 cm as a function of distance Z from the front surface. The distributions on R fall down fast with a distance from the axis. However, with growth of Z this dependence becomes not so strong. For the distributions on Z the number of registered nuclear fragments in the assemblies grows up to a maximum value with increasing Z and then smoothly decreases.

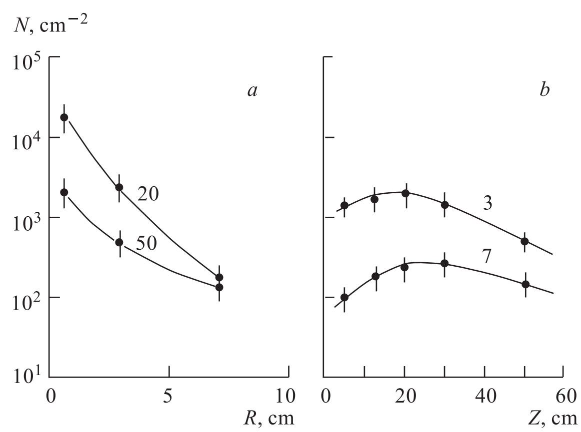

Fig. 3. Distributions of counts of nuclear fragments registered by SSNTDs in the assemblies Al–D–Al as a function of R at $Z = 20$ and 50 cm (*a*) and Z at $R = 3$ and 7 cm (*b*). The extended lead target was irradiated with 3.65-GeV protons with total flux of 10^{13}. Points — experimental data; curves — result of fitting

A dependence of the number of tracks on the mass number of disintegrated nuclei is shown in Fig. 4 for three cases:

1) the assemblies with layers of Al, Cu, Cd and Pb placed on the back surface of the target Ø 20 × 60 cm with $R = 0$, 3 and 7 cm (measurement was carried out on 3.17-GeV proton beam with a total flux of 10^{13});

2) the assembly with layers of Al, Ti, Cu, Cd, Ta and Pb irradiated with 2.2-GeV protons with a total flux of 10^{10};

3) the assembly with layers of Al, Cu, Cd and Pb placed at 1-m distance from the lead target Ø 20×20 cm at an angle of $10°$ (measurement was carried out with 3.65-GeV protons at a total flux of 10^{13}).

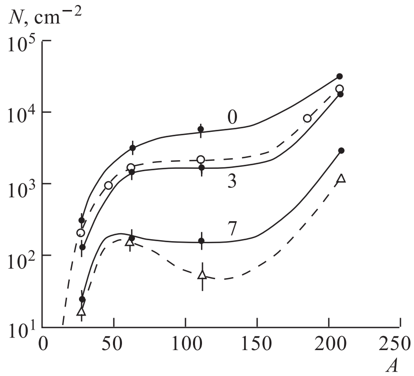

Fig. 4. A-dependence of nuclear fragment yield registered by SSNTDs in the assemblies T–D–T for three cases: ● — on the back surface of lead target Ø 20×60 cm, $E = 3.17$ GeV, proton flux of 10^{13}, $R = 0$, 3 and 7 cm; ○ — on a beam of protons with energy $E = 2.2$ GeV, proton flux of 10^{10}; △ — at an angle of $10°$ and distance of 1 m from lead target Ø 20×20 cm, $E = 3.65$ GeV, proton flux of 10^{13}. Curves — result of fitting

The protons that passed through the extended lead target without nuclear interactions lost about 25% of their energy because of ionization loss, and at the back surface they had the energy close to that which was used during irradiation of the assembly with 2.2-GeV proton beam. It explains similarity of the dependences represented in Fig. 4 for $R = 0$ and 3 cm and 3.17-GeV protons and for the assemblies bombarded with 2.2-GeV protons. As has been shown in Sec. 1 of this work, the shape of the A-distribution of the registered track number depends on the energy of incident hadrons, and at a reduction of the energy in a range of $A \sim 50$ a wide minimum is formed. The same dependence takes place with increasing distance R from the beam/target axis because the energy spectrum of particles becomes «softer». The effect of fragment yield suppression in the range of middle mass numbers becomes even more visible in the last case when the assembly was placed at an angle of $10°$.

The results of measurements with 3.65-GeV proton beam and the assemblies placed at a distance of 1 m from the center of the lead target Ø 20×20 cm are shown in Fig. 5, *a*. The assemblies located at angles of 10, 30, 60, 90, 120 and 150° to the beam direction. For layers of Al, Cu and Cd (a range of small and middle mass numbers) a sharp peak in the area of small angles is observed. In the area of angles 30–120° the indications of the detectors are small, which reflects a small output of high-energy neutrons and charged hadrons from the lateral surface of the target into this angular range. However, at further increasing of the angle the number of such neutrons grows due to their emission from the front surface of the target.

Similar but smoother tendency is observed for Pb–D–Pb assemblies where the dominant process of nuclear fragment formation is fission reaction. In the area of 30–120° the numbers of counts for the lead layers are approximately two orders of magnitude higher than the indications for other layers. Also in Fig. 5, *b*, the angular distributions of SSNTD indications for Cd and Pb layers obtained in experiments with 3.65-GeV protons and both lead targets are shown. For both targets the data are in good agreement at an angle of $10°$, but at larger

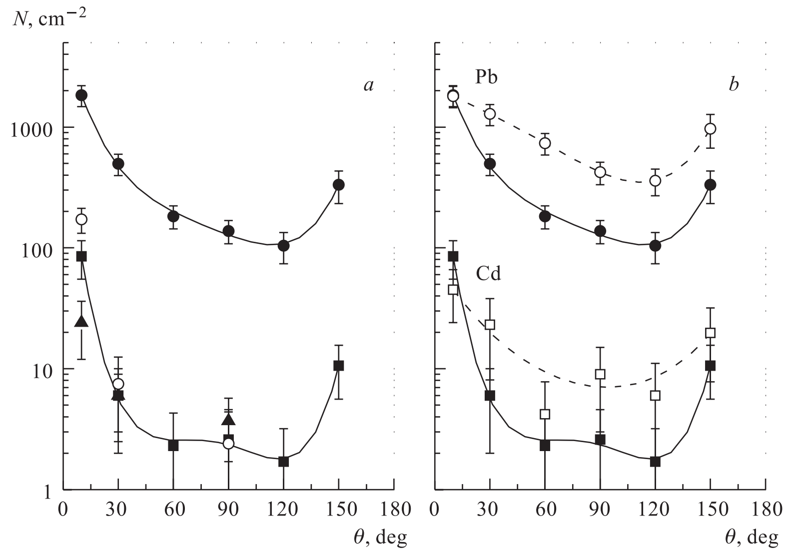

Fig. 5. Angular distributions of the number of counts for the assemblies T–D–T placed at 1 m from the center of lead target bombarded with 3.65-GeV protons (flux of 10^{13}): *a*) lead target Ø20 × 20 cm: ▲ — Al; ○ — Cu; ■ — Cd; ● — Pb; *b*) ●, ■ — lead target Ø20 × 20 cm; ○, □ — lead target Ø20 × 60 cm. Curves — result of fitting

angles the counting rate increases with target thickness, and for our targets and proton energy the difference achieves a factor of ~ 3.

CONCLUSION

The performed research showed that disintegration of nuclei of various materials from aluminum up to lead with formation of nuclear fragments registered by the lavsan SSNTD is most effective where there is a maximum flux of high-energy hadrons. For the extended lead target bombarded with protons with an energy of several GeV such areas are:

1) inside the target along the axis;

2) on the surface of the target: in the center of the front surface and on the lateral surface at $Z = 15-30$ cm;

3) at small angles to the beam direction.

Among the materials investigated, the greatest yield of registered nuclear fragments is given by fission reaction of lead.

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